# RESPIRATION

## (Obtaining energy from food to be used for powering cell activities)

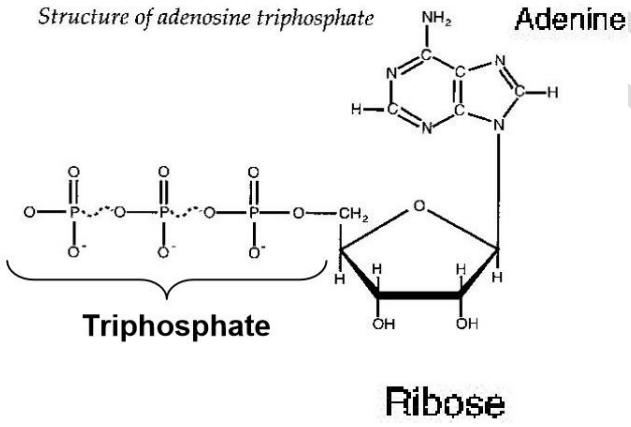
*Tissue or cell respiration*

- This is a process by which organic food materials are broken down in a cell to release energy in the form of ATP.

The process involves a series of enzyme controlled reactions in which an organic molecule is broken down through a series of redox reactions. The organic food material is oxidized to carbon dioxide.

The energy used to make ATP (Adenosine triphosphate) is unlocked from the chemical energy in the organic molecules during oxidation. The chemical energy is in each of the C-H bonds of the organic molecules, thus the more the number of C-H bonds, the more the energy that can be obtained from an organic molecule. (Size of organic molecule)

**ADENOSINE TRIPHOSPHATE**




### Structure of ATP

ATP is a molecule made up of a nitrogen base; adenine, a ribose sugar and three phosphate groups. Adenine is attached to carbon 1 of ribose sugar while the chain of phosphate groups is attached to carbon 5 of ribose.

ATP is a temporary energy store compound which releases energy when the bond between the phosphate groups is broken during hydrolysis. Due to its synthesis in all living organisms, ATP is referred to as a **universal energy currency.**

More energy is obtained from the hydrolysis of ATP to ADP and ADP to AMP than from hydrolysis of AMP. This explains why hydrolysis of AMP to release energy isn't feasible.

ATP is formed by a process called phosphorylation in which a phosphate is added to ADP. There are three types of phosphorylation;

i. ***Substrate level phosphorylation:*** this involves the transfer of phosphate group directly from a high energy compound to ADP to form ATP. Examples of high energy compounds include 1, 3-bisphosphoglycerate, creatinephosphate.

ii. ***Oxidative phosphorylation:*** is the process of ATP synthesis using energy from oxidation of compounds such as NADH and $FADH_2$

iii. ***Photophosphorylation:*** this is the process by which ATP synthesis takes place in a cell using energy from light. E.g. during photosynthesis.

ATP is preferred to other high energy compounds to provide energy for cell metabolism because;

- ✓ Provides the right amount of energy for cellular needs when hydrolyzed
- ✓ ATP can be moved to any place when need arises
- ✓ Is easily hydrolyzed to provide energy at the right time.

ATP can't be stored for long and is thus continually hydrolyzed and regenerated.

Brain cells only have a few minutes supply of ATP and thus must be continuously supplied with oxygen to regenerate it.

Muscle cells however store creatine phosphate which is a source of phosphate for rapid regeneration of ATP



*Uses of energy from ATP in cells*

- ❖ Enables loading and unloading of sugars in plants
- ❖ Enables translocation of organic food materials in phloem of plants
- ❖ Enables movement of cilia and flagella
- ❖ Enables contraction of muscles
- ❖ Enables active transport of molecules across cell membrane
- ❖ Used for synthesis of compounds and structures e.g. DNA and protein synthesis
- ❖ For activation of chemical compounds, to make them more reactive. E.g. phosphorylation of glucose during glycolysis
- ❖ For Contraction of microfilaments during cell division

- ❖ Powers movement of a sperm cell toward the secondary oocyte
- ❖ For Transmission of nerve impulses
- ❖ For secretion of substances such as hormones that are formed in cells

**Sites for cell respiration in cells**

| CELL | SITE |
|---|---|
| Prokaryotic cell | Cytoplasm, Mesosome |
| Eukaryotic cell | Cytoplasm, mitochondrion |

## STAGES OF CELLULAR RESPIRATION

Cellular respiration involves three stages.

| ***STAGE*** | ***SITE*** | ***CONDITION*** |
|---|---|---|
| *GLYCOLYSIS* | *CYTOPLASM* | *BOTH AEROBIC & ANAEROBIC* |
| *KREBS CYCLE /TRICARBOXYLIC ACID CYCLE/CITRIC ACID CYCLE* | *MITOCHONDRIAL MATRIX* | *AEROBIC* |
| *ELECTRON TRANSPORT SYSTEM* | *CRISTAE* | *AEROBIC* |

**GLYCOLYSIS** *(Break down of sugar)*

- ✓ This is a series of enzyme controlled reactions that involve the splitting of a single glucose molecule to form two molecules of pyruvate with release of 2ATP molecules

The pyruvate formed is a three carbon sugar compound.

DESCRIPTION OF GLYCOLYSIS

- ❖ Glucose is phosphorylated to form glucose-6-phosphate to raise its energy level and prevent it from leaving the cell since large ions can't

