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PRE-MEDICAL

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STUDY MATERIAL

Respiration in Plants

ENGLISH MEDIUM

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RESPIRATION IN PLANTS

01. INTRODUCTION

- **Introduction**
- **Do Plants Breathe?**
- **Types of Respiration**
- **Glycolysis**
- **Aerobic Respiration**
- **The Respiratory Balance Sheet**
- **Respiration : Amphibolic Pathway**
- **Fermentation/anaerobic respiration**
- **Respiratory Quotient**

- The **breaking of C – C single bond of complex compounds** through oxidation within the cells, leading to release of considerable amount of energy and the trapping of this energy for **synthesis of ATP** is called **cellular respiration.**
- During cellular respiration or oxidation within a cell, all the **energy** contained in compounds is **not released in a single step** because in single if the complete energy is released it, **may be converted into heat. So the energy during cellular respiration is released in a series of slow step wise reactions controlled by enzymes** and it is trapped as chemical energy in the form of ATP.
- ATP thus synthesised, is broken down whenever and wherever energy needs to be utilised, hence **ATP act as the energy currency of the cell.**
- The **compounds that are oxidised during the process of cellular respiration are called respiratory substrates,** these are usually carbohydrates but except these **fats, proteins & organic** acids can also be used as respiratory substrates.
- **Primarly carbohydrates (mainly glucose)** are used as repiratory substrate. In the absence or less availability of carbohydrates, the respiratory substrates can be **fats & proteins.**

Respiratory substrate	Gross Calorific Value	Physiological Value
Carbohydrate	4.1 kcal/g	4.0 kcal/g
Protein	5.65 kcal/g	4.0 kcal/g
Fat	9.45 kcal/g	9.0 kcal/g

- The sequence of use of respiratory substrates –

  (i) Carbohydrate (ii) Fat (iii) Protein

- **Organic acids such as malic acid etc. can be used as respiratory substrates in some plants, under certain conditions.**
- Cellular respiration is an **amphibolic process.**

  Reason : The carbon skeleton (Intermediates of respiration) produced during respiration is used as precursors for biosynthesis of other molecules in the cell.

- Cellular respiration is an **exergonic process.**

  Reason : The breaking of C–C bonds of complex compounds through oxidation within the cells, leading to release of considerable amount of energy.

02. DO PLANTS BREATHE?

- **Plants, unlike animals, have no specialised organs for gaseous exchange** but they have stomata and lenticels for this purpose.
- There are several **reasons why plants can get along without respiratory organs.**
- **First, each plant part takes care of its own gas-exchange needs.** There is very little transport of gases from one plant part to another.
- **Second, plants do not present great demands for gas exchange.** Roots, stems and leaves respire at rates far lower than animals do. Only during photosynthesis are large volumes of gases exchanged and, each leaf is well adapted to take care of its own needs during these periods. When cells photosynthesise, availability of O_2 is not a problem in these cells since O_2 is released within the cell.
- **Third, the distance that gases must diffuse even in large, bulky plants is not great.** Each living cell in a plant is located quite close to the surface of the plant. In stems, the 'living' cells are organised in thin layers inside and beneath the bark. They also have openings called lenticels. The cells in the interior are dead and provide only mechanical support. Thus, most cells of a plant have at least a part of their surface in contact with air. This is also facilitated by the loose packing of parenchyma cells in leaves, stems and roots, which provide an interconnected network of air spaces.

03. TYPES OF RESPIRATION

(1) ON THE BASIS OF TYPE OF RESPIRATORY SUBSTRATES

(A) Floating Respiration :

When carbohydrate or fats are oxidised inside the cell. Carbohydrates and fats are floating inclusions of cell thus, this is called floating respirations.

(B) Protoplasmic Respiration :

When protein is oxidised inside the cell. This occurs in starved cell. Protein is constituent of protoplasm thus, this is called protoplasmic respiration.

