

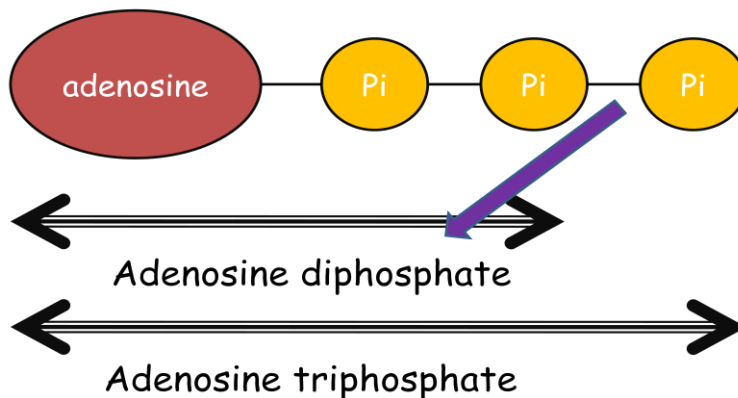
Cellular respiration

The metabolic pathways of cellular respiration are central to metabolism. They yield energy and are connected to many other pathways.

ATP (Adenosine Tri-Phosphate) is used to transfer energy to synthetic pathways and other cellular processes where energy is required.

ATP and energy transfer

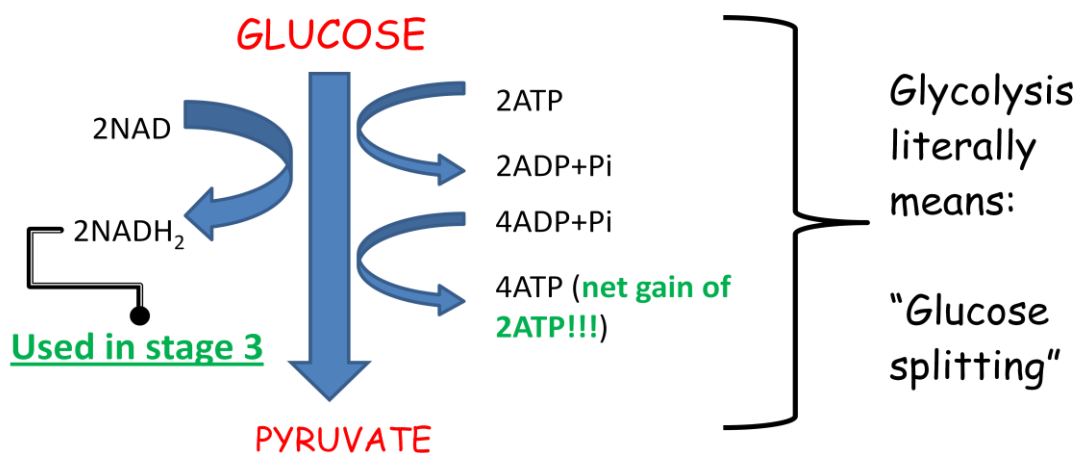
ATP molecules are the energy currency of the cell



Stage 1 – Glycolysis

Glycolysis is the starting point of respiration and DOES NOT REQUIRE OXYGEN

Glucose is broken down into two **pyruvate** molecules via a series of enzyme controlled steps.