move across the cell membrane. Reaction is catalyzed by the enzyme hexokinase

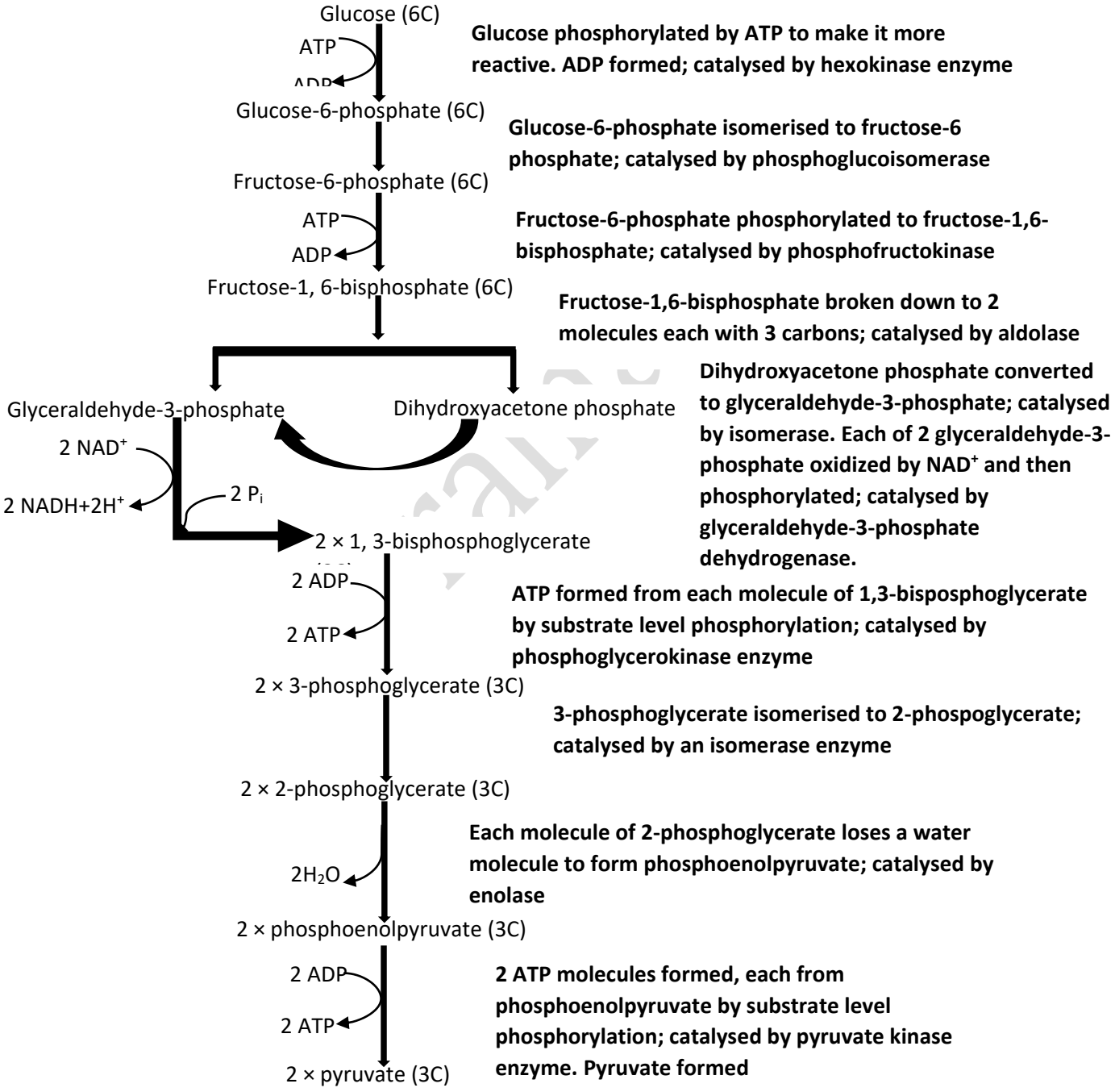
- The glucose-6-phosphate is isomerized to form fructose-6-phosphate, the reaction catalyzed by phosphoglucoisomerase enzyme.
- Fructose-6-phosphate is phosphorylated to form fructose-1, 6-bisphophate. Reaction catalyzed by enzyme phosphofructokinase
- The fructose-1, 6-bisphosphate is unstable and split to form two 3 carbon compounds which are isomers; dihydroxyacetone phosphate and glyceraldehyde-3-phosphate. Reaction is catalyzed by enzyme aldolase.
- Dihydroxyacetone phosphate is isomerized to glyceraldehyde-3-phosphate. The reaction is catalyzed by enzyme isomerase

Thus, each glucose molecule is cleaved to form 2 molecules of three carbon compound glyceraldehyde-3-phosphate.

- Each of the glyceraldehyde-3-phosphate is oxidized by oxidized Nicotinamide adenine dinucleotide ($NAD^+$) and then phosphorylated to increase its potential energy to form 1,3-bisphosphoglycerate
- Two molecules of reduced nicotinamide adenine dinucleotide ($NADH+H^+$) are formed. Reaction is catalyzed by triose phosphate dehydrogenase
- Each molecule of 1, 3-bisphosphoglycerate is used to from an ATP molecule during substrate level phosphorylation of ADP. Two molecules of 3-phosphoglycerate (PGA) are formed. Reaction is catalyzed by phosphoglycerokinase enzyme.
- Each of the PGA molecules isomerizes to form 2-phosphoglycerate. The molecules now lose a water molecule under catalysis of enzyme enolase to form 2 molecules of phosphoenolpyruvate (PEP)
- A phosphate group is transferred from each of the PEP molecules to ADP, forming 2 molecules of ATP, during substrate level phosphorylation. Two molecules of pyruvate are formed.
  Reaction is catalyzed by pyruvate kinase enzyme.

- Thus from each molecule of glucose, 2ATP molecules are invested and 4 molecules of ATP are formed during substrate level phosphorylation and 2 molecules of ($NADH+H^+$)
- The net gain in ATP during glycolysis for one glucose molecule is thus 2ATPs.

**SUMMARY OF GLYCOLYSIS**



## SIGNIFICANCE OF GLYCOLYSIS

- ✓ Formation of ATP used to power cell activities
- ✓ Formation of ($NADH+H^+$) from which more energy is extracted during the electron transport system
- ✓ Formation of pyruvate from which more energy can be extracted either in aerobic conditions or anaerobic conditions during Krebs cycle.

