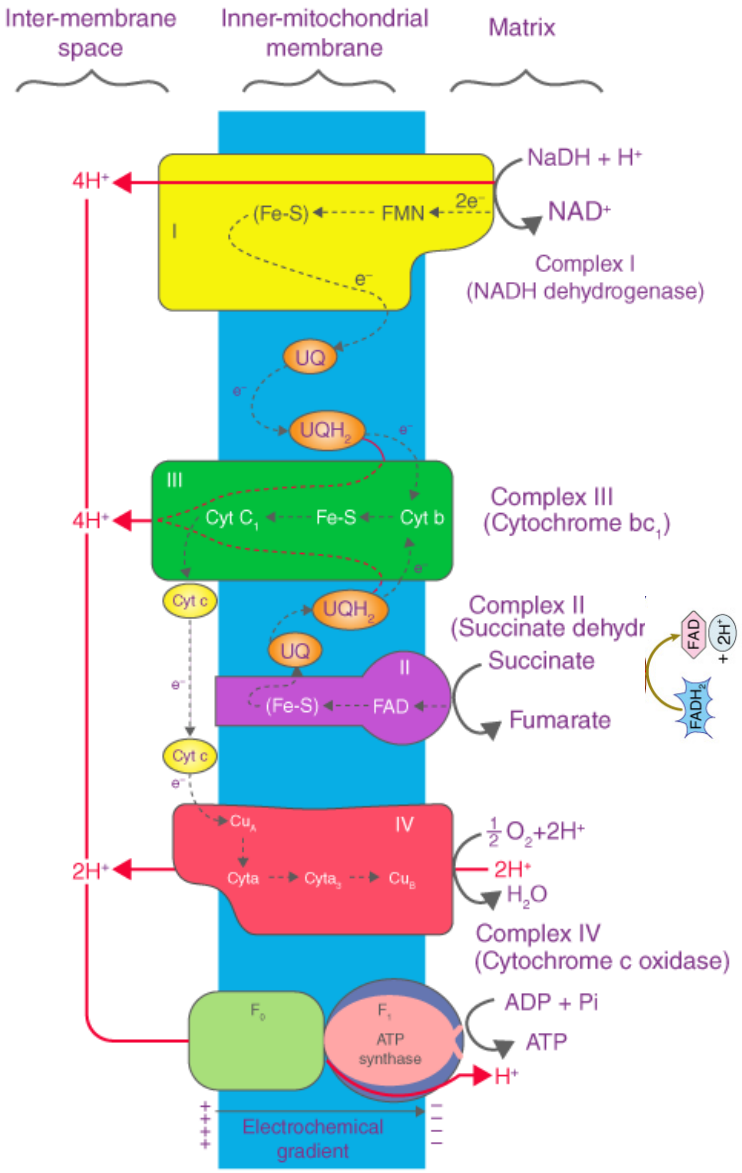
ELECTRON TRANSPORT SYSTEM

The metabolic pathway through which the electron passes from one carrier to another inside the inner mitochondrial membrane is called **ETC or mitochondrial respiratory chain.**
Consist of - 2 mobile electron carrier & 3 electron carrier complexes



Electron Donor - Oxidation
1 NADH forms 3ATP
1 $FADH_2$ forms 2 ATP

Complex I NADH dehydrogenase

- Oxidise e^- from NADH are transferred via electron carrier FMN (Flavin Mono Nucleotide) & Fe-S (Iron Sulphur Protein) to UQ.

Complex II Succinate Dehydrogenase

- Oxidised e^- from $FADH_2$ (produce during TCA cycle -Succinate to Fumarate) are transferred to UQ via electron carrier FAD (Flavin Di Nucleotide) & Fe-S.

UQ (Ubiquinone)- Mobile e^- Carrier

- UQ present in inner membrane space receives e^- from Complex I & complex II and
- UQ binds to $2H^+$ from matrix and reduced to UQH_2 (Ubiquinol).
- UQH_2 gets oxidised to UQ by transferring e^- to Complex III (Cyt bc_1) & H^+ to Inner membrane space.

