# RESPIRATION AND RELEASE OF ENERGY

Chemical reactions that take place in cells are called metabolism. It is divided into two;

i) Anabolic reactions (Anabolism)
ii) Catabolic reactions (Catabolism)

Anabolism: Is the synthesis of large molecules from smaller, simpler molecules. This reaction requires $ absorbs energy. It is therefore endergonic. Anabolic reaction is involved in building up structures, storage compounds & complex metabolites in the cell - eg protein synthesis, photosynthesis, e.t.c.

Catabolism: This is the breakdown of large molecules to smaller, simpler molecules. It involves the release of energy $ it is therefore referred to as exergonic e.g respiration.

Catabolic reactions liberate energy required for;-

- To drive the cells anabolic reactions such as photosynthesis, synthesis of proteins, storage compounds, etc.
- For work e.g contraction of muscles, transmission of nerve impulses, secretion from glands, etc.
- For maintenance of a constant internal environment and of the tissues $ organs in the state of health and functional efficiency.
- For active transport of materials into $ out of the cell.
- Used for growth and development.
- Secretion - formation of vescicles.

In this case, most metabolic activities taking place within cells require energy. This energy is obtained in form of Adenosine triphosphate (ATP) got from breakdown of organic molecules e.g sugars (glucose), in a process that occurs within cells called cell/tissue/internal respiration.

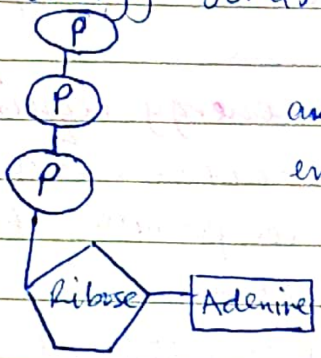
# ADENOSINE TRIPHOSPHATE (ATP)

The energy released during respiration is stored in form of ATP. ATP synthesis involves the attachment of a phosphate group to ADP (Adenosine diphosphate). The reactions are endergonic and energy for it comes from the oxidation of the hexose sugar.

$$\underset{\text{Sugar}}{C_6H_{12}O_6} + O_2 \xrightarrow{ADP+Pi \;\to\; ATP} CO_2 + H_2O$$

ATP is generally formed from the nucleotide Adenosine monophosphate (AMP) by addition of two further phosphate molecules. So, ATP is a nucleotide which consists of a purine adenine (Adenosine) attached to a 5C sugar ribose & to 3 phosphate groups by high energy bonds.

Structure of ATP




Hydrolysis of ATP takes place in presence of an enzyme ATPase & releases certain amount of energy.

$$ATP + H_2O \xrightarrow{ATPase} ADP + H_3PO_4 + \text{energy} = 34\,\text{K}$$

The 2nd $PO_4^{3-}$ group can be removed from ADP by breaking another high energy bond to form AMP.

## CELL RESPIRATION

Is the breakdown of organic compounds like glucose to yield chemical energy in form of ATP. The organic cpds which can be broken down to yield energy are called **Respiratory** substrates ~~and~~ they include;

- Carbohydrates (Glucose)
- Fats
- Proteins.

ATP is an appropriate chemical energy for use by living cells because it can be transferred within and between cells quickly & can be released in economically regulated amounts whenever needed.

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Cell respiration is divided into;- - Aerobic respiration &
- Anaerobic respiration

AEROBIC RESPIRATION

Is the oxidative breakdown of glucose to yield chemical energy (ATP) in presence of oxygen. This process is summerised by the equation below:

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + H_2O + \text{ENERGY}$ (in form of ATP)

This process takes place in both cytoplasm and mitochondria of the cell. Organisms that respire this way are called aerobes.

The above equation is misleading in the following ways; - It gives an impression that respiration occurs in one chemical step, which is not.
- It also suggests that some of the $O_2$ used ends up in $CO_2$ molecule, which is not true.

But it indicates the overall summary of the process.

Qn. Describe an experiment to show that $CO_2$ is produced during respiration.

ANAEROBIC RESPIRATION

Is the breakdown of organic food substances (glucose) sugars/ in absence of oxygen to release energy (ATP).

The amount of energy formed is less compared to aerobic respiration, because the food substance is partially broken down. Anaerobic respiration takes place in cytoplasm of the cell. Organisms that carryout anaerobic respiration are called anaerobes.

Comparison of aerobic and anaerobic respiration.

Similarities

i) Both yield chemical energy in form of ATP.
ii) In both, $H_2O$, $CO_2$ are released as bi-products (waste products)
iii) Both processes occur in plants and animals.
iv) In both the process is catalysed by enzymes.
v) Both occur in cytoplasmic matrix.

