RESPIRATION

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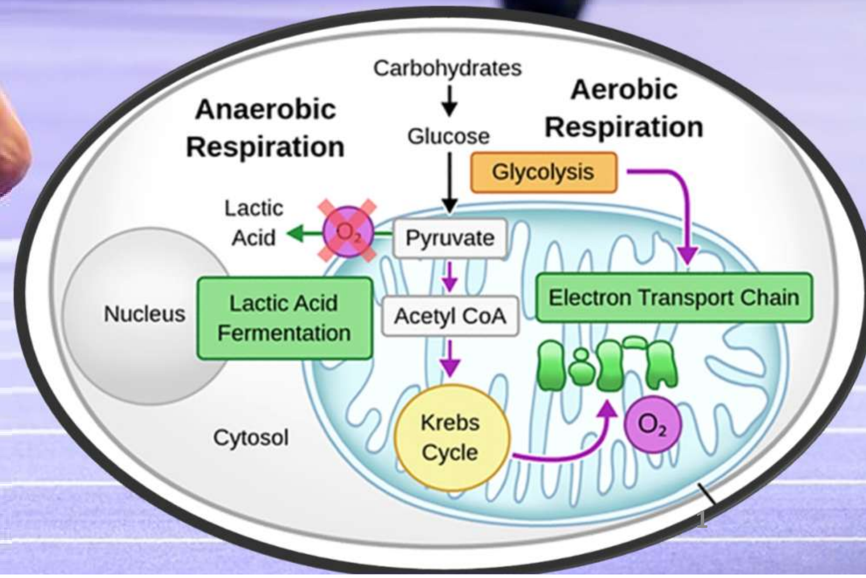
S.5 BIOLOGY



LEARNING OUTCOMES.

The learner should be able to;

❖Examine the relationship between the structure of the mitochondrion and the stages of cellular respiration in living organisms. (u, s)

❖Analyze the biochemical processes leading to ATP production in living organisms, and how these processes are affected by physical activities and respiratory poisons (cyanide). (u, s, gs, v/a).

CELLULAR RESPIRATION

- A series of enzyme catalyzed reactions in living cells during which ***complex organic substances are broken down to release energy*** in ***form of adenosine triphosphate (ATP).*** ***OR***
- A series of enzyme catalyzed reactions in living cells during which the ***chemical-bond energy of complex organic substances is released*** and ***converted into adenosine triphosphate (ATP).***

CHEMICAL ENERGY IN FOOD

- The **C-H** covalent bonds in organic substances formed by sharing pairs of fast-moving energetic electrons, and therefore ***contain potential energy***.
- The ***catalytic breakage of the C-H bonds releases energy***, some of which ***powers the formation of ATP***.
- The ***higher the C-H bonds, the more the energy yields***. This explains why lipids yield twice more energy than carbohydrates of same mass. Cellular respiration occurs in cell organelles called Mitochondria

RESPIRATORY SUBSTRATES

- Respiration involves oxidation of an organic compound i.e. Carbohydrates, fats and proteins.

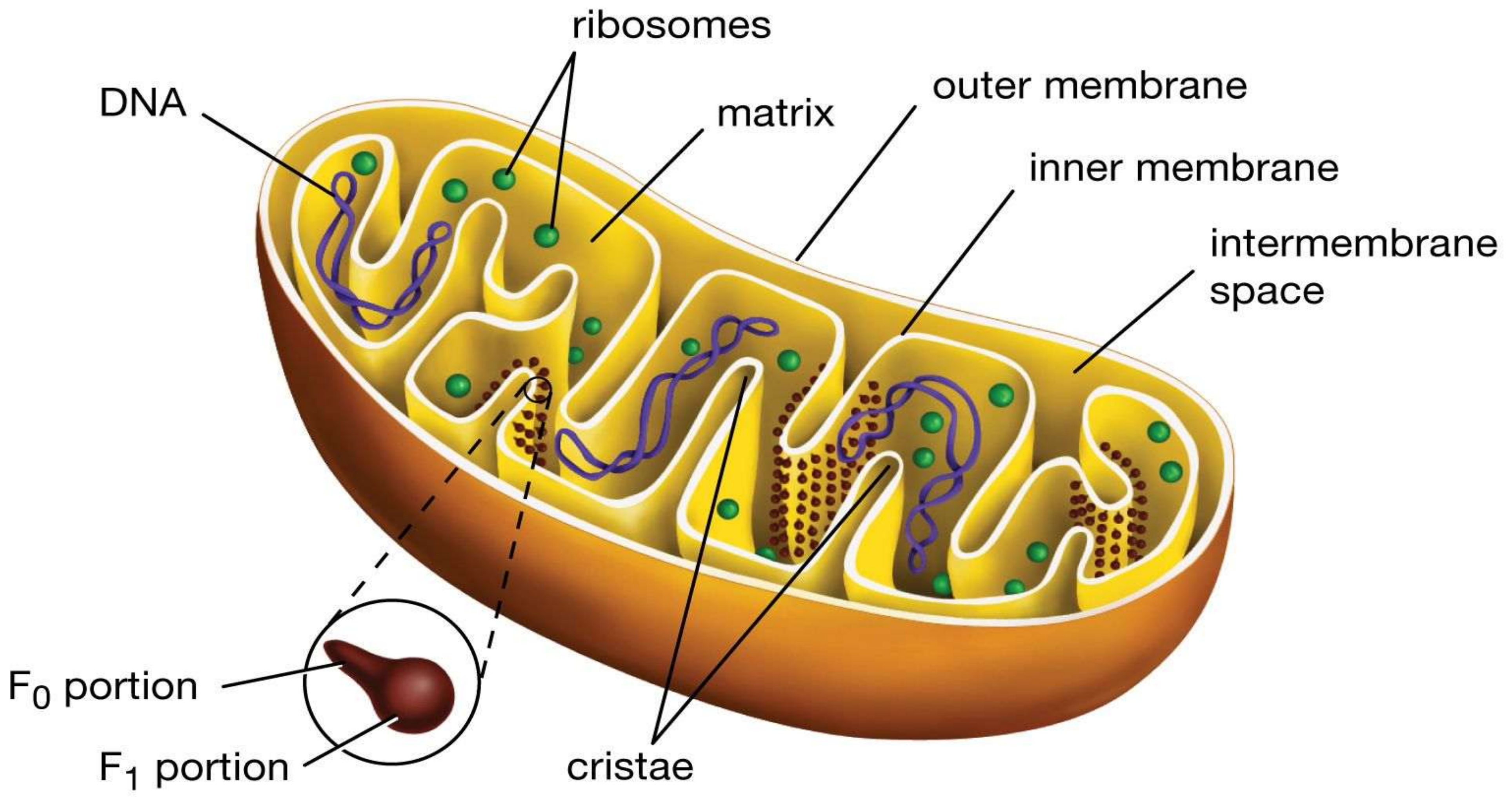
Carbohydrates. When these are available they are usually ***used first by most cells***. Polysaccharides such as starch (in plants) and glycogen (in animals and fungi) are hydrolyzed to monosaccharides before they enter the respiratory pathway.

Lipids (fats or oils). Lipids are ***used mainly when carbohydrate reserves have been exhausted***. They are first converted to glycerol and fatty acids which enter the respiratory pathway.

Proteins. Since proteins have other essential functions, they are ***only used when all carbohydrate and lipid reserves have been used up***, as during ***prolonged starvation***. Proteins are ***first hydrolyzed to amino acids*** and then ***deaminated*** (their amino groups are removed). The remaining acid can enter the Krebs cycle

STRUCTURE OF MITOCHONDRIA

- Mitochondria appear as ***rod-shaped or cylindrical organelle***, although occasionally they are more variable in shape.
- Each mitochondrion is ***bound by a double membrane***, the ***outer layer being a continuous smooth boundary.***
- Between the two membranes is the ***intermembrane space***. The inner membrane is ***extensively in folded to form partitions*** called **Cristae** (consisting of a head piece, stalk and base piece), which partially divide the interior.
- The Cristae in plants are ***commonly tubular and villus-like***. The inner membrane holds the oxysome and encloses are fluid filled space called the **Matrix**. The
- The matrix contains **enzymes** and **DNA**, the DNA directs or codes the synthesis of proteins and ***ribosomes in matrix*** for protein synthesis.



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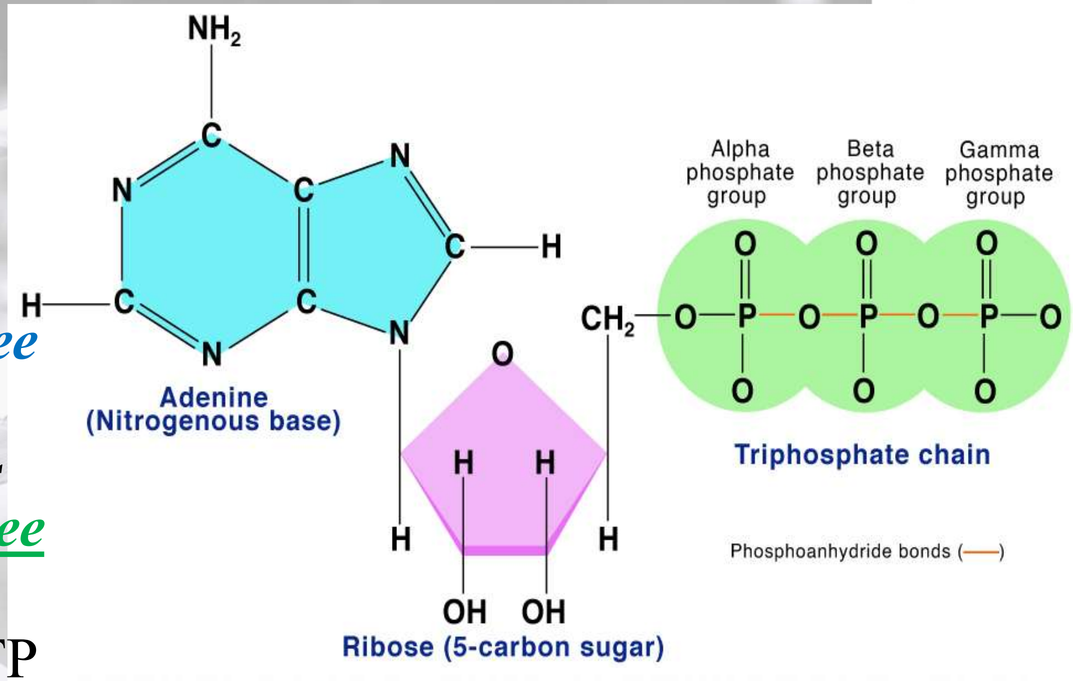
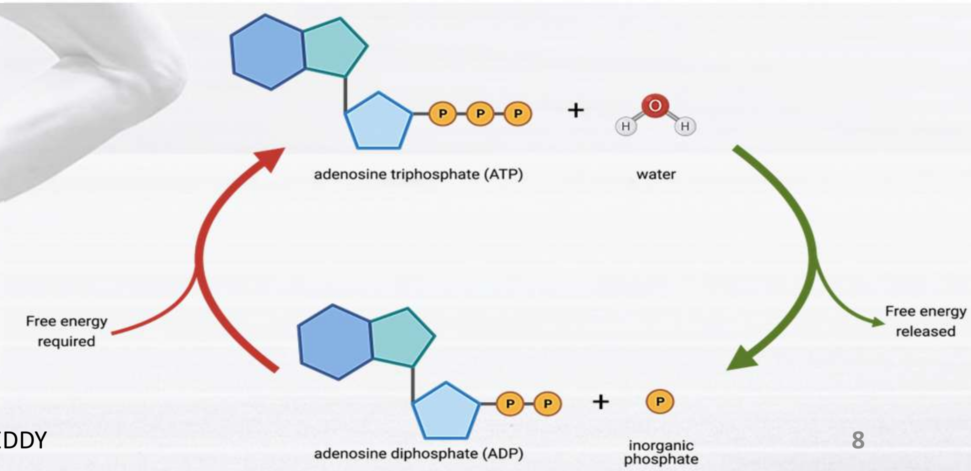
ADAPTATIONS OF THE MITOCHONDRION.