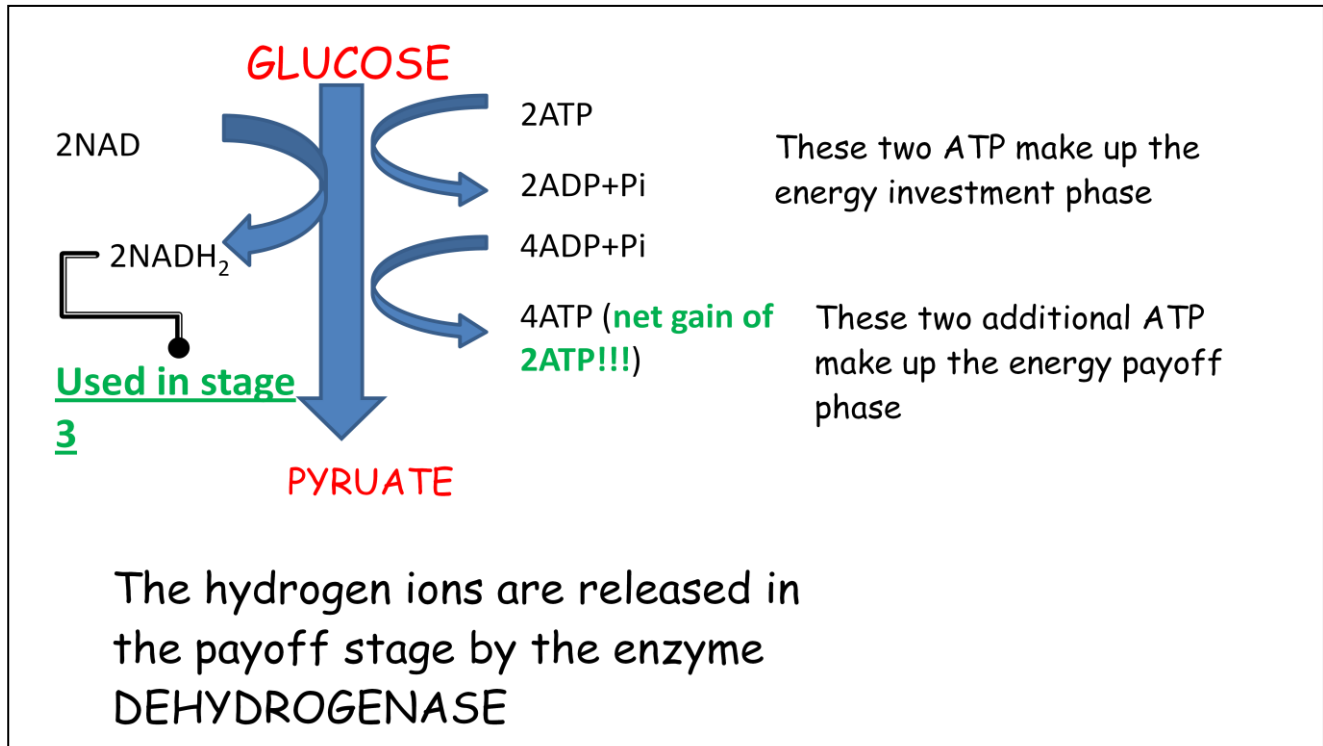


NAD is a molecule which is known as a HYDROGEN ACCEPTOR.

At the beginning of the respiration pathway glucose is **phosphorylated** (has a phosphate group added from ATP).

This leads to a product that can continue to a number of pathways and a second phosphorylation, catalysed by **phosphofructokinase** – this is an irreversible reaction leading only to the glycolytic pathway.