## DIFFERENCES

| Aerobic | Anaerobic |
| --- | --- |
| i) Occurs in presence of $O_2$ | Occur in absence of $O_2$. |
| ii) Takes place in both cytoplasm & mitochondria of cells. | Takes place only in cytoplasm of the cell. |
| iii) Yields greater amount of chemical energy inform of ATP (38 ATPs). | Yields less amount of chemical energy inform of ATP (2 ATPs). |
| iv) It involves complete oxidative breakdown of glucose molecule | It involves incomplete breakdown of glucose molecule. |
| v) Produces water and $CO_2$ as bi-products (wastes products) | Produces ethanol (in plants), lactic acid (in animals), and $CO_2$ as bi-products. |
| vi) Is a relatively permanent process. | Is a temporary process. |
| vii) Occurs at a slow rate / releases energy slowly. | Occurs at a faster rate. Releases energy quickly. |
| viii) Uses glucose molecules present in the system. | Uses stored carbohydrates such as glycogen, where they are broken down to glucose. |

## MEASURING RESPIRATION

The rate of respiration in small animals and germinating seeds may be measured in a simple respirometer in which the $CO_2$ given out is absorbed by soda lime, & the $O_2$ uptake is detected by displacement of manometric fluid in a glass U-tube.

Since the manometer may also respond to change in temperature / pressure, then a differential respirometer with a thermo barometer attached to the manometer which improves accuracy.

Respiration of tissue samples can be accurately measured in Warburg respirometer.

A respirometer can be used to;-

- determine RQ of a given tissue.
- Investigate factors that affect respiration.

## BASAL METABOLIC RATE (BMR)

This is the minimum amount of energy on wc the body can survive when at rest. It is expressed as the energy released per unit body surface or the total heat output per day.

The energy released in these cirmustances is used for maintaining body circulation, breathing, heart rate, and body temperatures.

### Factors that affect BMR.

- Age
- Sex of individuals – Man has higher BMR than females
- Health of individuals < Sick have higher BMR than normal; Expectant mother have higher BMR than the non-expectant.
- Weight

## RESPIRATORY QUOTIENT (RQ)

This is the ratio of volume of $CO_2$ given out to the volume of $O_2$ taken in simultaneously by a given weight of the tissue in a given period ~~of time~~ at s.t.p.

$$RQ = \frac{\text{volume of } CO_2 \text{ given out} / cm^3}{\text{volume of } O_2 \text{ absorbed} / cm^3}$$

**Note:** RQ can be 0, less than one, equal to one or greater than one

## RQ OF VARIOUS FOOD SUBSTRATES

Glucose: It is 1·0; This represents the aerobic respiration of glucose.

e.g $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$

$$RQ = \frac{\text{vol. of } CO_2}{\text{vol. of } O_2} = \frac{6}{6} = 1{\cdot}0$$

Anaerobic respiration of glucose shows a RQ that tends towards $\infty$; E.g

(i) In yeast alcoholic fermentation ~~fat~~

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + \text{Energy}$

$$RQ = \frac{\text{vol. } CO_2}{\text{vol. } O_2} = \frac{2}{0} = \infty$$

(ii) In lactate fermentation

$C_6H_{12}O_6 \longrightarrow 2CH_3CHOHCOOH + \text{Energy}$

$$RQ = \frac{\text{vol. } CO_2}{\text{vol. } O_2} = \frac{0}{0} = \infty$$

## FATS

Fats are poor in $O_2$ and the proportion of $O_2$ to Carbon in fats is invariably less as compared to carbohydrates, hence they require more $O_2$ for complete oxidation.

Fats are not oxidised directly. They are instead first hydrolysed to fatty acids and glycerol. A fraction of $O_2$ is used up in this process. Due to these reasons the RQ is less than one but above 0·7.

E.g

$2C_{51}H_{98}O_6 + 145O_2 \longrightarrow 102\,CO_2 + 98H_2O + \text{Energy}$

Tripalmitin

$$R.Q = \frac{\text{vol. } CO_2}{\text{vol. } O_2} = \frac{102}{145} = 0{\cdot}70.$$

$$C_{18}H_{36}O_2 + 26O_2 \longrightarrow 18CO_2 + 18H_2O + \text{Energy.}$$ ie

$$RQ = \frac{\text{vol. } CO_2}{\text{vol. } O_2} = \frac{18}{26} = 0.69$$ resp

nd

Fats liberate more energy than carbohydrates and proteins due to its higher proportions of hydrogen atoms in the fat molecule. s

ses

## SIGNIFICANCE OF RQ VALUE

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- Indicates the kind of food being oxidised i.e the substrate used in respiration. ~~heat energy produced~~ per unit time However, the theoretical RQ ~~for~~ may not practically be achieved b'se;- ed
+ Respiratory substrates are rarely oxidised fully.
+ A mixture of substrates is used.
- Indicates the sort of metabolism taking place. Anaerobic respiration has RQ above 1.0 $ aerobic respiration has RQ above 1.0 and below 1.0.
- Indicates interconversions e.g conversions of carbos ~~to~~ fats. th

be

## RESPIRATION OF GLUCOSE

Respiration of glucose as a substrate occurs in three distinct stages;-

(i) Glycolysis
(ii) Krebs | citric acid cycle | tricarboxylic acid cycle TCA (Oxidative decarboxylation)
(iii) Respiratory chain | hydrogen $ electron transport chain. e ycle

## GLYCOLYSIS

Is the systematic breakdown of glucose to form pyruvic acid (Pyruvate) and releasing energy in form of ATP. This is the first step of respiration. It occurs in the cytoplasm of the cell and does not require oxygen.