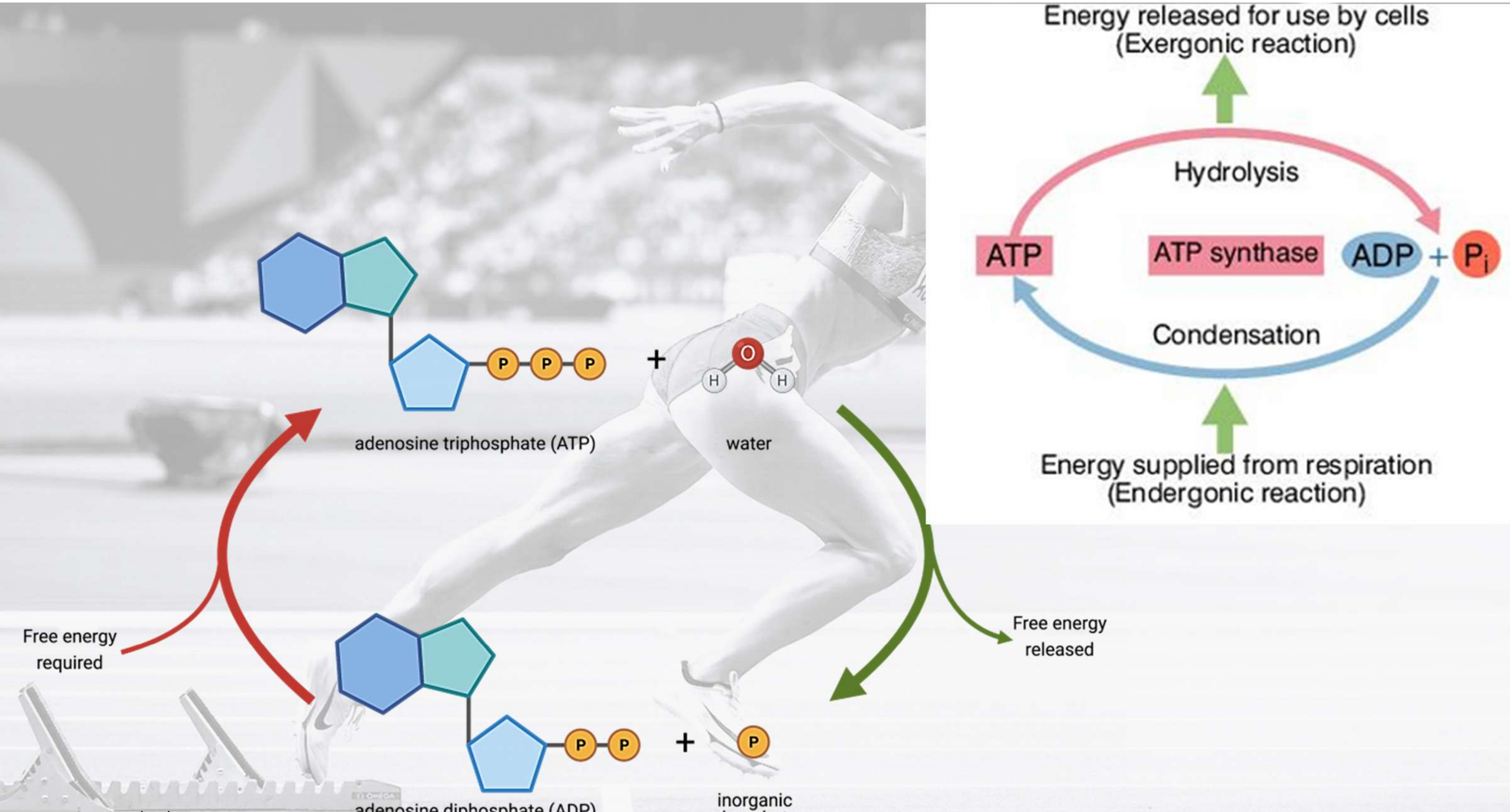
- ***Double membranes*** isolate the mitochondrion from ***interference by processes in the cytoplasm.***
- ***Small size*** gives ***large surface area to volume ratio for rapid uptake of respiratory substrates*** and release of products.
- ***Inner membrane is folded*** forming cristae to ***increase the surface area for electron transport chain.***
- The inner membrane has ***cristae with oxysomes*** that contain ***ATP synthetase (ATPase) on stalked particles that make ATP.***
- ***Narrow intermembrane space*** enables ***H+ ion concentration gradient to be rapidly established for chemiosmosis*** to occur hence generating ATP.
- Inner membrane contains ***molecules for electron transport pathway***
- ***DNA is present*** to ***code for synthesis of some proteins and enzymes*** that catalyze phosphorylation reactions.
- ***Many ribosomes*** for ***protein synthesis to reduce on importing proteins from cytoplasm.***

STRUCTURE OF ATP.

- ATP is the short-term energy store of all cells.
- It is made up of a molecule of ***adenine*** a nitrogenous base, a ***ribose*** sugar, and ***three phosphate molecules.***
- ATP is an energy carrier because ***it stores chemical energy***, which is ***released as free energy on hydrolysis.***
- Hydrolysis of the phosphate bonds in ATP to form ADP ***releases 30.6kJ of energy***.
- Further hydrolysis of the terminal phosphate bond of ADP to form adenosine monophosphate (AMP) yields 30.6kJmol, but hydrolysis of the phosphate in AMP ***is not feasible*** because ***releases very little energy***.






adenosine triphosphate (ATP)
+
water
Free energy required
Free energy released
adenosine diphosphate (ADP)
+
inorganic phosphate
Energy released for use by cells
(Exergonic reaction)
Hydrolysis
ATP
ATP synthase
ADP + P_i
Condensation
Energy supplied from respiration
(Endergonic reaction)

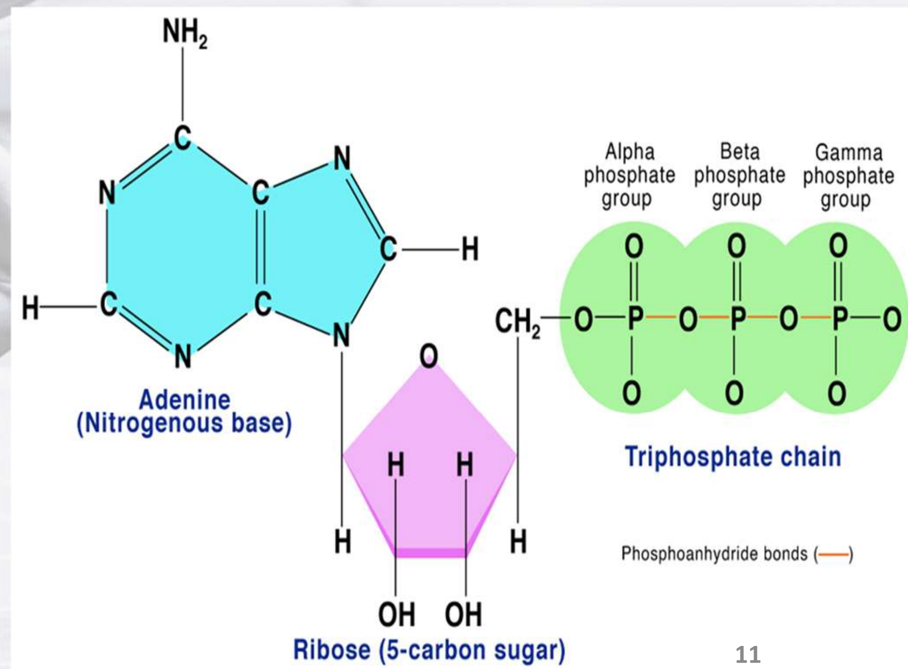
<u>***Uses of ATP.***</u>

A metabolically active cell ***may require up to two million ATP molecules every second***. ATP is the source of energy for:

- <u>***Anabolic processes***</u> - It provides the ***energy needed to build up macromolecules from their component units***, e.g. polysaccharide synthesis from monosaccharides ,protein synthesis from amino acids and DNA replication.
- <u>***Movement***</u> - It provides the energy for many forms of cellular movement including: ***muscle contraction***, ***ciliary action*** and ***spindle action*** in cell division.
- <u>***Active transport***</u> - It provides the energy necessary ***to move materials against a concentration gradient,*** e.g. ion pumps.
- <u>***Secretion-***</u> It is needed to ***form the vesicles necessary in the secretion*** of. cell products.
- <u>***Activation of chemicals***</u> **-** It ***makes chemicals more reactive***, enabling them to react more readily, e.g. the phosphorylation of glucose at the start of glycolysis.

Why ATP is used as an energy source.

- It doesn't diffuse out of the body cells
- It provides manageable quantities of energy in body cells
- It is readily hydrolyzed to release energy to body cells
- Releases exact amounts of energy required by cells.



ADP may be reconverted to ATP by ***the addition of phosphate molecules in a process*** called **Phosphorylation**, of which there are two main forms:

- ***Photophosphorylation*** — occurs during photosynthesis in chlorpplast- ***where ATP is generated using energy from light***.
- ***Oxidative phosphorylation*** — occurs during cellular respiration where ***ATP is generated using energy from oxidation of organic substances***. Cellular respiration is divided into three major stages that is to say:

➤ ***Glycolysis***

➤ ***Krebs cycle***

➤ ***Electron transport system.***

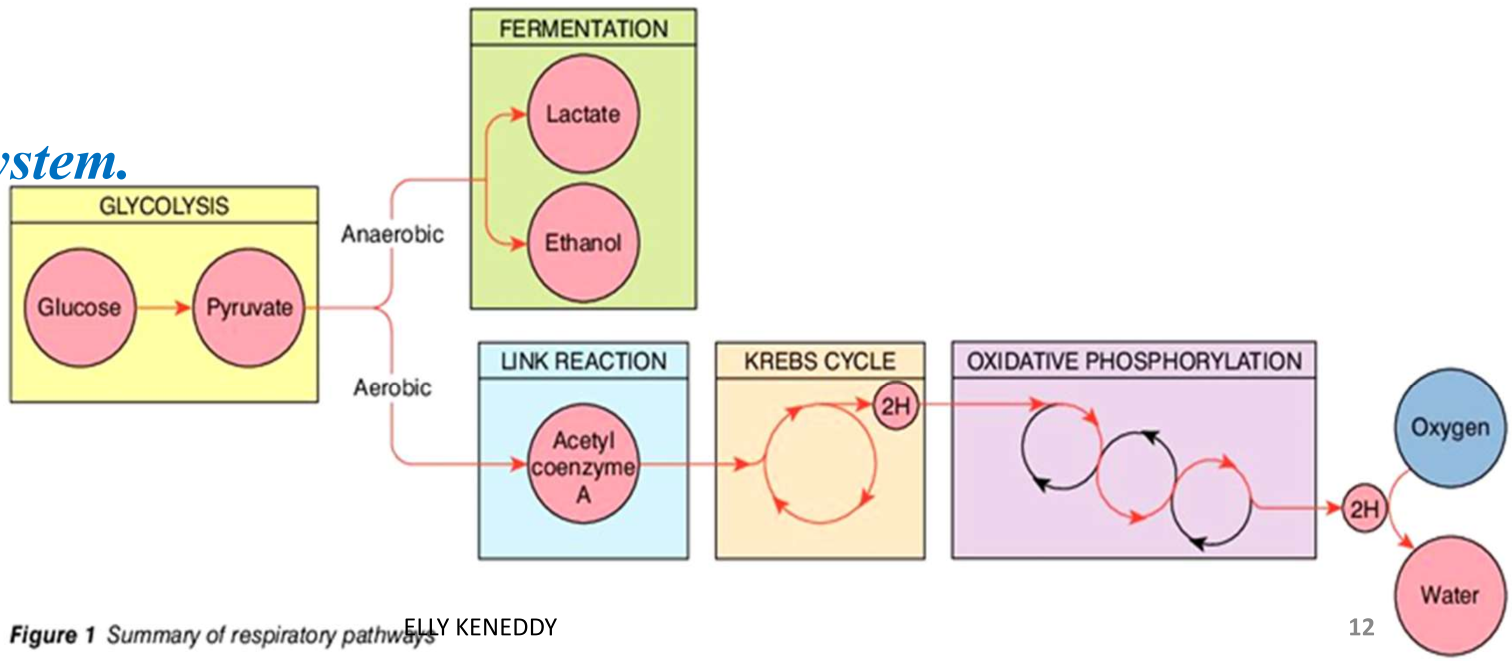
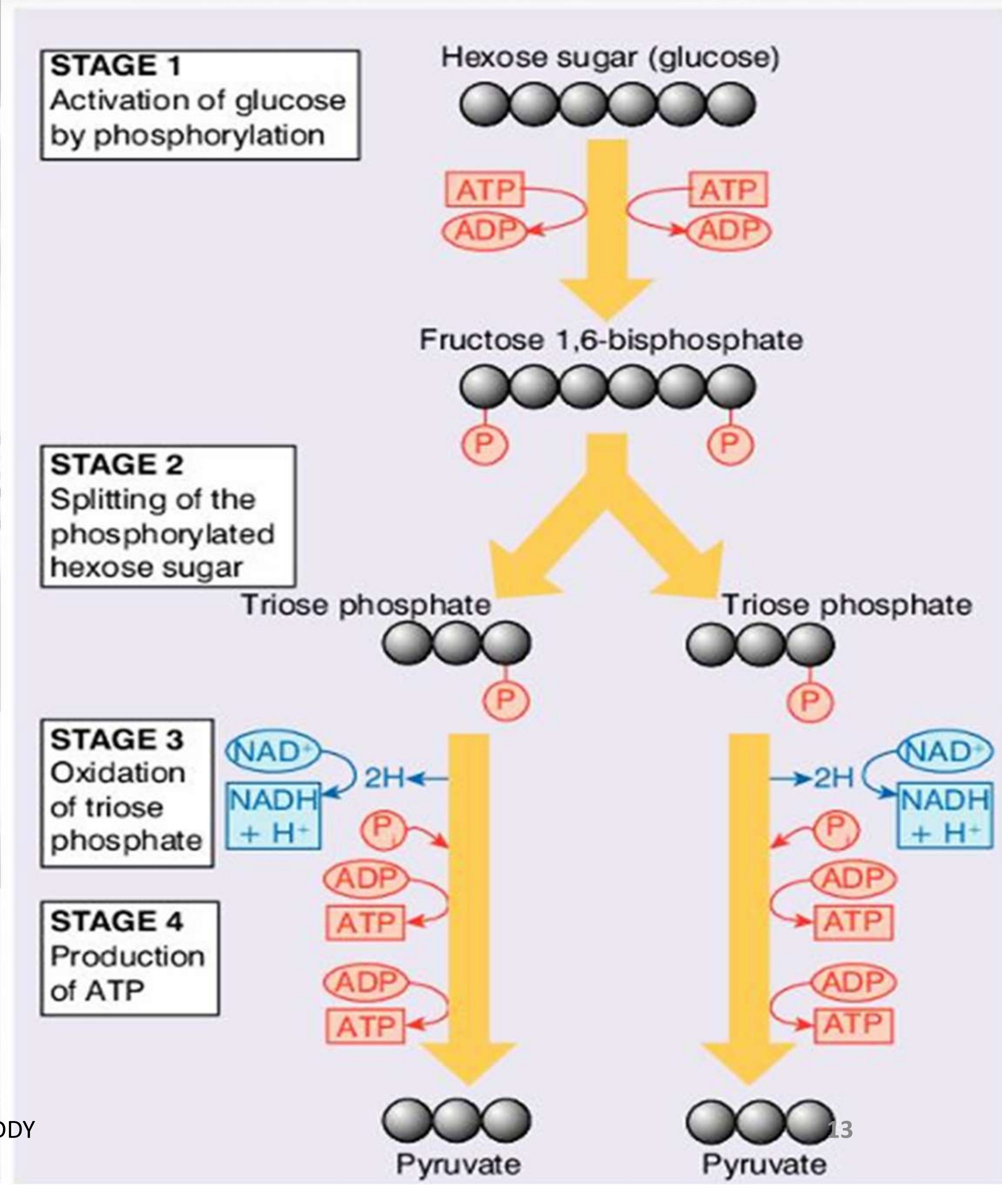


Figure 1 Summary of respiratory pathways

GLYCOLYSIS

- This is ***the process by which 6-carbon glucose*** molecules ***are converted into 3-carbon pyruvate molecules*** with a net out put of two ATP molecules.
- This occurs in the **cytoplasm** of both aerobic and anerobic cells.
- Glycolysis is divided into 3 main stages i.e.