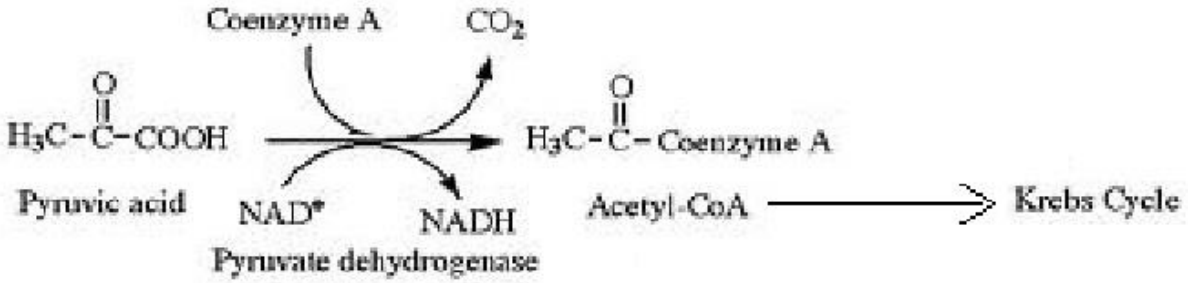
## ***FATE OF PRODUCTS OF GLYCOLYSIS DURING AEROBIC CONDITIONS***

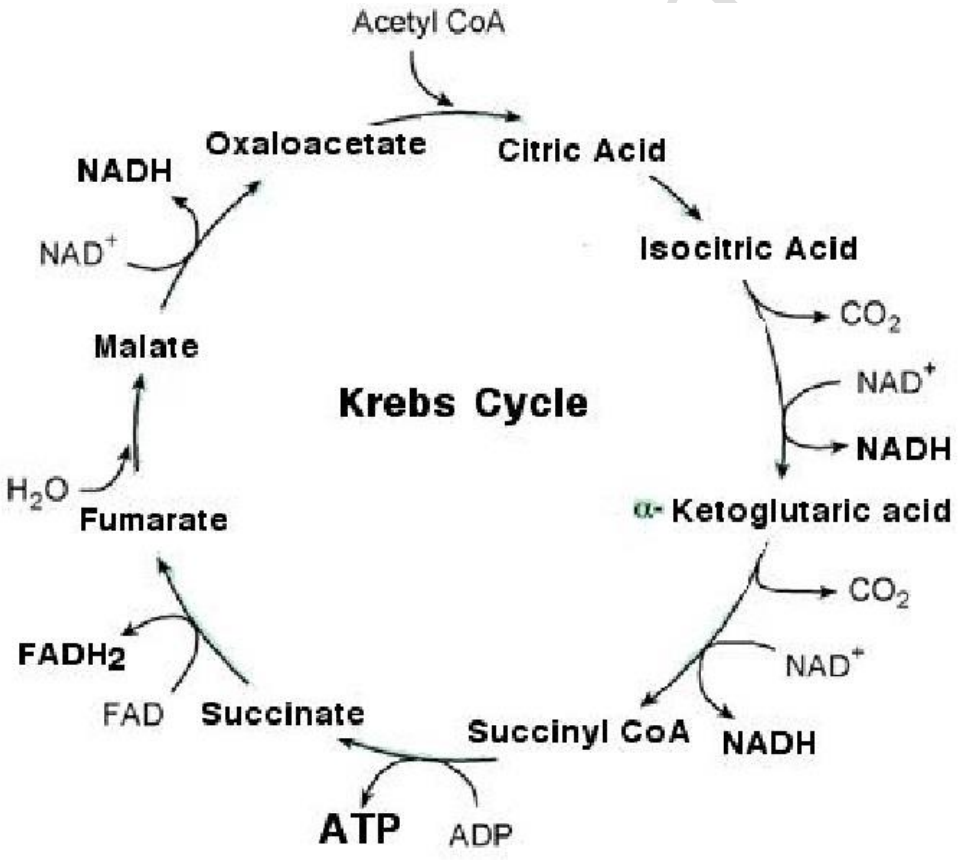
During aerobic conditions, pyruvic acid is transported across the mitochondrial membrane into the **matrix** where it is decarboxylated.

- First, the **pyruvate** is *decarboxylated* and then *oxidized* to form **acetate**, **carbon dioxide** and **($NADH+H^+$)**.
- The **acetate** combines with **coenzyme A** to form **acetyl coenzyme A**, making the acetyl group *very reactive*.
- Acetyl coenzyme A now joins the Krebs cycle where it is further oxidized to release more energy.
- In the Krebs cycle, acetyl CoA reacts with oxaloacetate a 4C compound to form citrate, a 6C compound.
- Coenzyme A is reformed and may be used to combine with another acetate molecule from pyruvate.
- Citrate isomerises to form isocitrate, a more reactive molecule by addition and removal of a water molecule.
- The isocitrate is oxidized by ($NAD^+$) to ($NADH+H^+$) and then decarboxylated by loss of carbon dioxide to form a-ketoglutarate
- The a-ketoglutarate loses a carbon dioxide molecule and oxidized by ($NAD^+$), the remaining product reacts with coenzyme A to form a 4C compound, succinyl CoA, which is unstable.
- The CoA is displaced, ATP is formed and a more stable 4C compound, succinate forms.

- The succinate is oxidized by removal of two hydrogen atoms by (Flavine adenine dinucleotide) FAD, to form $FADH_2$. Fumarate is formed.
- Addition of a water molecule to the fumarate results into formation of malate, a 4C compound.
- Malate is oxidized by $NAD^+$ to regenerate oxaloacetate. ($NADH+H^+$) is also formed

**SUMMARY**




**Krebs cycle results into the formation of 3 molecules of NADH and one molecule of $FADH_2$**

From the Krebs cycle, one ATP molecule is made directly by substrate level phosphorylation from each pyruvate molecule that enters the cycle. For one glucose molecule thus, two ATP molecules are formed.

## Role of coenzyme A

- Activates acetate so that more energy can be obtained from it
- Transfers the acetyl group formed from pyruvate to combine with 4C compound oxaloacetate, forming 6C compound citrate. This reaction is catalysed by the enzyme citrate synthatase.
- Provides a pathway by which fatty acids and proteins can be used as respiratory substrates via a central link of acetyl coenzyme A.

<u>ACETYL COENZYME A as a central metabolic intermediate</u>

❖ Before joining the Krebs cycle, glucose, lipids (fatty acids) and proteins are first converted to a metabolic intermediate **acetyl CoA**. This is important because it enables the body to have a wide range of respiratory substrates.

❖ Acetyl CoA also serves as the starting point for the anabolic synthesis of fatty acids.



**Importance of Krebs cycle**

✓ Brings about degradation of macromolecules; 3 carbon pyruvate is broken down to carbon dioxide

✓ It is a source of hydrogen atoms which are transferred to the electron transport system so that more energy can be harnessed from them

✓ It is a valuable source of intermediate compounds used in the manufacture of other substances e.g. fatty acids, amino acids and chlorophyll

***Similarities between glycolysis and Krebs cycle***

- ❑ In both, $NADH+H^+$ is formed
- ❑ In both, ATP is formed
- ❑ Both involve reduction in number of carbon atoms of initial substrate
- ❑ Both are enzyme catalysed
- ❑ Both occur in living cells

***Differences between glycolysis and Krebs cycle***

| **GLYCOLYSIS** | **KREBS CYCLE** |
|---|---|
| Electron acceptor FAD not involved | Electron acceptor FAD involved |
| Carbon dioxide not formed | Carbon dioxide formed |
| Occurs in cytoplasm of cell | Occurs in mitochondrial matrix |
| Doesn't require oxygen availability to occurs | Requires oxygen to occur |
| Doesn't involve coenzyme A | Involves coenzyme A |



**ELECTRON TRANSPORT SYSTEM (ETS)**

This a system of electron carrier molecules embedded in the **cristae** (inner membrane of mitochondria). The ETS couples the transport of electrons to the flow of hydrogen ions into the intermembrane space, creating a proton gradient which drives ATP synthesis by **chemiosmosis**.

Most electron carrier molecules in the electron transport system are proteins existing in **multi protein complexes**; I to IV with prosthetic groups essential for action of enzymes tightly attached.

Examples of prosthetic groups present include;

i. Flavine mono nucleotide (FMN)

