

## Understandings:

### 1. Explain oxidation and reduction in a biologist's perspective and distinguish it with the chemist's perspective. Then relate it to cell respiration.

- Redox reactions always happen together because redox is essentially the movement of electrons/hydrogen atoms (more detail soon). Thus the notion of oxidation and reduction is a name for the elements that has lost them or gained them. It is all about OIL RIG.

#### Biologist's perspective:

Oxidation is losing hydrogen. Reduction is gaining hydrogen.

Biologists use hydrogen because hydrogen is essentially present in all organic compounds together with carbon.

#### Chemist's perspective:

Oxidation is losing electrons. Reduction is gaining electrons.

Then, who are good at reducing and oxidizing? Well, it depends on the relative electronegativity and all, but special substances like electron carriers can reduce and oxidize as they want. Examples are Nicotinamide adenine dinucleotide (NAD) and Flavin adenine dinucleotide (FAD).

When NAD is reduced, we get  $\text{NADH} + \text{H}^+$  because NAD has gained 2 electrons: one from  $\text{H}^+$  and one together with H.

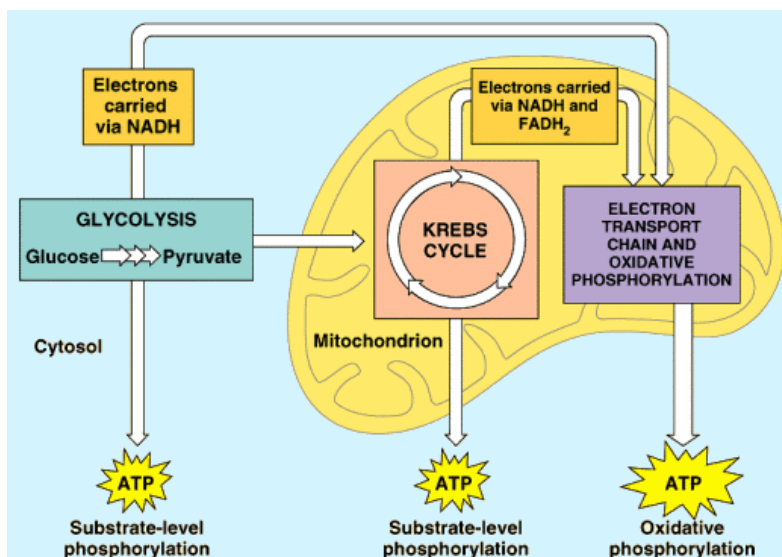
When FAD is reduced, we get  $\text{FADH}_2$ . Here FAD has also gained 2 electrons but both together with H.

#### Extra notes

- The overview of respiration:

Glycolysis → Link reaction → Krebs cycle → Electron chain transport.

It is also important to visualize exactly where these reactions take place.



Glycolysis happens in cytosol.

Pyruvate is moved all the way into matrix. Link reaction makes acetyl CoA. Krebs cycle takes place.

The accumulated electron carriers are used to pump  $\text{H}^+$  from matrix to intermembrane space.

## 2. Explain phosphorylation.

- Phosphorylation = adding a phosphate,  $\text{PO}_4^{-3}$ . This is the first step in glycolysis!

What purpose does adding a phosphate serve? Well, molecules bonded with phosphate tend to have very unstable bonds and loads of potential energy. That is why ATP is so enriched with energy. It is because it has three bonds with phosphate!

In other words, the phosphorylated molecule becomes more reactive, or activated.

Now, we are ready to tackle the first step of respiration. The first step is to “activate” glucose by phosphorylation.

Glucose + ATP → Glucose-6-phosphate + ADP

Now, this may seem contradictory since we add ATP to produce ATP, but pure energetically, it is spontaneous. Although the reaction is endergonic/endothermic (energy absorbing), ATP is split using hydrolysis which is exergonic/exothermic. Overall, it is spontaneous.

## 3. Explain glycolysis.

- Glycolysis = splitting of glucose, taking place in the cytoplasm.

Glycolysis is also the process where small amount of ATP is gained without oxygen, hence anaerobically.

We had glucose-6-phosphate right in the beginning. Then we make it into fructose-1,6-biphosphate by using additional ATP.

Now when our sugar molecule is very activated and unstable, we are able to split it with glycolysis into triose phosphate.

The next step is oxidation and as we oxidize the triose phosphate, the molecule will lose energy, and transfer it to mainly NADs. Reduced NAD (NADH) is now more energetic.

Triose phosphate +  $\text{NAD}^+$  → glycerate-3-phosphate + NADH +  $\text{H}^+$

Then, that glycerate-3-phosphate will go through bunch of reactions and produce a pyruvate and some ATP.

Thus the order of glycolysis is: phosphorylation → lysis into triose phosphate → oxidation

In conclusion, we get from glycolysis, per glucose molecule:

1. 2 pyruvates.
2. 2 ATP is used and 4 ATP produced. 2 NET ATP.
3. 2 NADH +  $2\text{H}^+$  that is later used for ATP production.

