

Respiration – what it is

Unlike photosynthesis – which is only found in some organisms – respiration is universal. All organisms need to convert the energy in “food” to ATP. Since ATP is the only form of energy that can be used by cellular processes.

So photo-autotrophes (and chemo-autotrophes) make food – which they can store - and then, as they need it, use the food as an energy source to make ATP. This is respiration.

NB food is not converted to ATP, it's just the energy in food that is used to manufacture ATP from its components. ATP is not stored but made constantly as it is needed though there are some short cuts for emergencies like running for the bus.

Respiration the overall process

In respiration food molecules are gradually dehydrogenated i.e. hydrogen is removed from the food molecules. In the mitochondria (mostly) this hydrogen – the protons and electrons – are used to provide the energy to make ATP. When the hydrogen has “lost” its energy it is combined with oxygen to make water.

As the hydrogen is separated from food carbon dioxide is produced. As this is not needed and is toxic it is removed from the cell and is lost to the environment.

So overall –

Food + oxygen → carbon dioxide + water + energy (used to make ATP)

Respiration takes place in small steps

If food chemicals were broken down to release their hydrogen quickly in one or two steps a lot of energy would be lost in the form of heat. Consider methane natural gas when it burns.

But it slow stepwise process –

Methane → alcohol → aldehyde → acid → anhydride (CO₂)

So in respiration there are many small steps each catalysed by a different enzyme. We don't need to look at all the steps to get some idea of the process as a whole.

The first few steps – glycolysis 1

Glycolysis takes place in the cytoplasm and involves the breakdown of glucose to **two** molecules of pyruvic acid (pyruvate)

Remembering our biochemistry –

Glucose is $C_6H_{12}O_6$ and Pyruvate is $CH_3COCOOH$

So how many hydrogens have been removed in glycolysis?

The first few steps – glycolysis 2

Four hydrogens have been removed and these are carried by 2 molecules of NAD. Which can be written simply as NADH_2 .

These hydrogens will later be used to generate energy but some of the many stages of glycolysis actually use up ATP. So overall glycolysis generates only a small amount of the energy of respiration.

Glycolysis summery

Input

Glucose

2 ATP

2 NAD⁺

4 Phosphate

4 ADP

Output

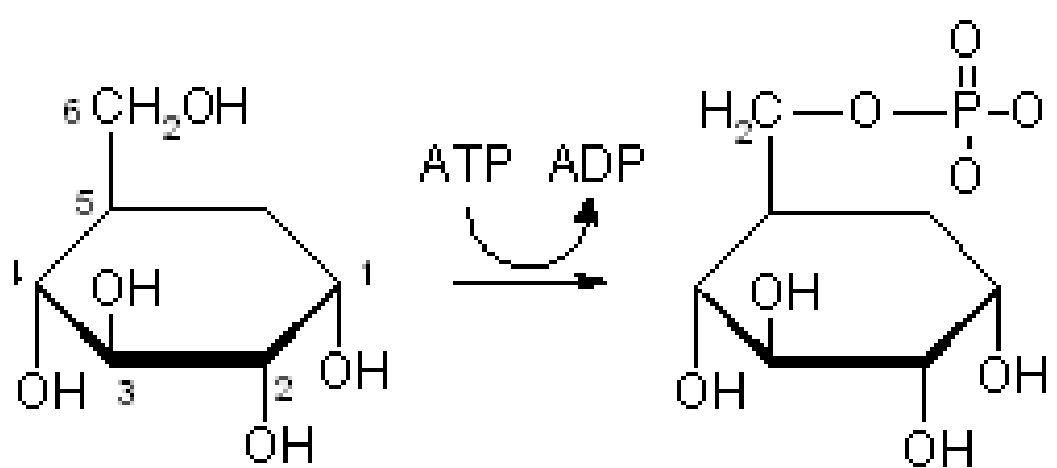
2 Pyruvate

4ATP (net gain of 2ATP)