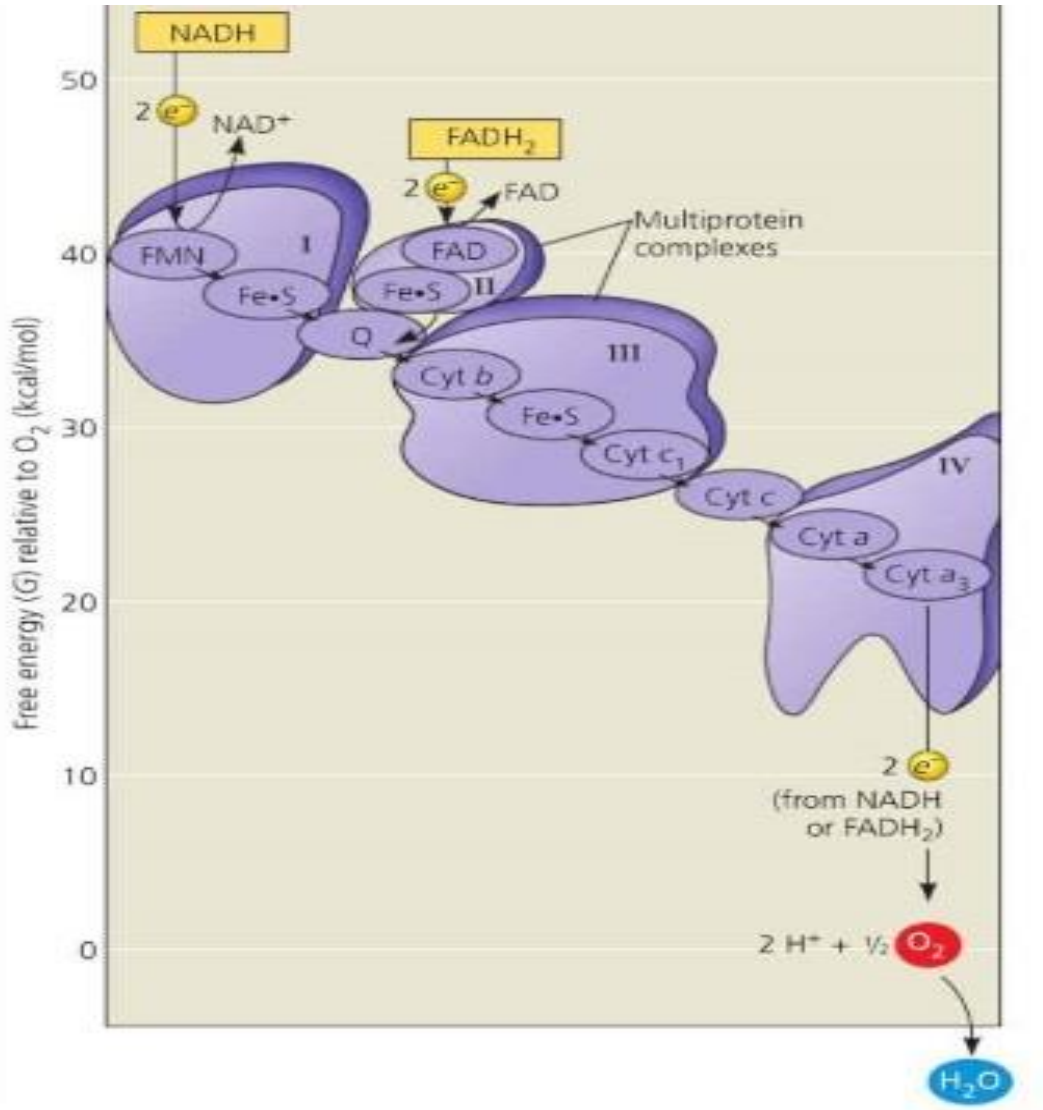
ii. Iron-sulphur (Fe.S)

iii. Haem (contains iron); found in electron carrier proteins called **cytochromes.**

Description of ETS

- Electrons removed from glucose during glycolysis and from Krebs cycle by coenzyme ($NAD^+$) are transported by NADH to electron carrier FMN in complex one, at a higher energy level. The electron carrier is thus reduced.
- Reduced FMN becomes oxidized again when it passes on its electrons to iron-sulphur protein, another electron carrier in complex I, which is thus reduced.
- The iron-sulphur electron carrier protein now becomes oxidized when it passes on its electrons to ubiquinone (cytochrome Q) which is not a protein, reducing it.
- Ubiquinone becomes oxidized when it passes on its electrons to cytochrome b which is itself oxidized. The cytochrome b in protein complex III is at a lower energy level, but more electronegative than ubiquinone, Fe.S and FMN.
- Electrons are passed on successively down a series of cytochromes during a series of redox reactions, from cytochrome $C_1$, cytochrome C, cytochrome a, with the last one in protein complex IV being cytochrome $a_3$.
- The final electron acceptor, which more electronegative than all the electron carriers is oxygen and it receives the electron and combines with hydrogen to form water.
- Another source of electrons from the Krebs cycle is $FADH_2$,however, since it joins the electron transport chain at a lower energy level than NADH i.e. at protein complex II, it yields a third less energy than NADH

NB: The Krebs cycle and electron transport system can only occur if oxygen is available since oxygen is the final electron acceptor




Is the ETS a sequence?

- The E.T.S is not a sequence even though it is demonstrated for clarity in texts as a sequence.
- The complexes and carriers are not locked in place.
- Each complex moves independently of another and electron flow occurs when they are in close proximity

**CHEMIOSMOSIS**

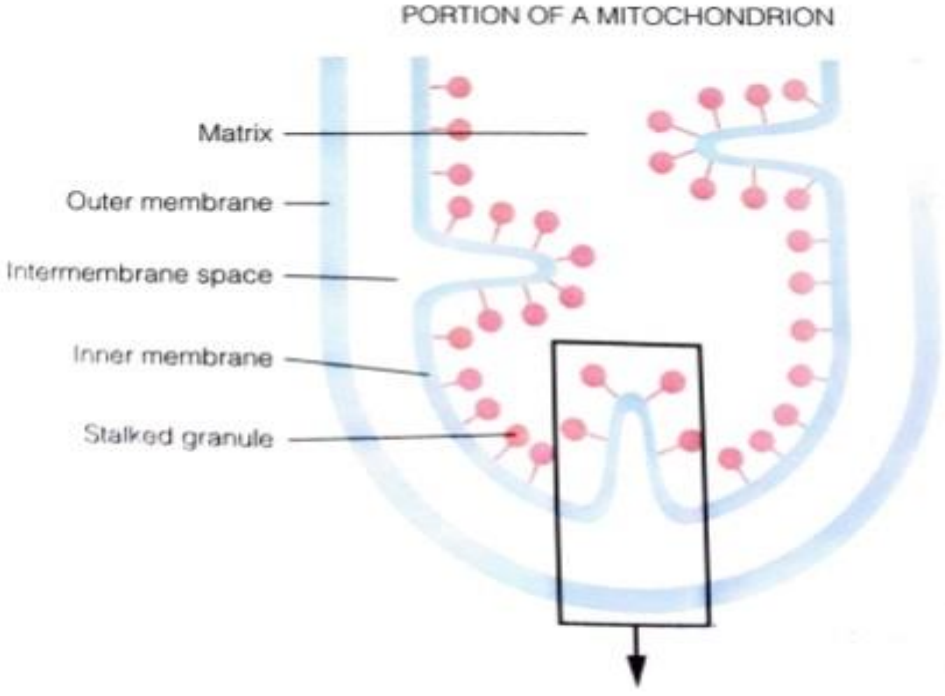
This is the process by which a hydrogen ion gradient generated across the inner mitochondrial membrane is used to provide energy for ATP synthesis.

