# CSIR NET UNIT 6 Notes – System Physiology – Plant: Respiration


**UNIT 6 – System Physiology – Plant: Respiration**

Students from Non-Botany background might think to skip this UNIT but one must not, as it has a weightage of almost 30 marks or more in the CSIR NET Life Science Exam. The topics in this UNIT are not very difficult. One can find Topics from UNIT 1 repeated here like Electron Transport Chain, nitrogen metabolism, etc. It's advisable not to skip this UNIT.



**Reference Book – Plant Physiology, by Lincoln Taiz and Eduardo Zeiger**

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- **Photosynthesis**
  Overall process – Carbon reduction
  CO2 ———> Organic Carbohydrates
- **Respiration**
  Overall process – Carbon oxidation
  Organic Carbohydrates ———-> CO2 + Energy

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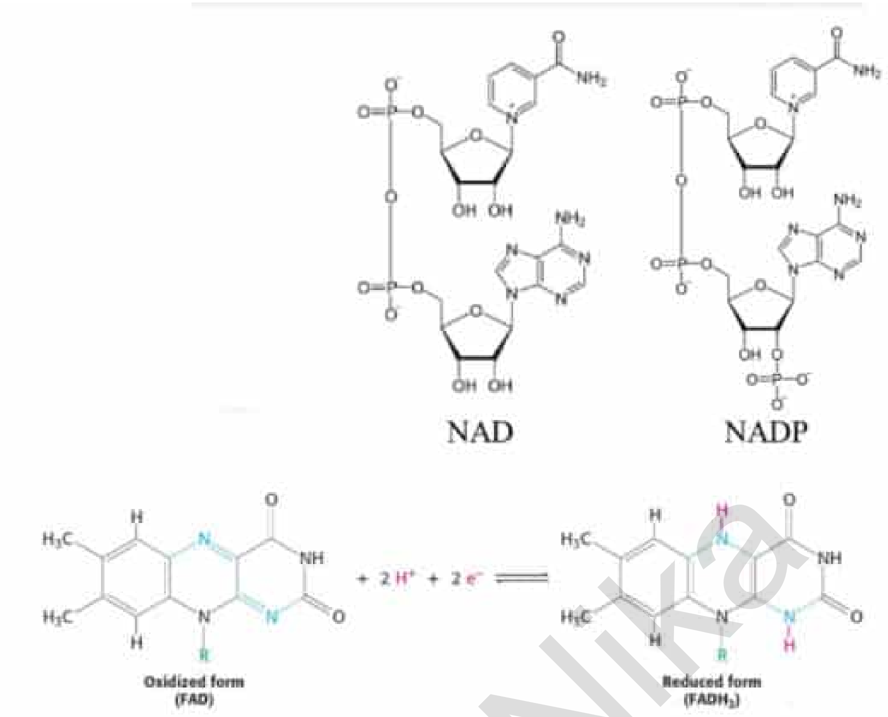
**Respiration**

$$C_{12}H_{22}O_{11} + 12\,O_2 \rightarrow 12\,CO_2 + 11\,H_2O$$

- Biological process whereby the energy stored in carbohydrates is released in a step-wise, controlled manner.
- The energy released is coupled to the synthesis of ATP.
- ATP is essential for plant cell maintenance, growth, and development

## Respiration: 3 Major Steps




1. **Glycolysis** (NADH produced)
   Pentose Phosphate Pathway (NADPH produced)
2. **Citric Acid Cycle** (NADH, FADH2 produced)
3. **Oxidative Phosphorylation** (e- from NADH and related species from steps 1, 2, and 3 are transferred to O2 , leading to the synthesis of ATP)