2 NADH₂

2 H₂O

2ADP

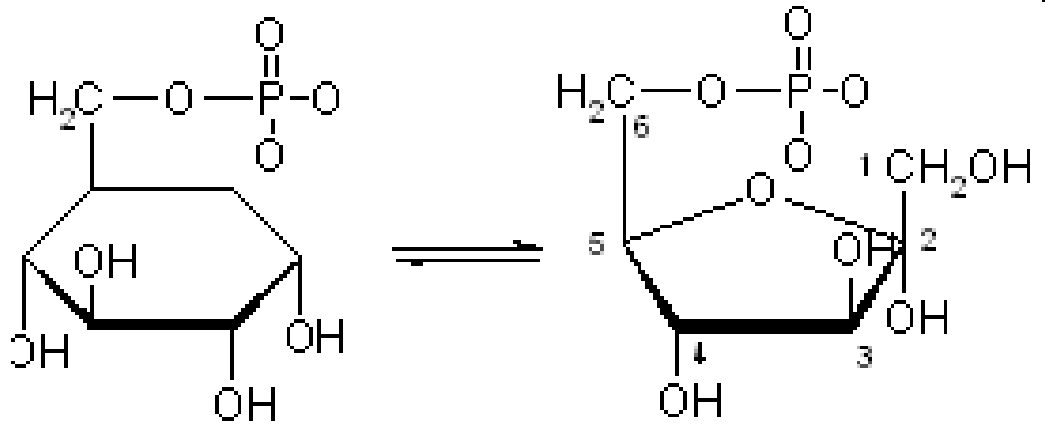


Glycolysis step 1:

Glucose phosphorylation catalysed
by Hexokinase:

α -D-Glucose + ATP \rightarrow α -D-
Glucose-6-phosphate + ADP + H⁺

$\delta G_0 = -16.7 \text{ kJ/mol}$

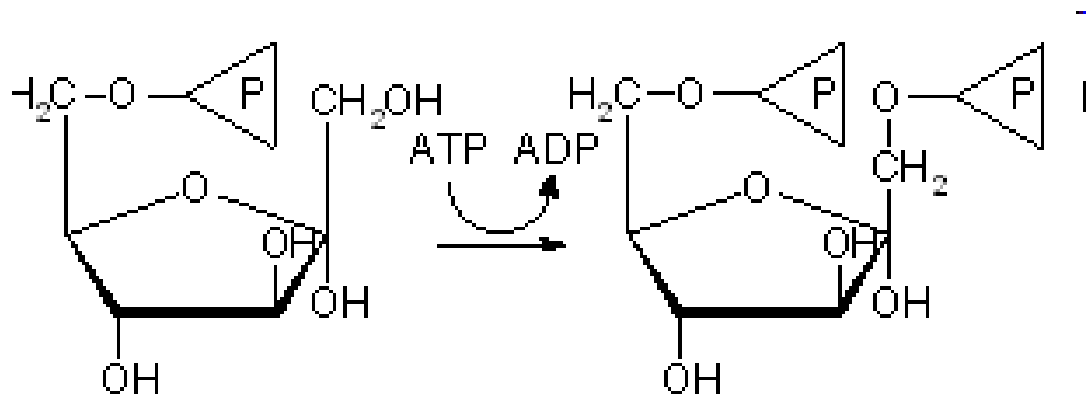


Glycolysis step 2:

Isomerization of glucose-6-phosphate catalysed by Phosphoglucosomerase:

α -D-Glucose-6-phosphate \rightleftharpoons D-Fructose-6-phosphate

$\delta G_0 = +1.7 \text{ kJ/mol}$

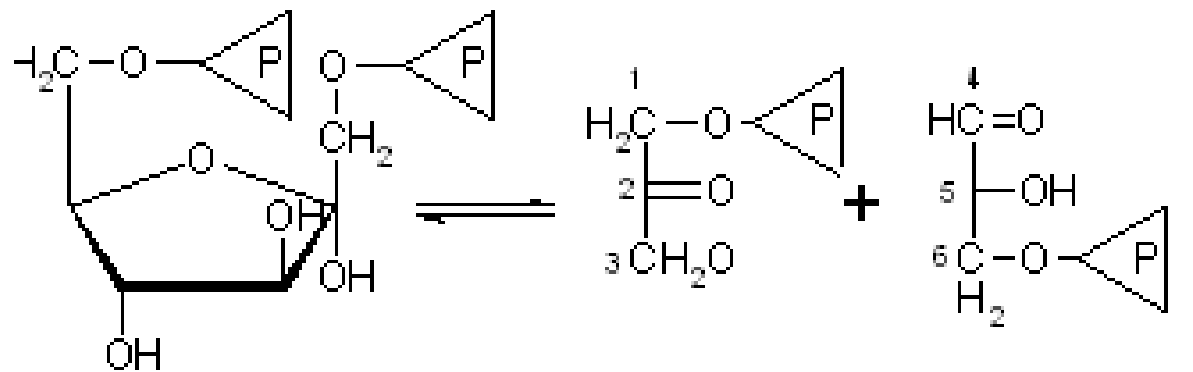


Glycolysis step 3:

Second phosphorylation catalysed
by Phosphofructokinase:

D-Fructose-6-phosphate + ATP ->
D-Fructose-1,6-bisphosphate +
ADP + H⁺

$\delta G_0 = -18.5 \text{ kJ/mol}$

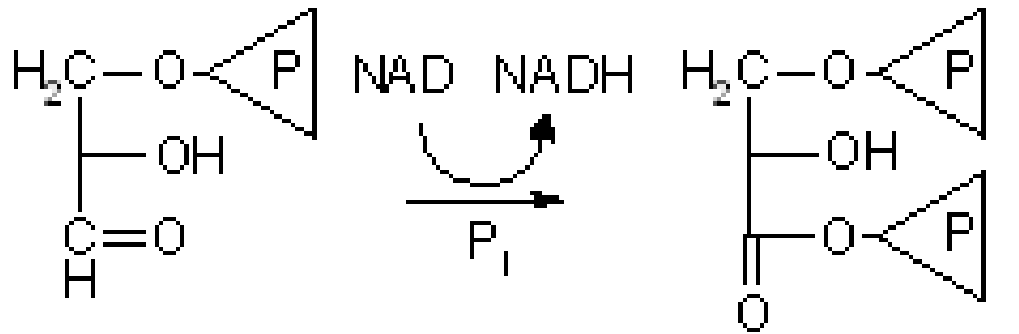


Glycolysis step 4:

Cleavage to two Triose phosphates
catalysed by Aldolase:

D-Fructose-1,6-bisphosphate \rightleftharpoons
Dihydroxyacetone phosphate + D-
glyceraldehyde-3-phosphate

$\delta G_0 = +28 \text{ kJ/mol}$

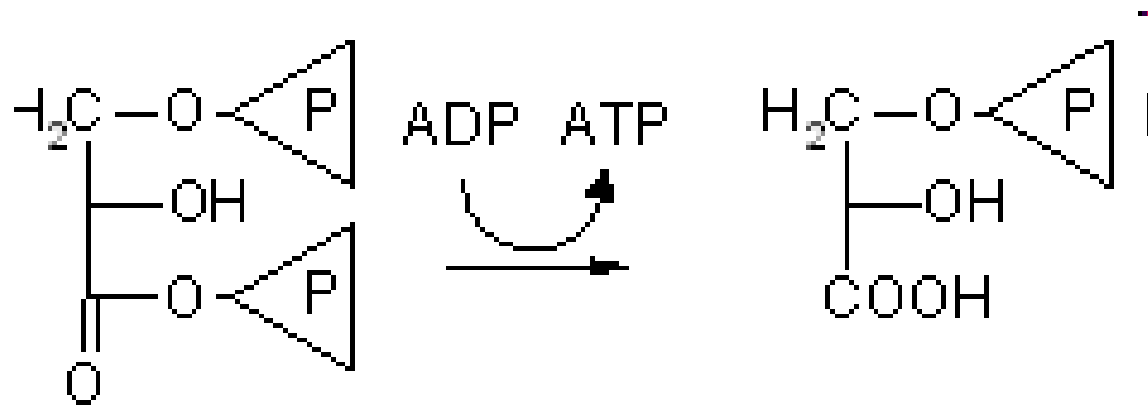


Glycolysis step 6:

Generation of 1,3-Bisphosphoglycerate catalysed by
Glyceraldehyde-3-phosphate dehydrogenase:

D-glyceraldehyde-3-phosphate + NAD⁺ + Pi \rightleftharpoons 1,3-
Bisphosphoglycerate + NADH + H⁺