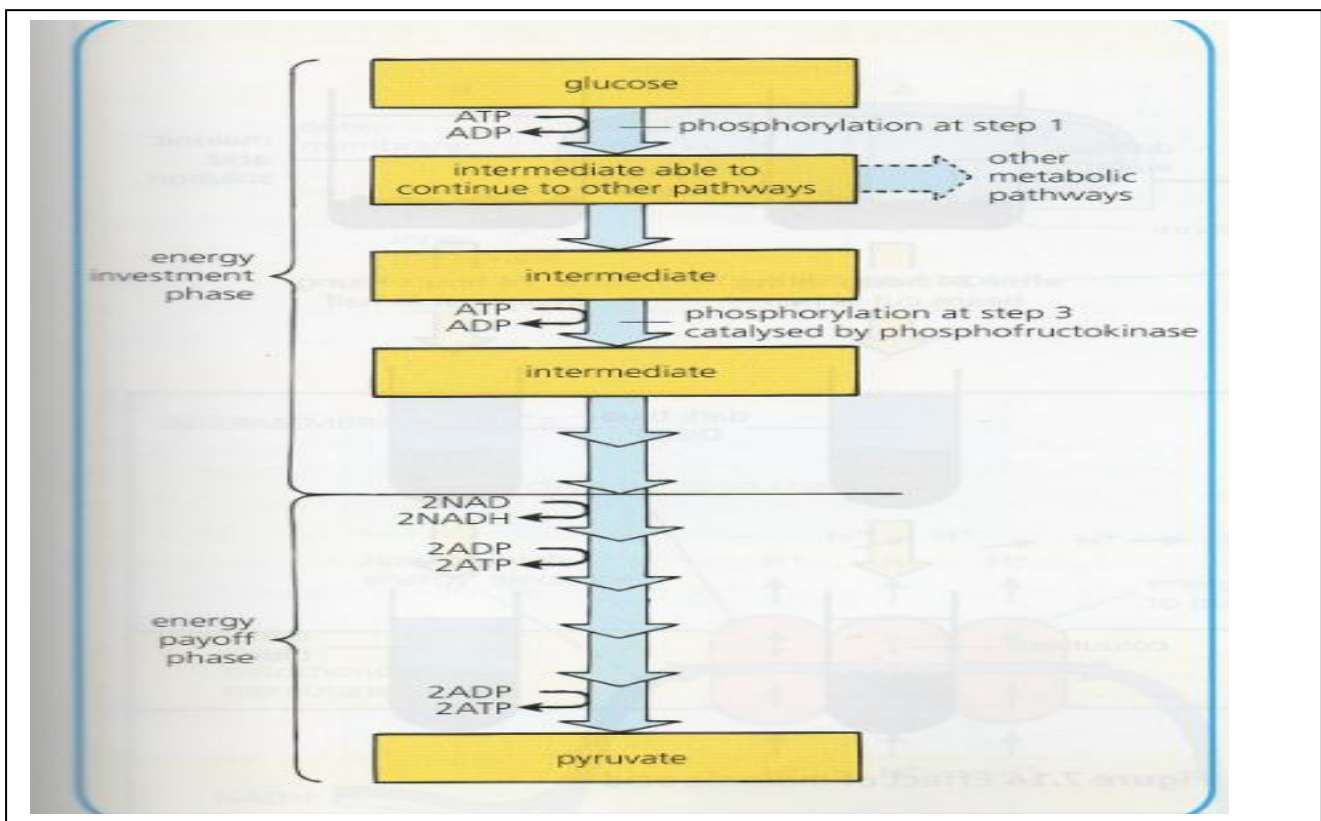
This is regarded as an “**investment**” phase where ATP is consumed.



In the latter part of glycolysis ATP is generated,

this is regarded as an **energy pay-off** phase.

At the end of the glycolysis stage **pyruvate** is formed which progresses to the citric acid cycle if oxygen is available.



Part 2 – Citric Acid Cycle

This cycle results in the :-

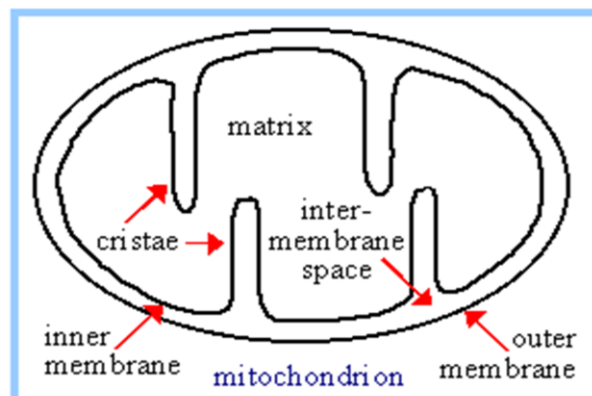
- generation of **ATP**
- **release of carbon dioxide**
- regeneration of oxaloacetate

The Citric Acid Cycle takes place in the matrix of the mitochondria.

