

Respiration in Plants

Cellular Respiration & Glycolysis

Cellular Respiration

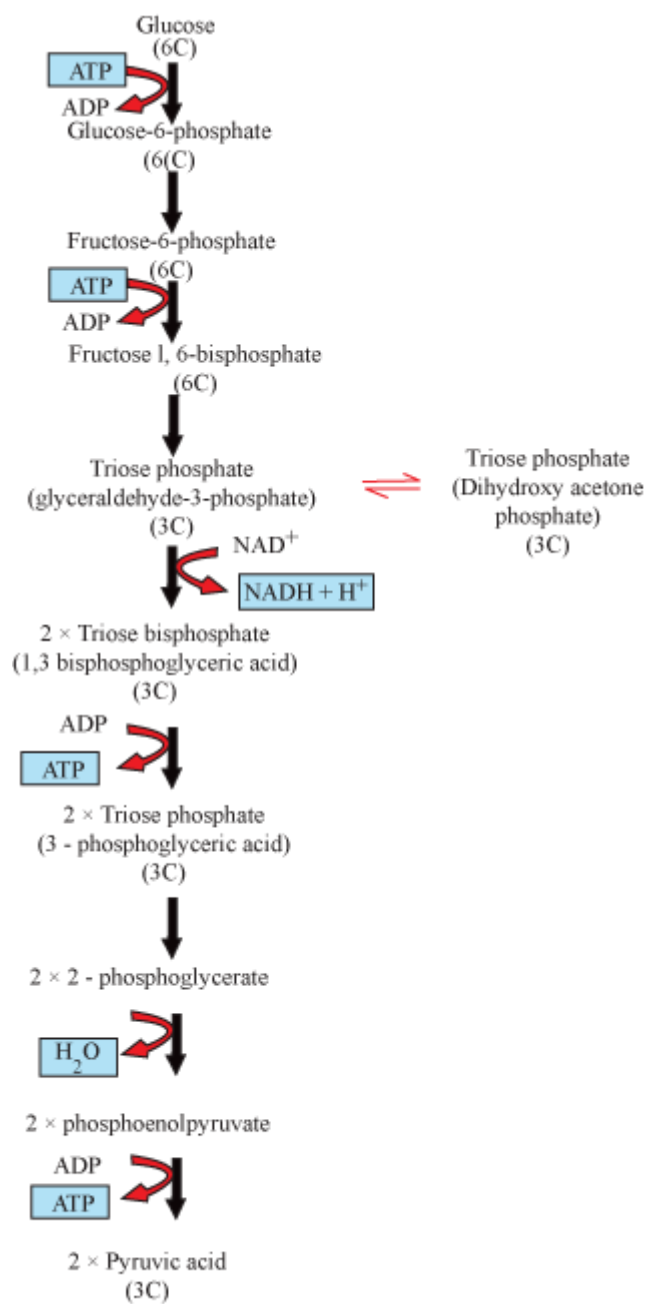
- Mechanism of breakdown of food materials within the cell to release energy, and the trapping of this energy for ATP synthesis.
- Respiratory substrates: Compounds oxidised during respiration; usually carbohydrates; these can also be proteins, fats or organic acids
- ATP: Energy currency of a cell; broken down whenever energy is needed
- Plants do not need specialised organs for respiration because:
- Gaseous exchange occurs in each part of a plant.
- Gaseous exchange is not a much-needed factor. During photosynthesis, the need for gaseous exchange is met.
- Each living cell is located close to the surface of a plant. So the distances that the gases must diffuse are not great.
- Equation for respiration:
$$\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy}$$

Glycolysis (*Glycos* – Sugar, *Lysis* – Splitting)

- Breakdown of glucose to pyruvic acid by partial oxidation
- Scheme given by Embden, Meyerhof and Parnas
- Common pathway for aerobic and anaerobic cellular respiration
- Occurs in the cytoplasm of a cell
- Present in all living organisms
- In plants, sucrose is converted into glucose.
- Sucrose $\xrightarrow{\text{Invertase}}$ Glucose \rightarrow Enters the glycolysis