During glycolysis, two phosphate groups are added to a molecule of glucose, a process known as phosphorylation.

ie

This process needs energy (endergonic) & this energy is obtained from hydrolysis of two ATP molecules. The phosphorylation reactions activate the sugar molecules & also prevent the sugar molecules from getting out of the cells.

The glucose molecule is phosphorylated in the presence of enzyme hexokinase (hexophosphokinase) to form Glucose-6-phosphate.

Glucose-6-phosphate is isomerised to fructose-6-phosphate a 6C compound, by enzyme Isomerase.

Further phosphorylation of the 6C compound formed occurs producing a diphosphorylated 6C compound called fructose-1,6-diphosphate. This compound is unstable and immediately splits into 2 molecules of 3C, phosphoglyceraldehyde and dihydroxyacetone phosphate.

Each of the two compounds formed undergo dehydrogenation and dephosphorylation. The dehydrogenation reaction is catalysed by the dehydrogenase enzyme. 4 hydrogen atoms are released and each pair of which is accepted by a hydrogen acceptor called NAD (Nicotinamide Adenine Dinucleotide). Two molecules of $NADH_2$ (reduced NAD) are formed. The dephosphorylation directly forms 4 ATP molecules.

The NAD is reduced according to the equation;-

$$2\,NAD^+ + 2H^+ \longrightarrow 2NADH_2$$

The hydrogen ion (Proton) is then shunted into mitochondria where they go through hydrogen-electron-carrier system, where each molecule of $NADH_2$ produces 3 ATPs.

Energy produced from glycolysis;

Total ATP = 4 produced directly

Energy used = 2 ATPs

Net gain = 2 ATPs

2 $NADH_2$ molecules which generate 6 ATPs.

The fate of pyruvate formed depends on whether the $O_2$ is present / not. In presence of $O_2$, pyruvate enters the mitochondrion where it undergoes the next step of respiration, called Kreb's cycle.

## Summary of glycolysis

Glucose (Animals)
Starch (plants)

↓

Glucose

ATP → ADP + Pi — Phosphorylation catalysed by hexokinase enzyme / hexophosphokinase

↓

Glucose – 6 – phosphate 6C

Isomerisation / rearrangement catalysed by Isomerase enzyme.

↓

~~Fructose~~

Fructose – 6 – phosphate 6C

ATP → ADP + Pi — Further phosphorylation catalysed by hexokinase

↓

Fructose-1,6-bisphosphate

Fructose-1,6-Diphosphate 6C

unstable, splits

Triose bisphosphate 3C → (ADP → ATP) → Triose phosphate

Dehydrogenation by dehydrogenase enzyme

Dephosphorylation

Dihydroxyacetone phosphate 3C → (2ADP + Pi → 2ATP; $NAD^+$ → $NADH_2$) → Pyruvate

Isomerises into glyceraldehyde-3-phosphate

Phosphoglyceraldehyde 3C → (2ADP + Pi → 2ATP; $NAD^+$ → $NADH_2$)

Dephosphorylation (2 events)

↓

Pyruvate, 3C

If $O_2$ is absent → Lactic acid in animals; Ethanol in plants.

If $O_2$ is present → To mitochondria undergoes oxidative decarboxylation

In absence of $O_2$, the pyruvate formed is prevented from entering the mitochondrion. In plants it undergoes oxidative decarboxylation losing $CO_2$ to form ethanal (acetaldehyde).

$$\underset{\text{(Pyruvate)}}{CH_3COCOOH} \xrightarrow{-CO_2} \underset{\text{Ethanal}}{CH_3CHO}$$

Alcoholic fermentation – plants, some bacteria & yeast

The ethanal combines with hydrogen ions to form ethanol, a process called alcoholic fermentation; it occurs in yeast.

$$CH_3CHO \xrightarrow{NADH_2 \;\to\; NAD^+} CH_3CH_2OH$$

(ethanol)

In animals, the pyruvic acid accepts the hydrogen atom from $NADH_2$, Lactate is formed; the presence of Lactate causes muscle cramps and so prevent the muscles operating

$$CH_3COCOOH \xrightarrow{NADH_2 \;\to\; NAD^+} CH_3CHOHCOOH$$

(Pyruvic acid) (lactic acid)

Qn: Why is lactic acid broken down in animals, but ethanol is not? Formulate it as a qtn:

Unlike alcoholic fermentation, lactic acid can further be broken down if $O_2$ is available, and the quantity of $O_2$ required for oxidation to break down of lactic acid is called $O_2$ debt

Examples of anaerobic conditions in plants.