(2) ON THE BASIS OF PRESENCE OR ABSENCE OF O_2

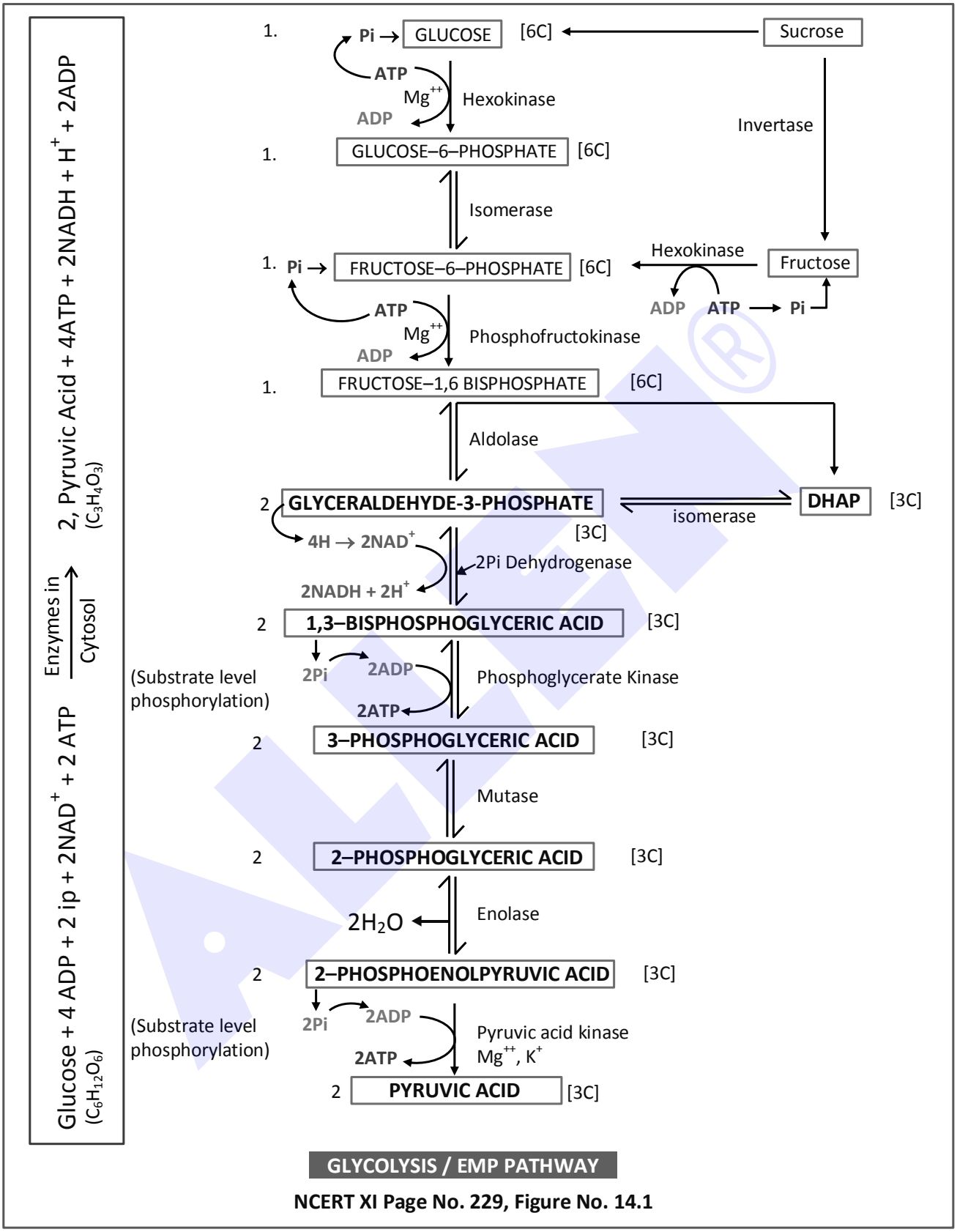
Aerobic		Anaerobic/Fermentation	
(1)	This accounts for complete oxidation of glucose to CO_2 and H_2O	(1)	This accounts for only a partial breakdown of glucose to either lactic acid or ethanol and CO_2
(2)	Its an intermolecular respiration.	(2)	Its an intramolecular respiration
(3)	36 or 38 molecules of ATP gain for each molecule of glucose	(3)	There is gain of only two molecules of ATP for each molecule of glucose
(4)	NADH is oxidised to NAD^+ vigorously.	(4)	NADH is oxidised to NAD^+ rather slowly.
(5)	O_2 remove hydrogen from the system and acts as the final hydrogen acceptor.	(5)	O_2 is absent. Hydrogen acceptor in the system is either acetaldehyde (during alcoholic fermentation) or Pyruvate (during lactic acid fermentation)
(6)	**Reaction** $C_6H_{12}O_6 + 6O_2 + 6H_2O \rightarrow 6CO_2 + 12H_2O + 686$ kcal	(6)	**Reaction** $C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$ + less than 7% of energy of glucose **'or'** $C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$ + less than 7% of energy of glucose

04. GLYCOLYSIS

OR

EMP (EMBDEN, MEYERHOF, PARNAS) PATHWAY

- The term glycolysis has originated from the greek words **glycos – sugar, lysis** means **splitting.** The scheme of glycolysis was given by **Gustav Embden, Otto Meyerhof** & **J.Parnas** so glycolysis is often called **EMP pathway.**
- **In all living organisms whether it is aerobic or anaerobic,** the first step in cellular respiration is **partial breakdown or partial oxidation of glucose into two molecules of pyruvic acid** and it is called glycolysis.
- Glycolysis **occurs in the cytoplasm of the cell,** this process is independent of oxygen, it means it can occur in both conditions, presence of O_2 or absence of O_2.
- **In plants, the glucose is derived from sucrose (product of photosynthesis) or from starch (storage carbohydrate).**
- **Sucrose is converted into glucose and fructose by the enzyme invertase and these two monosaccharides enter the glycolytic pathway.**
- Glucose and fructose are phosphorylated to give rise to glucose-6-phosphate and fructose-6-phosphate respectively by the activity of the enzyme hexokinase. This phosphorylated form of glucose then isomerises to produce fructose-6-phosphate. Subsequent steps of metabolism of glucose and fructose are same.
- In glycolysis, a chain of ten reactions, under the control of different enzymes, takes place to produce pyruvate from glucose.



GLYCOLYSIS / EMP PATHWAY

NCERT XI Page No. 229, Figure No. 14.1

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- In Glycolysis, no consumption of oxygen & no liberation of CO_2 takes place.
- Pyruvic acid is the key product of glycolysis.
- 2 NADH + $2H^+$, produced during the process enter into ETS (In mitochondria) to produce 4ATP (if glycerol phosphate shuttle is present) or 6ATP (if malate aspartate shuttle is present), this ATP formation is called oxidative phosphorylation (In aerobic organisms).
- **Substrate level phosphorylation** [When the substrate releases energy for phosphorylation of ADP **(formation of ATP) without ETS** then this method of ATP formation is called as **substrate level phosphorylation], forms 4 ATP, 2ATP** consumed, so **2ATP gained by SLP (Direct gain)**.

CONTROL OF GLYCOLYSIS

- In glycolysis first, third and last step are irreversible, these are control points of glycolysis, where process can be controlled, if required.
- **Step third is the most important control point of glycolysis,** this step is regulated by an **allosteric enzyme phophofructokinase.** This enzyme is **allosterically activated by AMP** and **allosterically inhibited by ATP.** This enzyme is called **pacemaker enzyme** of glycolysis.