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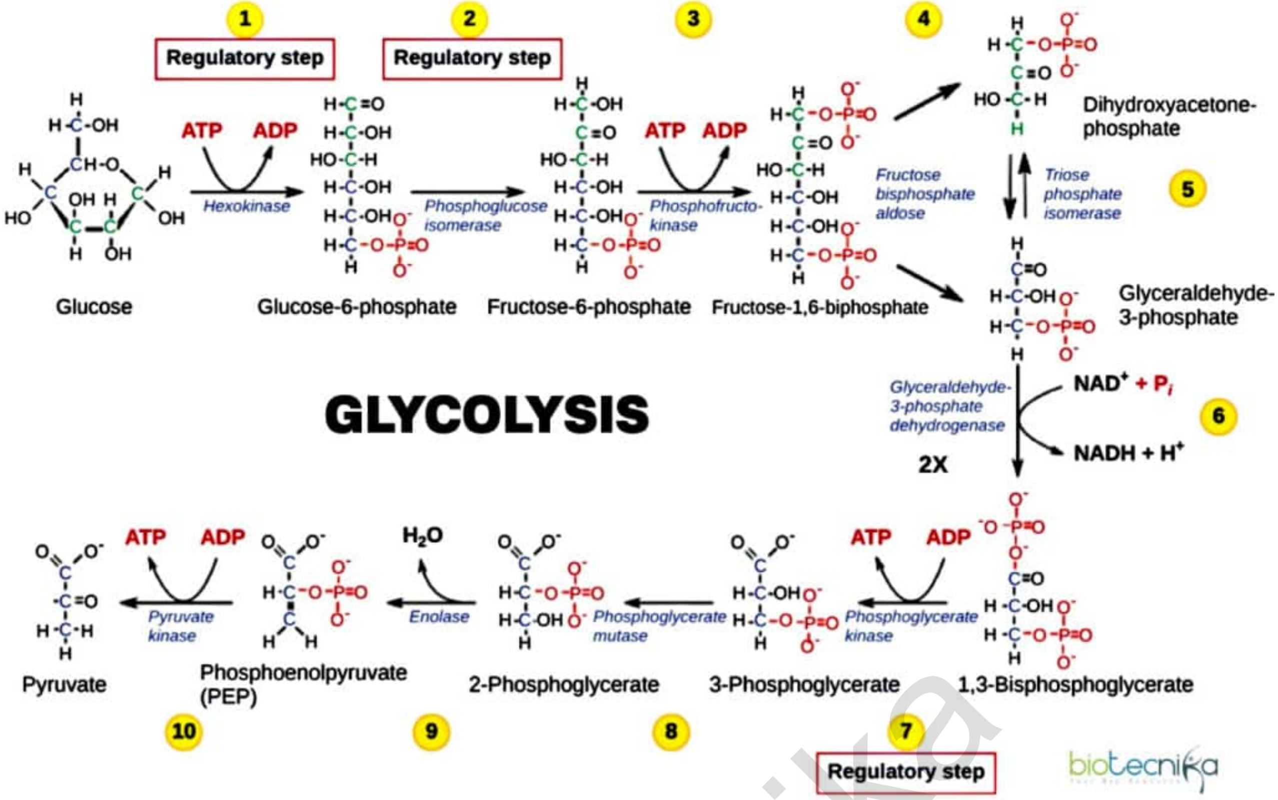
## Glycolysis

- glykos, “sugar,” and lysis, “splitting”
- Source: Sucrose, Starch
- 1st Part: ATP input




- 2nd Part: Generation of ATP and Reducing Equivalents
- At the end of the glycolytic sequence, plants have alternative pathways for metabolizing PEP
- End Products: Pyruvate and Malate
- Malate can be stored in the vacuole or transported to the mitochondrion where it enters the citric acid cycle

### Glycolysis Stoichiometry

### If glucose is the source

- 2 ATPs consumed
- 2 NADH produced
- 4 ATP produced
- Net production: 2 ATP and 2 NADH

### If Sucrose is the source

- 4 ATPs consumed
- 4 NADH produced
- 8 ATP produced
- Net production: 4 ATP and 4 NADH

