

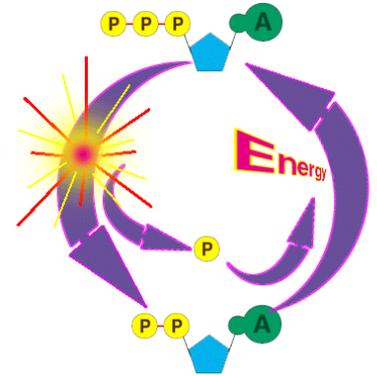
Chapter 5

The vital role of ATP

This is the energy-rich compound that is the source of energy for all living things. It is a **nucleotide**, comprising a 5C sugar (**ribose**); an organic base (**adenosine**); and 3 phosphate groups (2 in ADP). This is continually recycled thus:



The amount of energy released from the hydrolysis of one molecule of ATP is small and can thus be used to energise a single reaction, whilst, being a single reaction, it is also very fast. These are significant advantages over using glucose directly.



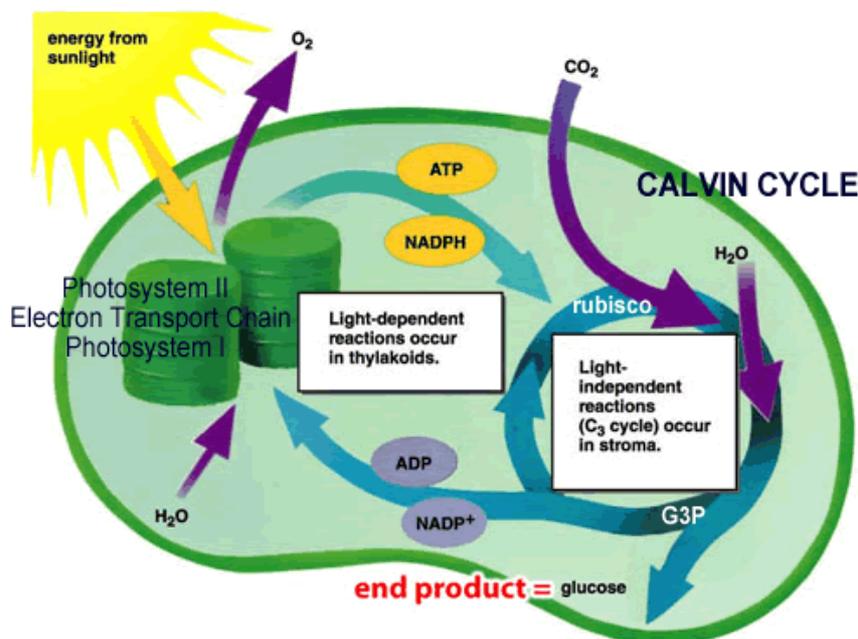
Photosynthesis ($\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2$)

(Nearly) all life on Earth depends on this process, yet it is **very** inefficient. Half of all energy from the Sun is used to evaporate water; 15% is reflected and 32% passes through the leaf untouched. That leaves (sorry!) only 2% of the incident radiation to be trapped and used in photosynthesis.