1. ***Activation of glucose by phosphorylation***
2. ***Splitting/ lysis of activated sugar***
3. ***Oxidation of GP to produce ATP and reduced NAD.***

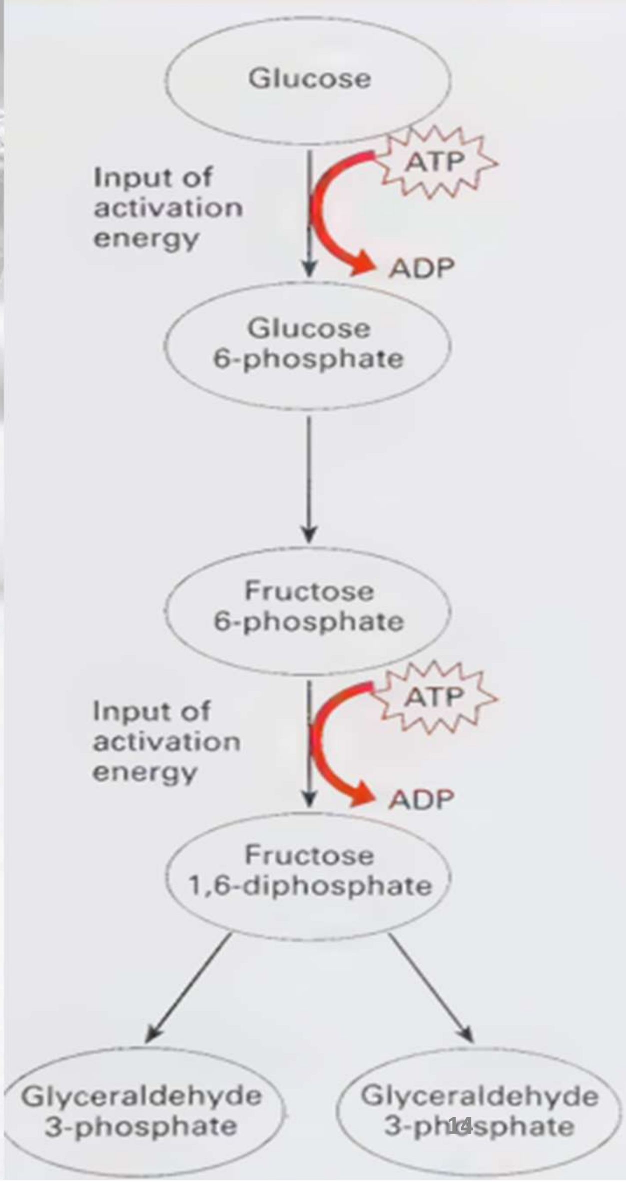


Phosphorylation of the sugar

- ***Glycolysis starts with phosphorylation of glucose by ATP*** to form **glucose-6-phosphate**.
- This process chemically activates glucose making it more reactive and ***traps glucose in the cell because the phosphate group bears a negative charge*** yet the cell membrane is impermeable to ions.
- Glucose-6-phosphate ***isomerizes to form*** **fructose-6-phosphate** to ease another Phosphorylation.
- Fructose-6-phosphate is ***phosphorylated by ATP*** to form **Fructose-1, 6-bisphosphate** (Fructose-1, 6-diphosphate)

Lysis

- Fructose-1, 6-bisphosphate ***splits at once into two molecules*** each with three-carbons i.e. **Glyceraldehyde 3 phosphate** and **Dihydroxyacetone**, which isomerizes into Glyceraldehyde 3 phosphate

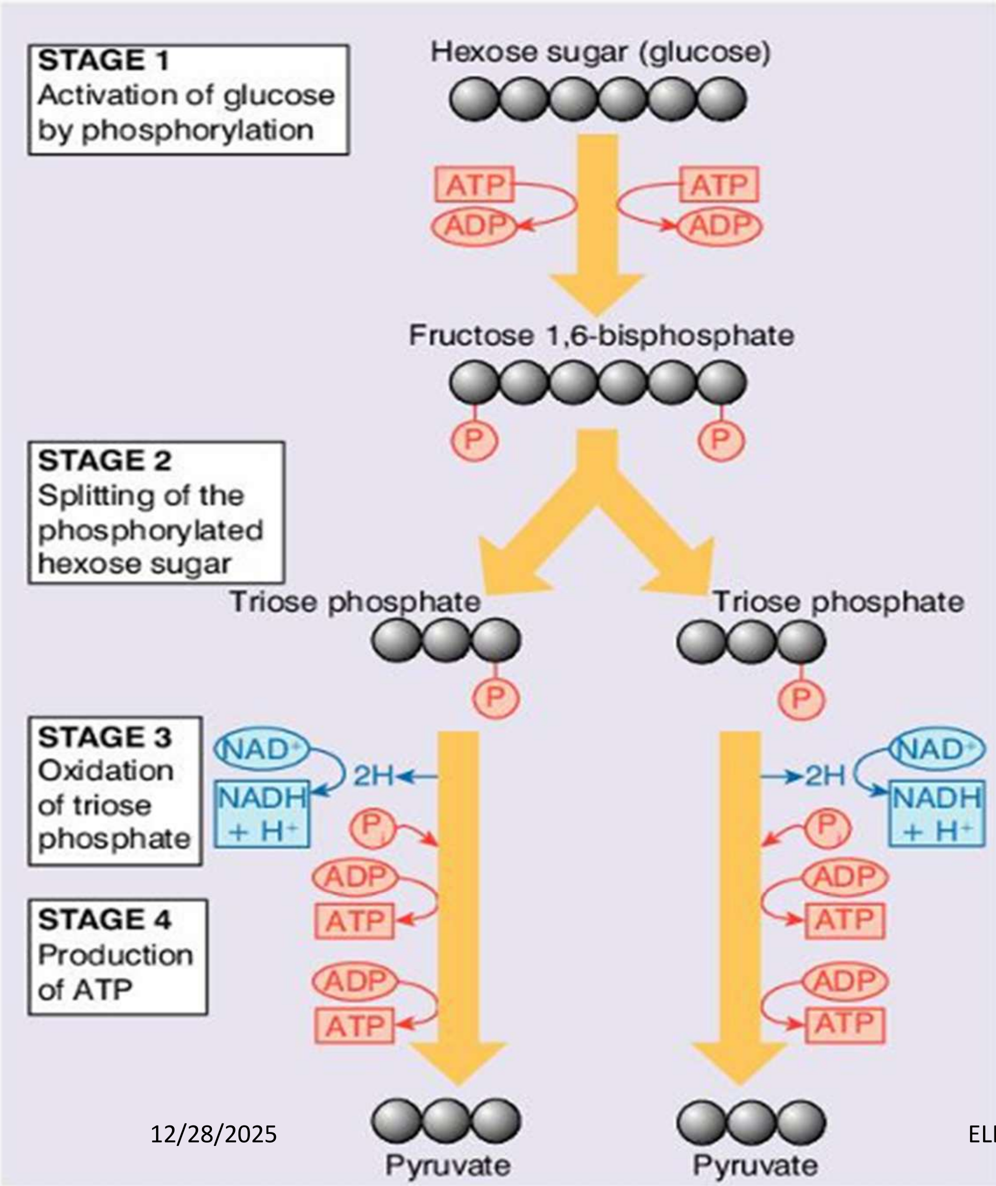


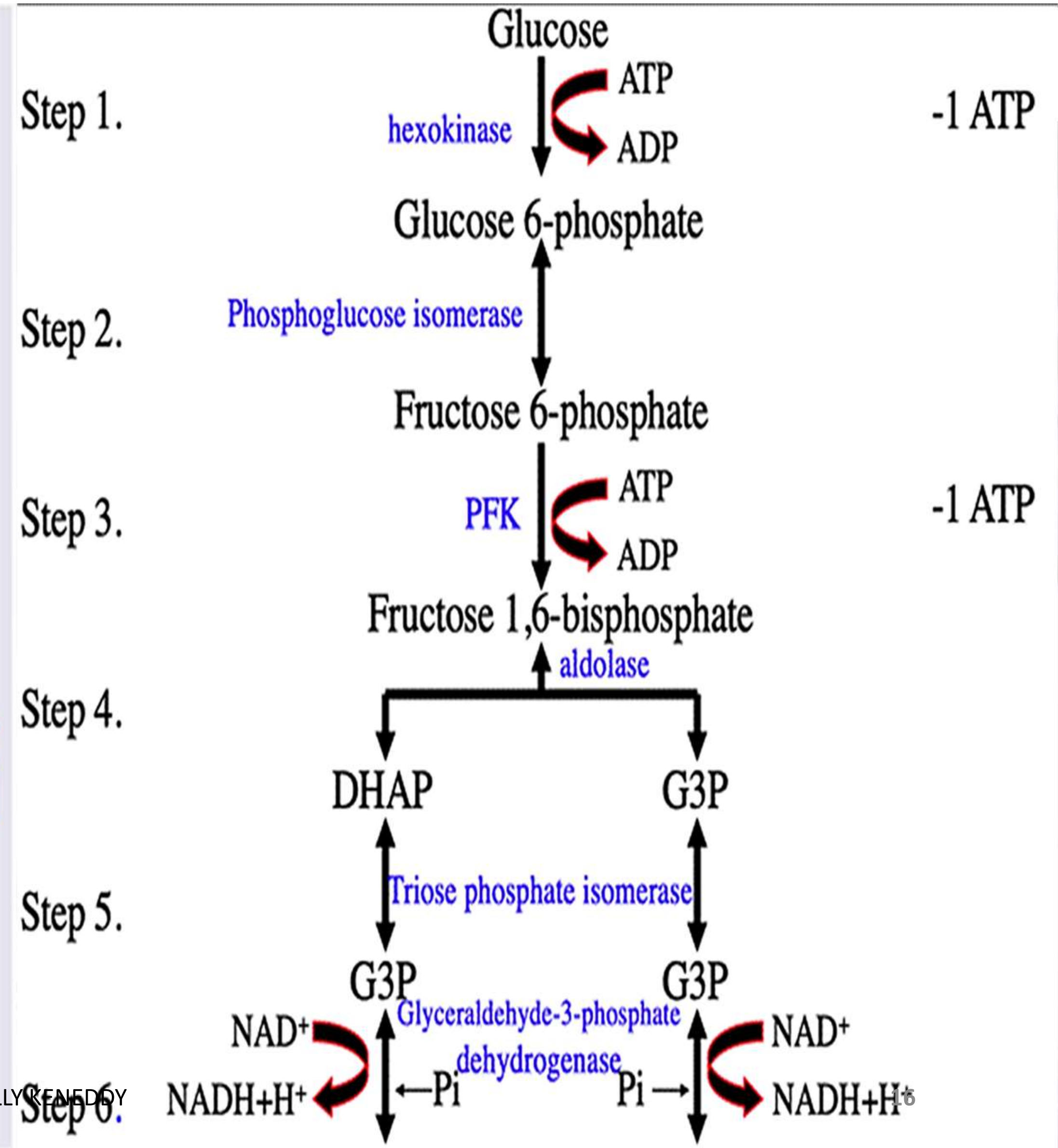
Oxidation by dehydrogenation

- Each 3C sugar phosphate is converted to pyruvate. This ***involves a dehydrogenation of PGA***, ***making a reduced NAD molecule***, and ***production of two ATP molecules***.
- The process happens twice, once for each 3C sugar phosphate molecule, so ***two reduced molecules are made.***
- Overall, two ATP molecules are used for phosphorylation reactions in the first stage, whilst four ATP molecules are produced in the third stage.
- Therefore there is ***a net gain of two ATP molecules***. ***Four hydrogen atoms are also released and added to NAD.***

Significance of glycolysis

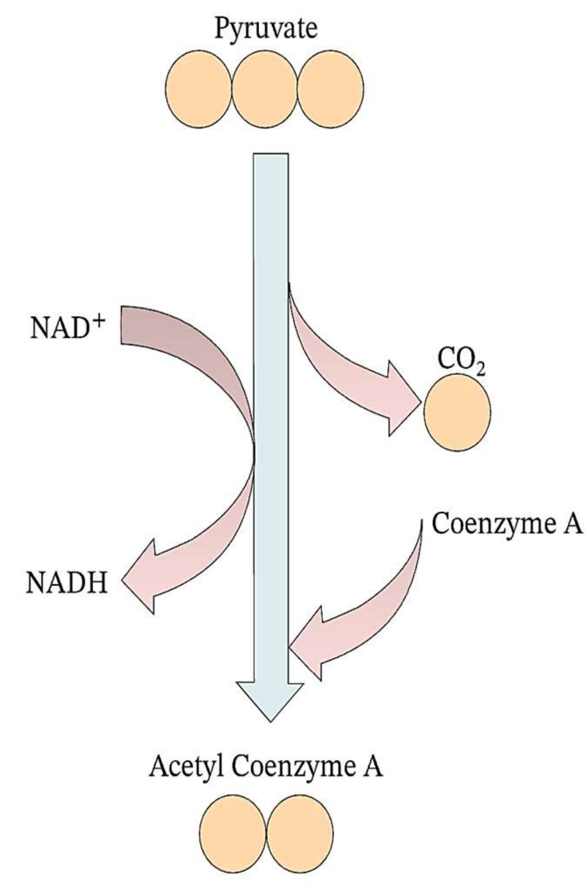
- Forms ATP which is used to power cell activities
- Forms NADH and Pyruvate which may be further oxidized to generate additional ATP.