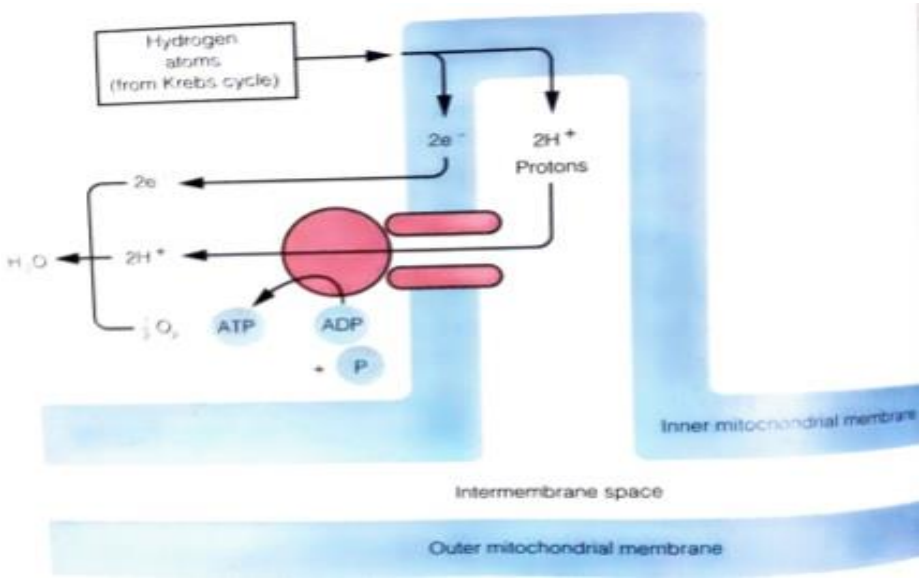
*ATP synthesis during the electron transport chain is by oxidative phosphorylation since the hydrogen ion gradient across the membrane couples oxidation in the ETS to ATP synthesis.*

## DESCRIPTION OF CHEMIOSMOSIS

- As electrons flow from one electron carrier to the next, energy is generated which is used to pump protons from the matrix of the mitochondrion into the intermembrane space.
- Protons accumulate such that a steep proton gradient develops between the intermembrane space and the matrix.
- The cristae is generally impermeable to protons.
- protons can only move down their electrochemical gradient through stalked granules embedded in the membrane which are basically enzymes i.e ATP synthase
- The energy generated due to flow of protons down their electro-chemical gradient is used by the enzyme at its bulbous end to synthesize ATP from ADP and inorganic phosphate

$$ADP + P_i \xrightarrow{\text{ATP SYNTHASE}} ATP$$

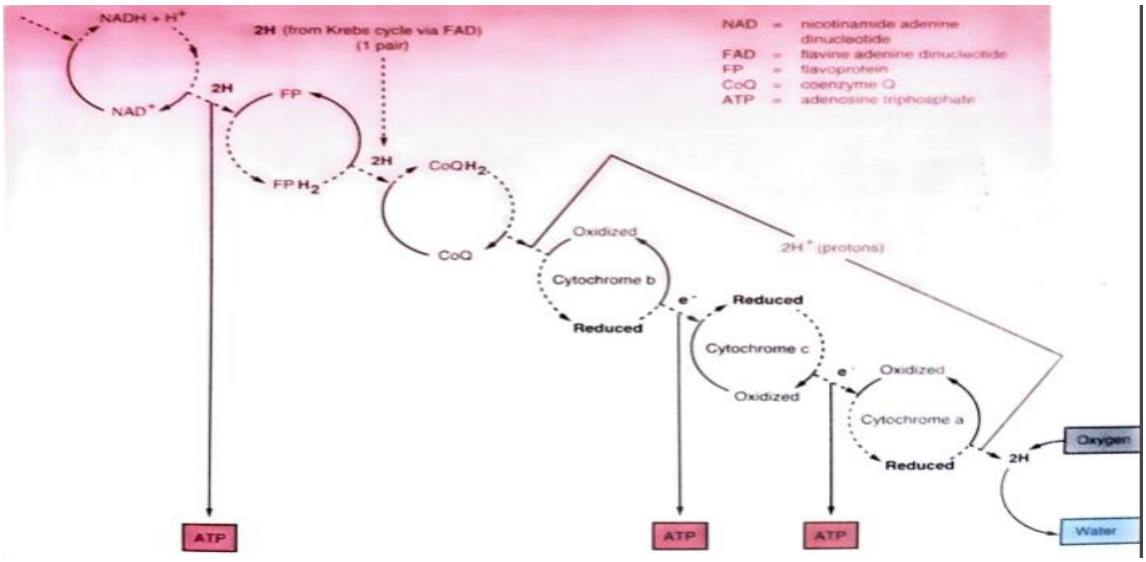





## NUMBER OF ATP MOLECULES GENERATED FROM ONE GLUCOSE MOLECULE DURING CHEMIOSMOSIS

- One ATP molecule is generated from each proton activated in the electron transport chain.
- Electrons from NADH activate 3 proton channels, 3ATP molecules are synthesized.
- Electrons from $FADH_2$ activate 2 proton channels thus only 2ATPs are synthesized.

The illustration below shows flow of electrons from NADH and $FADH_2$



**An account of ATPs from ETS per glucose molecule**

| SOURCE OF ELECTRONS | NUMBER OF ELECTRON CARRIERS | NUMBER OF ATPS FORMED |
|---|---|---|
| GLYCOLYSIS | 2 NADH | 6 |
| KREBS CYCLE | 2 NADH | 4 |
| | 6 NADH | 18 |
| PYRUVATE DECARBOXYLASE | 2 NADH | 6 |
| TOTAL | | 34 |

**Yield of ATP from substrate level phosphorylation**

| PROCESS | NUMBER OF ATPS |
|---|---|
| GLYCOLYSIS | 2 ATPS |
| KREBS CYCLE | 2 ATPS |
| TOTAL NUMBER OF ATPS | 4 ATPS |

Work out question

Calculate the total number of ATPs produced in aerobic respiration?

Reasons why the actual yield of ATP is less than 38

i. The inner mitochondrial membrane allows some protons to re-enter the matrix without passing through ATP-generating channels.

ii. Mitochondria often use the proton gradient generated by chemiosmosis for other purposes other than ATP synthesis e.g. transporting pyruvate into the matrix. As a result, ATP molecules generated are close to 2.5 for each NADH and 1.5 ATPs from each $FADH_2$

## ANAEROBIC RESPIRATION

This is a process by which organic materials such as sugars are broken down to release ATP without oxygen.

Generally, less energy is obtained from anaerobic respiration than from aerobic respiration. This is because less (no) oxidative phosphorylation takes place in anaerobic conditions, yet most of the ATP is formed from oxidative phosphorylation.