Complex III Cytochrome bc_1

- Receive e^- from UQH_2 & transfer to Cyt c via electron carrier Cyt b (Cytochrome b), Fe-S & (Cytochrome c_1)

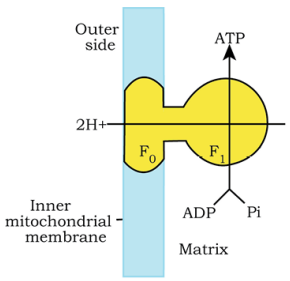
Cyt c (Cytochrome c)- Mobile e^- Carrier

- Cyt c present at outer surface of the membrane receives e^- from Complex III & carries to Complex IV.

Complex IV Cytochrome c oxidase

- In complex VI e^- is carried by two copper centres (Cu_A & Cu_B) & cytochrome a & a_3
- e^- from Cyt c are transferred to Cu_A → → cyt a → cyt a_3 → Cu_B.
- Finally these e- are accepted by oxygen (present in matrix).

- NAD^+/FAD^+ return back to Glycolysis or Kerb's Cycle.
- Each next complex has a greater electronegativity than the one before it, hence release energy with each transfer.
- Energy released during transfer of e^- is use to pump H^+ (proton) from matrix to Inner membrane space resulting in high H^+ concentration in Inner membrane space.



Complex V ATP Synthase- Utilise ETC energy to make ATP

- Consists of two parts **F_0** & **F_1**.
- **F_0** (integral membrane protein) form channel for proton.
- **F_1** – head piece (peripheral membrane protein) consist of ATP synthase that synthesis of ATP from ADP and iP (inorganic phosphate) .
- For each ATP produced 4 H^+ passes through F_0 from the intermembrane space to the matrix down the electrochemical proton gradient.

- Finally Oxygen accept H^+ (Proton) in matrix and form metabolic H_2O.

Que: Differentiate between Oxidative phosphorylation & Photophosphorylation.

Oxidative phosphorylation	Photophosphorylation
a) It occurs in respiration process. **b)** Energy of oxidation-reduction is used for production of proton gradient required for phosphorylation.	**a)** It occurs in photosynthesis. **b)** Light energy is utilized for production of proton gradient for phosphorylation.

The Respiratory Balance Sheet

- All pathway (Glycolysis, Krebs Cycle, ETS) work simultaneously.
- Substrate enter pathway and withdrawn from it as & when necessary.
- ATP is utilised as & when needed.
- Enzymes rates are controlled by multiple means.

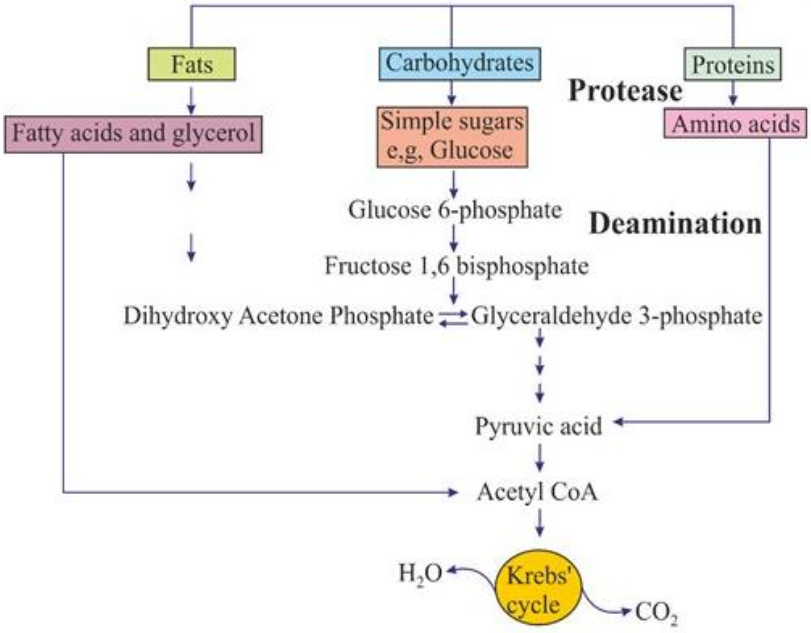
Process	ATP	NADH	$FADH_2$	Total ATP in 1 Turn	No. of Turns	Net Gain
Glycolysis/ EMP Pathway	2	2×3=6	0×2=0	8	×1	8
Link Reaction/ Acetylation of Pyruvic Acid	0	1×3=3	0×2=0	3	×2	6
Kreb's/ TCA cycle	1	3×3=9	1×2=2	12	×2	24
1 NADH= 3 ATP,			**$FADH_2$= 2 ATP**		Total=	**38**

Que: Differentiate between Fermentation & Aerobic Respiration.