STAGE 1
Activation of glucose by phosphorylation
Hexose sugar (glucose)
ATP
ADP
ATP
ADP
Fructose 1,6-bisphosphate
P
P
STAGE 2
Splitting of the phosphorylated hexose sugar
Triose phosphate
Triose phosphate
P
P
STAGE 3
Oxidation of triose phosphate
NAD+
2H
NADH + H+
NAD+
2H
NADH + H+
Pi
Pi
STAGE 4
Production of ATP
ADP
ATP
ADP
ATP
ADP
ATP
ADP
ATP
Pyruvate
Pyruvate


Glucose
Step 1.
hexokinase
ATP
ADP
-1 ATP
Glucose 6-phosphate
Step 2.
Phosphoglucose isomerase
Fructose 6-phosphate
Step 3.
PFK
ATP
ADP
-1 ATP
Fructose 1,6-bisphosphate
aldolase
Step 4.
DHAP
G3P
Step 5.
Triose phosphate isomerase
G3P
G3P
Step 6.
Glyceraldehyde-3-phosphate dehydrogenase
NAD+
NADH+H+
Pi
Pi
NAD+
NADH+H+

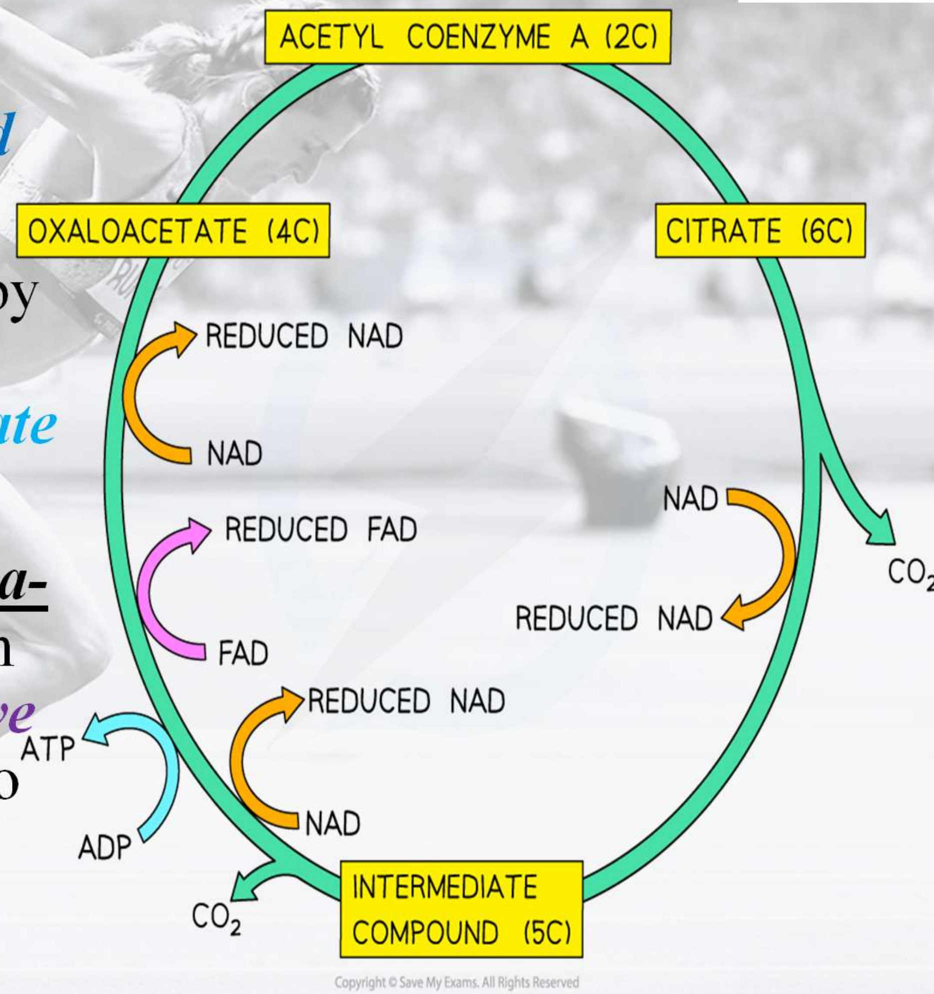
THE LINK REACTION.

- The pyruvate molecule produced in Glycolysis are ***actively transported into the matrix of the mitochondria***.
- Before pyruvate enters the Krebs cycle ***it combines with a compound*** called **Coenzyme A** to form **Acetyl Coenzyme A.**
- The conversion ***involves the removal of carbon dioxide*** (**decarboxylation**) and a ***pair of hydrogen atoms are removed***(**oxidation**) from the pyruvate: the process is called ***oxidative decarboxylation***
- The ***2-carbon acetyl*** combines with ***coenzyme* A** to form **Acetyl coenzyme A** which enters the Krebs cycle

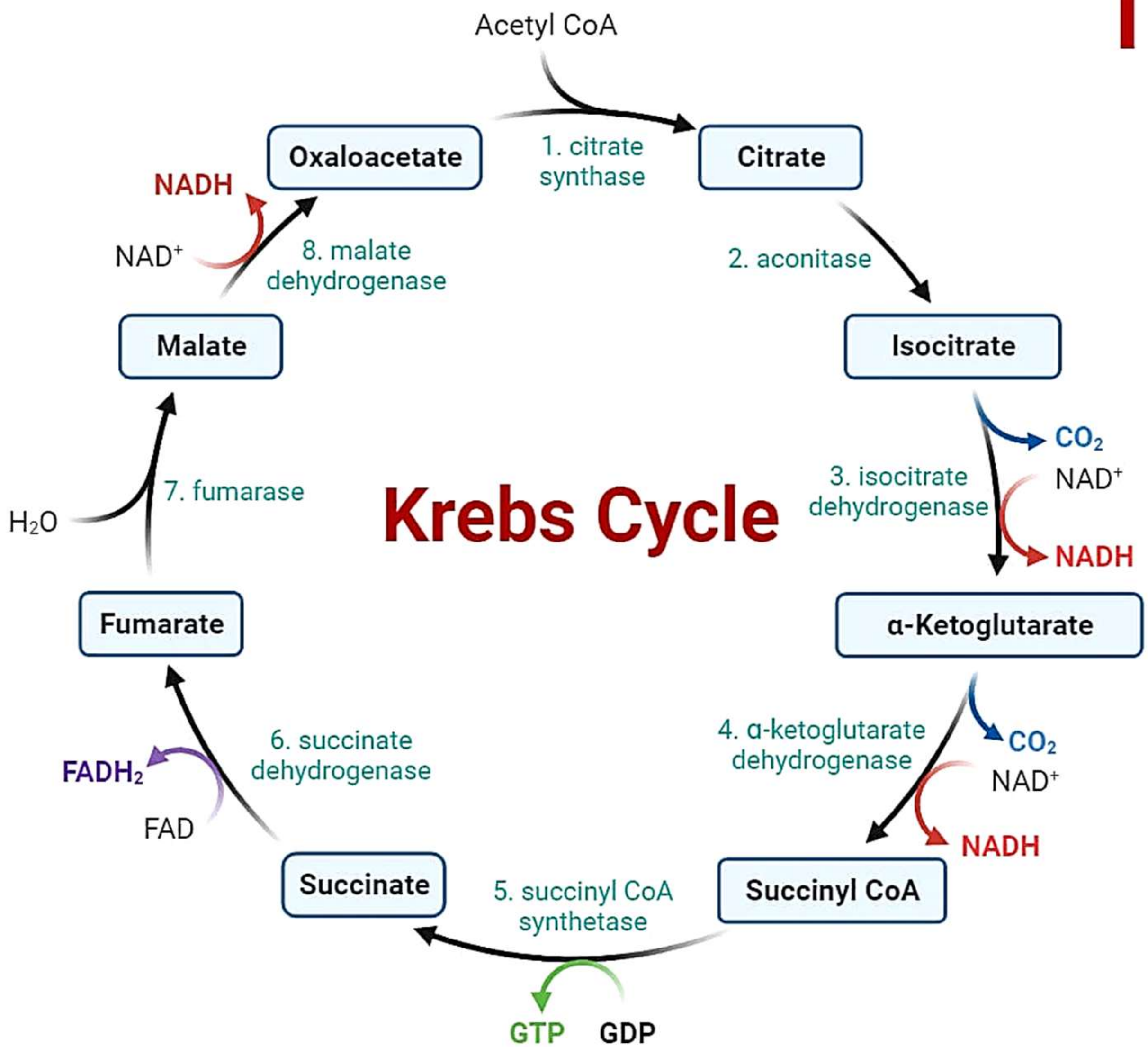


KREBS CYCLE.

- It is also known as the TCA cycle (***tricarboxylic acid cycle***) and ***the citric acid cycle*** because of the acids it contains.
- Acetyl coenzyme A enters the Krebs cycle by ***combining with the 4-carbon oxaloacetate*** (oxaloacetic acid) to give the ***6-carbon*** *citrate* (citric acid).
- The citrate is ***decarboxylated*** to a 5-carbon ***a-ketoglutarate*** (a- ketoglutaric acid) and then the 4-carbon ***oxaloacetate*** by the ***progressive loss of two carbon dioxide molecules*** in two decarboxylation reactions
- For each turn of the cycle, a total of ***four pairs of hydrogen atoms*** are also formed.



TCA Cycle



Products

(Each Cycle)

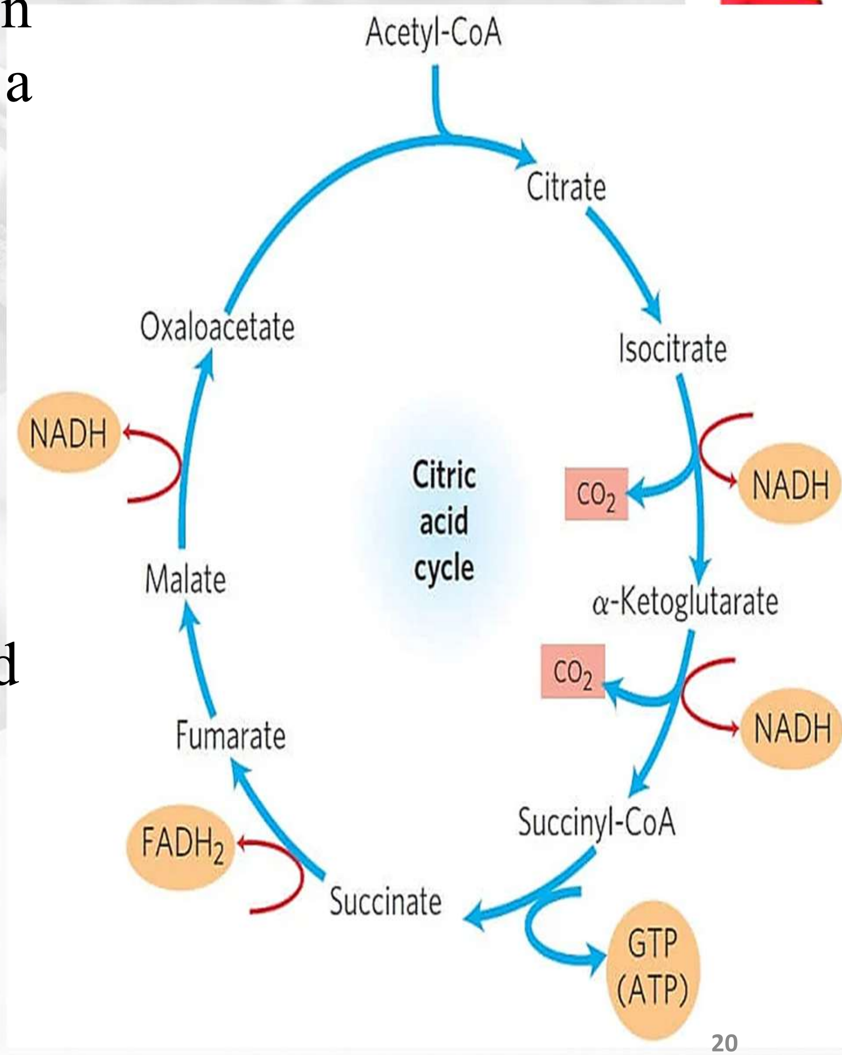
1 ATP (GTP)