FATE OF PYRUVIC ACID

The **fate of pyruvic acid depends on the availability of oxygen and cellular need.** There are three major ways in which different cells handle pyruvic acid produced by glycolysis. These are lactic acid fermentation, alcoholic fermentation and aerobic respiration. Fermentation takes place under anaerobic conditions in many prokaryotes and unicellular eukaryotes. For the complete oxidation of glucose to CO_2 and H_2O, however, organisms adopt Krebs' cycle which is also called as aerobic respiration. This requires O_2 supply.

05. AEROBIC RESPIRATION

For aerobic respiration to take place within the mitochondria, the final product of glycolysis, pyruvate is transported from the cytoplasm into the mitochondria. The crucial events in aerobic respiration are:

- The complete oxidation of pyruvate by the stepwise removal of all the hydrogen atoms, leaving three molecules of CO_2 (Link reaction and Krebs cycle).
- The passing on of the electrons removed as part of the hydrogen atoms to molecular O_2 with simultaneous synthesis of ATP (ETS and Oxidative phosphorylation).
- What is interesting to note is that the first process takes place in the matrix of the mitochondria while the second process is located on the inner membrane of the mitochondria.

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(1) LINK/GATEWAY REACTION (FORMATION OF ACETYL-CO-A)

- This process connects Glycolysis and Krebs cycle so it is called Link reaction or Gateway reaction. During this process Ist time CO_2 is evolved during respiration.
- Decarboxylation and dehydrogenation/oxidation (Oxidative decarboxylation) takes place during formation of acetyl Co-A.
- **Acetyl Co-A is formed from pyruvic acid in the matrix by enzyme pyruvate dehydrogenase complex.**
- In this process, cofactors required are : NAD^+, TPP (Thiamine pyrophosphate), FAD^+, Lipoic acid (LA) and Coenzyme-A (Co-A), Mg^{2+}

$$\text{Pyruvic acid} + \text{CoA} + NAD^+ \xrightarrow[\text{Pyruvate dehydrogenase}]{Mg^{2+}} \text{Acetyl CoA} + CO_2 + NADH + H^+$$

(2) TCA (TRICARBOXYLIC ACID) CYCLE OR KREBS CYCLE/CA (CITRIC ACID) CYCLE

- This cycle was discovered by **H.A. Krebs. (Nobel prize)**
- TCA cycle occurs in **mitochondrial matrix. All the enzymes of TCA cycle, except Succinate dehydrogenase (in the inner mitochondrial membrane) present in matrix.**
- **During Krebs cycle acetyl CoA is completely oxidised into CO_2.**
- Krebs cycle is also called **Citric acid (CA) cycle** because Ist Compound is Citric acid (6C). In this acid, **3 carboxylic groups** (COOH) are found so process is also called **TCA (Tricarboxylic Acid) cycle**
- In Krebs cycle oxaloacetic acid (OAA) is the first member and it also act as first acceptor of acetyl Co-A. In the end of this cycle OAA re-formed.
- The TCA cycle starts with the condensation of acetyl group with oxaloacetic acid (OAA) and water to yield citric acid. The reaction is catalysed by the enzyme citrate synthase and a molecule of CoA is released.
- Citrate is then isomerised to isocitrate. It is followed by two successive steps of decarboxylation, leading to the formation of α-ketoglutaric acid and then succinyl-CoA.
- In the remaining steps of citric acid cycle, succinyl-CoA is oxidised to OAA allowing the cycle to continue. During the conversion of succinyl-CoA to succinic acid a molecule of GTP is synthesised. This is a substrate level phosphorylation. In a coupled reaction GTP is converted to GDP with the simultaneous synthesis of ATP from ADP.
- Also there are three points in the cycle where NAD^+ is reduced to NADH + H^+ and one point where FAD^+ is reduced to $FADH_2$.
- The continued oxidation of Acetyl CoA via the TCA cycle requires the continued replenishment of oxaloacetic acid, the first member of the cycle. In addition it also requires regeneration of NAD^+ and FAD^+ from NADH and $FADH_2$ respectively.
- Oxidation or dehydrogenation occurs at 4 places in one Krebs cycle, results in the formation of 3NADH, 1$FADH_2$. Along with 1GTP (ATP) produced by substrate level phosphorylation in each turn of TCA cycle (12 ATP).