Fermentation	Aerobic Respiration
a. Incomplete oxidation of glucose in absence of Oxygen. **b.** In fermentation, there is net gain of only two molecules of ATP. **c.** NADH is oxidized to NAD+ very slowly.	**a.** Complete oxidation of glucose in presence of Oxygen **b.** In aerobic respiration, there is more net gain of ATP. **c.** NADH is oxidized to NAD+ very fast.

Amphibolic Pathway

- Respiration is called an **Amphibolic Pathway** because it involves both **catabolism** (breakdown of carbohydrates, fats, proteins for energy) and **anabolism** (using intermediates like Acetyl CoA, α-ketoglutarate which are withdrawn for synthesis of fatty acids, amino acids, etc.).
- All carbohydrates are usually converted into glucose before used for respiration.
- Other substrates may respire do not enter at first step of respiratory pathway.
- Fats broken down (catabolic) into glycerol (converted to PGAL) and fatty acid (converted to Acetyl Co A).
- Proteins are broken (catabolic process) into amino acids **by Protease** and enter into Krebs cycle at Pyruvic acid or Acetyl Co after **deamination.**
- Acetyl Co is withdrawn from respiratory pathway in organisms need to synthesise fatty acids (anabolic process). & Similarly for protein from link reaction.



Respiratory Quotient is the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed in respiration over a period of time.

RQ for: Carbohydrate=1
Protein = 0.9
Fatty acid = less than 1.

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

Tripalmitin

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

Pure protein & fats are never used as respiratory substrate (enter breaking down as simpler substance only).

Name the respiratory substrates that have RQ more than 1. Why are they not commonly used as respiratory substrates?

Ans. Respiratory substrates with **RQ > 1** are **organic acids** such as **malic acid (1.33), oxalic acid (2), tartaric acid (2), and citric acid(2)**.

- They are **not commonly used** because:
    1. They are **less energy-rich** compared to carbohydrates and fats.
    2. They serve as important **Krebs cycle intermediates**, and using them would disturb metabolism.
    3. They are usually **by-products**, not stored as primary energy reserves.

Malic Acid

$$C_4H_6O_5 + 3O_2 \rightarrow 4CO_2 + 3H_2O$$

$$RQ = \frac{CO_2\ released}{O_2\ consumed} = \frac{4}{3} = 1.33\ (> 1)$$

Oxalic Acid

$$C_2H_2O_4 + O_2 \rightarrow 2CO_2 + H_2O$$

$$RQ = \frac{CO_2\ released}{O_2\ consumed} = \frac{2}{1} = 2\ (> 1)$$

Arrange in sequence the order of substrate utilization during respiration.

Ans: Carbohydrates → Fats→ Protein.

Under what conditions are fats and proteins used as respiratory substrates? Why are they not preferred over carbohydrates?

Ans: Fats and proteins are used as respiratory substrates **when carbohydrates are unavailable** (e.g., starvation, fasting, diabetes, seed germination). They are **not preferred** because their breakdown is slow, **Fats** need β-oxidation → more steps before entering Krebs cycle. **Proteins** must undergo **deamination**, producing toxic ammonia/urea, and they are essential for structural and functional roles.

Under what conditions are proteins broken down during respiration? From which body parts are they mobilized? Is protein breakdown a disease?

Ans: Proteins are broken down when **carbohydrates and fats are insufficient**, such as during **starvation, prolonged fasting, uncontrolled diabetes, heavy exercise, or muscle-wasting diseases**.

- They are mainly mobilized from **skeletal muscles**, the **liver** and some times plasma proteins.
- Protein breakdown itself is **not a disease**, but **excessive or continuous protein breakdown** indicates an **underlying disorder** like malnutrition, diabetes, or chronic illness like cancer, severe infections, cachexia-muscle-wasting diseases.