- A chain of 10 reactions converts glucose into pyruvate.
- Hexokinase: Enzyme that phosphorylates glucose to produce glucose – 6 – phosphate
- 2 ATPs are utilised in two steps:
- Glucose → Glucose – 6 – phosphate (1 ATP)
- Fructose – 6 – phosphate → fructose 1, 6 – bisphosphate (1 ATP)
- Fructose 1, 6 bisphosphate splits into glyceraldehyde – 3 – phosphate and dihydroxy acetone phosphate.
- Glyceraldehyde – 3 – phosphate converts into two molecules of 1, 3 bisphosphoglycerate (BPGA), with subsequent conversion of NAD^+ to $\text{NADH} + \text{H}^+$.
- 4 ATPs are yielded in two steps:
- BPGA → PGA ($1 \times 2 = 2$ ATPs)
- Phosphoenol pyruvate → Pyruvic acid ($1 \times 2 = 2$ ATPs)
- ATPs produced directly = 4 (produced) – 2 (consumed) = 2 ATPs
- Net ATPs Produced = 2 ($\text{NADH} + \text{H}^+$) = 6 ATPs + 2 (Directly synthesised) = 8 ATPs



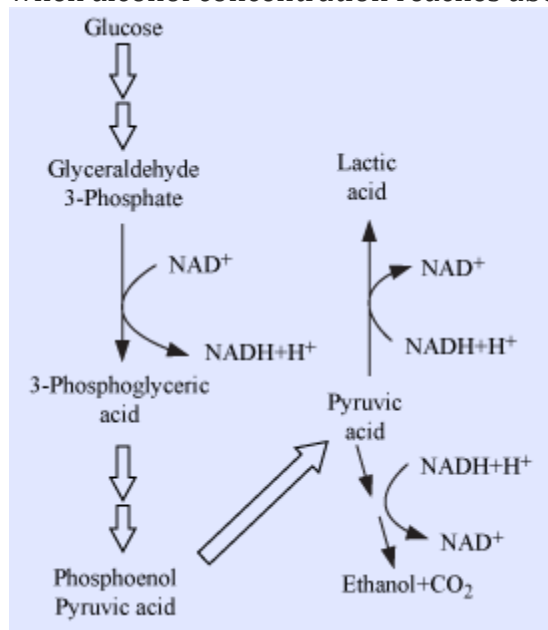
Steps of glycolysis

The pyruvate, so produced, may undergo:

- Lactic acid fermentation
- Alcoholic fermentation
- Aerobic respiration (Krebs cycle)

Fermentation

- Fermentation: Incomplete oxidation of glucose under anaerobic conditions
- In yeast fermentation:
 - Pyruvic acid \rightarrow Ethanol + CO_2
 - Enzymes involved – Pyruvic acid decarboxylase, Alcohol dehydrogenase
- In bacterial fermentation:
 - Pyruvic acid \rightarrow Lactic acid
 - Enzyme involved – Lactate dehydrogenase
- Similar reaction occurs in animal muscles in anaerobic conditions, say during exercise.
- Reducing agent in both reactions is NADH.
 $\text{NADH} + \text{H}^+ \rightarrow \text{NAD}^+$
- Only 7% of energy of glucose is released during fermentation.
- Process can be hazardous as alcohol or acid is produced. Yeasts poison themselves to death when alcohol concentration reaches about 13%.



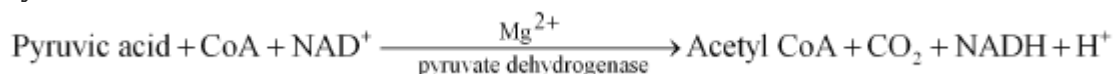
Tricarboxylic Acid Cycle

Aerobic Respiration

- Site: Mitochondria
- Events:
- **TCA cycle** (in the mitochondrial matrix) – complete oxidation of pyruvate by stepwise removal of all hydrogen atoms, which leaves three molecules of CO₂
- **Electron Transport Chain and Oxidative phosphorylation** (in the inner membrane of the mitochondria) – electrons removed as a part of hydrogen atoms are passed on to molecular oxygen, with the simultaneous synthesis of ATP

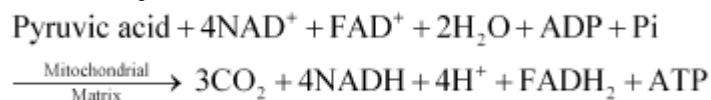
Formation of Acetyl Coenzyme A

- The product of glycolysis, i.e., pyruvate, on entering the mitochondrial matrix, undergoes *Oxidative Decarboxylation*, thereby producing acetyl CoA which enters Krebs cycle.