3 NADH

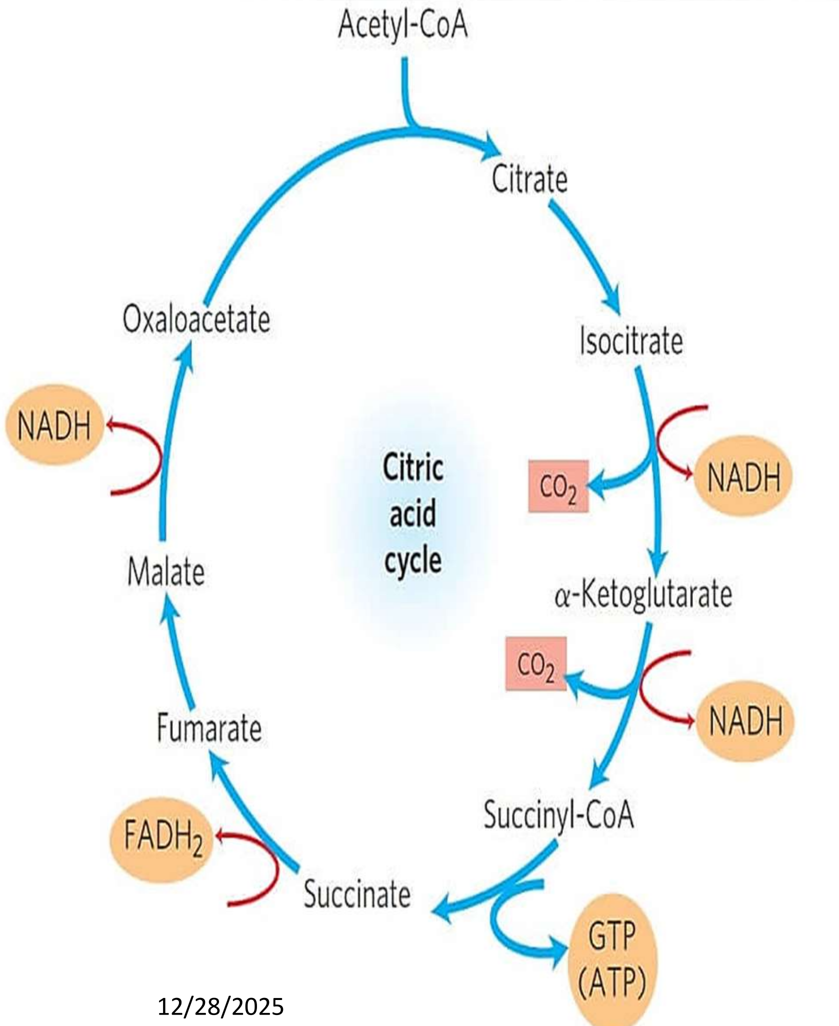
1 $FADH_2$

2 CO_2

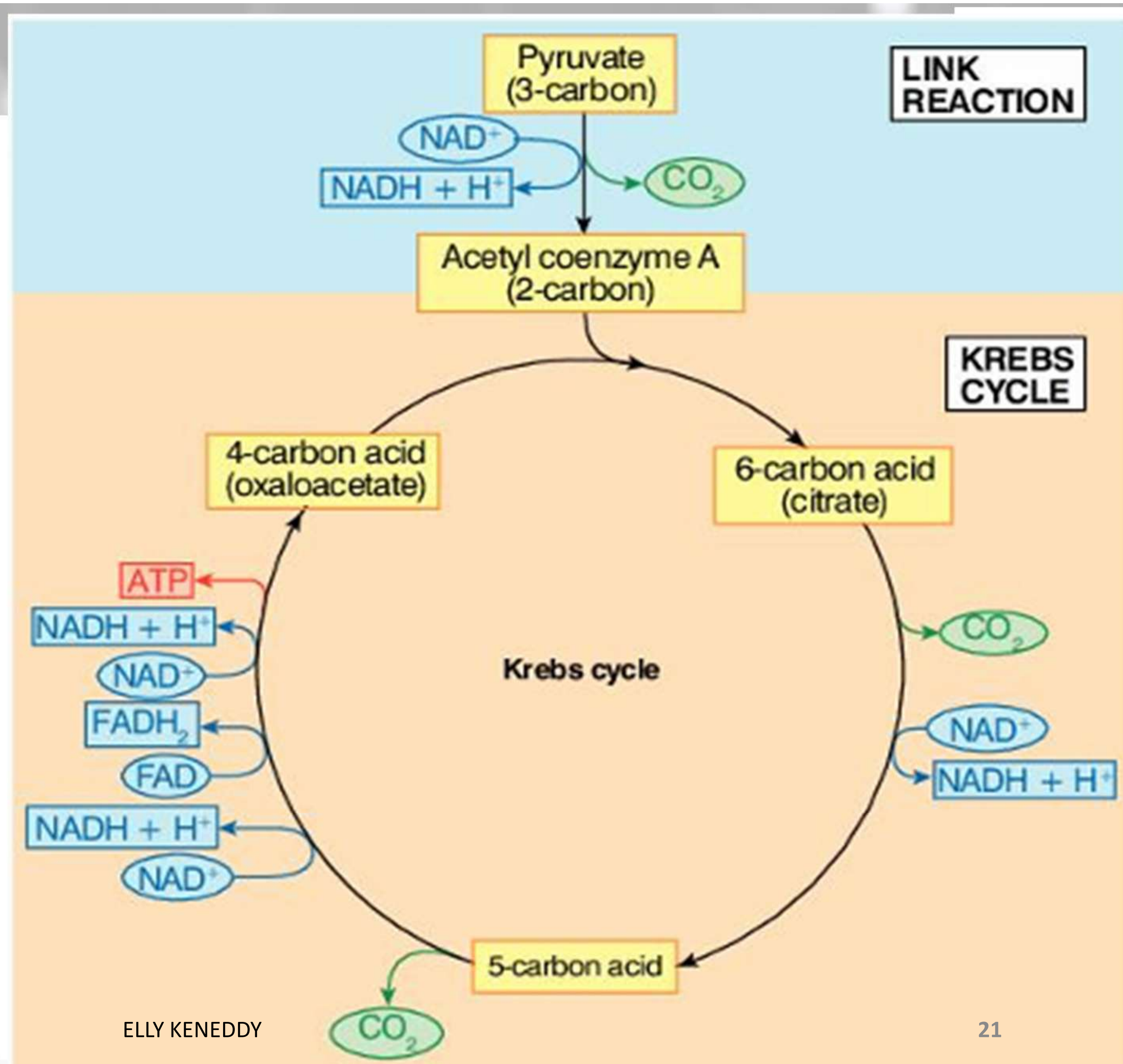
- The hydrogen is added to hydrogen carriers in ***four dehydrogenation reactions***, resulting in a total of ***three reduced NAD*** and ***one reduced FAD*** molecules.
- **NAD** ***yields three ATPs*** for each pair of hydrogen atoms. **FAD** ***yields only two ATPs***.
- One molecule of ATP is also made directly.
- All these products are ***formed from a single pyruvate molecule*** of which two are produced from each glucose molecule.
- The total yields from a single glucose molecule are thus double those stated.



KREBS CYCLE.



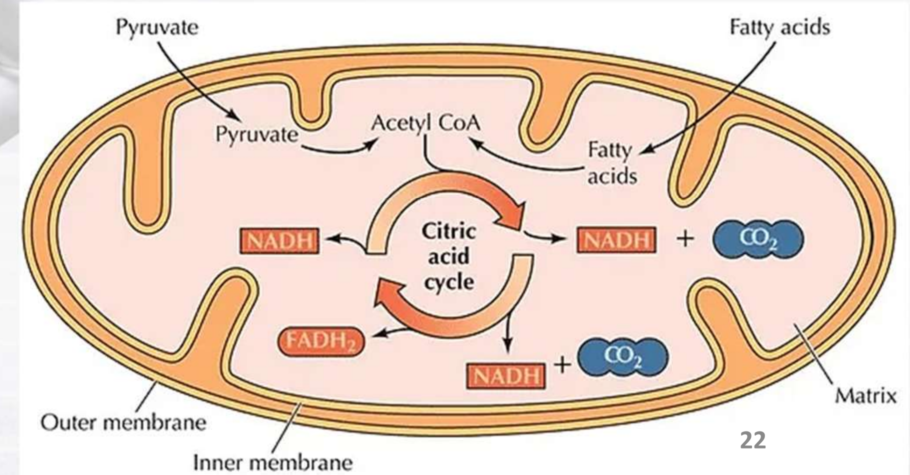
Acetyl-CoA
Citrate
Isocitrate
NADH
CO_2
α-Ketoglutarate
CO_2
NADH
Succinyl-CoA
GTP (ATP)
Succinate
$FADH_2$
Fumarate
Malate
NADH
Oxaloacetate
Citric acid cycle



LINK REACTION
Pyruvate (3-carbon)
NAD^+
NADH + H^+
CO_2
Acetyl coenzyme A (2-carbon)
KREBS CYCLE
6-carbon acid (citrate)
CO_2
NAD^+
NADH + H^+
5-carbon acid
CO_2
4-carbon acid (oxaloacetate)
ATP
NADH + H^+
NAD^+
$FADH_2$
FAD
NADH + H^+
NAD^+
Krebs cycle

Importance of Krebs cycle.

- It brings about the ***degradation of macromolecules*** - The carbon pyruvate is broken down to carbon dioxide.
- It provides the ***reducing power for the electron (hydrogen) transport system*** - It produces pairs of hydrogen atoms which are ultimately the source of metabolic energy for the cell.
- It is an ***interconversion center*** - It is a valuable source of intermediate compounds used in the manufacture of other substances, e.g. fatty acids, amino acids, chlorophyll



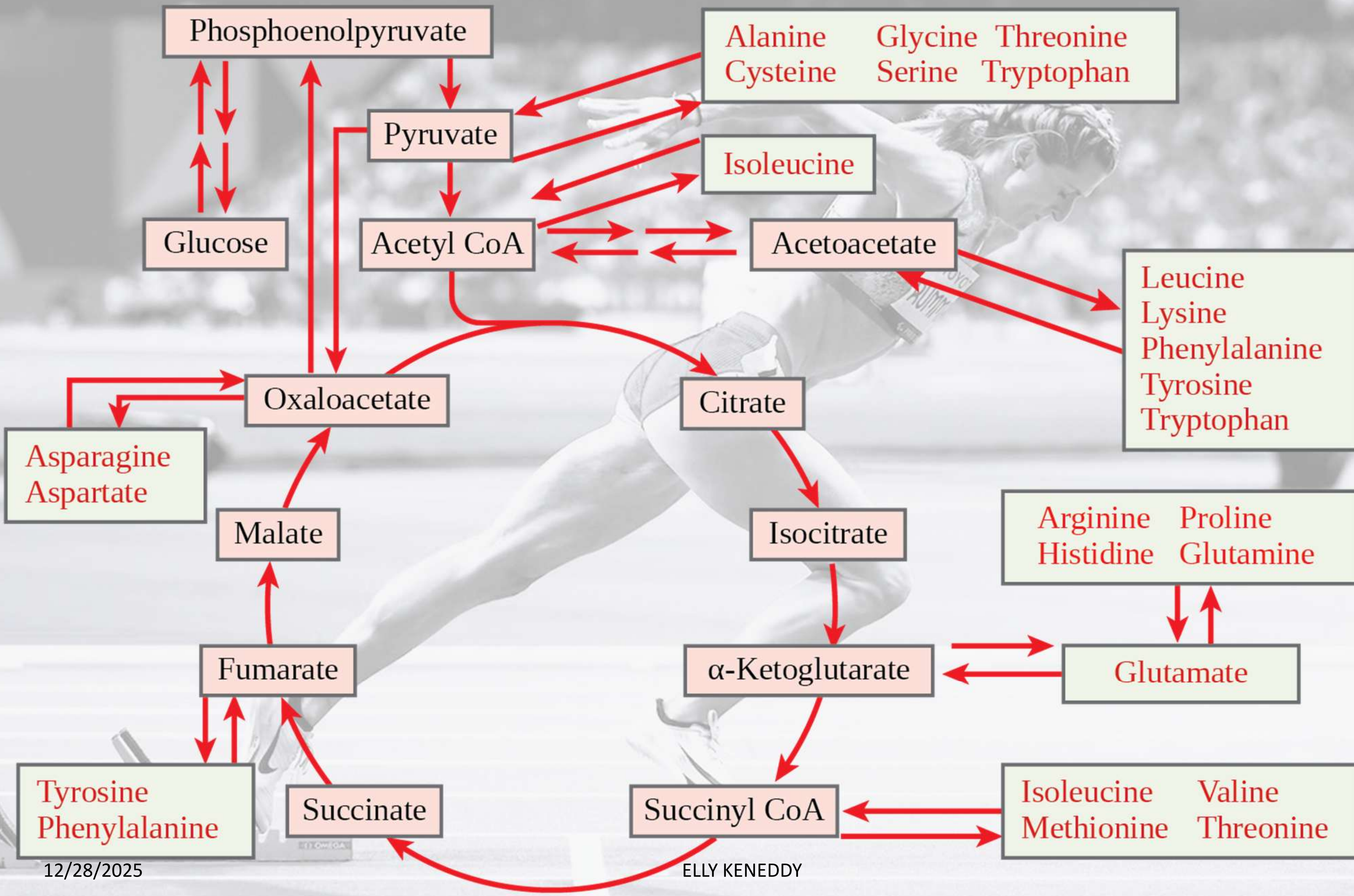
RESPIRATION OF PROTEINS.(ROLE OF ACETYL-CoA)

- Protein is another potential source of energy but is ***only used in cases of starvation***. Proteins must first be ***hydrolyzed to its constituent amino acids*** which then have their ***amino group(s) removed*** in the liver a process called **deamination**.
- The remaining portions of the amino acids i.e. ***carboxylic chain then enter the respiratory pathway*** at a number of points ***depending on their carbon content***:

➢ **5**-carbon amino acids (e.g. glutamate) and **4**-carbon amino acids (e.g. aspartate) are ***converted into the Krebs cycle intermediates***, **a-ketoglutarate** and **oxaloacetate** respectively