#### 4. Explain what happens to the pyruvate.

- From this point on, the aerobic and anaerobic respiration get distinguished. What we are focusing on now is the aerobic respiration.

Pyruvate gets absorbed into mitochondrion and undergoes decarboxylation and oxidations.

The steps will be explained below.

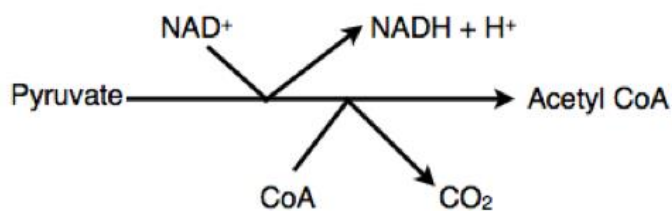
#### 5. Explain link reaction.

- Link reaction will take place in the mitochondrion matrix. One could think this as a preparation stage for Krebs cycle, hence called link reaction.

The main thing that takes place is that pyruvate gets decarboxylated, making it into a 2 carbon chain. Then, the two carbon chain gets oxidized while NAD<sup>+</sup> gets reduced into NADH + H<sup>+</sup>.

Thus pyruvate → Acetyl CoA (coenzyme A)

Acetyl CoA is a very complicated molecule with formula C<sub>23</sub>H<sub>38</sub>N<sub>7</sub>O<sub>17</sub>P<sub>3</sub>S.



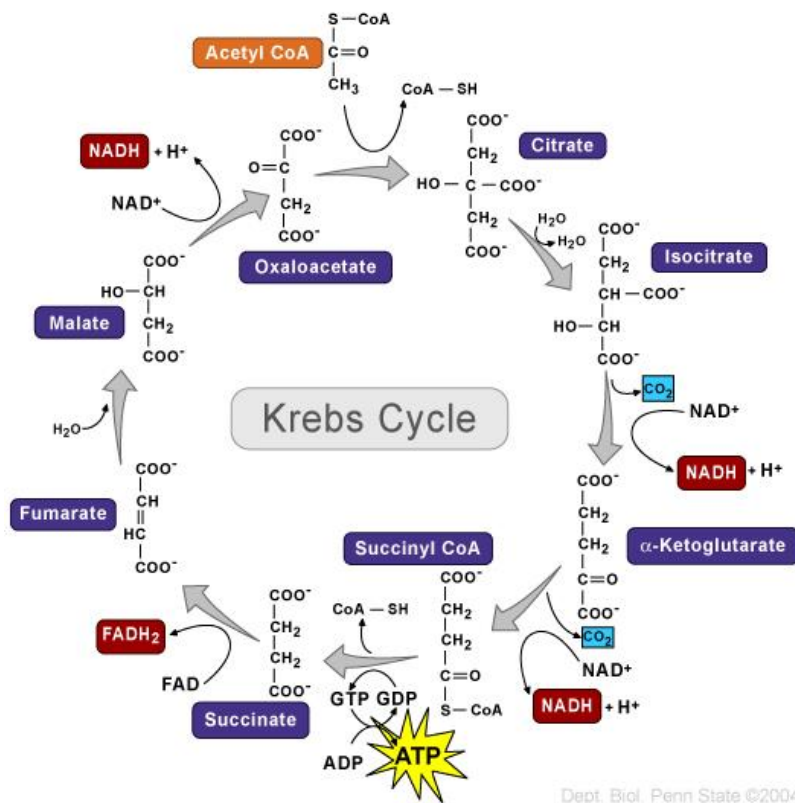
In conclusion, we got 2 pyruvates from 1 glucose, thus from link reaction we get:

1. 2 acetyl CoA
2. 2 NADH + 2H<sup>+</sup>
3. 2CO<sub>2</sub>

## 6. Explain Krebs cycle.

- This cycle follows with 4 further oxidations and 2 decarboxylations per pyruvate.

So, acetyl CoA gets fused with oxaloacetate to produce 6-carbon chain. Then the molecule gets oxidized while the electron carriers NAD and FAD get reduced.



In conclusion, we get:

1. Reduction of NAD<sup>+</sup> three times.
2. 2CO<sub>2</sub>.
3. Reduction of FAD<sup>+</sup> once.
4. 1 NET ATP.

## 7. Explain oxidative phosphorylation.

- We have now created a bunch of energy rich NADH + H<sup>+</sup> and FADH<sub>2</sub>. We can oxidize these to release energy, and that energy can be used to phosphorylate ADP into ATP.

This is why we call this process oxidative phosphorylation. The energy from oxidation is used for phosphorylation.

One may formulate this as “coupling of ATP synthesis to electron transport”.

### 8. Explain the electron transport chain.

- We know that oxidative phosphorylation is the last step, but the question is of course, how does it happen?

As stated, the energy we get to phosphorylate comes from oxidizing  $\text{FADH}_2$ s and NADHs (mainly NADHs because they are slightly more energy rich and we simply have more of them).