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- Roots in water logged soil conditions.
- Plants growing in soil with low $O_2$ content due to hard pans,
- Yeast fermentation.
- In ponds / rivers.
- Impermeable seed coats during seed germination.
- Within the centre of large ~~#~~ stem & fruits.

For animals;-

- Very high $O_2$ demand due to high / increased metabolic rates, arising from increased muscle contractions during strenous exercise.
- Low $O_2$ carrying capacity due to sickle cell anaemic conditions.
- Very low red blood cell count.
- Reduced volume of blood in general circulation / low cardiac output arising from slow rate of heart beat.
- In-efficiency of lungs due respiratory diseases e.g emphysema.
- Carbon monoxide poisoning.
- Sperms swimming towards ovum in the oviduct.
- At high altitudes.
- During hibernations.

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# KREBS | CITRIC ACID | TRICARBOXYLIC ACID CYCLE (TCA)

This is the final common pathway in the oxidative breakdown of carbohydrates, proteins and lipids in aerobic respiration.
It occurs in the matrix of mitochondria in presence of $O_2$.

In this cycle, pyruvate undergoes oxidative decarboxylation and dehydrogenation to form a 2C compound called **acetyl**. $CO_2$ and hydrogen atoms are released; the hydrogen atoms are accepted by NAD to form $NADH_2$.
The acetyl combines with a co-enzyme A to form acetyl co-enzyme A. The acetyl CoA then combines with oxaloacetic acid (OAA), 4C to form a 6C compound called **Citric acid** (citrate).
The citric acid undergoes dehydrogenation and decarboxylation reactions to form an intermediate 5C compound called **alpha-ketoglutaric acid** | α-Ketoglutarate; during decarboxylation, $O_2$ is taken from two molecules of water and used to oxidise two carbon atoms to form $CO_2$. This is termed as oxidative decarboxylation.

α-Ketoglutarate
-dephosphorylation
-decarboxylation
-dehydrogenation

The α-Ketoglutaric acid also undergoes oxidative decarboxylation, dehydrogenation & dephosphorylation reaction to form a **4C** compound called succinic acid | succinate. $CO_2$, ATP & hydrogen atoms are released.
The hydrogen atoms are accepted by NAD to form $NADH_2$. Series of dehydrogenation reactions occur converting succinic acid to fumaric acid (4C), which is then converted to mallic acid | mallate;
Mallate is dehydrogenated to regenerate oxaloacetic acid | oxaloacetate.
The hydrogen released from dehydrogenation of the succinic acid is accepted by FAD to form $FADH_2$.
In general, **2ATP** molecules, **8NADH₂** molecules, and **2 FADH₂** molecules are produced during Kreb's cycle.

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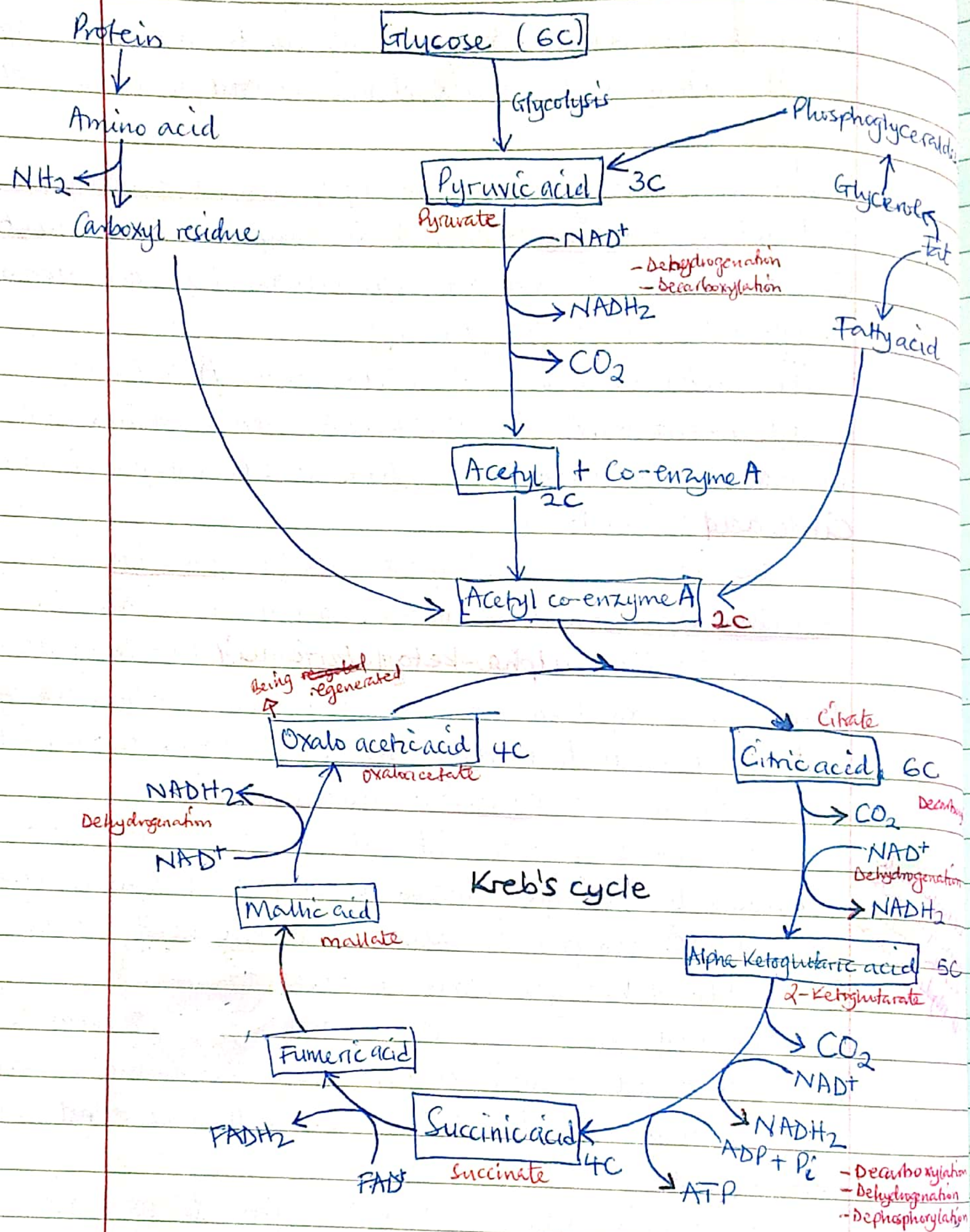
# Summary of Kreb's cycle.