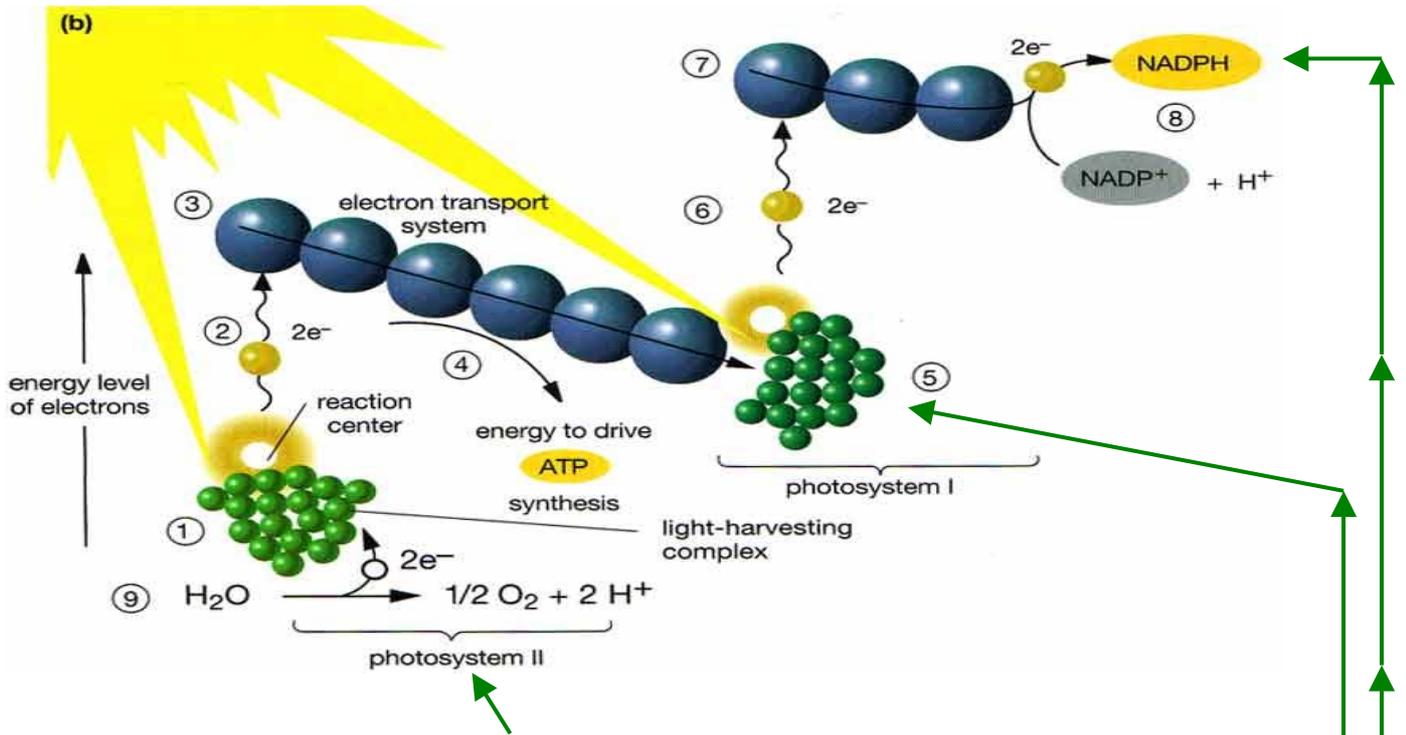
There are two parts to this process:

1. The **light-dependent reactions** (which take place in the **thylakoid membranes**, or **grana**, of the **chloroplasts**), in which light energy, trapped by chlorophyll, is used:
 - to split water into O_2 and H^+ ions, stored as reduced **NADPH** and
 - to be stored as chemical energy by converting **ADP + Pi** to **ATP**.
2. The **light-independent reactions**, (take place in the **stroma** of the chloroplasts) in which:
 - the **ATP and reduced NADP** (from the light-dependent reactions) are used to reduce CO_2 to glucose.

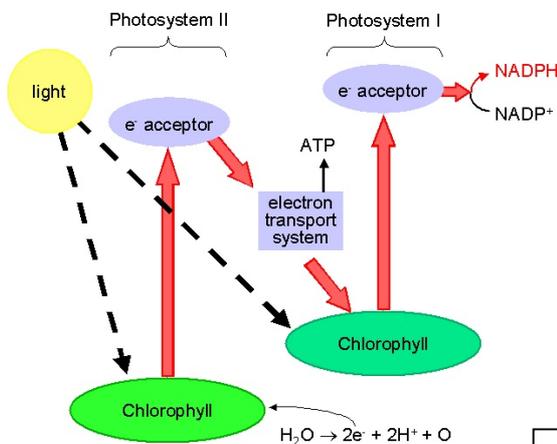
The **thylakoid membranes provide a large surface area** (to trap light), and contain molecules of chlorophyll arranged in clusters called **photosystems**. Each photosystem contains several hundred molecules of chlorophyll and acts as a single light-harvesting system.