Mitochondria

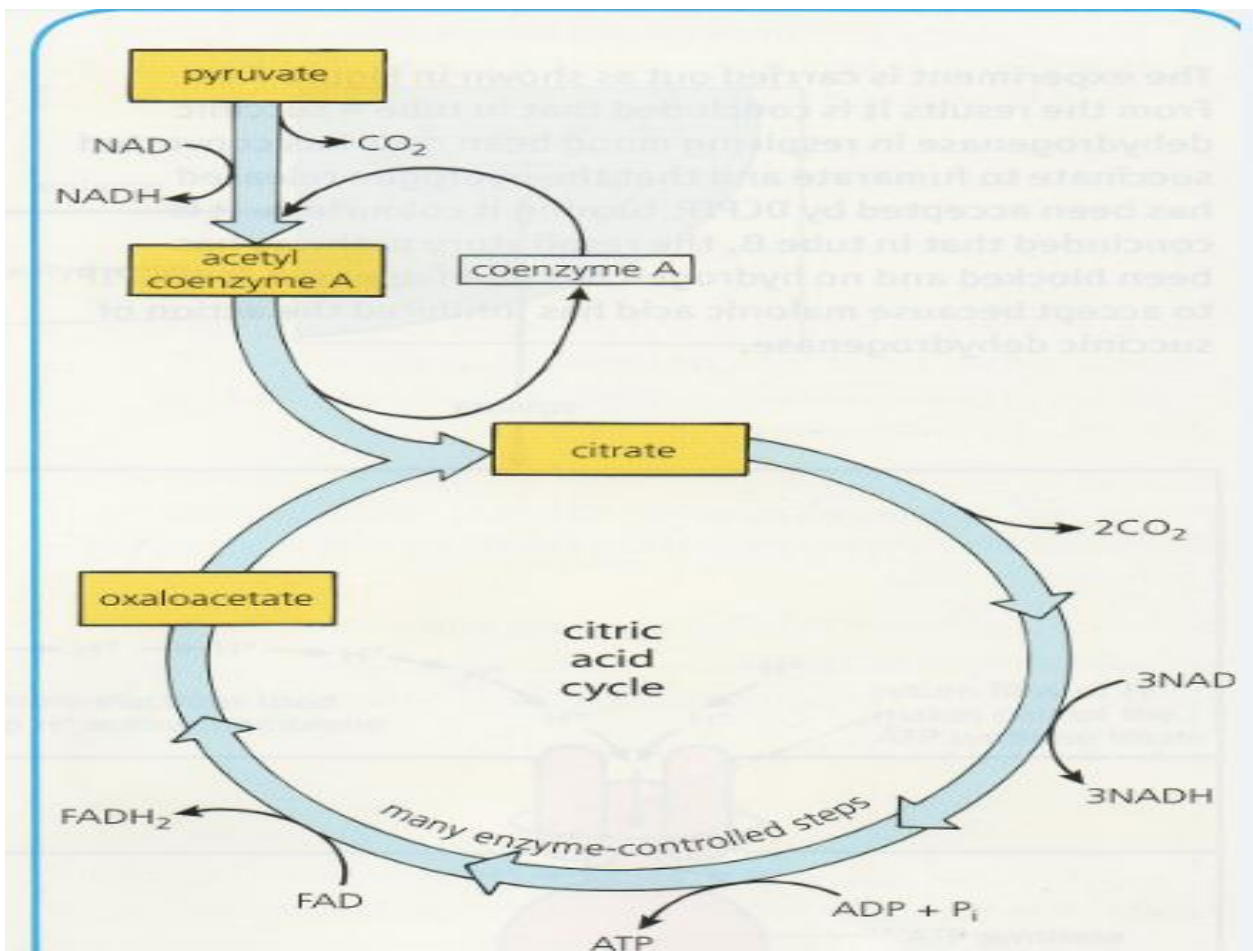
When O_2 is present, aerobic respiration occurs in the cell's **mitochondria**.

The sausage shaped organelles are within the cytoplasm. The inner membrane is folded into many extensions (**CRISTAE**) which increases the surface area for ATP production.



Stages of the Citric Acid Cycle

- Pyruvate is broken down to an **acetyl group** that combines with **coenzyme A** to be transferred to the citric acid cycle as **acetyl coenzyme A**.
- Acetyl coenzyme A combines with **oxaloacetate** to form **citrate**
- **Citrate is gradually broken down** back to the original oxaloacetate **by a series of enzyme controlled steps** which involve :-
 - ✓ the removal of carbon as carbon dioxide
 - ✓ hydrogen which is picked up by a carrier