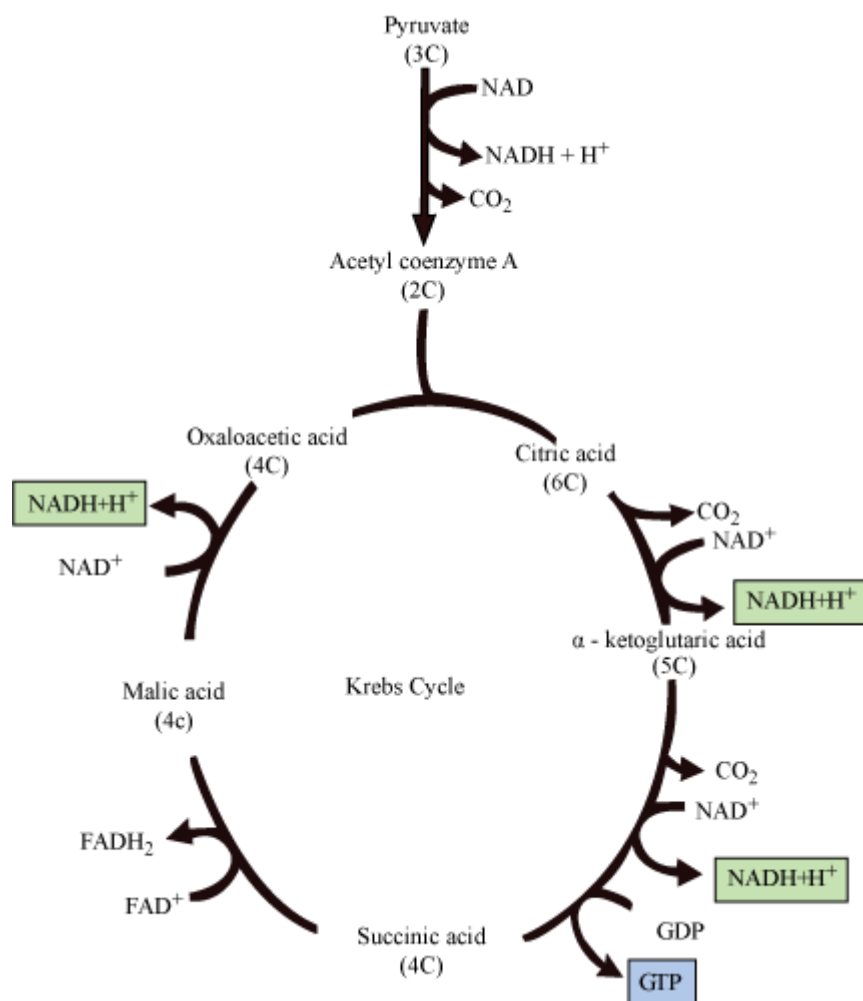
Krebs cycle (Tricarboxylic acid cycle; TCA)

- Acetyl group condenses with oxaloacetic acid and water to yield citric acid (catalysed by the enzyme citrate synthase)
- Citrate isomerises into isocitrate
- Two successive decarboxylation steps follow, leading to the formation of α ketoglutaric acid, followed by succinyl CoA
- This is followed by the conversion of succinyl CoA into succinic acid. During this process, GDP is converted into GTP (substrate level phosphorylation).
- In a coupled reaction, GTP is converted into GDP, simultaneously synthesising ATP from ADP.
- Conversion of one molecule of pyruvate into acetyl CoA yields 1 molecule of CO₂ and 1 NADH.
- One Kreb's cycle yields 2 CO₂ + 3 NADH + 1 FADH₂ + 1 ATP
- Overall equation:



- For continued oxidation of acetyl CoA in TCA 2 things are required:
- Continued replenishment of oxaloacetic acid
- Regeneration of NAD⁺ and FAD⁺ from NADH and FADH₂ respectively.