1. The light-dependent reactions



This (confusingly!) begins with **Photosystem II**, where **trapped light energy is used to split water**, a process known as **photolysis**:

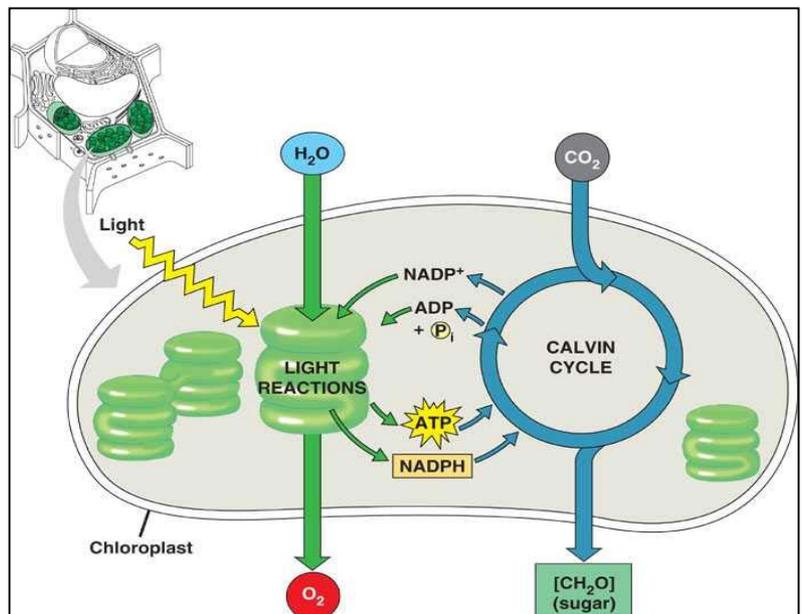


The electrons are used to generate **ATP**, by passing them **along a series of electron carriers**, losing energy as they do so, **before they join Photosystem I**, replacing electrons lost there.

Photosystem I also traps light energy, and uses it to excite electrons along a series of carrier molecules. **Combined with the H⁺ ions formed in Photosystem I**, they react with **NADP** to produce **reduced NADP (also known as NADPH₂)**:



The **end-products of the light reaction** are thus **ATP** and **reduced NADP**, (also called **NADPH**) which move into the **stroma** of the chloroplast ready to act as the raw materials for the **light-independent reactions** (see right).

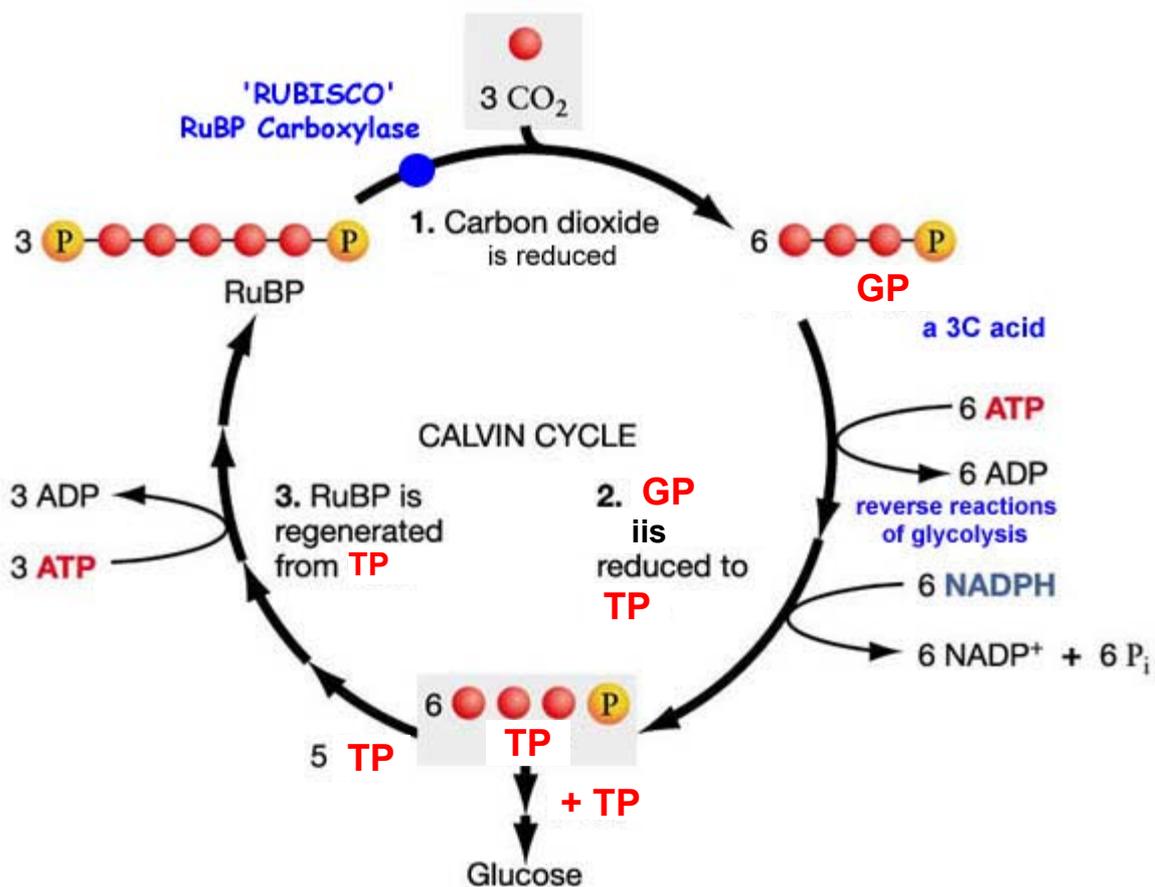
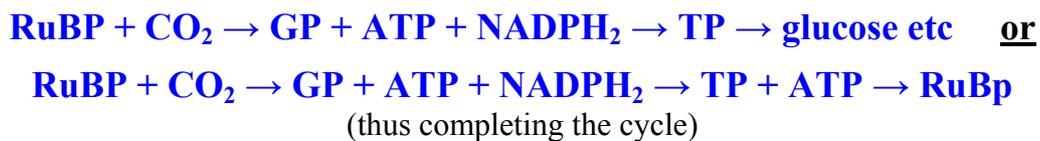