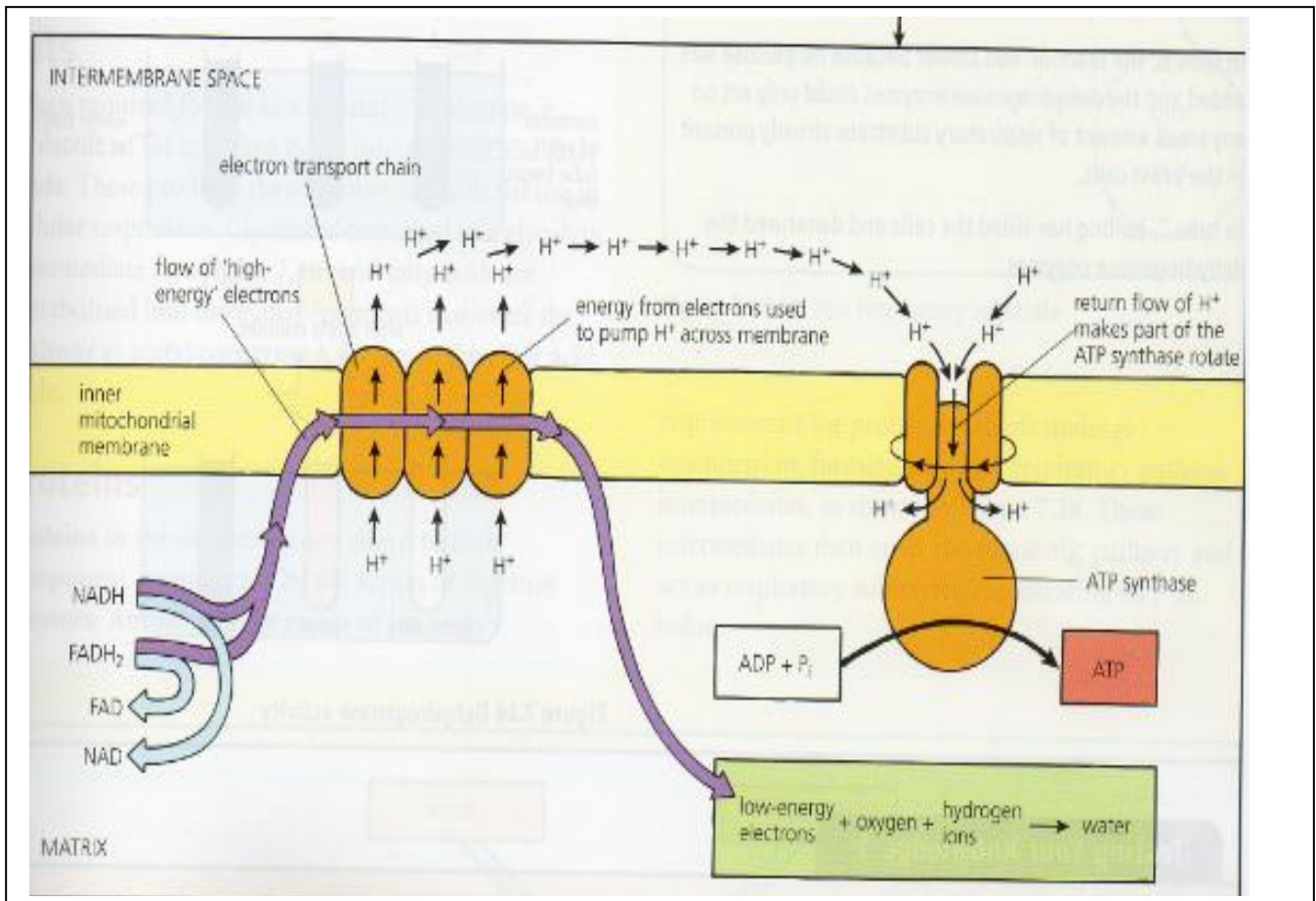
The role of enzymes and carriers

Dehydrogenase enzymes remove hydrogen ions and electrons which are passed to the coenzymes NAD or FAD to form NADH or FADH₂ (this also happens in glycolysis)

NADH and FADH₂ release the high-energy electrons to the electron transport chain on the mitochondrial membrane and this results in the synthesis of ATP. (part 3 3)