The exact mechanism is done in electron transport chain. Since the two electron carriers get oxidized, we have free available electrons. As electrons are moved along the membrane, their energy is used to actively pump  $\text{H}^+$  from matrix to intermembrane space.

#### Extra notes

- One could wonder where the electrons go after they have provided with all the necessary energy. Indeed, oxygen accepts the electrons, thus reduced, and then becomes an  $\text{O}_2^-$  radical. That radical then reacts with two  $\text{H}^+$  to form water!

### 9. Explain chemiosmosis.

- Now that we have accumulated bunch of  $\text{H}^+$  (potential energy) in the intermembrane space, it is naturally going to diffuse back into the matrix. This diffusion across membrane is called chemiosmosis.

The protons diffuse into the matrix through a “motor” called ATP synthase because it is the motor that synthesizes ATP.

Be aware that chemiosmosis is not simply a diffusion of  $\text{H}^+$  or any other molecules. This is a mechanism where ATP is generated by a proton gradient.

### 10. Explain the role of oxygen in respiration.

- To repeat, oxygen accepts the electrons and then binds with  $\text{H}^+$ . Presumably the most significant thing here is to know that as  $\text{H}^+$  are depleted in the matrix after it has been through ATP synthase, the potential gradient can continuously be low at matrix and high at inter membrane space.

Thanks oxygen!

## 11. Explain the structure and function of mitochondrion, and how structure aids its function.

- Multicellular organisms have existed for a very long time and they have evolved since then including the mitochondria. With mitochondrion that produces ATP, it is more efficient = high chance of reproducing. Then, how is its structure adapted for its function?

They contain their own naked DNA and 70s ribosomes:

This enables them to make their own proteins and enzymes. Also, remember that naked DNA and 70s ribosomes (small ones) are found in bacteria, so mitochondrion is actually a prokaryote.

Outer membrane:

This separation of outer contents and inner contents enables mitochondrion to specialize in aerobic respiration. It is like mitochondrion having its own little closed system.

Folding of inner membrane (cristae):

Inner membrane is the place for oxidative phosphorylation, and electron chain transport of course, thus the cristae contributes with high surface area for maximized efficiency.

Intermembrane space:

This is the site where  $H^+$  gets accumulated. Now, what if the volume of this was large? It would take forever to build up a significant potential gradient, right? Therefore, the intermembrane space is very small so  $H^+$  potential gradient will be built up rapidly.

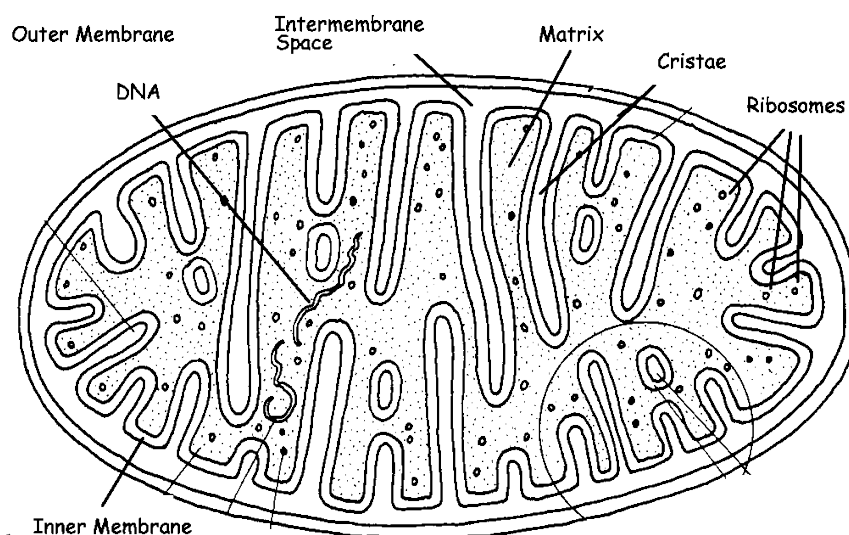
Matrix:

This place contains many enzymes that are produced by the naked DNA and 70s ribosomes.

## Applications and skills:

### 1. Annotate the basic structures of mitochondria.

- You should be able to identify these 7 parts in mitochondria.



**2. Be able to identify the redox reactions and decarboxylation in diagrams representing aerobic respiration.**

- For redox reactions, see for any gain/loss of hydrogen atoms (not ions). For decarboxylation, look for any release in  $\text{CO}_2$ .

**3. Explain what electron tomography has provided us about mitochondrion membrane.**

- Tomography is a technique that enables one to get a three-dimensional image of an object, including very small ones.

This has shown that the cristae are not merely an invagination of membrane, but much more dynamic and flexible that is constantly changing according to its need.

**TOK:**

**1. Peter Mitchell's chemiosmosis theory encountered years of opposition before it was finally accepted. For what reasons does falsification not always result in an immediate acceptance of new theories or a paradigm shift?**