In anaerobic respiration of some *prokaryotes* however, some oxidative phosphorylation occurs such that more ATP is synthesised by using an *electron transport chain* that has $\boldsymbol{SO_4^{2-}}$ as the final electron acceptor. However fewer ATP molecules of formed as compared to aerobic respiration since oxygen is *much more electronegative.*

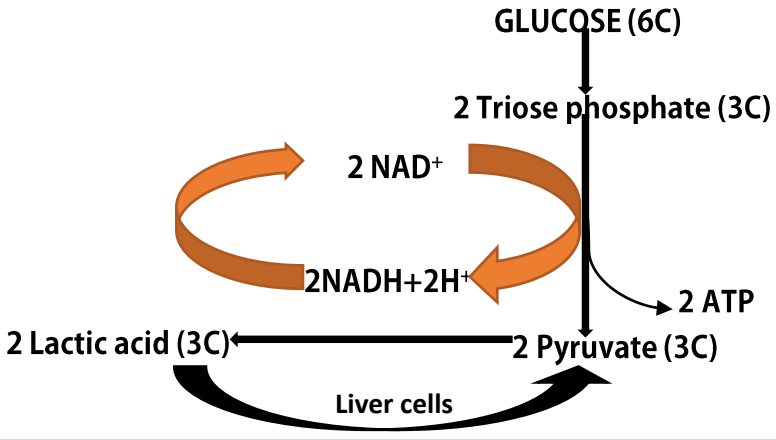
Another form of respiration without oxygen is **fermentation.** During fermentation, there is no electron transport chain present, therefor, *Krebs cycle* and *ETS* ***do not*** occur. The ATPS are formed exclusively by **substrate level phosphorylation** during **glycolysis,** for which only 2ATPs are formed per glucose molecule as compared to the 38 ATPs expected in aerobic conditions.

There are many types of fermentation but the two common types based on the product formed at the end of the process;

a) Lactic acid fermentation.
b) Alcohol fermentation (plant & fungi cells)

**a) Lactic acid fermentation.**

Here, in anaerobic conditions, the pyruvate formed is reduced directly by NADH to form lactic acid (lactate). No carbon dioxide is formed. The $NAD^+$ formed enabled continuation of glycolysis.



In human muscle cells, during strenuous exercise in which more ATP is required at a faster rate than rate of oxygen delivery, muscle cells resort to lactate fermentation to form more ATP molecules at a faster rate.

The excess lactate is transported gradually to the liver where in presence of oxygen, it can be converted back to pyruvate in liver cells.

**Significance of lactic acid fermentation**

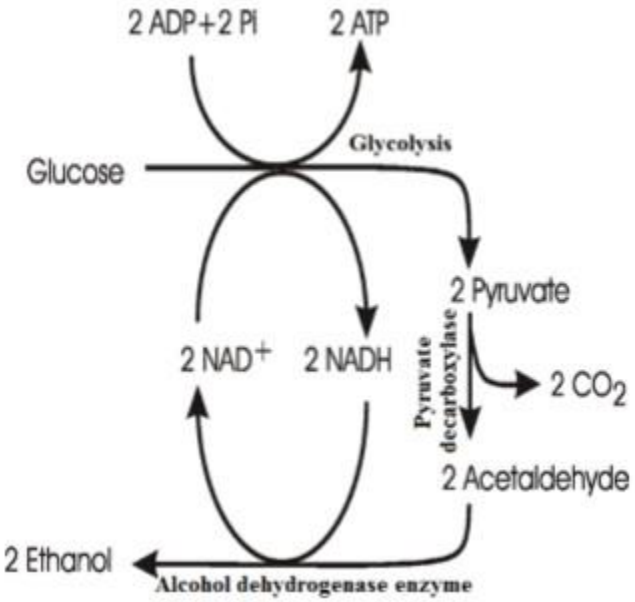
- ❖ Enables rapid formation of ATP for muscle contraction in skeletal muscles when oxygen is scarce
- ❖ Lactic acid fermentation in certain fungi and bacteria used in dairy industry to make cheese and yoghurt.

**b) Alcohol fermentation**

Here, the pyruvate is converted to ethanol in two steps;

i. Pyruvate is decarboxylated to give ethanal (acetaldehyde) and carbon dioxide. Reaction is catalysed by *pyruvate decarboxylase*
ii. The acetaldehyde formed is then reduced by NADH to form ethanol and $NAD^+$. Reaction catalysed by alcohol dehydrogenase.

The $NAD^+$ that is regenerated is essential for the continuation of glycolysis.




**Significance of alcohol fermentation**

- ❖ Enables brewing of alcohol using yeast cells
- ❖ Carbon dioxide produced by baker's yeast allows dough/bread to rise

## Industrial applications of fermentation

- ✓ In brewing industry, fermentation of sugars results into formation of alcoholic drinks like wines and spirits
- ✓ In baking industry, yeast fermentation results into production of carbon dioxide which rises the dough
- ✓ Industrial lactic acid fermentation results into formation of yoghurt and cheese
- ✓ Anaerobes such as bacteria are used in sewage treatment plants to break down solid and semi-solid waste.

## Comparison between aerobic respiration and fermentation in cells

### *Similarities*

- ATP is produced in both
- In both, glycolysis results into formation of pyruvate
- In both $NAD^+$ oxidizes glucose to form pyruvate
- Both involve phosphorylation of glucose to raise its energy level

### *Differences*

| AEROBIC RESPIRATION | FERMENTATION |
|---|---|
| Requires oxygen for ATP formation | Oxygen not required for ATP synthesis |
| Net production of 38 ATPs per glucose molecule | Net production of 2ATPs per glucose molecule |
| Occurs in cytosol and mitochondria | Occurs in cytosol |
| Complete oxidation of sugar | Incomplete oxidation of sugar |
| Water formed | Water not formed |
| Does not involve respiratory chain | Involves respiratory chain |
| Acetyl Co A formed as intermediate product | Acetyl Co A not formed as intermediate product |



## ALTERNATIVE RESPIRATORY SUBSTRATES

### Fructose

Availed from fruit diet and the digestion of sucrose. In muscles and kidneys, fructose is phosphorylated to form fructose-6-phosphate which joins glycolysis, reaction catalysed by hexokinase enzyme.

In liver cells, fructose is phosphorylated to form fructose-1-phosphate, catalysed by fructose kinase enzyme. The fructose-1-phosphate splits to form glyceraldehyde-3-phosphate and dihydroxyacetone phosphate both of which join the glycolysis pathway.

**Galactose**

Mostly obtained from digestion of lactose. Galactose is phosphorylated to form Galactose-1-phosphate which is then converted to glucose-1-phosphate which then joins glycolysis pathway.

This is part of Galactose pathway and inability to metabolise Galactose thus results into galactosaemia.

**Lipids (fats and oils)**

Fats are digested to form fatty acids and glycerol.

**Glycerol**

The glycerol is phosphorylated and dehydrogenated by $NAD^+$ to form glyceraldehyde-3-phosphate which joins the glycolysis pathway.

**The fatty acids**

Most of the energy of fats is in the fatty acids. Beta oxidation of the fatty acids occurs such that it is broken down into fragments of 2 carbon compound in the matrix of a mitochondrion forming acetyl CoA which joins the Krebs cycle

Metabolism of fatty acids yields a high quantity of hydrogen ions and electrons which are fed into the ETS pathway via carriers such as NADH and $FADH_2$. This explains why a given mass of fat yields more ATP (energy) than the same mass of carbohydrate.