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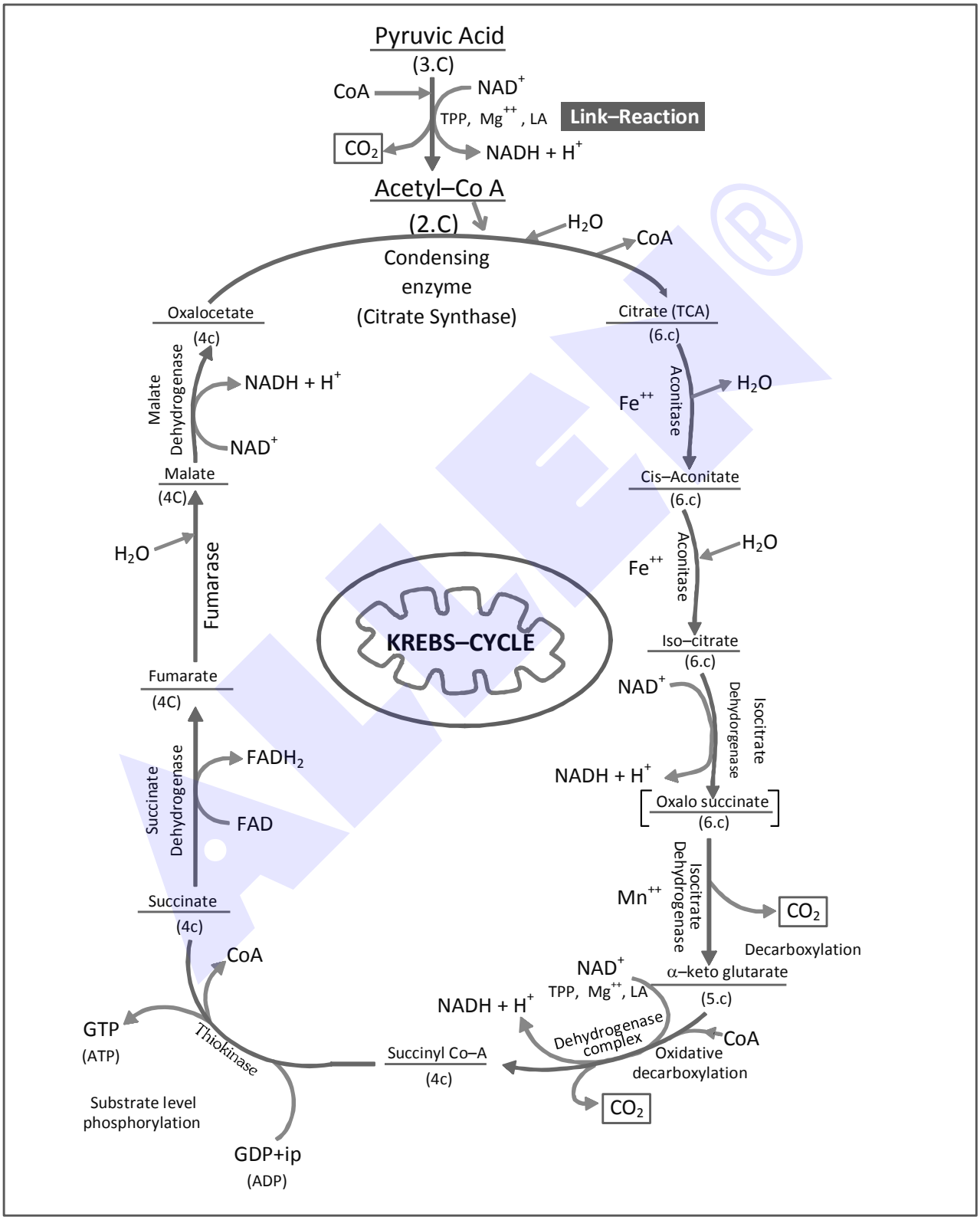
- Link reaction and Krebs cycle occurs two times during complete oxidation of 1 hexose molecule because by glycolysis one hexose converts into two pyruvic acid and both the molecules undergo separate link reaction and Krebs cycle.

DETAILED DIAGRAM OF KREBS CYCLE



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Golden Key Points

- **ATP act as the energy currency of the cell.**
- **Plants, unlike animals, have no specialised organs for gaseous exchange** but they have stomata and lenticels for this purpose.
- **Step third is the most important control point of glycolysis,** this step is regulated by an **allosteric enzyme phophofructokinase.**
- The **fate of pyruvic acid depends on the availability of oxygen and cellular need.**
- The complete oxidation of pyruvate by the stepwise removal of all the hydrogen atoms, leaving three molecules of CO_2. (Link reaction and Krebs cycle)
- **Acetyl Co-A is formed from pyruvic acid in the matrix by enzyme pyruvate dehydrogenase complex.**
- **All the enzymes of TCA cycle, except Succinate dehydrogenase (in the inner mitochondrial membrane) present in matrix.**
- There are three points in the Krebs cycle where NAD^+ is reduced to NADH + H^+ and one point where FAD^+ is reduced to $FADH_2$.

BEGINNER'S BOX

INTRODUCTION, DO PLANTS BREATH?, TYPES OF RESPIRATION, GLYCOLYSIS, AEROBIC RESPIRATION, (LINK REACTION AND TCA CYCLE)

1. Which of the following sequences is correct regarding gross calorific value of respiratory substrates?
(1) Fat > Protein > Carbohydrate (2) Protein > Fat > Carbohydrate
(3) Carbohydrate > Fat > Protein (4) Fat > Carbohydrate > Protein

2. When protein is oxidised in cell, the respiration is called :-
(1) floating (2) anaerobic
(3) fermentation (4) prototoplasmic

3. For Glycolysis choose correct one :-
(1) Occurs in the cytoplasm (2) is a partial oxidation of glucose
(3) results in formation of pyruvic acid (4) all of the above

4. Oxidative decarboxylation of pyruvic acid occurs :-
(1) in the cytoplasm (2) in the matrix of mitochondria
(3) at the cell membrane (4) at the outer membrane of mitochondria

5. Substrate level phosphorylation (SLP) occurs during ?
(1) Link reaction and Krebs cycle (2) Glycolysis and link reaction
(3) Krebs cycle and glycolysis (4) Glycolysis only

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3. ELECTRON TRANSPORT SYSTEM (ETS)/OXIDATIVE PHOSPHORYLATION

OR

RESPIRATORY CHAIN (TERMINAL OXIDATION OF NADH + H^+ & $FADH_2$)

(i) All the **reduced hydrogen acceptors like NADH + H^+ and $FADH_2$** move to the ETS where they release their hydrogen and get **reoxidised to NAD^+ & FAD^+,** so that they can again enter into the respiration process.