NADH2 molecules X2 = 8

FADH2 molecule X2 = 2

ATP molecule X2 = 2

## OXIDATIVE PHOSPHORYLATION & HYDROGEN CARRIER SYSTEM / ELECTRON TRANSPORT CHAIN

### OXIDATIVE PHOSPHORYLATION

This is the ~~oxidative~~ conversion of ADP to ATP by addition of inorganic phosphate to the molecule of the ADP. The energy for the process is obtained from the break down of glucose.

### HYDROGEN CARRIER SYSTEM / ELECTRON TRANSPORT CHAIN

This is the assemble of enzymes and proteins in biological system that is capable of accepting electrons or hydrogen atoms which are then transferred in an orderly sequence from one component to the other via a series of redox reaction, ~~the~~ until at the end, the hydrogen combines with molecular oxygen to form water, ETC occur on the inner membranes of ~~a~~ cristae of the mitochondria of eukaryotic cells and the cell membranes (mesosomes) of the prokaryotic ones.

The 1st hydrogen acceptor in the hydrogen-electron carrier chain is the NAD, when it accepts the the 2 hydrogen atoms, NAD becomes reduced to form $NADH_2$.

$$NAD^+ + 2H^+ \longrightarrow NADH_2.$$

The hydrogen atoms are then passed to the 2nd electron carrier, FAD, which is reduced to $FADH_2$. Each time a hydrogen atom is transmitted from NAD to FAD an energy is released which is used to convert ADP to ATP.

$$FAD + 2H^+ \longrightarrow FADH_2.$$

After this stage, the $H_2$ atoms is passed to a co-enzyme Q and it splits into protons and electrons.

$$2H \longrightarrow 2H^+ + 2e^-$$

The electrons pass via a system of electrons carrier known as **cytochromes**. Cytochromes are proteins and enzymes containing iron prosthetic group called **Haem**. Each time an electron is passed from one cytochrome to another, from a higher to a lower energy level, an energy is emitted which is used to convert ADP to ATP.