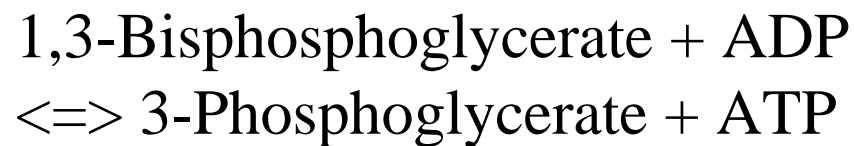
$\delta G_0 = +6.3 \text{ kJ/mol}$



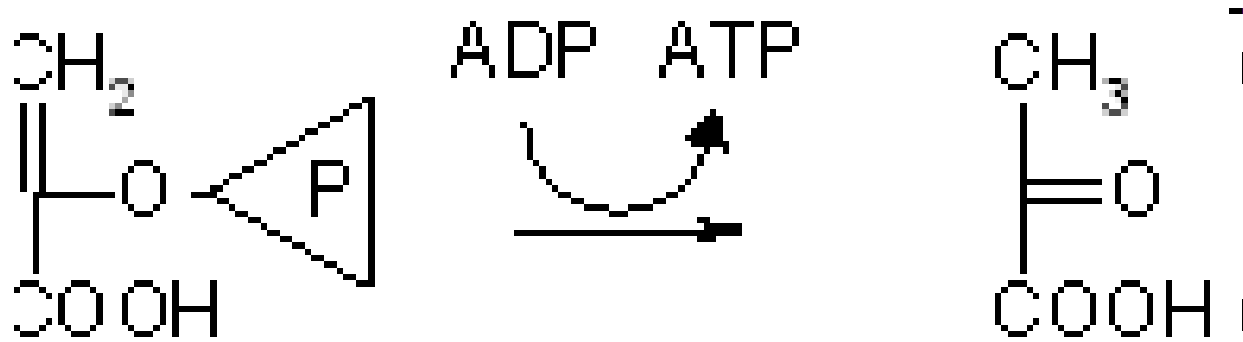
This happens twice as we have 2 3C compounds

Glycolysis step 7:

Substrate-level phosphorylation, 3-Phosphoglycerate catalysed by Phosphoglycerate kinase:



$$\delta G_0 = -18.8 \text{ kJ/mol}$$



Glycolysis step 10:

Substrate-level phosphorylation.

Pyruvate synthesis catalysed by
Pyruvate kinase:

Phosphoenolpyruvate + H⁺ + ADP
→ Pyruvate + ATP

$\delta G_0 = -31.4 \text{ kJ/mol}$

Krebs Cycles

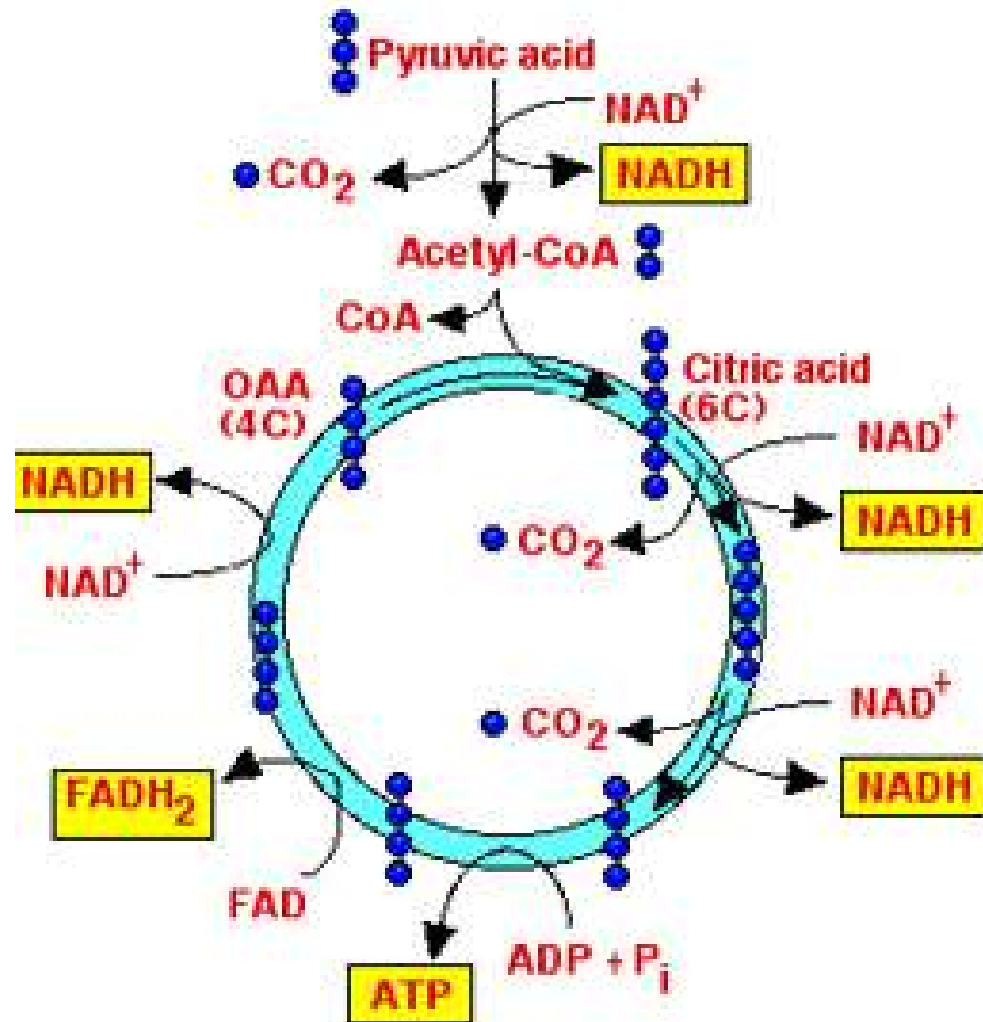
Hans Krebs was to this stage of respiration what Calven was to photsynthesis.