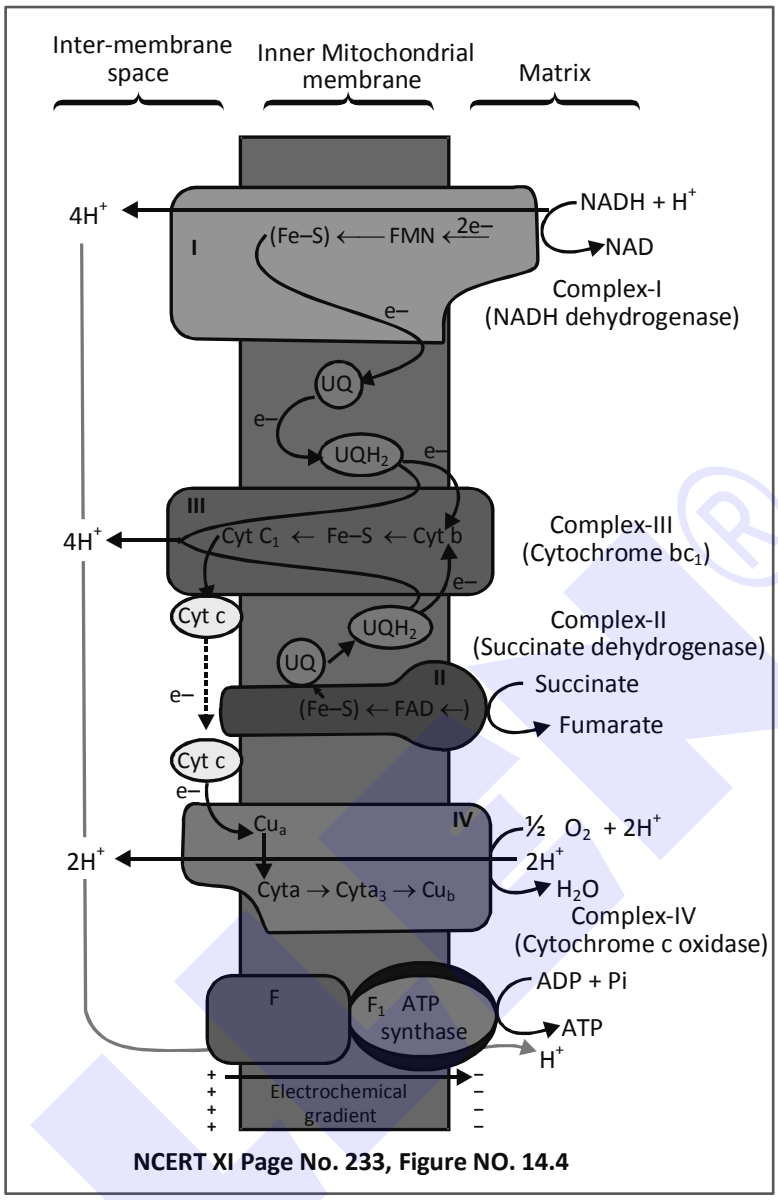
(ii) ETS is the chain of some hydrogen and electron carriers present in the inner mitochondrial membrane.

(iii) The significance of ETS is to remove hydrogens from reduced hydrogen acceptors NADH + H^+ & $FADH_2$. During this process hydrogen acceptors get reoxidised and ATP are produced.

- Now components of ETS are categorised as follows :

Name of complexes	Component(s) of complexes
Complex-I (NADH Dehydrogenase complex)	FMN, Fe-S
Complex-II (Succinic Dehydrogenase complex)	FAD, Fe-S
Complex-III (Cytochrome bc_1 complex)	Cytochrome b-Cyt c_1, Fe-S
Complex-IV (Cytochrome c oxidase complex)	Cyt. a and Cyt. a_3 , 2Cu centres
Complex-V (ATP synthase/ATPase/Oxysome)	F_0(Integral) – F_1(peripheral)

- **Electrons from NADH + H^+ produced in the mitochondrial matrix during citric acid cycle are oxidised by an NADH dehydrogenase (complex I), and electrons are then transferred to ubiquinone located within the inner membrane.**
- Ubiquinone also receives reducing equivalents via $FADH_2$ (complex II) that is generated during oxidation of succinate in the citric acid cycle.
- The reduced ubiquinone (ubiquinol) is then oxidised with the transfer of electrons to cytochrome c via cytochrome bc_1 complex (complex III).
- Cytochrome c is a small protein attached to the outer surface of the inner membrane and acts as a **mobile carrier** for transfer of electrons between complex III and IV.
- Complex IV refers to cytochrome c oxidase complex containing cytochromes a and a_3, and two copper centres.



NCERT XI Page No. 233, Figure NO. 14.4

- When the electrons pass from one carrier to another via complex I to IV in the electron transport chain, they are coupled to ATP synthase (complex V) for the production of ATP from ADP and inorganic phosphate.
- The number of ATP molecules synthesised depends on the nature of the electron donor. Oxidation of one molecule of NADH + H^+ gives rise to 3 molecules of ATP, while that of one molecule of $FADH_2$ produces 2 molecules of ATP.
- Passage of $4H^+$ through F_0 particle or proton channel leads to synthesis of 1 ATP.
- Although the aerobic process of respiration takes place only in the presence of oxygen, the role of oxygen is limited to the terminal stage of the process. Yet, the presence of oxygen is vital, since it drives the whole process by removing hydrogen from the system. Oxygen acts as the final hydrogen acceptor.
- Unlike photophosphorylation, where it is the light energy that is utilised for the production of proton gradient required for phosphorylation, in respiration it is the energy of oxidation-reduction utilised for the same process. It is for this reason that the process is called oxidative phosphorylation

- CoQ/UQ (Ubiquinone) is a mobile H (electron + H^+) carrier and cyt-c is mobile electron carrier.
- O_2 is last H acceptor in oxidative phosphorylation & due to its reduction, water is formed.
- **Shuttle system :-**

  Cytosolic or extra mitochondrial or **glycolytic NADH** transported to ETS by **two type of shuttles (only in eukaryotes)** :

  (a) **Glycerol phosphate shuttle** $2NADH + 2H^+ \longrightarrow 2FADH_2$

  (b) **Malate aspartate shuttle** $2NADH + 2H^+ \longrightarrow 2NADH + 2H^+$

  - In **prokaryotes, shuttle mechanism is absent.** They **always get 38 ATP** from aerobic respiration of 1 glucose.