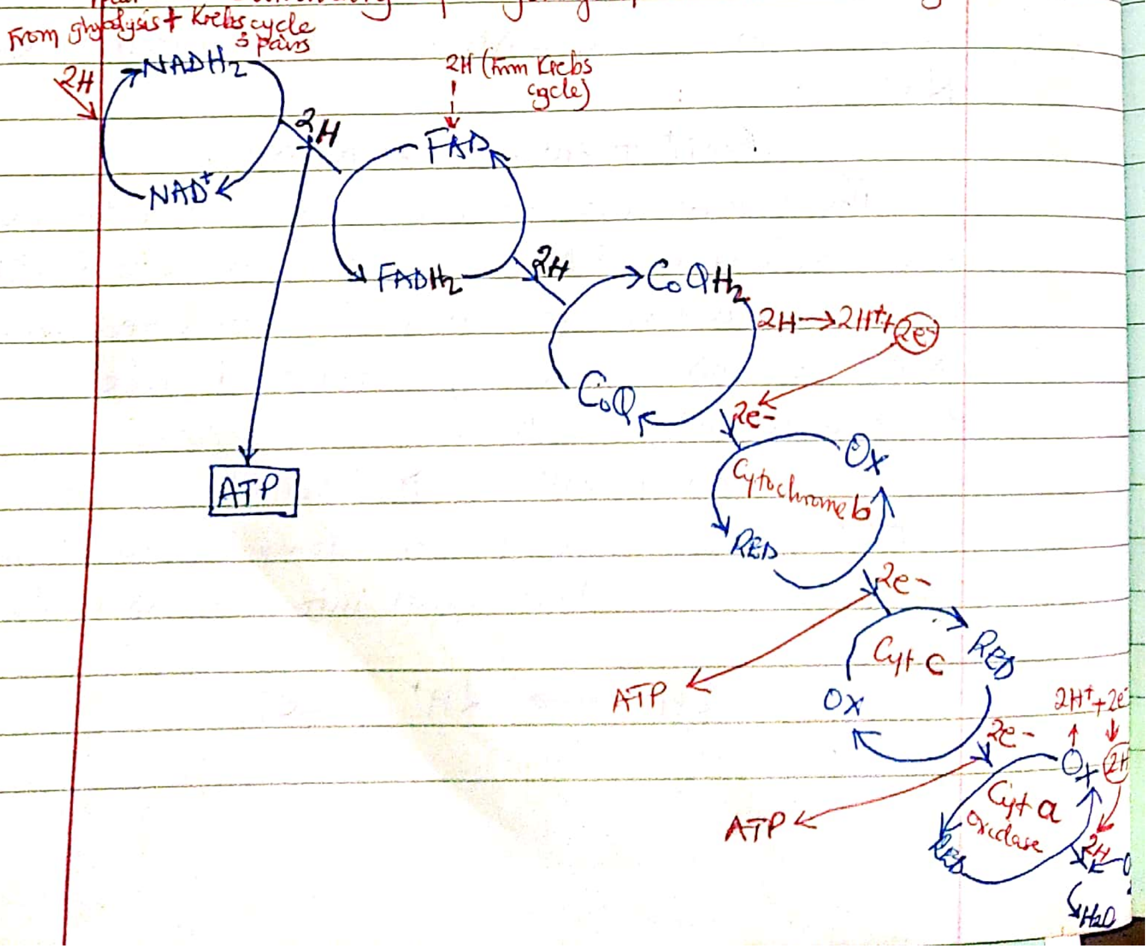
The $H^+$ are temporarily deposited into the surrounding medium until required in the cycle again.

The last electron carrier is Cytochrome oxidase which is also reduced. The cytochrome oxidase catalyses the combination of the protons ($H^+$) found in the Cristae with the electrons to form hydrogen atoms.

The hydrogen atoms then combine with oxygen to form water molecule, so, oxygen molecule is the last ~~oxygen~~ hydrogen acceptor.

In this process, 3 ATPs are formed for each $NADH_2$ molecule and 2 ATPs are formed for each $FADH_2$ molecule.

## Summary of hydrogen/Electron Carrier system.



Notes:- The synthesis of ATP w/c occurs as a result of this process is called oxidative phosphorylation.
- The ETs occurs in the cristae of mitochondria.
- Although $O_2$ is closely associated with aerobic respiration, its nevertheless vital since it drives the whole process. Its absence leads to accumulation of hydrogen atoms and aerobic respiration would cease.

## Summary of aerobic respiration of one glucose molecule.

| Stage | Products | | | |
|---|---|---|---|---|
| | $CO_2$ | $NADH_2$ | $FADH_2$ | ATP formed |
| Glycolysis | - | 2 | - | 2 |
| Kreb's cycle | 6 | 8 | 2 | 2 |
| Electron transport syst | - | - | - | 34 |
| Total | $6CO_2$ | $10NADH_2$ | $2FADH_2$ | 38 ATPs |

## CHEMIOSMOTIC THEORY OF ATP SYNTHESIS
### (THE P. MITCHEL PATHWAY)

This theory explains how ATP molecules are synthesised in the inner membrane of mitochondria when $H^+$ (protons) diffuse along the chemiosmotic channels into the matrix of the mitochondria from the compartment between the inner and outer membrane.

-The H+ are formed in the matrix from the dessociation of the hydrogen atoms accepted by the Co-enzyme Q.

- The proton pump actively pumps these $H^+$ protons from the matrix ~~cristae~~, across the inner membrane into the compartment between the inner and outer mitochondrial membranes. The energy for this active process is synthesised in the ETS in the cristae of mitochondria.