2. The light-independent reactions

The diagram (below) shows **very** clearly all that AQA expect you to know! The cycle involves:

1. A 5-carbon sugar (**ribulose biphosphate – RuBP**) combines with CO_2 , forming
2. two molecules of a 3-carbon compound, **glycerate 3-phosphate, GP** ($2 \times 3\text{C} = 6\text{C}$!).
3. The GP is then reduced to **triose phosphate, TP**, which requires both **ATP** and reduced **NADP** (which were made in the light-dependent reactions).
4. Some of the TP is used to make **glucose**, amino-acids and lipids, whilst
5. the rest is converted back into **RuBP** – which requires another molecule of **ATP**.

The sequence is thus:



N.B. When answering a question on this cycle, remember that **an increase in the level of a substance means that the next step is blocked**. So, for example, if there is an increase in RuBP levels, it would suggest that there is a lack of CO_2 . The same applies for the other stages – a build-up of GP suggests a lack of ATP (i.e the light reaction is not working).

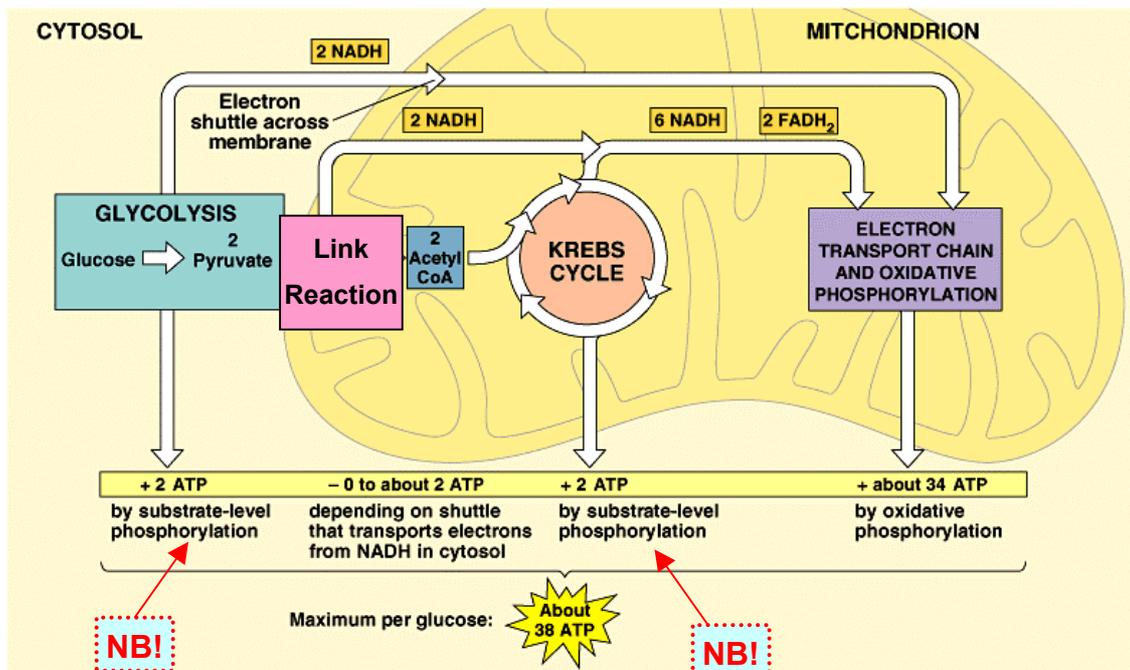
Note that it is **NADP** that is used in **P**hotosynthesis, and **NOT** NAD!!!

Respiration $(C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O)$ (forming 38 ATP)

This is the process by which all living things obtain energy. We are only interested in the version of the process that takes place inside Eukaryotic cells. The many steps of the whole process allow small amounts of energy to be released at each step and also allows for substances other than glucose (fatty-acids, glycerol, amino-acids) to be used for respiration when needed.

There are 4 main stages:

1. **Glycolysis:** Glucose \rightarrow 2 x pyruvate (in the cytoplasm, no oxygen required). **A net gain of 2 molecules of ATP and two molecules of reduced NAD (NADH).**
2. **The Link Reaction:** Pyruvate \rightarrow Acetyl CoA + NADH + CO₂ The 'link' to mitochondria
3. **The Krebs (or TCA) Cycle:** In the **mitochondrial matrix**, this **uses oxygen to breakdown the Acetyl CoA through a complex cycle to release CO₂ and 'store' hydrogen as reduced NAD (NADH) and reduced FAD (FADH).** **Two molecules of ATP** are also made per glucose molecule.
4. **The Electron Transport Chain (E.T.C.):** On the **mitochondrial cristae**, this uses oxygen to **oxidise all the NADH molecules and FADH molecules** made in **all** the earlier stages **to water** and release a great deal of energy – stored as ATP. By far the main site of ATP synthesis (34 molecules of ATP).



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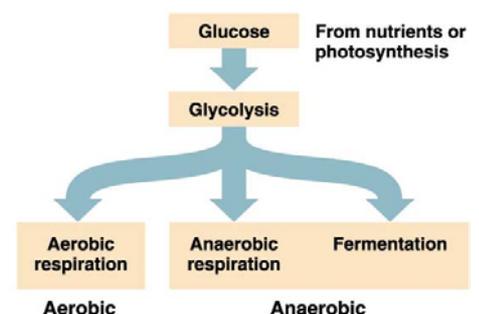
Note that respiration can also be **anaerobic**, i.e. **take place without oxygen**. This is much **less efficient, forming only 2 molecules of ATP per glucose**. There are two different types of anaerobic respiration, or **fermentation**:

Animals (only!): Glucose \rightarrow 2 x lactic acid + 2ATP

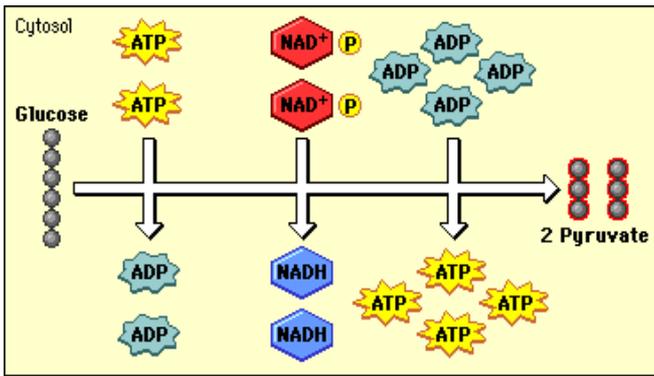
Plants and Fungi: Glucose \rightarrow 2 x ethanol + 2CO₂ + 2ATP

BOTH forms of anaerobic respiration **recycle the reduced NAD (NADH) back to NAD, thus allowing glycolysis to continue.**

The **lactic acid** animals produce is **broken down in the liver** (aerobically), causing the **oxygen debt** we experience at the end of violent (anaerobic) exercise.