### Fermentative Metabolism

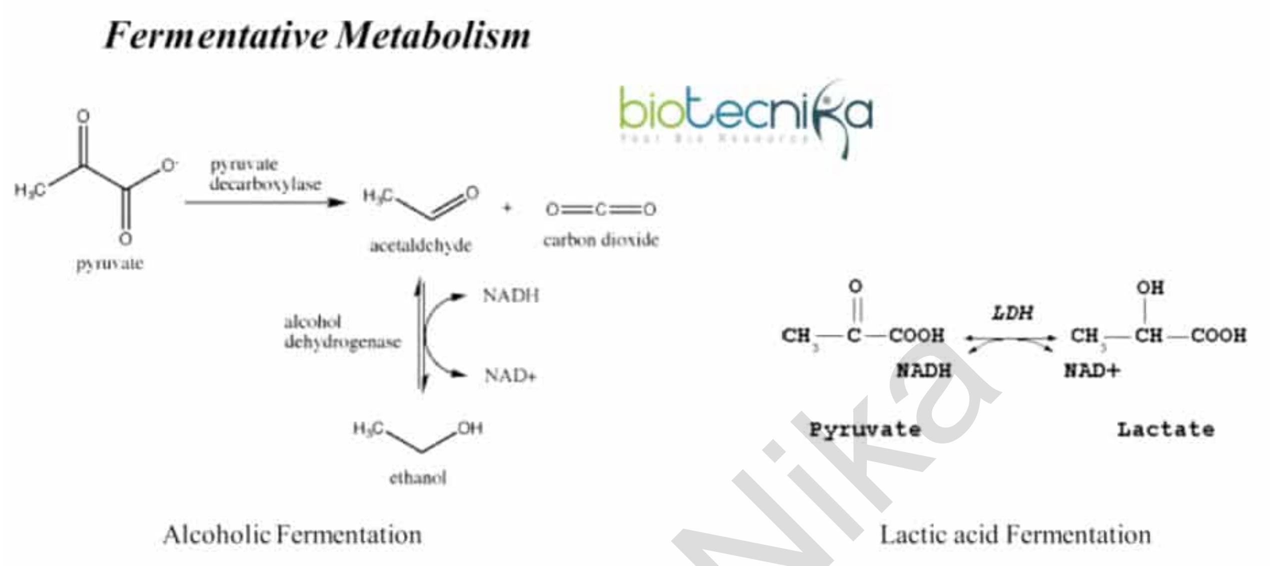
In absence of O2 citric acid cycle and oxidative phosphorylation cannot occur

• In absence of O2, Fermentation Regenerates the NAD+ Needed for Glycolysis

• 2 Pathways:

✓Lactate dehydrogenase forms Lactate (High acid production)
✓Pyruvate decarboxylase and Alcohol dehydrogenase form Ethanol with the release of $CO_2$

- Regeneration of $NAD^+$
- Low $O_2$ (hypoxic) or zero $O_2$ (anoxic) conditions
- Eg. Flooded or water-logged soil
- Ethanol is thought to be less toxic compared to lactate




### The efficiency of Fermentative Metabolism

- Glucose to Ethanol: net synthesis of 2 ATP
- Sucrose to Ethanol: net synthesis of 4 ATP
- Efficiency of Anaerobic fermentation compared to aerobic respiration: 4-6%
- Most energy remains in the form of lactate/ethanol
- High rate of glycolysis required to sustain ATP production
- Pasteur Effect: increased glycolysis when yeast switch from aerobic respiration to anaerobic alcoholic fermentation



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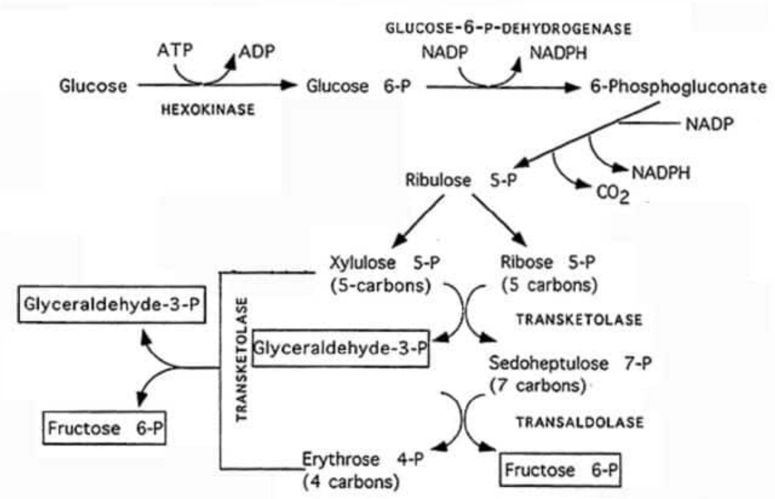
### Pentose Phosphate Pathway (PPP)