Part 3 – The Electron Carrier System

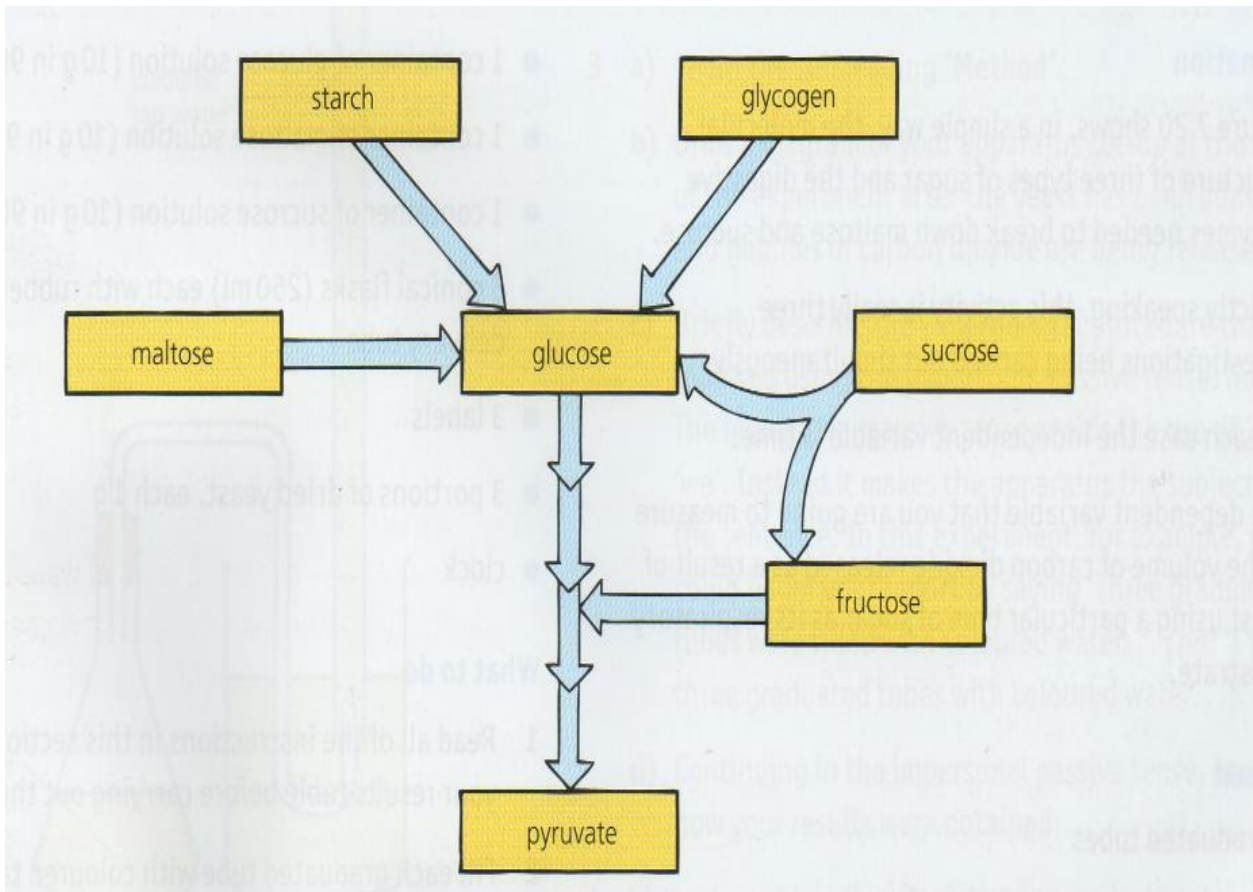
- The electron transport chain is a collection of proteins attached to the folded inner membranes of the mitochondria.
- NADH and FADH₂ release the high-energy electrons to the electron transport chain where they pass along the chain, releasing energy.
- The energy is used to pump H⁺ ions across the inner mitochondrial membrane.
- The return flow of H⁺ ions rotates part of the membrane protein **ATP synthase** and produces the bulk of the ATP generated by cellular respiration.
- The final electron acceptor is **oxygen**, which combines with **hydrogen ions** and **electrons** to form **water**.