06. THE RESPIRATORY BALANCE SHEET

Theoretical energy calculation for complete oxidation of one glucose molecule :

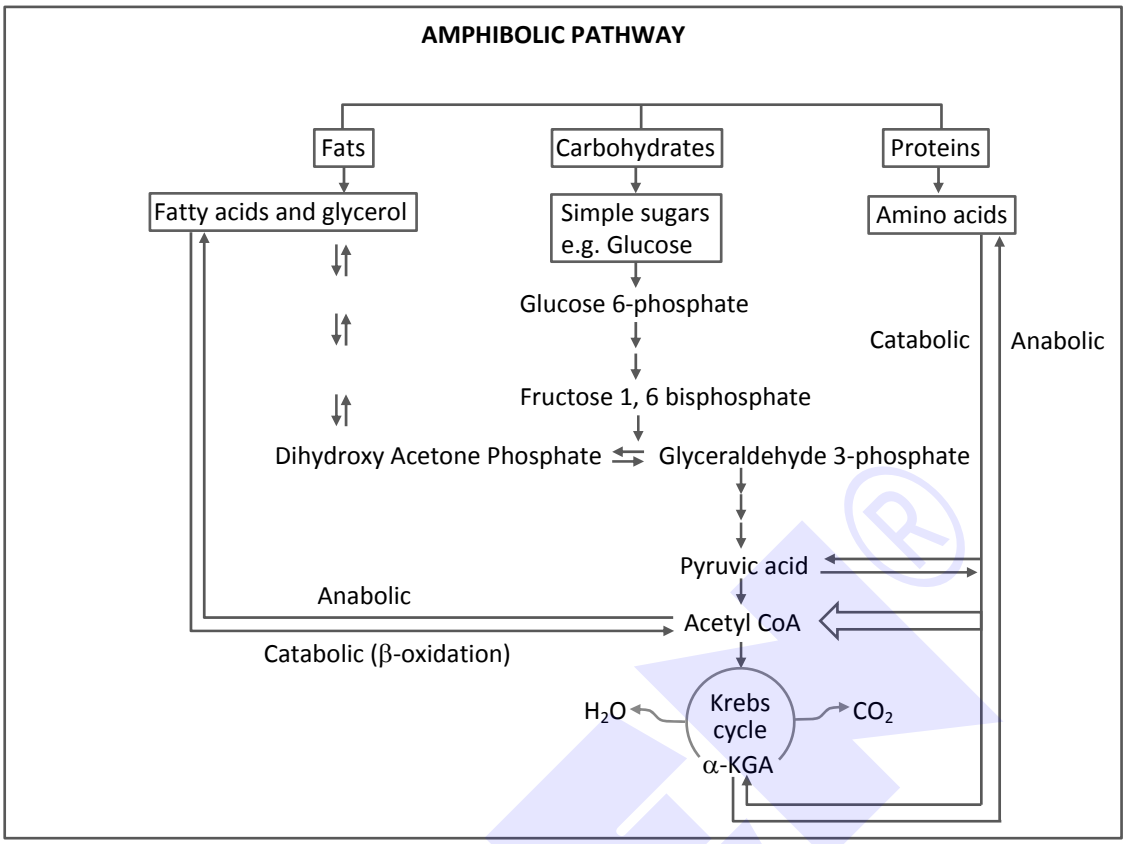
Step	Number of turn	ATP synthesis Through substrate Level phosphorylation	ATP gain through Oxidative phosphorylation	ATP consumed	Net gain
EMP pathway	1	4	6 or 4	2	8 or 6
Link reaction	2	0	6	0	6
Krebs cycle	2	2	22	0	24

- It is possible to make calculations of the **net gain of ATP for every glucose molecule oxidised; but in reality** this can remain only a theoretical exercise. **These calculations can be made only on certain assumptions that :**
- There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway following one after another.
- The NADH + H^+ synthesised in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.
- None of the intermediates in the pathway are utilised to synthesise any other compound.
- Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.
- But this kind of assumptions are not really valid in a living system; all pathways work simultaneously and do not take place one after another; substrates enter the pathways and are withdrawn from it as and when necessary; ATP is utilised as and when needed; enzymatic rates are controlled by multiple means. Yet, it is useful to do this exercise to appreciate the beauty and efficiency of the living system in extraction and storing energy.

07. RESPIRATION – AMPHIBOLIC PATHWAY

- Glucose is the favoured substrate for respiration. All carbohydrates are usually first converted into glucose before they are used for respiration. Other substrates can also be respired, as has been mentioned earlier, but then they do not enter the respiratory pathway at the first step.
- Fats would need to be broken down into glycerol and fatty acids first. If fatty acids were to be respired they would first be degraded to acetyl CoA and enter the pathway. Glycerol would enter the pathway after being converted to PGAL.
- The proteins would be degraded by proteases and the individual amino acids (after deamination) depending on their structure would enter the pathway at some stage within the Krebs' cycle or even as pyruvate or acetyl CoA.
- Since respiration involves breakdown of substrates, the respiratory process has traditionally been considered a catabolic process and the respiratory pathway as a catabolic pathway. But is this understanding correct? We have discussed above, at which points in the respiratory pathway different substrates would enter if they were to be respired and used to derive energy. What is important to recognise is that it is these very compounds that would be withdrawn from the respiratory pathway for the synthesis of the said substrates. Hence, fatty acids would be broken down to acetyl CoA before entering the respiratory pathway when it is used as a substrate. But when the organism needs to synthesise fatty acids, acetyl CoA would be withdrawn from the respiratory pathway for it. Hence, the respiratory pathway comes into the picture both during breakdown and synthesis of fatty acids. Similarly, during breakdown and synthesis of protein too, respiratory intermediates form the link.
- Breaking down processes within the living organism is catabolism, and synthesis is anabolism. Because the respiratory pathway is involved in both anabolism and catabolism, it would hence be better to consider the respiratory pathway as an amphibolic pathway rather than as a catabolic one.