- Alternate Pathway for oxidation




- Occurs in both cytosol and in the plastids
- Importance of this pathway:

✓Production of NADPH ✓Production of Ribose-5-phosphate (precursor of ribose and deoxyribose in RNA and DNA)
✓Erythrose-4-Phosphate precursor for plant phenolic compounds
✓Early stage supply of Calvin cycle intermediates

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**Citric Acid Cycle**

Citric acid cycle/ Tricarboxylic acid ( TCA) cycle/ Krebs cycle

• Occurs in Mitochondria
• The citric acid cycle, refers to the first molecule that forms during the cycle's reactions—citrate.
• Tricarboxylic acid (TCA) cycle, for the three carboxyl groups on its first two intermediates
• Krebs cycle, after its discoverer, Hans Krebs
• Second stage of respiration

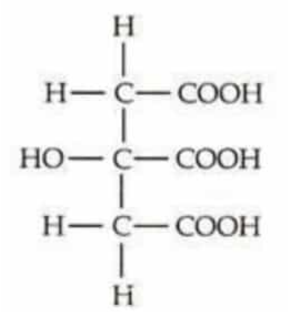


Fig: Citric Acid Structure

- The citric acid cycle occurs in the mitochondrial matrix
- Catalyzed by a series of enzymes located in the mitochondrial matrix (exception is succinate dehydrogenase)
- Pyruvate generated in the cytosol during glycolysis is transported into the mitochondrial matrix
- Transport protein – Pyruvate Translocase (transports pyruvate in a symport fashion with a proton)
- Pyruvate is decarboxylated (removal of CO2) to acetyl CoA
- Acetyl CoA is thus the connecting link between glycolysis and the next series of reactions that yield more energy in the form of ATP