He minced pigeon muscle, isolated and identified the chemicals produced in respiration

Then he was able to work out the pathway that is named after him.

It starts with the 2 pyruvate molecules produced in glycolysis and takes place in the matrix of the mitochondria

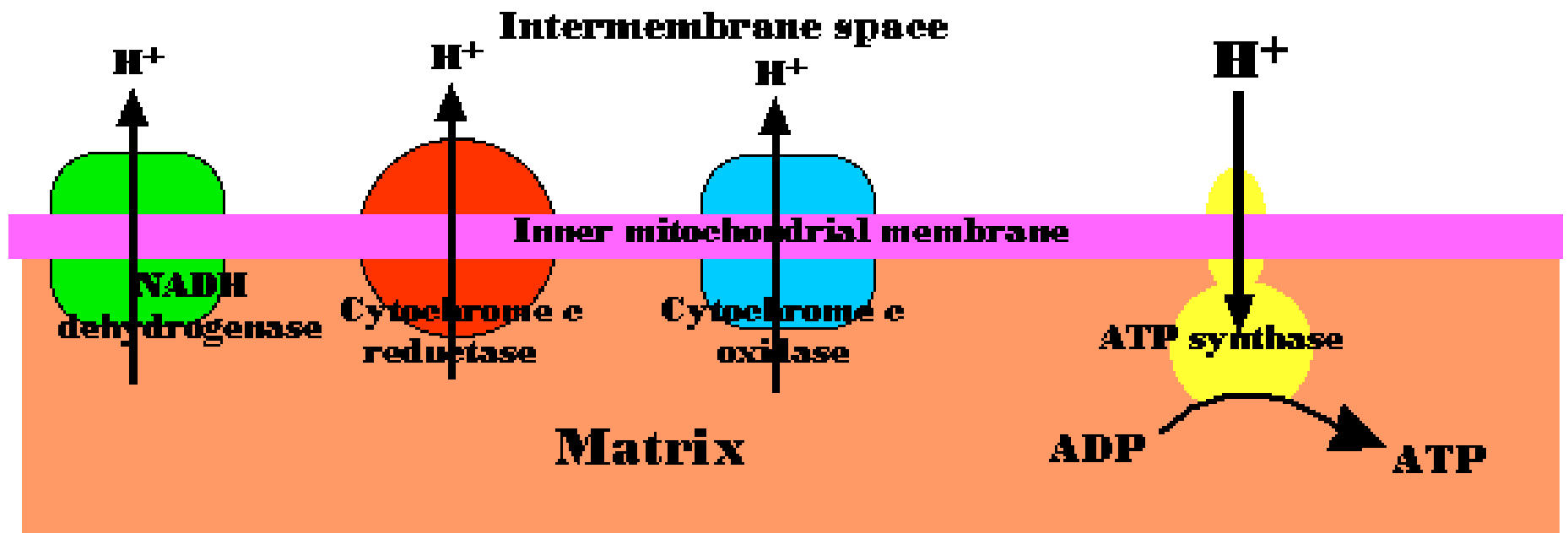
Krebs Cycle (Citric Acid Cycle)