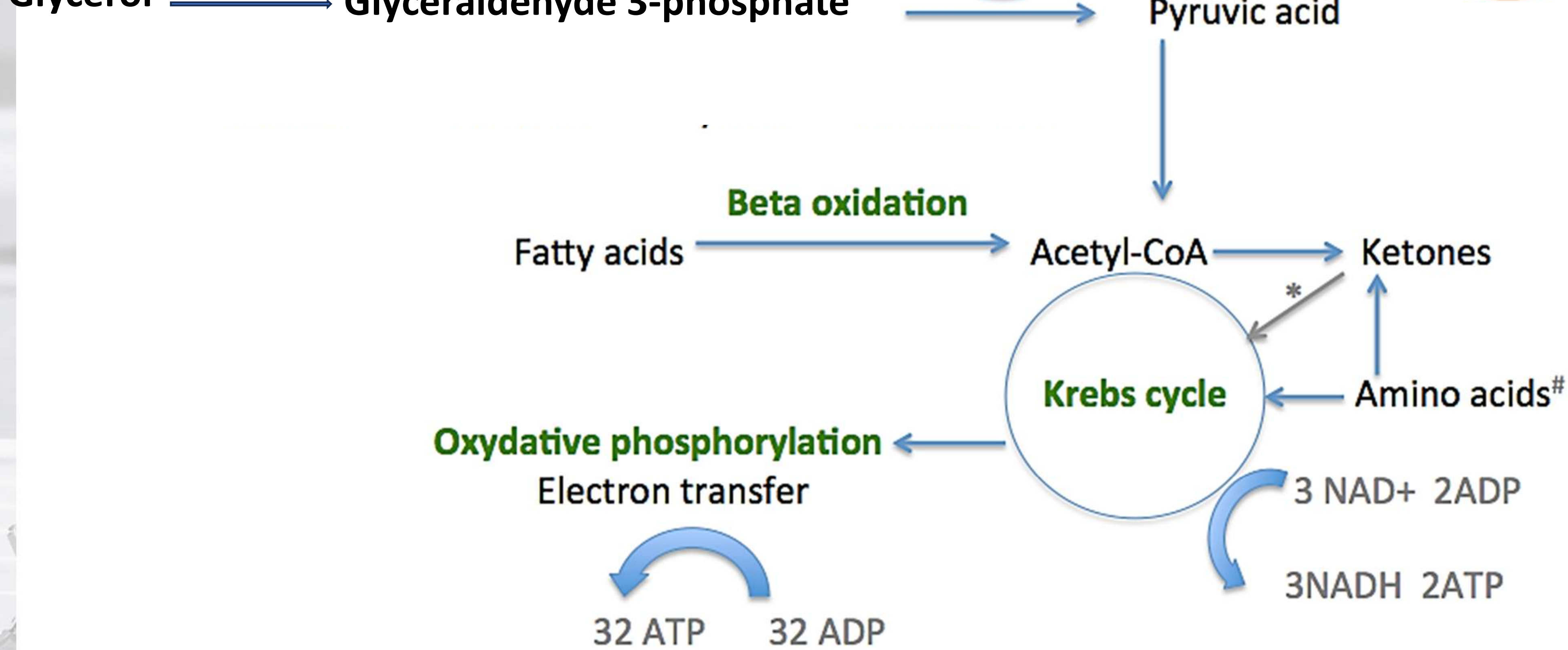
➢ **3**-carbon amino acids like alanine are ***converted to pyruvate ready for conversion to acetyl coenzyme A***.

- Other amino acids with larger quantities of carbon ***undergo transamination reactions*** to convert them into 3, 4 or 5 carbon amino acids.


Phosphoenolpyruvate
Pyruvate
Glucose
Acetyl CoA
Alanine Glycine Threonine
Cysteine Serine Tryptophan
Isoleucine
Acetoacetate
Leucine
Lysine
Phenylalanine
Tyrosine
Tryptophan
Oxaloacetate
Citrate
Asparagine
Aspartate
Malate
Isocitrate
Arginine Proline
Histidine Glutamine
Fumarate
α-Ketoglutarate
Glutamate
Tyrosine
Phenylalanine
Succinate
Succinyl CoA
Isoleucine Valine
Methionine Threonine

RESPIRATION OF FATS. (ROLE OF ACETYL-CoA)

- The oxidation of fat begins with ***hydrolysis of fats*** to ***glycerol*** and ***fatty acids***. The ***glycerol is phosphorylated and converted into the triose phosphate*** *(*glyceraldehyde 3-phosphate).
- This can then be ***incorporated into the glycolysis pathway thus converted to*** **pyruvate** ***which enters the Krebs cycle***.
- The fatty acid component is progressively **broken down in the matrix of the mitochondria into 2-carbon fragments** which are converted to ***Acetyl coenzyme A.***
- This then ***enters the Krebs cycle with consequent release of its energy***. The oxidation of fats has the advantage of producing a large quantity of hydrogen ions.
- These can be transported by hydrogen carriers and used to produce ATP in the electron (hydrogen) transport system.


2 ADP
2 NAD+
2 ATP
2 NAHD
Glycolysis
Glycerol
Glyceraldehyde 3-phosphate
Pyruvic acid
Beta oxidation
Fatty acids
Acetyl-CoA
Ketones
*
Krebs cycle
Amino acids#
Oxydative phosphorylation
Electron transfer
3 NAD+ 2ADP
3NADH 2ATP
32 ATP
32 ADP

ELECTRON TRANSPORT SYSTEM.

- ***A sequence of oxidation-reduction*** (redox) reactions whereby the ***transfer of electrons between protein complexes*** in inner mitochondrial membrane is ***coupled with the transport of protons into intermembrane space*** to create a proton gradient that ***drives synthesis of about 34 ATP molecules***.

Chemiosmosis.

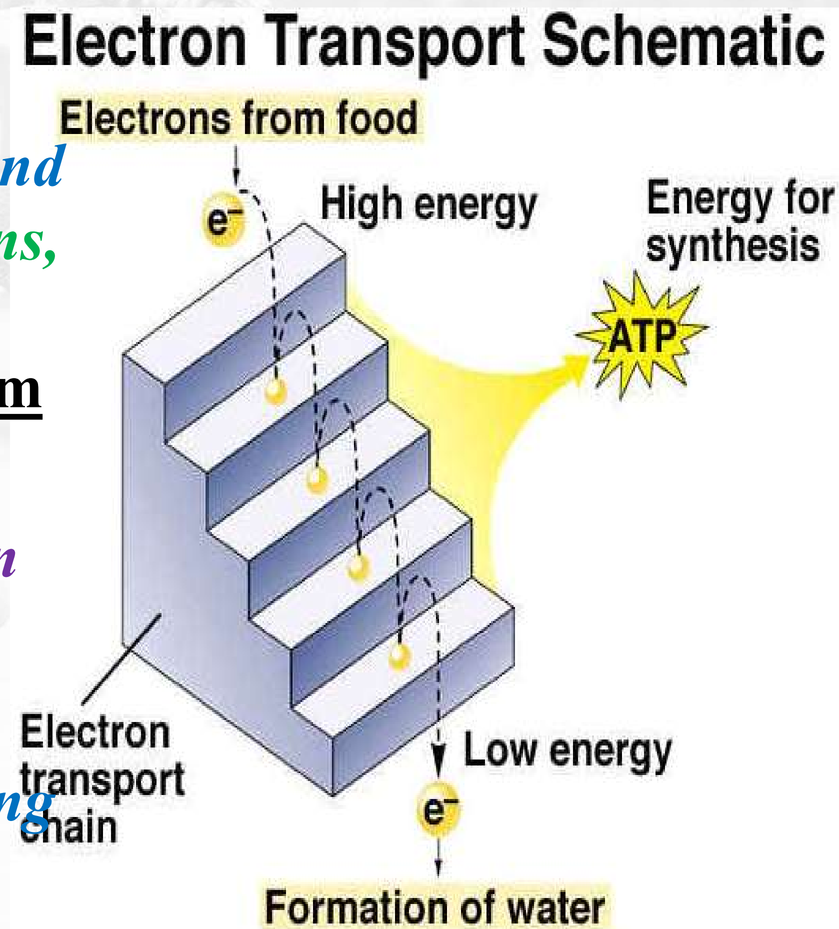
- The process by which chemical ions e.g. H+ move from an area of high concentration to an area of low concentration through transport proteins on the selectively permeable membrane as a result of proton gradient that forms across the membrane that is not readily permeable to ions.

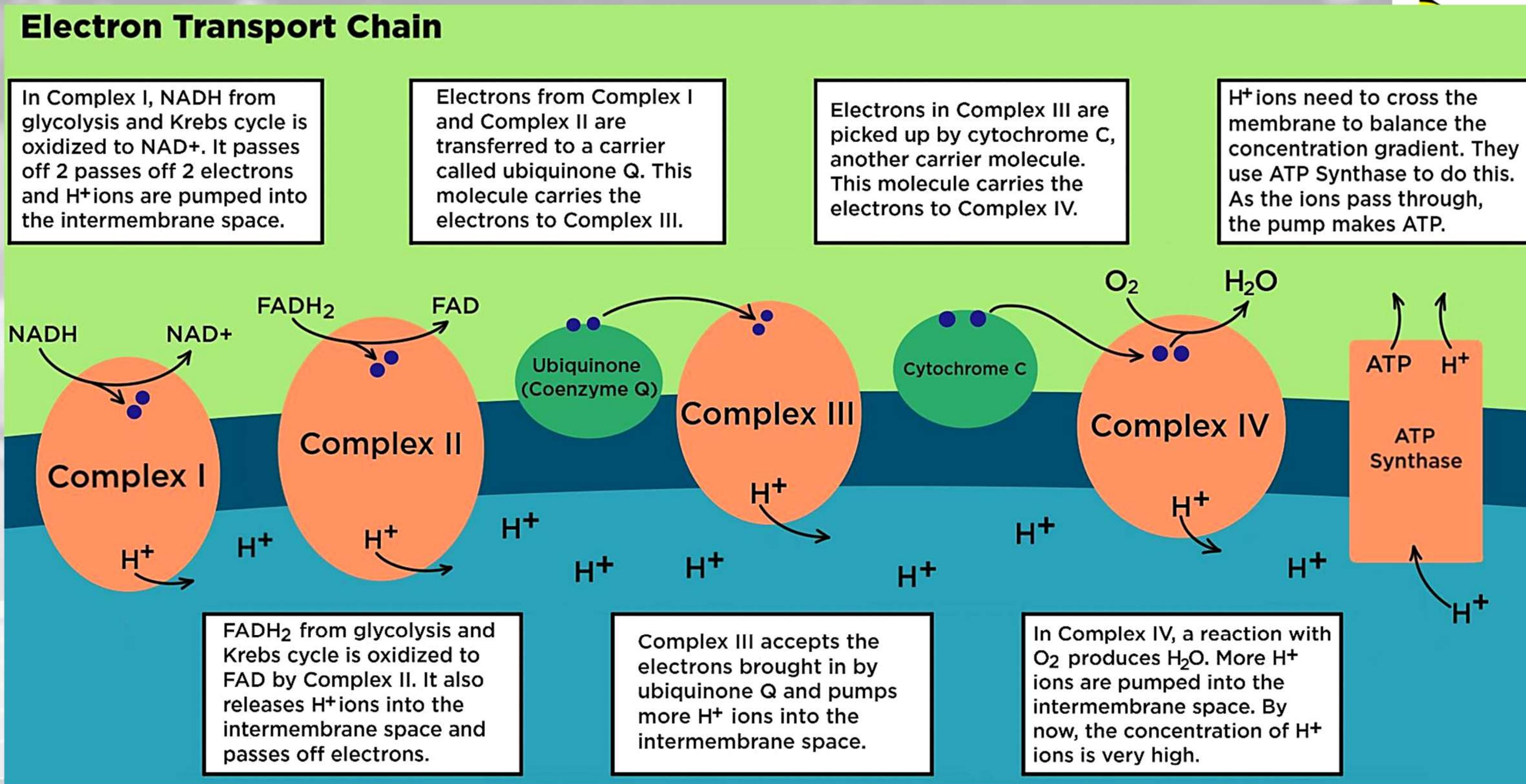
Oxidative Phosphorylation:

- Use of energy supplied by transmembrane proton gradients across the inner mitochondrial membrane during electron transport system to form ATP.

CONT…………..

- The main purpose of the Krebs cycle is ***to feed electrons into the ETS.***
- The hydrogen atoms ***carried by reduced NAD and FAD molecules*** which are the ***source of electrons, which are passed along a chain of carrier molecules*** called the **Electron Transport System** (ETS).
- Reduced FAD and NAD ***pass on electrons when donate hydrogen to the next electron carrier***.
- As these molecules ***lose electrons***, they become **oxidized** while the next ***electron carrier receiving electrons*** becomes **reduced**.




Electron Transport Chain
In Complex I, NADH from glycolysis and Krebs cycle is oxidized to NAD+. It passes off 2 passes off 2 electrons and H+ ions are pumped into the intermembrane space.
Electrons from Complex I and Complex II are transferred to a carrier called ubiquinone Q. This molecule carries the electrons to Complex III.
Electrons in Complex III are picked up by cytochrome C, another carrier molecule. This molecule carries the electrons to Complex IV.
H+ ions need to cross the membrane to balance the concentration gradient. They use ATP Synthase to do this. As the ions pass through, the pump makes ATP.
NADH
NAD+
FADH2
FAD
Ubiquinone (Coenzyme Q)
Cytochrome C
O2
H2O
ATP
H+
Complex I
Complex II
Complex III
Complex IV
ATP Synthase
H+
FADH2 from glycolysis and Krebs cycle is oxidized to FAD by Complex II. It also releases H+ ions into the intermembrane space and passes off electrons.
Complex III accepts the electrons brought in by ubiquinone Q and pumps more H+ ions into the intermembrane space.
In Complex IV, a reaction with O2 produces H2O. More H+ ions are pumped into the intermembrane space. By now, the concentration of H+ ions is very high.

- There are ***series of carriers*** is termed the **respiratory chain**. These include **NAD**, **FAD**, **flavoprotein**, **coenzyme Q** and iron-containing proteins called **cytochromes**.
- Initially ***hydrogen atoms are passed along the chain***, which **later split** into their **protons** and **electrons.** Only the *electrons pass from carrier to carrier*.
- The ***protons formed accumulate into the mitochondria matrix*** which are ***later pumped into the intermembrane space*** by proton pumps.
- At the end of the chain the ***protons and electrons recombine***, and the ***hydrogen atoms combine with oxygen*** to form **water**.
- This formation of ATP through the oxidation of the hydrogen atoms is called **oxidative phosphorylation** and It occurs in the mitochondria.
- The ***role of oxygen*** is to act as the *final acceptor of the hydrogen*

NOTE.