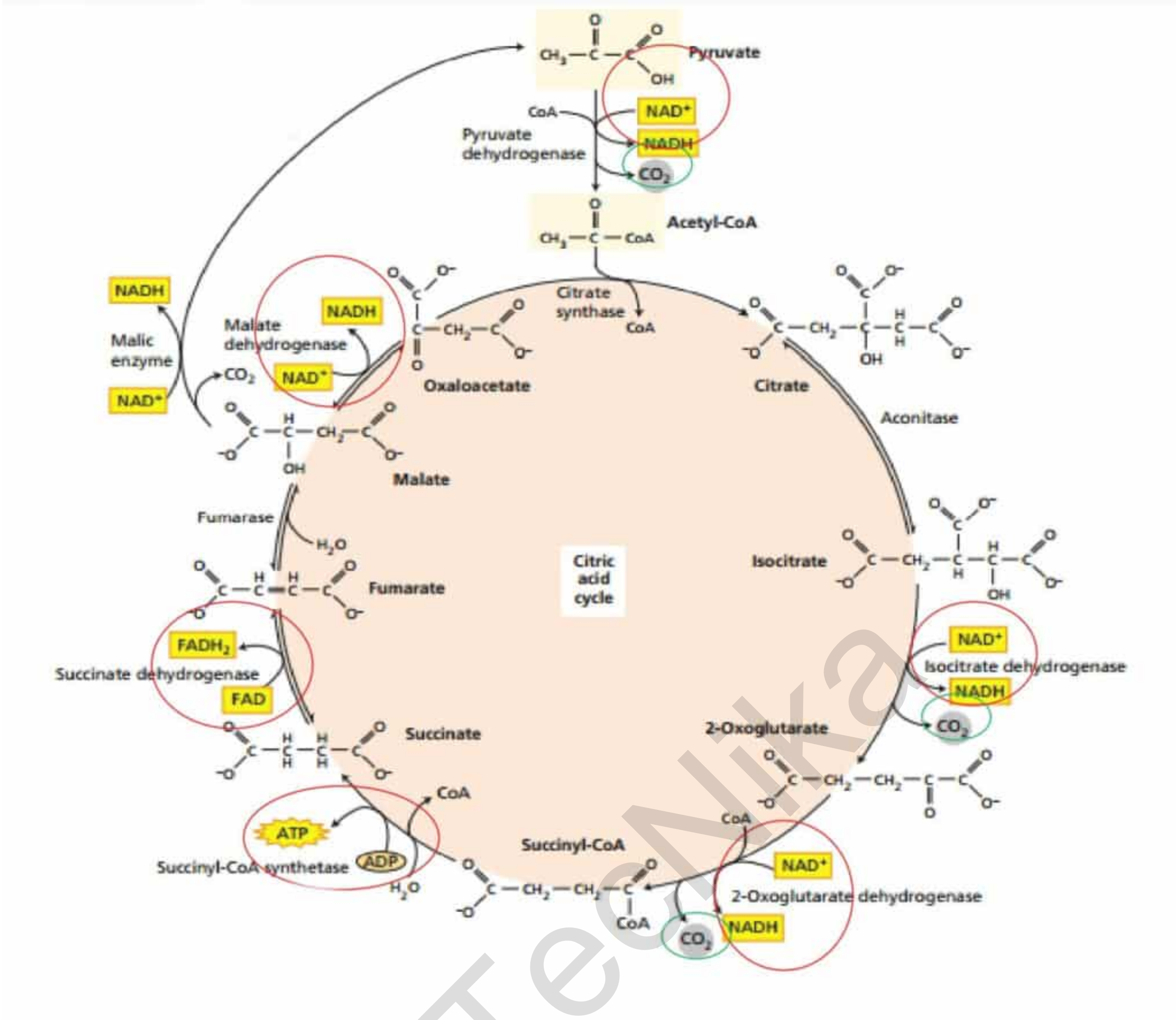
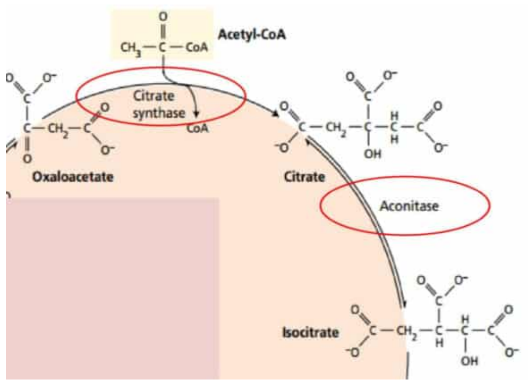


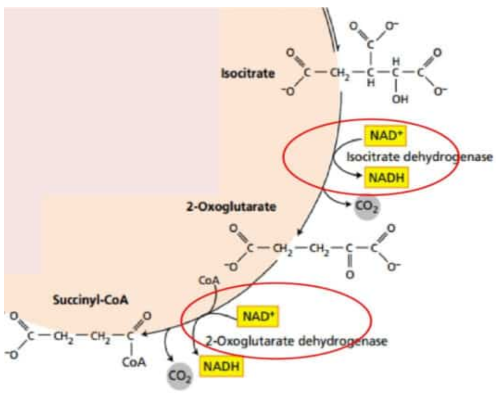

Fig: Citric Acid Cycle

- Pyruvate is decarboxylated in an oxidation reaction by the enzyme pyruvate dehydrogenase
- NADH, CO2, and acetyl-CoA are formed