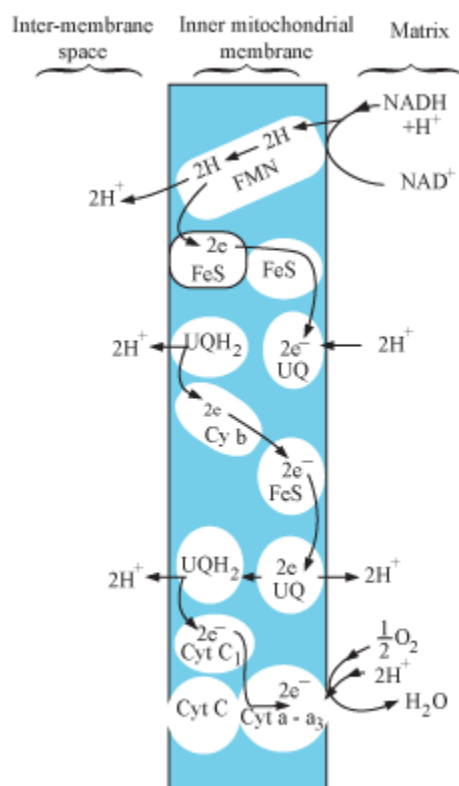




Electron Transport Chain and Oxidative Phosphorylation

Electron Transport Chain (ETS)

- NADH and FADH₂ are oxidised to release the energy stored in them.
- Electrons are passed from one carrier to another, and finally to oxygen, resulting in the formation of water.

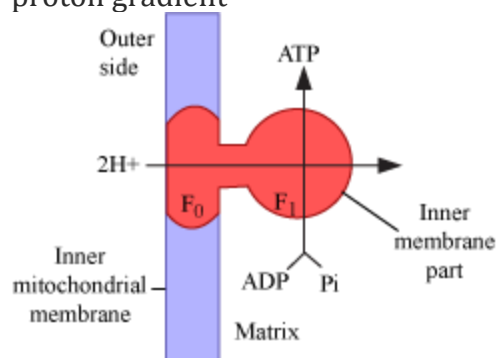


Electron Transport System (ETS)

- Electrons produced by NADH in the mitochondrial matrix are oxidised by **Complex I** (NADH dehydrogenase).
- Electrons are then transferred to ubiquinone, located in the inner mitochondrial membrane. Ubiquinone receives reducing equivalents through **Complex II** ($FADH_2$).
- Reduced ubiquinone (ubiquinol) is then oxidised by the transfer of electrons from **Complex III** (cytochrome bc_1 complex) to cytochrome c .
- Cytochrome c transfers the electrons between Complex III and **Complex IV** (Cytochrome c – oxidase complex consists of cyt a and a_3 , along with two copper centres).
- In the course of passing from one carrier to another, electrons couple with **Complex V** (ATP synthase) and produce ATP.
- Oxidation of 1 NADH produces 3 ATPs.
Oxidation of 1 $FADH_2$ produces 2 ATPs.
- Role of oxygen in the terminal stage of ETS: It acts as the final hydrogen acceptor; removes hydrogen from the process and drives the whole process

Oxidative Phosphorylation

- Production of proton gradient needed for the production of ATP is provided by the energy of oxidation–reduction reaction. Therefore, the process is called oxidative phosphorylation.
- **Complex V** (ATP synthase) is involved. It has two major components
- F_0 – integral membrane protein; forms a channel through which H^+ cross the inner membrane
- F_1 – passage of H^+ induces conformational changes in F_1 , which forms a site for synthesis of ATP from ADP; for each ATP produced, $2H^+$ pass through F_0 , down the electrochemical proton gradient