**Proteins**

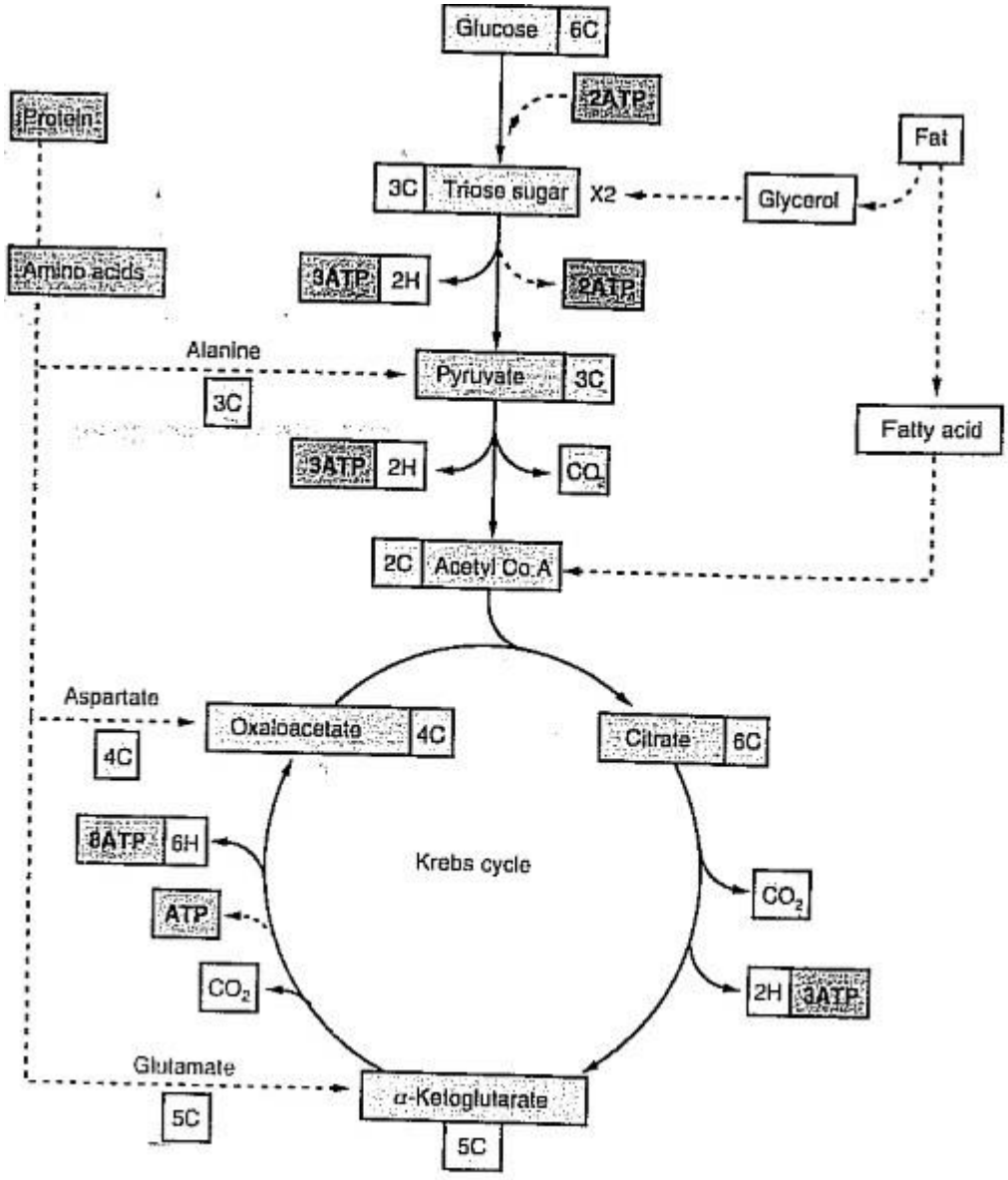
They are first digested to form amino acids. The amino acids are deaminated to remove the amino group which is excreted. The remaining amino acid portion is converted into an intermediate under catalysis by enzymes such that it joins the glycolysis pathway or the Krebs cycle depending on the number of carbon atoms it contains.

- 3 carbon intermediates from amino acids such as alanine form pyruvate and then form acetyl CoA in glycolysis pathway.

- 4 carbon intermediates from amino acids like aspartate form oxaloacetate which joins the Krebs cycle.
- 5 carbon intermediates from amino acids like glutamic acid form α-ketoglutarate which joins the Krebs cycle
- Large chain amino acids undergo transamination reactions to form 3C, 4C and 5C amino acids.

NB: The compounds made as intermediates for glycolysis and Krebs cycle can be used in anabolism to form compounds required by cells.

<u>The illustration below shows a summary of the intermediates fed into glycolysis and Krebs cycle.</u>



## REGULATION OF CELLULAR RESPIRATION

Regulation of cellular respiration is by negative feedback inhibition mechanism. During this mechanism, the end product of a metabolic pathway inhibits an enzyme that catalyses an early step in the pathway.

Negative feedback inhibition mechanism prevents cells from wasting energy and vital intermediates (metabolites).

In ATP synthesis, the enzyme phosphofructokinase, which is an allosteric enzyme with receptor sites for both ATP and AMP is key.

When the cell is working hard and ATP is quickly depleted such that more ADP and AMP. The AMP attaches to phosphofructokinase enzyme, activating it to speed up synthesis of more ATP.

However, when there is more ATP in the cell, than being used by the cell, the ATP binds to the phosphofructokinase enzyme, inhibiting its activity.

Phosphofructokinase is also sensitive to citrate. A high citrate concentration inhibits enzyme activity such that glycolysis reduces and less acetyl CoA is supplied to the matrix of mitochondria.

A reduction in the concentration of citrate due to its use in Krebs cycle results into an increase in the rate of glycolysis to supply the required acetyl group.

*External factors that affect the rate of respiration*

### a) Temperature

Low temperature results into increase in respiration rate. The increased rate of respiration is to provide much needed heat to ensure optimum temperature for enzyme activity. However, extremely low temperature will result into decrease in respiration rate

High temperature generally results into low respiration rate and this explains sluggishness of most animals at high environmental temperature in tropics, however, beyond high critical temperature of an organism, further increase in temperature results into increased metabolic rate (respiration rate).

### b) Body size

Smaller organisms with a larger surface area to volume ratio lose heat faster than larger organisms thus have a higher respiration rate.

**c) Level of activity**

More active organisms have a higher respiration rate to enable supply of much needed ATP as compared to less active ones.

**d) Growth**

Organisms or parts of organisms that are actively undergoing growth have a higher respiration rate as compared to dormant organisms or those in senescence.

**RESPIRATORY QUOTIENT (RQ)**

This is a measure of the ratio of carbon dioxide evolved to the oxygen consumed by an organism at the same time period.

$$RQ = \frac{Volume\ of\ carbon\ dioxide\ evolved}{Volume\ of\ oxygen\ taken\ in}$$

**RQ for hexose sugar like glucose**

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$

$RQ = \frac{6CO2}{6O2}$

RQ = 1.0

**RQ for fats**

Fats have a lower proportion of oxygen to carbon thus require more oxygen for complete oxidation during respiration. This results into an RQ value of less than 1.

$C_{18}H_{36}O_2 + 26O_2 \longrightarrow 18CO_2 + 18H_2O$

**Stearic acid**

$RQ = \frac{18CO2}{26O2}$

RQ = 0.7

**RQ for proteins**

Proteins do not have a uniform RQ value. Their RQ however varies from 0.5 to 0.8. The lack of a uniform RQ is mainly due to variation in composition of proteins.