Substrates for Respiration

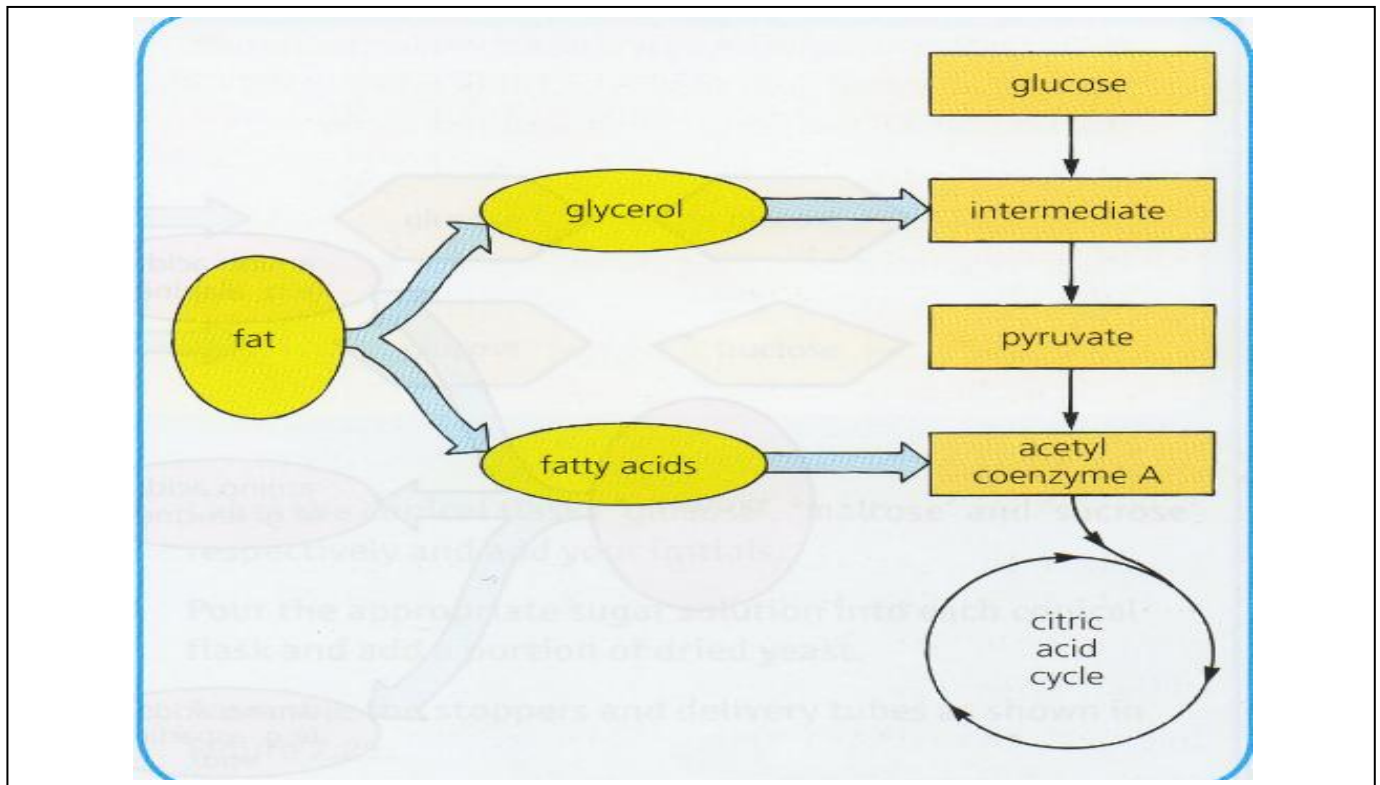
If glucose is not available then the cell can use other substrates including:-

- **Other sugar molecules**, e.g. fructose, can be converted to glucose or glycolysis intermediates for use as respiratory substrates.
- **Starch and glycogen** are broken down to glucose for use as a respiratory substrate.