- **The** ***protons formed accumulate into the mitochondria matrix*** **which are** ***later pumped into the intermembrane space*** **by proton pumps**.

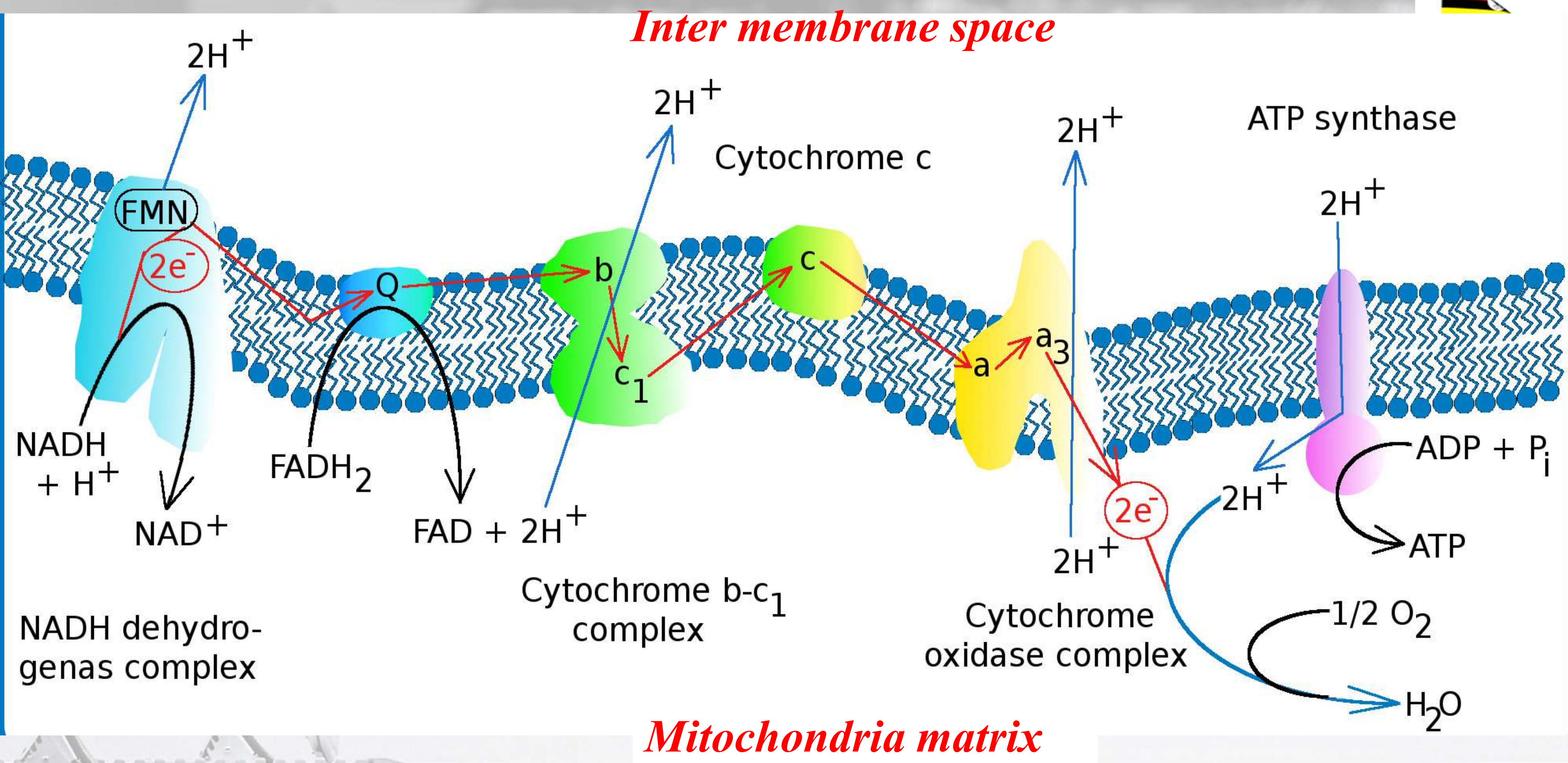
Must be written

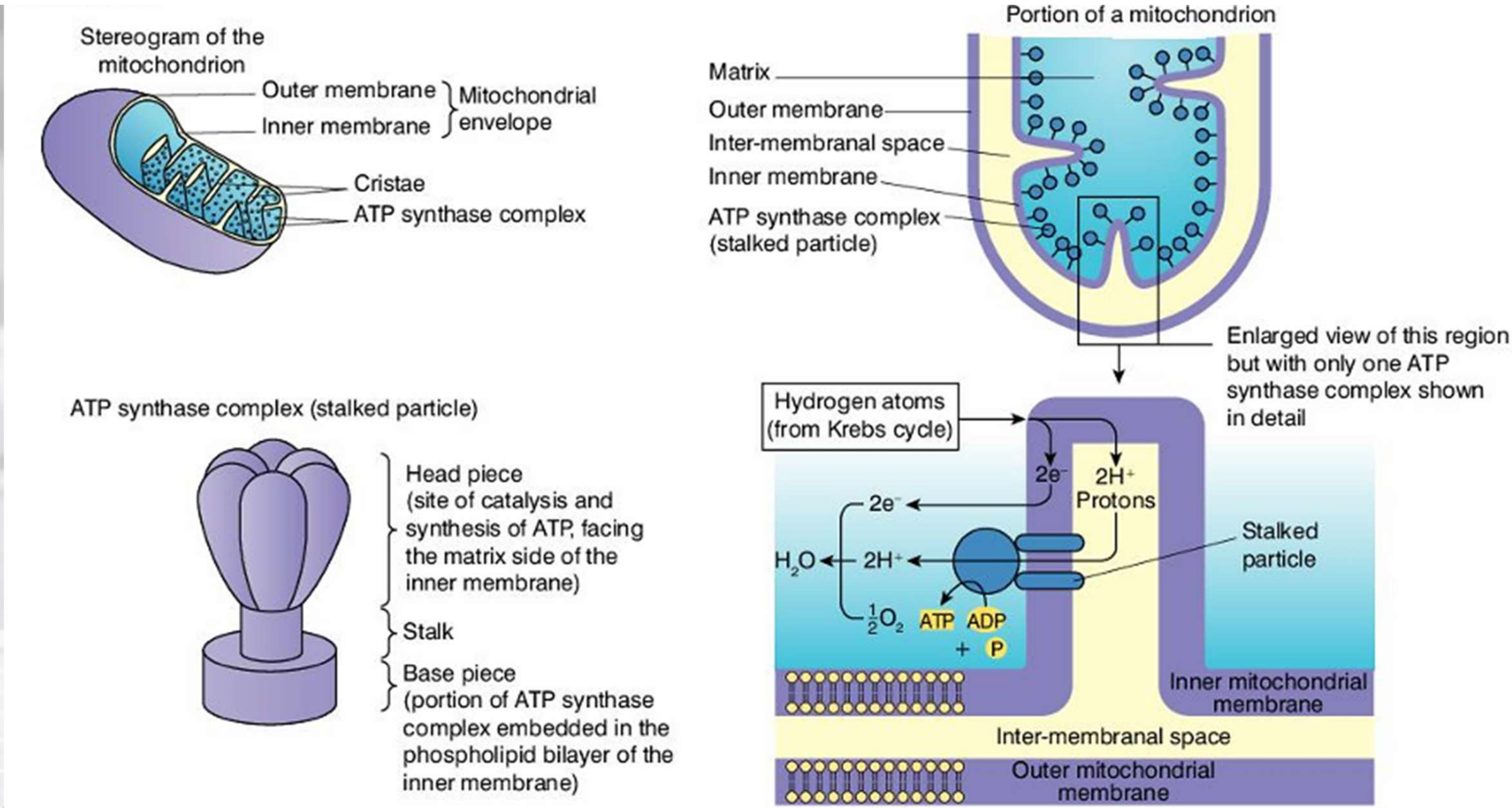
- Oxygen is nevertheless vital as it drives the whole process. In its absence***, only the anaerobic glycolysis stage can continue***.
- The ***transfer of hydrogen atoms to oxygen*** is catalyzed by the enzyme **Cytochrome oxidase**.
- This enzyme is ***inhibited by cyanide***, so ***preventing the removal of hydrogen atoms at the end of the respiratory chain***.
- In these circumstances the hydrogen atoms accumulate and aerobic respiration ceases, making cyanide a most effective respiratory inhibitor.

CHEMIOSMOSIS

- This explains the production of ATP in the mitochondrion ***resulting from a proton gradient*** established ***in the intermembrane space***. ***Energy released from the electron transport system is used to pump protons*** (H+), ***from the mitochondrial matrix into the intermembrane space*** (compartment between the inner and outer mitochondrial membranes).
- The ***protons accumulate so that a steep concentration gradient*** develops between the compartment and the matrix. The inner membrane is generally impermeable to protons, which can ***only diffuse back into the matrix through chemiosmotic channels*** located in special structures in the inner membrane called ***stalked particles***.
- The ***energy released during the movement of protons*** through chemiosmotic channels drives the synthesis of ATP from ADP catalyzed by the enzyme **ATPase**

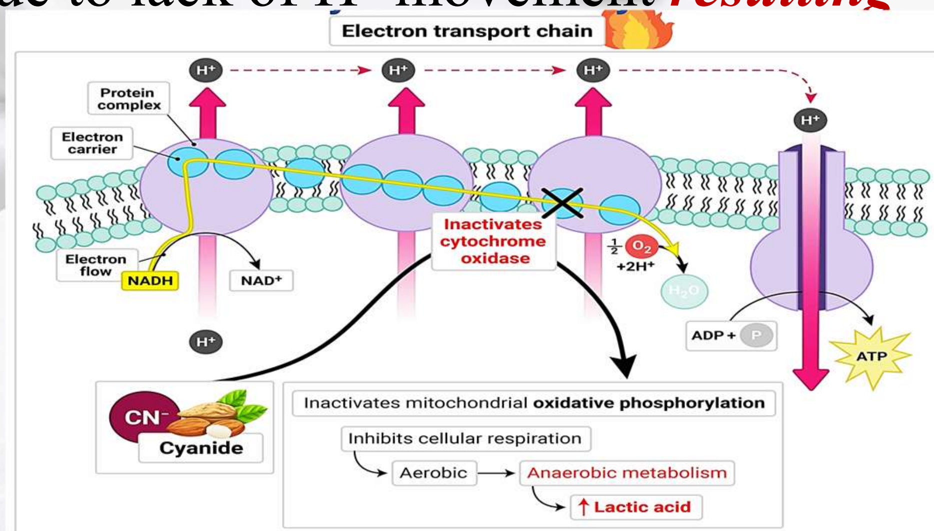
$$\textbf{ADP + Pi} \longrightarrow \textbf{ATP}$$

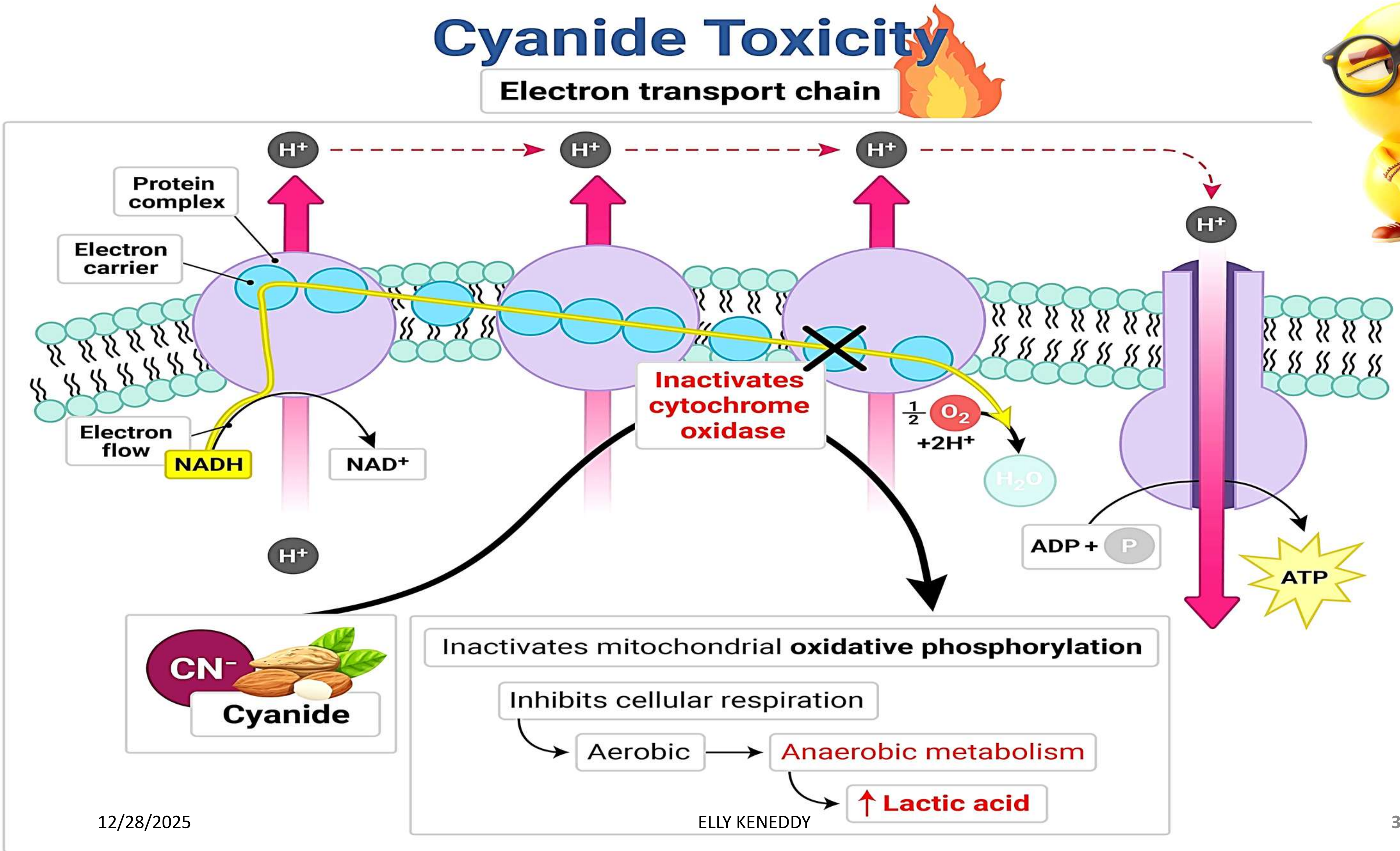

Inter membrane space
2H+
2H+
Cytochrome c
2H+
ATP synthase
2H+
FMN
2e-
Q
b
c
c1
a
a3
NADH
+ H+
FADH2
NAD+
FAD + 2H+
2e-
2H+
ADP + Pi
ATP
2H+
1/2 O2
H2O
Cytochrome b-c1
complex
NADH dehydro-
genas complex
Cytochrome
oxidase complex
Mitochondria matrix