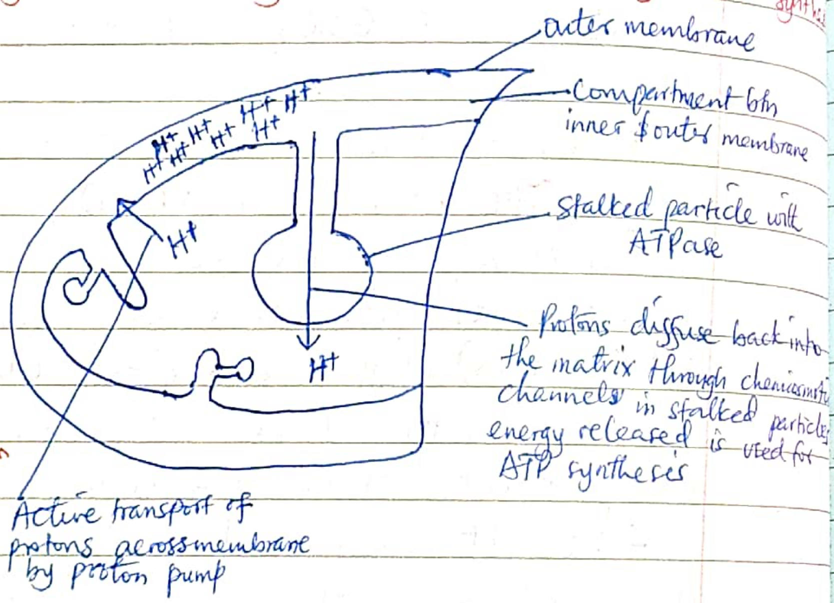
-The protons accumulate in the compartment until a steep proton concentration gradient

develops between the compartment and the mat[illegible]
The inner membrane is generally impermeable to protons ($H^+$), so they are only allowed to diffuse back into the matrix along the chemiosmotic channels that are located in special structures in the inner membrane called stalked particles.

Some energy is lost when the protons are carried from a higher to a lower energy levels in chemiosmotic channels and this energy is used for the synthesis of ATP molecules by combining ADP & inorganic phosphate units (oxidative phosphorylation).

The phosphorylation of ADP is catalysed by the enzyme ATPase in the bulbous ends of the stalked particles.

Diagram illustrating chemiosmotic theory of ATP synthesis




Qn: Compare oxidative phosphorylation & photophosphorylation

Comparison of oxidative phosphorylation and photophosphorylation

Similarities

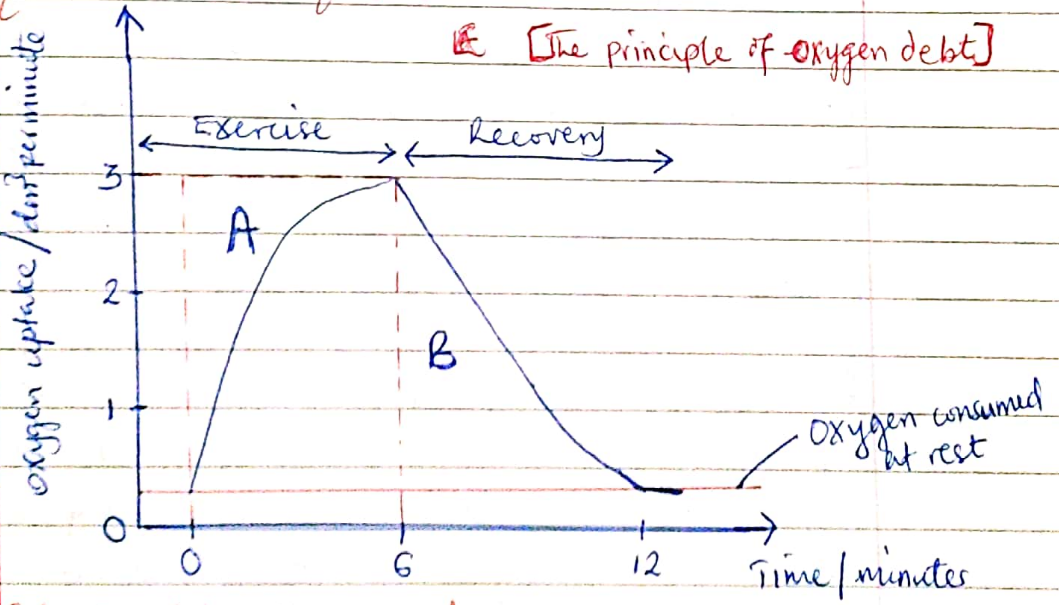
- There is flow of electrons along electron carriers in both;
- Both processes are enzyme controlled.
- Both require special organelles i.e mitochondria and chloroplasts.
- Both occur in living cells/organisms.
- Both require an initial input of energy.
- Both result in synthesis of ATP.

## Differences:

| Oxidative phosphorylation | Photophosphorylation. |
| --- | --- |
| - Takes place in mitochondria | - Takes place in chloroplasts |
| - Produces ATP, $CO_2$ and water | - Produces ATP, $CO_2$ and $NADH_2$. |
| - Energy is derived from oxidation of organic food substances. | - Uses sunlight energy trapped by chlorophyll. |
| - Final electron acceptor is Oxygen. | - Final electron acceptor is chlorophyll and NADP. |
| - Hydrogen acceptor is NAD and FAD | - Hydrogen acceptor is NADP. |
| - Takes place throughout lifetime of all living cells. | - Occurs only in cells containing chloroplasts in presence of light. |
| - Uses oxygen | - Releases oxygen. |
| - Sources of electrons is only hydrogen | - Sources of electrons are water and Chlorophyll. |
| - Occurs in all aerobic organisms. | - Occurs in green plants, algae & photosynthetic bacteria. |

Qn: A study was carried out to investigate the variation of effect of oxygen uptake with time during exercise and recovery ~~of~~ in an individual. Use the graph below to answer questions that follow.