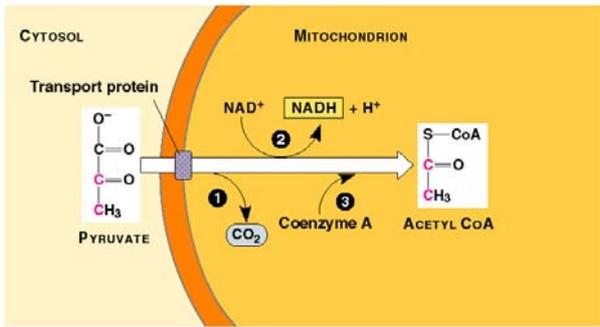


Glycolysis



Glycolysis is the **first stage of respiration**. It **breaks glucose down into two 3-C molecules (called pyruvate)** and at the same time makes it much more reactive. **Two molecules of ATP are used up** in this process, but **4 ATP molecules are formed (so net +2 ATP overall)**. At the same time, **2 molecules of NAD are reduced (to NADH)** - see left. Since our cells have only a little NAD (it's a B-group vitamin), this **must** be recycled if glycolysis is to continue. This takes place in the ETC in the mitochondria - see below.

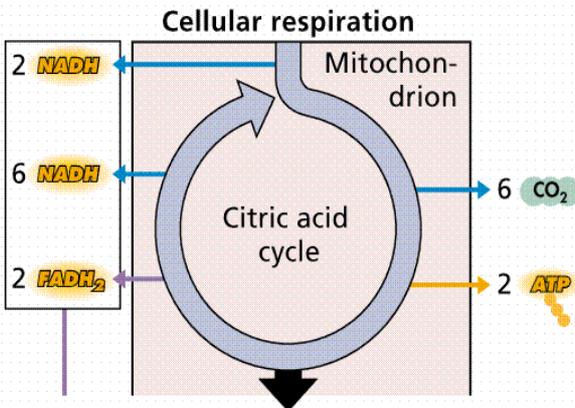
The link reaction



This is the 'link' between the cytoplasm and the mitochondrion. The diagram (left) shows that, as the 3C pyruvate is converted to the 2C Acetyl CoA, **as well as a molecule of CO₂, a further molecule of NAD is reduced (to NADH)**.

This is the first time that oxygen is required (for anaerobic respiration, see later)

The Krebs cycle (or TCA cycle)



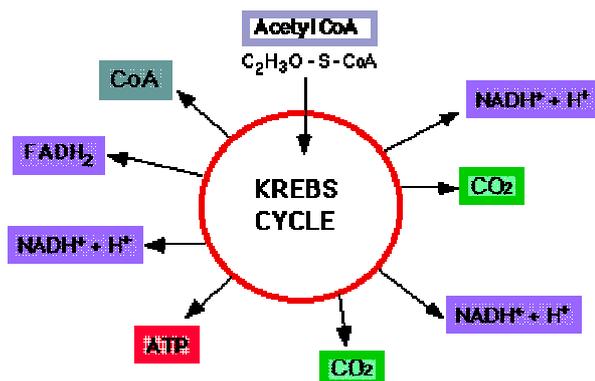
This takes place in the **matrix of the mitochondria** and questions on Krebs' Cycle take the form of 'count the carbons'! The **2C acetyl** group (*the CoA returns to the cytoplasm to repeat the link reaction*) **combines with the 4C oxaloacetate** to form the **6C citrate** molecule. This then gets converted **back** into the **4C oxaloacetate** in the rest of the cycle, so releasing **2 molecules of CO₂**.