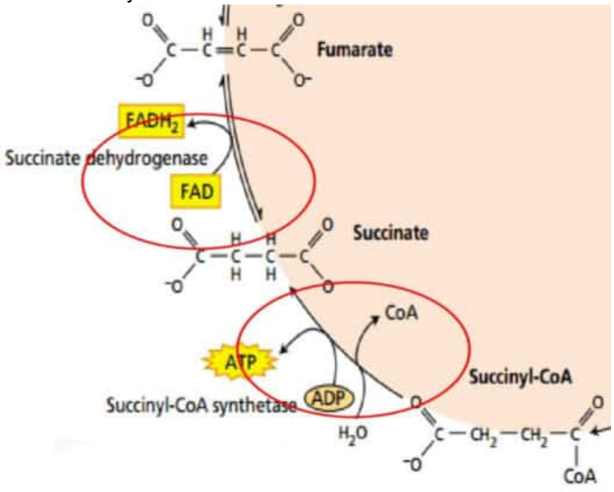
- Citrate synthase combines the acetyl group of acetyl-CoA with oxaloacetate (4C-dicarboxylic acid to give Citrate (6C-tricarboxylic acid)
- Citrate is then isomerized to isocitrate by the enzyme aconitase



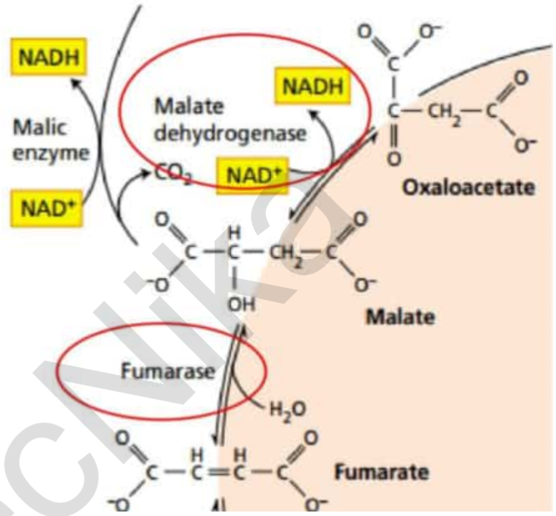

- Next 2 reactions are successive oxidative decarboxylation reactions, each of which produces one NADH and releases one molecule of CO2, yielding a four-carbon molecule, succinyl-CoA
- At this point, 3 molecules of CO 2 have been produced for each pyruvate that entered the mitochondrion



- Succinyl-CoA is converted to succinate. The synthesis of ATP via phosphorylation reaction is catalyzed by the succinyl-CoA synthetase
- Succinate is oxidized to fumarate by succinate dehydrogenase, which is the only membrane-associated enzyme of the citric acid cycle and also part of the electron transport chain




- Fumarate is hydrated to produce malate
- Malate is then oxidized by malate dehydrogenase to regenerate OAA and produce another molecule of NADH
- The OAA produced is now able to react with another acetyl-CoA and continue the cycle






## The Citric Acid Cycle Stoichiometry

- 1 molecule of pyruvate gives 3 CO2
  Much of the energy is conserved in the form of reducing equivalents
- 1 molecule of pyruvate gives 4 NADH and 1 FADH2 (also 1 ATP) 1 sucrose gives 16 NADH, 4 FADH2 and 4 ATP (1 sucrose gives 4 pyruvates)
- Reducing Equivalents enter the next phase known as the respiratory chain or Electron-Transport-Chain (E.T.C.) for further release of energy

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## Electron transport chain (ETC)

- ATP is the primary energy carrier
- NADH and FADH2 must be converted to ATP for the energy to be usable
- ETC involves the transfer of e- from NADH and FADH2 to O2 via 4 Multi-protein complexes (named Complex I, II, III, and IV)
- O2 is the final electron acceptor in the respiratory chain
- Location of Multi-protein complexes: Inner Mitochondrial membrane