- Succinyl Co–A is important for the synthesis of porphyrin ring containing compounds like Chlorophylls, Phytochromes, Cytochromes, Haemoglobin etc.
- α-ketoglutaric acid (5c) is involved in various amino acid formation.



08. FERMENTATION

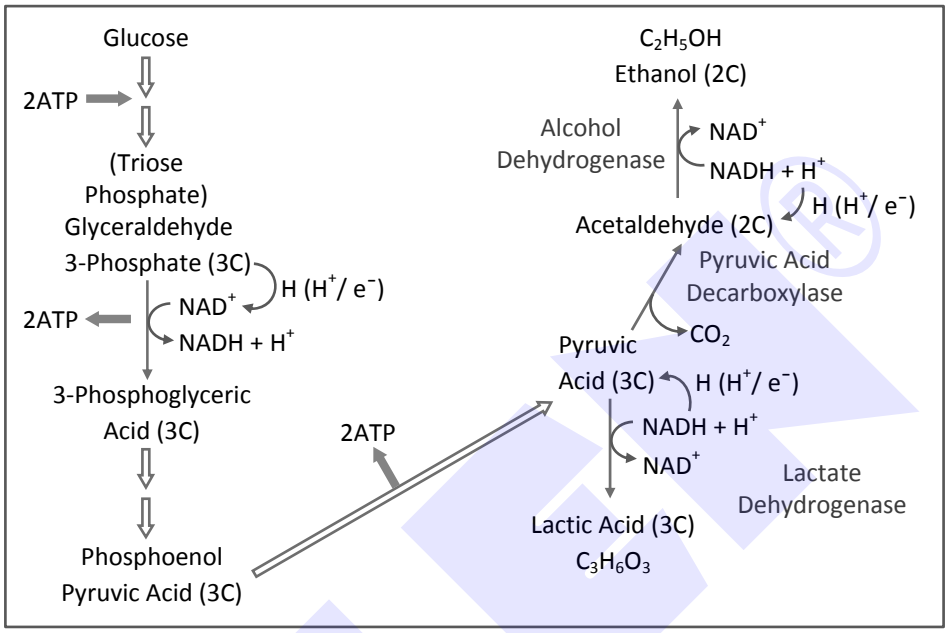
OR

ANAEROBIC RESPIRATION

- Fermentation takes place under anaerobic conditions in many prokaryotes, unicellular eukaryotes and in germinating seeds.
  (i) **Lactic acid fermentation :** In human muscles (during exercise when oxygen is inadequate).
  (ii) **Alcoholic fermentation :** In yeast.
- **Alcoholic fermentation is used in the formation of beverages (alcoholic drinks) and bread. Bread become puffed or spongy due to release of CO_2 during the process.**
- In both lactic acid and alcohol fermentation not much energy is released; less than seven percent of the energy in glucose is released and not all of it is trapped as high energy bonds of ATP. Also, the processes are hazardous – either acid or alcohol is produced.
- Yeasts poison themselves to death when the concentration of alcohol reaches about **13 percent**.
- In Anaerobic respiration or fermentation the net gain of ATP is 2 ATP because during the process, in glycolysis, 4 ATP are synthesised by the substrate level phosphorylation and 2 ATP are consumed, so **net gain : 4 – 2 = 2 ATP**
  (The 2NADH + H^+ produced during glycolysis do not enter into ETS, instead they are utilised to form alcohol or lactic acid).

- Lactic acid fermentation is also performed by bacteria *Lactobacillus*. It is used in curd and other dairy products formation. Curd becomes sour due to excess lactic acid fermentation.

- **In aerobic respiration, there is an external final electron acceptor i.e. O_2** while in fermentation, there is no external electron acceptor. The final electron acceptor is organic intermediate of the process.



- **Pasteur effect :**

  It is an **inhibitory effect** of oxygen on the fermentation process.

  Explanation :

  The effect can be easily explained; as the yeast being **facultative anaerobes** can produce energy using two different metabolic pathways.

  (i) While the oxygen concentration is low, the product of glycolysis, **pyruvate** is turned into **ethanol** and **CO_2** and the energy production efficiency is low (2 moles of ATP per mole of glucose).

  (ii) If the oxygen concentration grows, **pyruvate** is converted into **acetyl CoA** that can be used in the **citric acid cycle,** which increases the efficiency to 36 or 38moles of ATP per mole of glucose.

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09. RESPIRATORY QUOTIENT (R.Q.)

The ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration is called the respiratory quotient (RQ) or respiratory ratio.

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

The respiratory quotient depends upon the type of respiratory substrate used during respiration.

RQ = 1

- When **carbohydrates** are used as substrate and are completely oxidised, the RQ will be 1, because equal amounts of CO_2 and O_2 are evolved and consumed, respectively, as shown in the equation below :

$$C_6H_{12}O_6 + 6O_2 + 6H_2O \longrightarrow 6CO_2 + 12H_2O + 686 \text{ kcal}$$

$$RQ = \frac{6\ CO_2}{6\ O_2} = 1.0$$

RQ = ∞

- For alcoholic fermentation

$$C_6H_{12}O_6 \longrightarrow 2CH_3CH_2OH + 2CO_2 + 59 \text{ kcal}$$

$$RQ = \frac{2\ CO_2}{\text{Zero } O_2} = \infty$$

RQ = Zero

- **In succulent** plants due to availability of insufficient O_2 glucose oxidise partially and **RQ will be zero.**

$$2C_6H_{12}O_6 + 3O_2 \longrightarrow \underset{\text{Malic acid}}{3C_4H_6O_5} + 3H_2O + \text{Energy}$$

RQ = Less than one

- During complete oxidation of protein and fat
- During **protoplasmic respiration** (In case of a **starved cell**)
- In case of mixed diet
- In case of **germinating fatty seeds.**

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

Triplamitin

$$RQ = \frac{102\ CO_2}{145\ O_2} = 0.7$$

When proteins are respiratory substrates the ratio would be about 0.9.