In the body, not a single food substrate is respired but since proteins are respired during periods of starvation, the main respiratory substrates are sugars and fats. These give an RQ of 0.8 or 0.9 in animals at rest

NB: RQ during anaerobic respiration is infinite.

**SUMMARY OF THE POSSIBLE INTERPRETATIONS OF R.Q VALUES:**

| Subject | R.Q. | Possible interpretations |
|---|---|---|
| Germinating starchy seeds<br>Leaves rich in carbohydrate | 1.0<br>1.0 | Complete oxidation of a carbohydrate substrate |
| Wheat seedlings in nitrogen | ∞ | Anaerobic respiration |
| Germinating seeds | 0.64 | Oxidation of a fatty substance |
| Germinating peas (testa intact) | 3.0 to 4.0 | Slow entry oxygen causing some anaerobic respiration |
| Germinating peas (testa removed) | 1.5 to 2.5 | More rapid entry of oxygen, but some anaerobic respiration |
| Man (average) | 0.8 to 0.85 | Mixed fat and carbohydrates substrate |
| *Lumbricus terrestris* | 0.75 | Mainly fat substrate |
| *Drosophila* (at rest) | 1.23 | Conversion of carbohydrate to fat / organic acids : excess $CO_2$ produced by decarboxylation |
| *Drosophila* (flying) | 1.0 | Complete oxidation carbohydrate |
| Nerve tissue (resting) | 0.77 | Possibly mainly fat substrate |
| Nerve tissue (active) | 0.97 | Almost entirely carbohydrate substrate |

TRIAL QUESTIONS

1) Table **1** shows the relative contribution of aerobic and anaerobic respiration to the total energy output in an individual during exercise.
**TABLE 1**

| **Duration of exercise (min)** | Relative contribution of energy (%) | |
|---|---|---|
| | **From aerobic respiration** | **From anaerobic respiration** |
| **0.5** | **83** | **17** |
| **2.0** | **40** | **60** |
| **10.0** | **9** | **91** |
| **60.0** | **1** | **99** |

a) Compare the relative contribution of aerobic and anaerobic respiration to the total energy output, with duration of exercise (03 marks)
b) Explain the changes in relative contributions of aerobic and anaerobic respiration with duration of exercise. (04 marks)

c) Explain why diving mammals have a reduced heart beat rate. (03 marks)

2) a) Differentiate between aerobic and anaerobic respiration. (05 marks)

b) Describe what happens to end products of glycolysis in absence of oxygen. (10 marks)

c) Why is it important to produce ATP during cellular respiration? (05 marks)

3. An experiment was carried out to investigate the rate of respiration in yeast cells mixed with three different carbohydrates (glucose, sucrose and lactose), using methylene blue as an indicator. (Methylene blue is blue in alkaline conditions and colourless in acidic condition)

$1cm^3$ of 0.1M methylene blue was added to a mixture of $5cm^3$ of a suspension of yeast in $10cm^3$ of 0.5% glucose solution in a boiling tube. The boiling tube was placed in a water bath at $30^oC$ for 20 minutes. The rate of respiration was measured as a percentage of the intensity of the blue colour at the beginning of the experiment at intervals of 2 minutes. The experiment was repeated using 0.5% sucrose and lactose. The results are shown in figure **2**. Study the figure and answer the questions that follow.

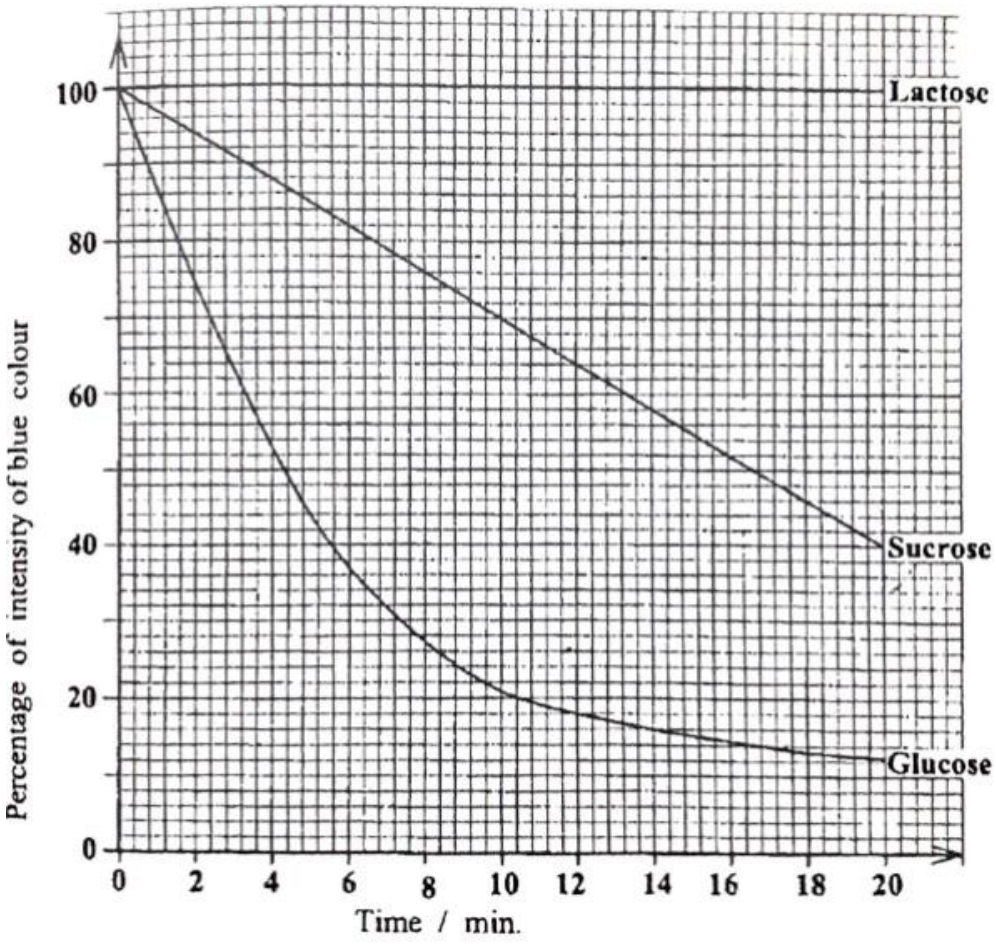



**Fig. 2**

a) Calculate the average rate of respiration of yeast in glucose solution during rst four minutes in terms of percentage intensity of the blue colour. (3 marks)

b) Describe the changes in the intensity of the blue colour with time, for each carbohydrate. (05 marks)

c) Explain the relationship described in (b) foe each carbohydrate.

i. Lactose (03 marks)

ii. Sucrose (05 marks)

iii. Glucose (08 marks)

d) Suggest what would happen to the colour for glucose and sucrose if the experiment continued for 10 more minutes. Give an explanation in each case. (10 marks)

e) Explain why the boiling tubes were

i. Kept covered during the experiment (03 marks)

ii. Placed in a water bath at 30$^{o}$C