### Number of Reducing Equivalents

### If glucose enters glycolysis (animal cell):

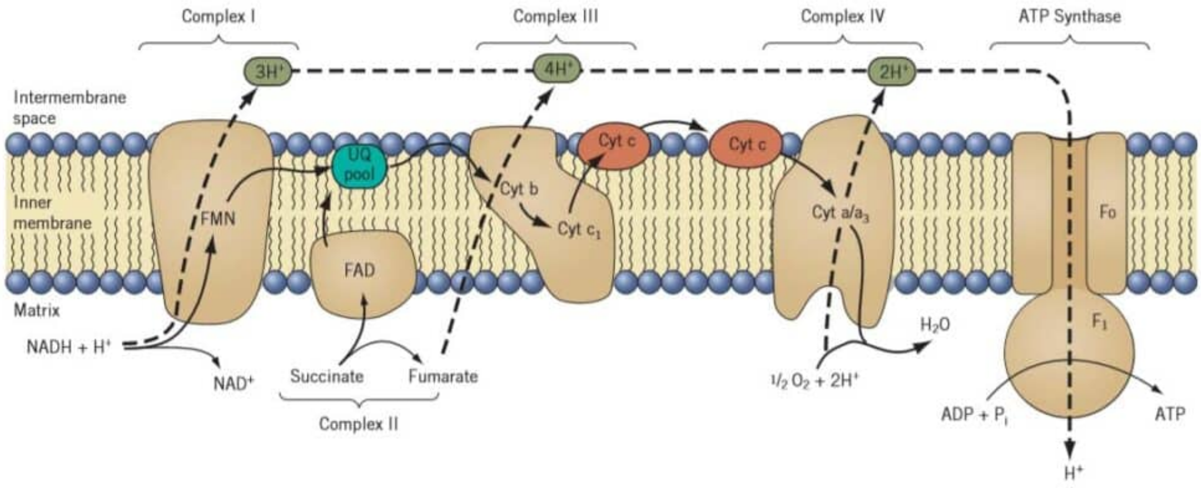
• 2 NADH produced in glycolysis
• 8 NADH produced in the Citric Acid cycle
• 2 FADH2 produced in Citric Acid cycle

### If Sucrose enters glycolysis (Plant cell):

• 4 NADH produced in glycolysis (cytosol)
• 16 NADH produced in Citric Acid cycle (mitochondrial matrix)
• 4 FADH2 produced in Citric Acid cycle (mitochondrial matrix)

### Total: 20 NADH and 4 FADH2

• These reducing equivalents must be re-oxidized (converted to NAD+ and FAD+)




## Complex I (NADH dehydrogenase)

- Electrons from NADH are oxidized by complex I
- The electron carriers in complex I include a tightly bound cofactor FMN and several FeS centers
- Complex I transfers these electrons to Ubiquinone/Coenzyme Q (a small lipid-soluble electron and proton carrier, located within the inner membrane)
- 4H+ are pumped from the matrix to the intermembrane space for every electron pair passing through the complex
- e- transfer to quinone cannot occur without H+ translocation

## Complex II (Succinate dehydrogenase)

- Oxidation of succinate in the citric acid cycle is catalyzed by this complex II
- The resulting electrons are transferred via the FADH2 and a group of Fe-S proteins into the ubiquinone pool
- This complex does not pump protons

## Complex III (cytochrome bc1 complex)

- This complex oxidizes reduced ubiquinone and further transfers the electrons to cytochrome c
- 4 H+ are pumped per electron pair by complex III
- Cytochrome c is a small protein loosely attached to the outer surface of the inner membrane and serves as a mobile carrier to transfer electrons between complexes III and IV

## Complex IV (cytochrome c oxidase)

- Complex IV is the terminal oxidase
- Complex IV contains two copper centers and cytochromes a and a3
- e- transferred to O2 to produce H2O
- 2H+ are pumped per electron pair

- Complex IV is inhibited by Carbon monoxide, cyanide, and azide (bind to CuB:Cyta3 binuclear center)