Three molecules of reduced NAD (NADH) are also formed, together with **one molecule of reduced FAD (FADH₂)**, and **one molecule of ATP**.

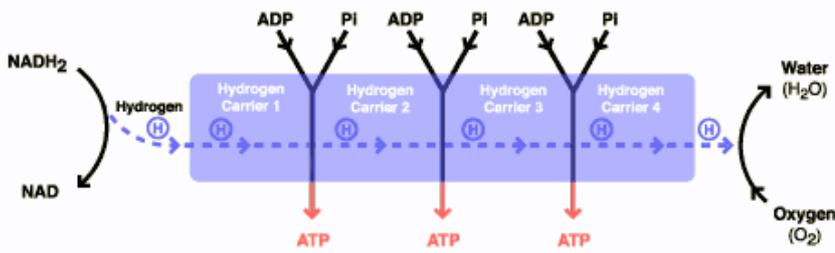
Now, since **two** molecules of acetyl CoA were formed from **each** molecule of glucose, it follows that **there are two turns of Krebs' cycle for each glucose molecule**. That means that **all the above numbers need to be doubled** to get the overall totals:

- 6 molecules of NADH and
- 2 molecules of FADH and
- 2 molecules of ATP

all **from one molecule of glucose!**



The Electron Transport Chain (ETC)

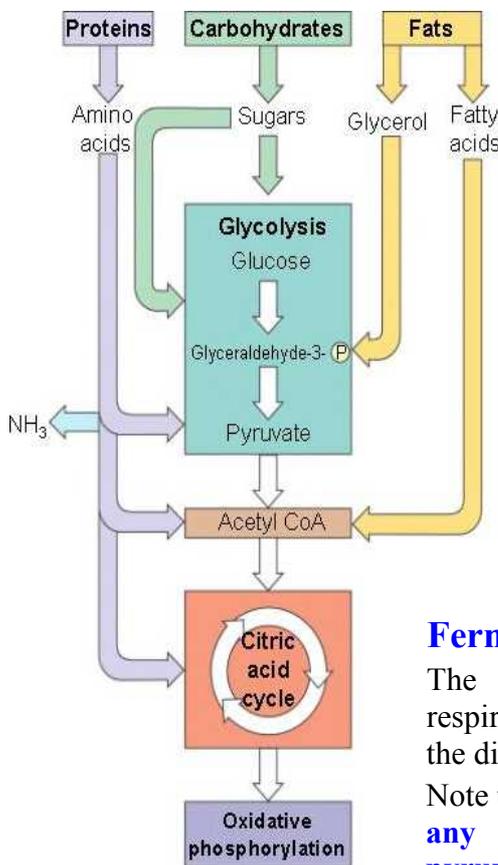


This series of reactions **takes place on the cristae**, the inner membrane of the mitochondria. A series of reactions **combines the H⁺ ions and electrons released from the reduced NAD (NADH) with oxygen**. This forms water and the energy released is trapped as ATP.

- From each molecule of reduced NAD (NADH), **3 molecules of ATP are formed**
- From each molecule of reduced FAD (FADH), **2 molecules of ATP are formed**.

Respiration is about 40% efficient - the other 60% is lost as heat (mammals and birds rely on this).

Other respiratory substrates



These feed in at various places (*see diagram*); the central role of Acetyl CoA is very apparent.

Respiratory Quotient

This is used to calculate what substance an organism is respiring. It is calculated from the formula:

$$RQ = \frac{\text{CO}_2 \text{ produced}}{\text{O}_2 \text{ consumed}}$$

If the RQ is **0.7**, then lipids are being respired

If the RQ is **0.9**, then amino-acids are being respired OR a mixture of lipid and carbohydrates

If the RQ is **1.0** then carbohydrates (any) are being respired

If the RQ is **above 1.0**, then respiration is anaerobic.

Fermentation

The **two** forms of anaerobic respiration are both shown in the diagram (*right*).

Note that **neither method gains any more ATP from the pyruvate**, but, by **recycling the pyruvate**,

reduced NAD (NADH), they both allow glycolysis to **continue**, even in the absence of oxygen.

A side-effect is that the chemicals formed (**ethanol** and **lactic acid**) are **less toxic** than pyruvic acid (**pyruvate**).