Respiratory Balance Sheet and Respiratory Quotient

Respiratory Balance Sheet

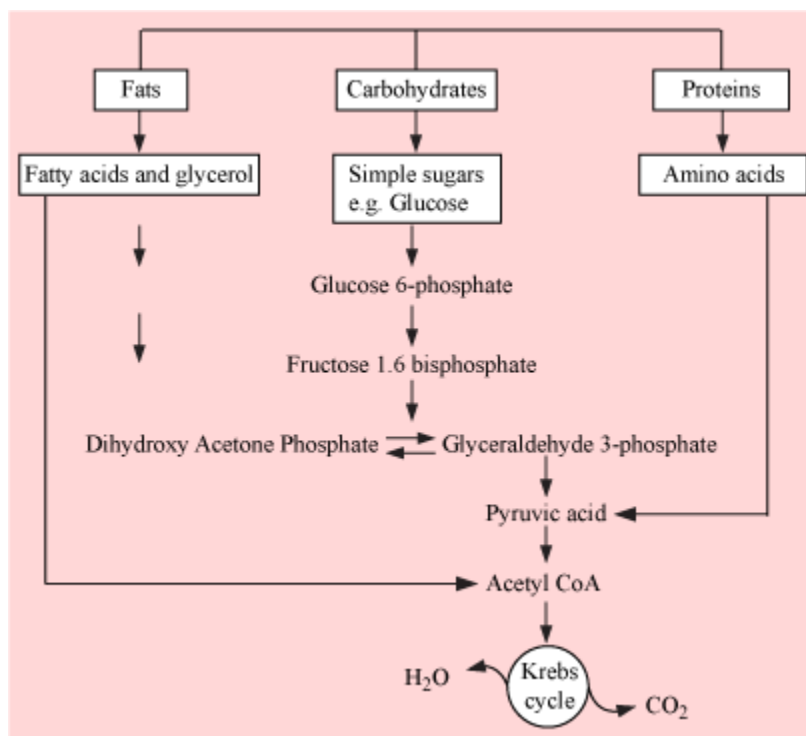
- It gives the net gain of ATP for every 1 molecule of glucose oxidised.
- Certain assumptions are made for calculating the net gain of ATP:
- An orderly pathway is followed – Glycolysis, followed by TCA cycle, followed by ETS
- NADH synthesised during glycolysis enters the mitochondria to undergo oxidative phosphorylation.
- Except glucose, no other substrate enters the pathway at any stage.
- Intermediates do not synthesise any other compound in the pathway.
- There can be a net gain of 36 ATPs during aerobic respiration of 1 molecule of glucose.
$$\text{Glucose} + 6O_2 + 36ADP + 36Pi \rightarrow 6CO_2 + 42H_2O + 36ATP$$

Comparison between fermentation and aerobic respiration

Fermentation	Aerobic Respiration
1. Partial breakdown of glucose	1. Complete breakdown of glucose into CO_2 and H_2O
2. Net gain of only 2 molecules of ATP	2. Net gain of 36 molecules of ATP
3. Here, oxidation of NADH to NAD^+ is a slow reaction	3. Here, oxidation of NADH to NAD^+ is a vigorous reaction

Amphibolic Pathway

- Favoured substrate for respiration is glucose. All carbohydrates first convert into glucose to enter the pathways.
- Other substrates do enter the respiratory pathways, but not during the first stage.
- Fats:
- Fats \rightarrow Glycerol + Fatty acid
- Fatty acids \rightarrow Acetyl CoA
Acetyl CoA enters the pathway
- Glycerol \rightarrow PGAL
- Proteins:
- Proteins $\xrightarrow[\text{deamination}]{\text{Proteases}}$ Amino acids
- Enter intermediate stages of TCA



- Amphibolic pathway: Involved in both anabolism and catabolism
- Fatty acids break into acetyl CoA to enter the respiratory pathway (Anabolism).
- Acetyl CoA is removed from the respiratory pathway whenever fatty acids need to be synthesised (catabolism).
- Thus, respiratory intermediates form a link during anabolism and catabolism.

Respiratory Quotient (RQ)

- Ratio of the volume of CO₂ evolved to the volume of O₂ consumed during respiration is called the respiratory quotient (RQ).

$$RQ = \frac{\text{Volume of CO}_2 \text{ evolved}}{\text{Volume of O}_2 \text{ consumed}}$$

- Depends upon the type of respiratory substrate
- RQ = 1 (When carbohydrate is used as substrate)

- $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy}$

$$\text{RQ} = \frac{6\text{CO}_2}{6\text{O}_2} = 1.0$$

- $\text{RQ} < 1$ (When fat is used as respiratory substrate)
E.g. When fatty acid, tripalmitin is used, $\text{RQ} = 0.7$
- $\text{RQ} \approx 0.9$ (When protein is used as substrate)
- RQ is infinity in anaerobic respiration as CO_2 is evolved, but O_2 is not utilised.