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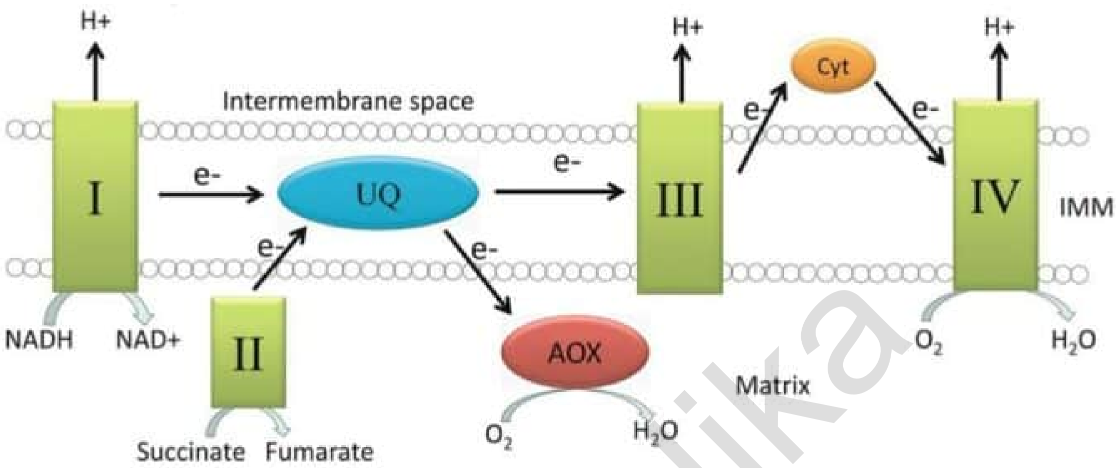
## Alternative oxidase (AOX)

- In animal cells, cyanide inhibits Cytochrome c oxidase (Complex IV)
- Many plant tissues show varying degrees of cyanide resistance
- Cause: Presence of Cyanide-resistant Oxidase in Plant ETC




- Proton Pumping at Complex III and IV is bypassed
- Energy conservation in form of ATP synthesis is reduced
- Energy is lost as heat in AOX pathway

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## Why Plants need Alternative oxidase (AOX)

- During floral development in certain members of the Araceae (the arum family)
- Tissues of the clublike inflorescence exhibit a dramatic increase in the rate of respiration via the alternative pathway
- This leads to an increase in temperature for a couple of hours
- Due to high temp., volatile amines, terpenes, and indoles are volatilized
- The odor attracts pollinators (insects)
- “Energy Overflow” Pathway
- e – flows through AOX only when the Main Pathway is saturated
- Mitochondria can adjust the relative rate of ATP production required by the cell
- Another possible role in stress management of the plant
- Over-reduction of Ubiquinone pool in the main pathway can lead to the synthesis of ROS
- AOX can diffuse the e- and lessen the detrimental effect of ROS

## Practice Questions:

## Q 1. The reaction catalyzed by Phosphofructokinase-1:

a. Is activated by a high concentration of ATP and Citrate
b. Uses Fructose-1-phosphate as substrate.
c. Is the rate-limiting reaction of the glycolytic pathway.
d. Is inhibited by Fructose-2,6-bisphosphate

**Q 2. How much Phosphoglyceraldehyde is required to form a glucose molecule?**

a. 1
b. 2
c. 3
d. 4

**Q 3. Which of the following steps releases much of the energy stored in the carbohydrate during oxidation?**

a. Sugar is converted to pyruvate
b. Sugar is converted to alcohol and carbon dioxide
c. Pyruvate is converted to acetyl CoA
d. Pyruvate is converted to carbon dioxide and water

**Q 4. Which of the following represents the correct pathway of the electron transport chain?**

a. Ubiquinone → Cytochrome bc1 → Cytochrome c → cytochrome c oxidase → $O_2$
b. Cytochrome bc1 → Ubiquinone → Cytochrome c oxidase → cytochrome c → $O_2$
c. Ubiquinone → Cytochrome c → Cytochrome bc1 → cytochrome c oxidase → $O_2$
d. Cytochrome bc1 → Cytochrome c → Ubiquinone → cytochrome c oxidase → $O_2$

**Q 5. All of the following electron carriers are components of the mitochondrial electron transport chain except**

a. Nicotinamide-adenine dinucleotide
b. Nicotinamide-adenine dinucleotide phosphate
c. Flavin mononucleotide
d. Flavin-adenine dinucleotide

**Answers: 1-c, 2-b, 3-d, 4-a, 5-b**

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