Pure proteins or fats are never used as respiratory substrates because before entering the respiratory pathway they must be converted into such compounds which can enter into the glycolysis or link reaction or Krebs cycle at their respective stages.

RQ = More than one

- During complete oxidation of **organic acids.**
- **In case of maturing fatty seeds.**

$2(COOH)_2 + O_2 \longrightarrow 4CO_2 + 2H_2O$ + Energy RQ = 4.0

Oxalic acid

$C_4H_6O_5 + 3O_2 \longrightarrow 4CO_2 + 3H_2O$ + Energy RQ = 1.33

Malic acid

$2C_4H_6O_4 + 7O_2 \longrightarrow 8CO_2 + 6H_2O$ + Energy RQ = 1.14

Succinic acid

Energy efficiency of cellular respiration :

1 ATP = 8.1 Kcal 1 Glucose = 686 Kcal

If gain is 36 ATP then efficiency = $36 \times 8.1 = \frac{291.6}{686} \times 100 = 42.50\%$

If gain is 38 ATP then efficiency = $38 \times 8.1 = \frac{307.8}{686} \times 100 = 44.86\%$

Golden Key Points

- **The significance of ETS is to remove hydrogens from reduced hydrogen acceptors NADH + H^+ & $FADH_2$. During this process hydrogen acceptors get reoxidised and ATP are produced.**
- Cytochrome c is a small protein attached to the outer surface of the inner membrane and acts as a mobile carrier for transfer of electrons between complex III and IV.
- Passage of $4H^+$ through F_0 particle or proton channel leads to synthesis of 1 ATP.
- Glucose is the favoured substrate for respiration.
- In both lactic acid and alcohol fermentation not much energy is released; less than seven percent of the energy in glucose is released.
- Yeasts poison themselves to death when the concentration of alcohol reaches about 13 percent.
- The respiratory quotient depends upon the type of respiratory substrate used during respiration.

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BEGINNER'S BOX

AEROBIC RESPIRATION (ELECTRON TRANSPORT SYSTEM), THE RESPIRATORY BALANCE SHEET, RESPIRATION–AMPHIBOLIC PATHWAY, FERMENTATION, RESPIRATORY QUOTIENT (R.Q.)

1. Which of the following are components of cytochrome-c oxidase complex of mitochondrial ETS?

(1) Cyt-c and Cyt-c_1 (2) Cyt-a and Cyt-a_3

(3) FAD and Cyt-b (4) F_0 and F_1

2. During complete oxidation of one glucose, ATP gain through link reactions, is :-

(1) 8 ATP (2) 22 ATP

(3) 38 ATP (4) 6 ATP

3. Glycerol enter into the respiratory pathway in the form of :-

(1) Glyceraldehyde-3-phosphate (2) Acetyl CoA

(3) Pyruvic acid (4) Glucose

4. Curd become sour due to excess :-

(1) Alcoholic fermentation (2) Krebs cycle

(3) Lactic acid fermentation (4) Link reaction

5. The respiratory quotient [R.Q.] for alcoholic fermentation is :-

(1) infinite (∞) (2) Zero

(3) 1 (4) 0.7

BEGINNER'S BOX — ANSWER KEY

INTRODUCTION, DO PLANTS BREATH?, TYPES OF RESPIRATION, GLYCOLYSIS, AEROBIC RESPIRATION (LINK REACTION AND KREBS CYCLE)

Que.	1	2	3	4	5
Ans.	**1**	**4**	**4**	**2**	**3**

AEROBIC RESPIRATION (ELECTRON TRANSPORT SYSTEM), THE RESPIRATORY BALANCE SHEET, RESPIRATION–AMPHIBOLIC PATHWAY, FERMENTATION, RESPIRATORY QUOTIENT (R.Q.)

Que.	1	2	3	4	5
Ans.	**2**	**4**	**1**	**3**	**1**

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Glycolysis :
- In Cytoplasm
- Common in both aerobic and anaerobic organisms

Glucose (6C) $C_6H_{12}O_6$

2ATP → 2NADH+H$^+$ + 4ATP

2X Pyruvic Acid (3C) $C_3H_4O_3$

MAS → 6ATP

GPS → 4ATP

MAS = Malate Aspartate Shuttle
GPS = Glycerol Phosphate Shuttle

In Anaerobic conditions

Anaerobic Respiration or Fermentation

2X Pyruvic Acid (3C) $C_3H_4O_3$

- 2X Ethyl Alcohol $C_2H_5OH + 2CO_2$
- 2X Lactic Acid $C_3H_6O_3$

or

In Aerobic conditions

2X Pyruvic Acid (3C) $C_3H_4O_3$

Link Reaction :
- In Matrix of mitochondria
- Link between Glycolysis and Krebs Cycle

NADH + H$^+$, CO_2

Acetyl Co-A (2C)

OAA (4C) → Citric Acid (6C) + NADH+H$^+$

Fumaric Acid (4C) → Succinic Acid (4C) + $FADH_2$

Citric Acid (6C) → α- Ketoglutaric acid (5C) + NADH+H$^+$ + CO_2

Succinic Acid (4C) → GTP + CO_2 + NADH+H$^+$

ETS (Electron transport system) & Oxidative Phosphorylation
- In inner membrane of mitochondria
- 1 NADH+H$^+$ = 3 ATP
- 1 $FADH_2$ = 2 ATP

Step	Number of turn	ATP synthesis through substrate level phosphorylation	ATP gain through oxidative phosphorylation	ATP consumed	Net gain
EMP pathway	1	4	6 or 4	2	8 or 6
Link reaction	2	0	6	0	6
Krebs cycle	2	2	22	0	24