Stereogram of the mitochondrion
Outer membrane
Inner membrane
Mitochondrial envelope
Cristae
ATP synthase complex
ATP synthase complex (stalked particle)
Head piece (site of catalysis and synthesis of ATP, facing the matrix side of the inner membrane)
Stalk
Base piece (portion of ATP synthase complex embedded in the phospholipid bilayer of the inner membrane)
Portion of a mitochondrion
Matrix
Outer membrane
Inter-membranal space
Inner membrane
ATP synthase complex (stalked particle)
Enlarged view of this region but with only one ATP synthase complex shown in detail
Hydrogen atoms (from Krebs cycle)
2e⁻
2H⁺ Protons
2e⁻
H₂O
2H⁺
½O₂
ATP
ADP
+ P
Stalked particle
Inner mitochondrial membrane
Inter-membranal space
Outer mitochondrial membrane

EFFECT OF CYANIDE ON ATP PRODUCTION.

- Cyanide ***binds to the*** **Cytochrome C Oxidase enzyme** (also known as Complex IV) in the mitochondrial inner membrane. This binding ***prevents electrons from being transferred to oxygen***, which is the final electron acceptor in ETS.
- Without electron flow, ***the proton gradient across the inner mitochondrial membrane collapses***.
- Absence of proton gradient results into ***no diffusion of protons via the stalked particles*** hence **ATP synthase is inactive** due to lack of H^+ movement ***resulting into no ATP formation.***




Cyanide Toxicity
Electron transport chain
H+
Protein complex
Electron carrier
Electron flow
NADH
NAD+
Inactivates cytochrome oxidase
1/2 O2
+2H+
H2O
ADP + P
ATP
CN-
Cyanide
Inactivates mitochondrial **oxidative phosphorylation**
Inhibits cellular respiration
Aerobic
Anaerobic metabolism
↑ Lactic acid

IMPORTANT TO KNOW.(*ANAEROBIOSIS*)

Alcoholic fermentation

- In alcoholic fermentation ***the pyruvate from glycolysis is first converted to ethanal*** through the removal of a carbon dioxide molecule catalyzed by pyruvate ***decarboxylase enzyme***.

$$\underset{\text{Pyruvate}}{CH_3COCOOH} \xrightarrow[\textit{pyruvate decarboxylase}]{} \underset{\text{ethanal}}{CH\ CHO} + CO_2$$

- The ethanal then ***combines with the hydrogen ions, which are transported by the hydrogen carrier NAD***, to form the alcohol ethanol catalyzed by dehydrogenase.

$$\underset{\text{Ethanal}}{CH_3CHO} \xrightarrow[\textbf{Dehydrogenase}]{2\ NAD^+ \ \to\ 2\ NADH} \underset{\text{Ethanol}}{CH_3CH_2OH}$$

- This form of fermentation occurs in yeast, where the alcohol produced may accumulate in the medium around the cells until its ***concentration rises to a level which prevents further fermentation***, and ***so kills the yeast***. The ethanol cannot be further broken down to yield additional energy.

LACTATE FERMENTATION

- This ***form of fermentation is common in animals***. In lactate fermentation the ***pyruvate from glycolysis accepts the hydrogen atoms*** from reduced NADH directly.

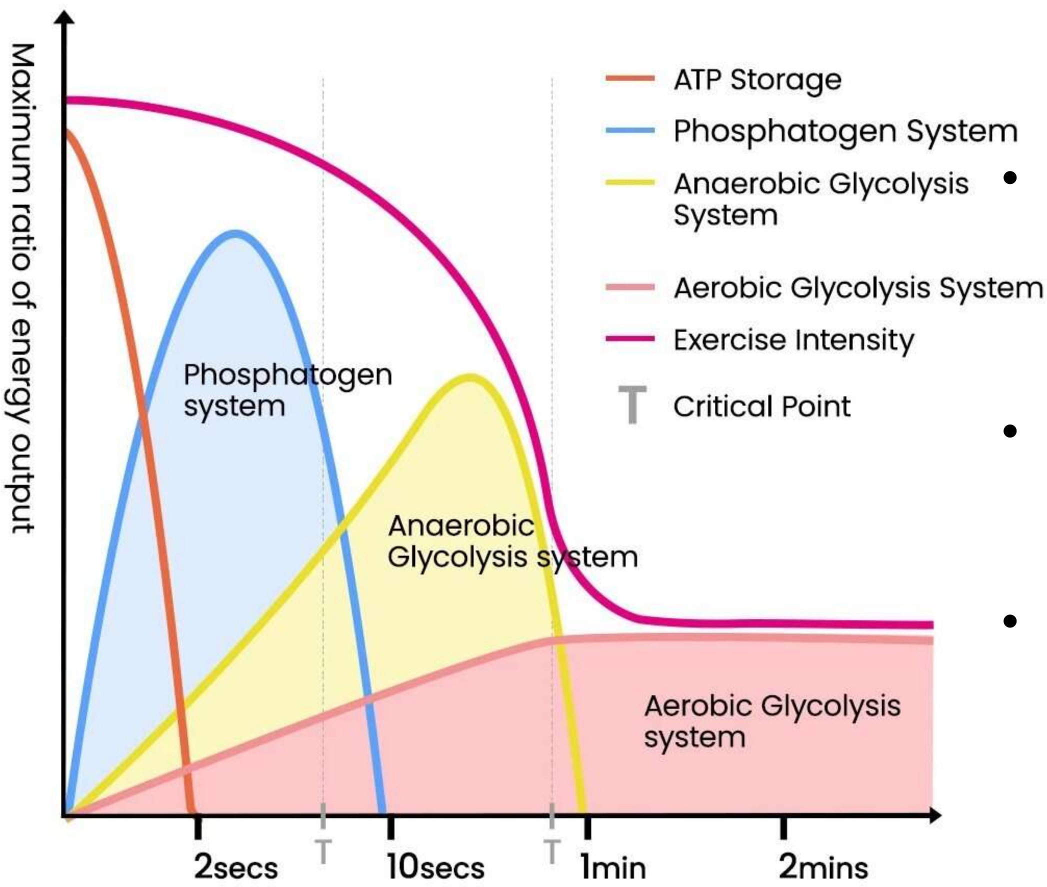
$$\textbf{Pyruvate} \xrightarrow[\text{Lactate dehydrogenase}]{2\ NAD^+ \quad 2\ NADH} \textbf{Lactate} + \textbf{2 ATP}$$

- Unlike alcoholic fermentation, the ***lactate can be further broken down, if oxygen is made available***, thus releasing its remaining energy.
- Alternatively, it may be ***converted into carbohydrates***, or ***excreted***. Lactate fermentation not ***only yields a little energy***, but ***removes the pyruvate which would otherwise accumulate.***
- Lactate ***accumulates causing muscle cramps*** and so ***prevent the muscle from contracting***. In the process of lactate fermentation, the organism accumulates an oxygen debt.

CONT……….

- The ***oxygen absorbed is used to oxidize the lactate to carbon dioxide and water***, thereby removing it, and at the same time ***replenishing the depleted stores of ATP and oxygen in the tissue***.
- In some organisms such as parasitic worms, ***where the food supply is abundant***, the ***lactate is simply excreted***, ***obviating the need to repay an oxygen debt.***

EFFECT OF EXERCISE INTENSITY ON ATP PRODUCTION.



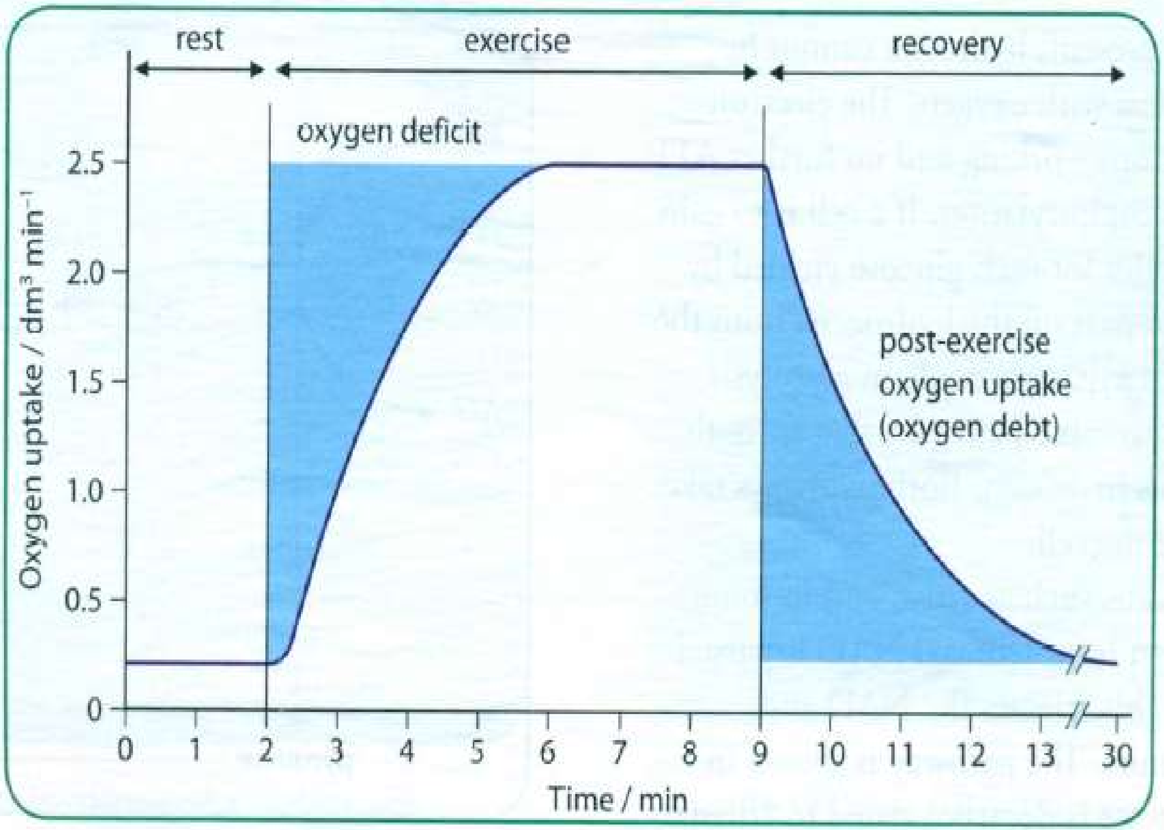
- During ***the first 2 seconds of exercise***, energy for muscle contraction is ***provided by ATP stored*** in muscle cells. ATP can supply energy for a ***maximum of 4 seconds***
- When the ATP molecules are depleted, ***creatine phosphate*** (high energy compound) ***provides energy for ATP formation*** for muscle contraction between ***2 to 10 seconds***.
- Then ***anerobic respiration supplies energy*** during straineous exercises however its ***energy supply is short lived.***
- If the ***exercise is prolonged***, energy supply for muscle contraction ***is provided by aerobic respiration***. ***Adjustments in the ventilation and circulatory system occur*** to increase supply of substrates to muscles to sustain ATP synthesis.

EXPLANATION.

- The amount of ATP in muscles is ***sufficient only for about three seconds*** of maximal muscle contraction.
- Creatine phosphate is ***another chemical like ATP*** which contains ***a phosphate group that can be removed to release energy***. It ***releases enough energy to make ATP*** from ADP and Pi.
- Muscle cells ***have 2-4 times as much creatine phosphate as ATP***, so energy can very rapidly be switched to ATP from phosphate when needed.
- ATP and creatine phosphate together can provide maximum muscle power for about ***8-10 seconds***.
- After the stores of ATP and creatine phosphate are exhausted, energy supply for muscle contraction is provided ***by anerobic respiration***.

- Although ***anaerobic respiration only produces 2 molecules of ATP*** per glucose molecule compared with ***38 ATP for aerobic respiration***, anaerobic respiration can ***operate much faster than aerobic respiration***.
- Its rate of ATP production is about ***2.5 times faster*** than that of aerobic respiration Anaerobic respiration can therefore supply energy rapidly.
- It uses ***glycogen stored in the muscle as a source of glucose***. It can provide enough energy for about ***<u>90 seconds</u>*** of maximum muscle activity.
- If exercise if prolonged, ***energy supply for muscle contraction is provided by aerobic respiration***. The muscles ***use myoglobin oxygen stores*** to provide oxygen for respiration as ***adjustments in ventilation and heart rate occur*** to ***increase oxygen supply to body muscles*** to facilitate aerobic respiration to form ATP required for muscle contraction.

RESEARCH.



Oxygen uptake before, during and after strenuous exercise.

Describe the graph above.

Explain what occurs during the recovery period.


A+
ALWAYS AIM FOR EXCELLENCE.
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