[The principle of oxygen debt]




(a) Explain the effect of oxygen uptake on the rate rate of excercise / Explain the graph above.

- Explain the mechanisms that maintain energy supply in the 1st 6 minutes.

(b) Give reasons for the gradual decline in uptake of oxygen from 6th to 12th minute of recovery.

Solution:

During exercise in the first 6 minutes, $O_2$ uptake increased rapidly and later gradually until it reach a maximum; There was increased muscle contractions, which resulted into high energy demands and metabolic rate increased during the exercise; The amount of $O_2$ required to sustain this high energy demand of the exercise aerobically is about $3 dm^3$; This is achieved until the 6th minute after the exercise began; this is shown in region A;

During the 1st 6mins of exercise various mechanisms operate to maintain the supply of energy; these include;

- Increased rate of breathing that supply oxygen in the alveoli of lungs; $O_2$ diffuses into blood capillaries and combines with haemoglobin & is delivered in large amounts to the tissues fluid & diffuses into respiring tissues. $O_2$ is extracted by body cells and is utilised in aerobic respiration to release energy
- Stored $O_2$ in myoglobin of the muscle tissues is also released for aerobic respiration. for further production of energy. But this only occurs when $O_2$ in the haemoglobin is depleted.
- Energy is also released from the creatine phosphate system. It is another energy reserve which contains phosphate groups that can be removed to release energy. This energy is used for synthesis of ATP molecules
- Anaerobic respiration also supplies the most needed energy rapidly. It uses glycogen stored in muscle tissues as a source of glucose.

During recovery phase; from 6th to 18th minute oxygen uptake declines rapidly and later gradually. After the exercise oxygen uptake does not return immediately to resting normal. The body continues to breath in and use extra $O_2$; as shown in B; This amount is known as the $O_2$ debt (The amount of $O_2$ required by the body immediately after a period of exercise).

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## Importance of the oxygen debt.

- It restores the creatine phosphate. After exercise the creatine combines with phosphate again using energy from aerobic respi
- Reloading of the myoglobin with oxygen.
- For complete breakdown of lactic acid to carbon dioxide and water. This repays the oxygen debt.

- The gradual decline in uptake of oxygen is due to the slow breakdown of lactic acid using energy from anaerobic respiration. The lactic acid formed in the muscle tissue diffuses into blood and is transported to the liver via blood circulation; In the liver its oxidatively dehydrogenated to form pyruvic acid and $NADH_2$; The pyruvic acid, enters the glycolytic pathway through Kreb's cycle to be oxidised to energy. ATP molecules are generated and is used to break down most of the lactic acid in the liver to glucose.

## RESPIRATION OF OTHER SUBSTRATES

Carbohydrates are not the only materials which can be oxidised by living cells to release energy. Both fats and proteins under certain circumstances may be used as respiratory substrates without first being converted to carbohydrates.

### a) Respiration of fats / lipids

The lipid is first hydrolysed to glycerol and fatty acids, the process is catalysed by enzyme lipase. The glycerol is phosphorylated and converted into glyceraldehyde-3-phosphate which is incoporated into glycolysis pathway and subsequently be broken down in Kreb's cycle. The fatty acid component is progressively broken down in the matrix of the mitochondria into 2C acetyl fragments which combine with CoA to form acetyl CoA. This then enters the Kreb's Cycle with subsequent release of energy.

Note: The oxidation of fats has the advantage of producing a large quantity of hydrogen atoms which can be transported by hydrogen carriers (NAD or FAD) to produce more energy in the ETS. For this reason, fats liberate more ~~energy~~ than double the energy obtained from the same quantity of carbohydrates.

b) Respiration of proteins (used only in cases of starvation)

The protein is hydrolysed into amino acids. The amino acids are deaminated in the liver. The remaining organic acid enter the respiratory pathway at a number of points depending on their carbon content. E.g 5C amino acids like glutamate acid and 4C amino acids like aspartate are converted into Krebs cycle intermediates α-Ketoglutarate and oxaloacetate respectively.

The 3C amino acids like alanine are converted to pyruvate, ready for conversion into acetyl CoA.

Summary of respiratory Pathways of different substrates

Questions:

- Understanding biology for A level - S. Toole P381 — 384.

(a) Describe the process of non-cyclic photophosphorylation
(b) Explain P. Mitchell's physiology that occurs in the chloroplast

a) Compare the suitability of water and air as gaseous exchange media. (8 mks)
b) ~~Give an account~~ Explain how the efficiency in gas exchange across the gills of a fish is achieved.
(12marks)