Electron transport chain

So at the end of these two stages there are a number of molecules of reduced NAD (NADH + 2 electrons) and Carbon dioxide which diffuses from cell into the blood and is carried to the lungs where it is breathed out.

As in the chloroplast inside the mitochondria there are electron carriers which pass the 2 electrons associated with NAD along, releasing energy each time. This energy is used to pump the protons of the hydrogen from the matrix into the intermembrane space.



ATP synthesis

The protons (H) in the intermembrane space have electrochemical potential energy and this energy is released to make ATP as they pass back through the inner membrane of the mitochondrion via an enzyme complex called ATP synthase.

The hydrogens then combine with oxygen to make water.

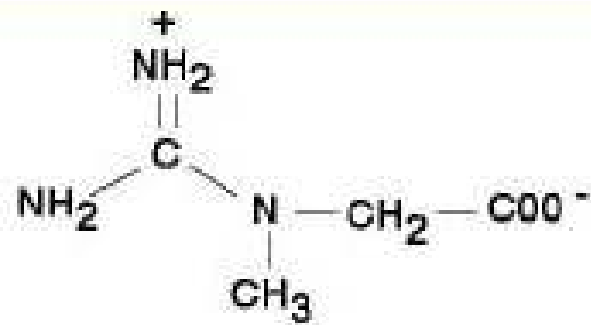
Anaerobic respiration

If there is no oxygen available as in wine making for yeast. The reduced NADH produced in glycolysis gives up its hydrogen to pyruvate to make ethanol and carbon dioxide. This only generates a very small amount of ATP but enough for the yeast to survive.

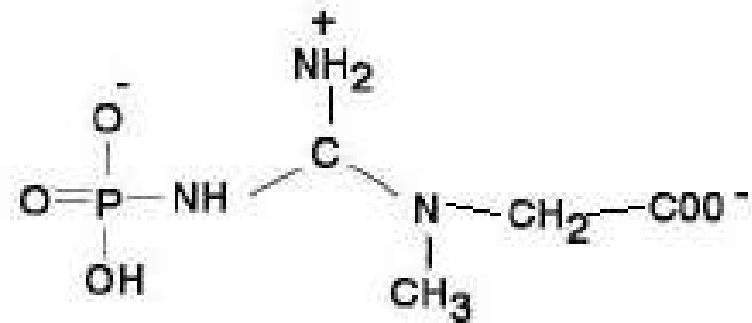
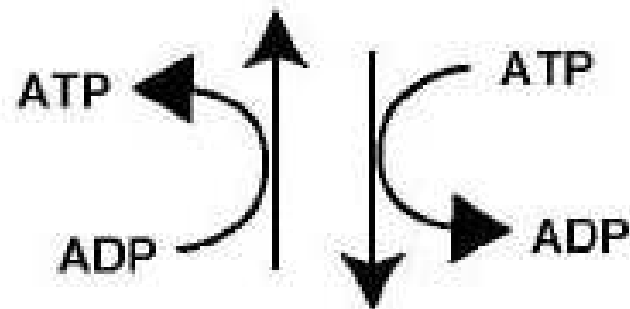
In our muscles if the blood cannot get oxygen quickly enough to muscles then the reduced NADH gives up its hydrogen to pyruvate to make lactic acid. This is toxic if it builds up and causes cramp. Lactic acid is broken down using oxygen later when the "oxygen debt" is "paid off".

Phosphocreatine

The muscles' limited ATP supply is used very quickly in muscle activity. One of the ways that this ATP supply is regenerated quickly is through the molecule creatine phosphate (or phosphocreatine). Creatine phosphate transfers a high-energy phosphate to ADP. The products of this reaction are ATP and creatine.



CREATINE



PHOSPHOCREATINE