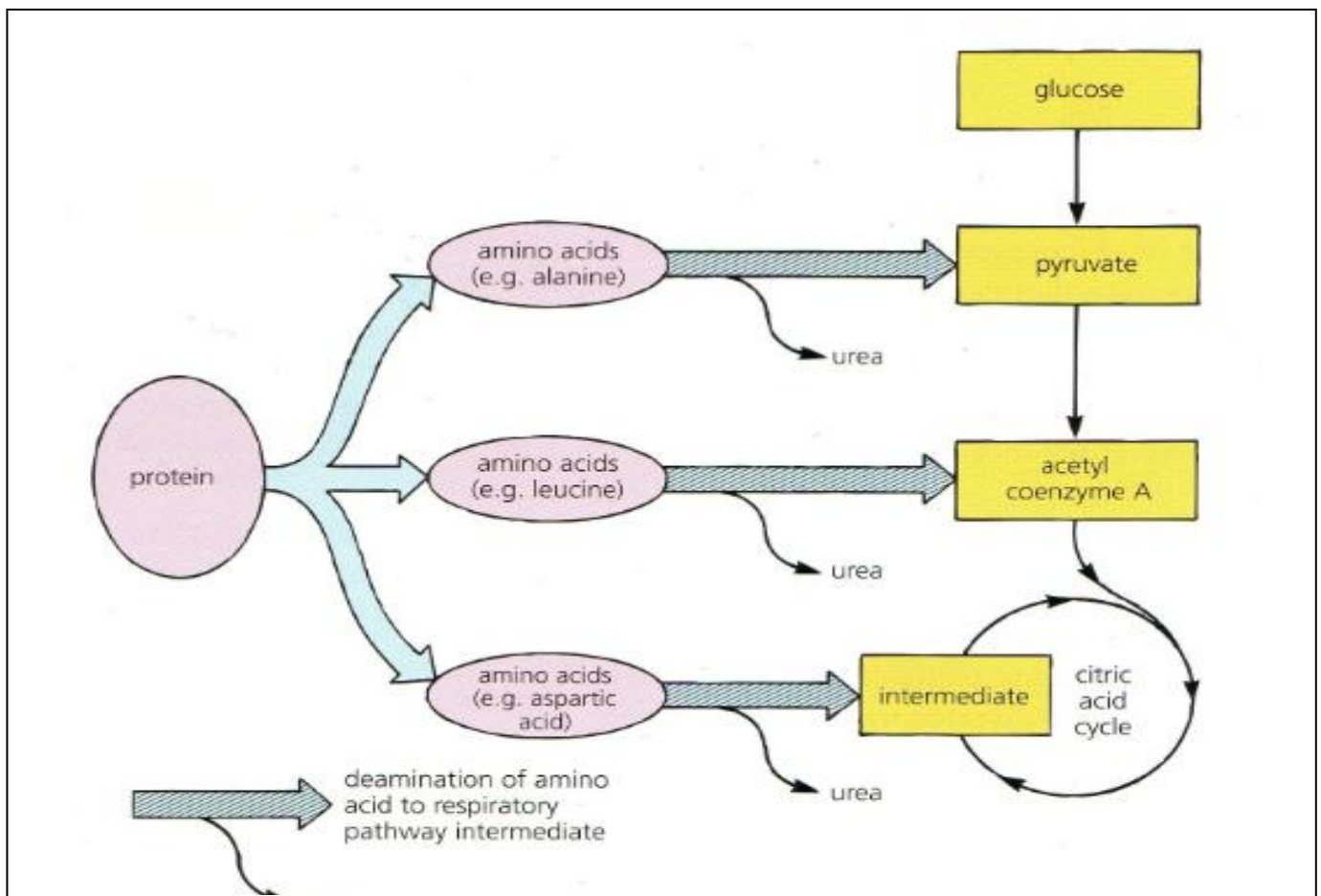


Warning – Please don't learn the details of these diagrams – they are only there to show you how the various alternative substrates feed into the respiration pathways

- **Fats** can also be broken down to intermediates of glycolysis and the citric acid cycle.



- **Proteins** can be broken down to amino acids and converted to intermediates of glycolysis and the citric acid cycle for use as respiratory substrates.



Regulation of Respiration Rate

The cell conserves its resources by only producing ATP when required.

ATP supply increases with increasing rates of glycolysis and the citric acid cycle, and decreases when these pathways slow down.

Remember

- In stage 1 of respiration, the use of the enzyme phosphofructokinase into make the intermediate compound is irreversible.
- This continues the process of glycolysis and is known as the key regulatory point.

Glycolysis can be slowed down by feedback inhibition

- When the cell acquires more ATP than it needs, this inhibits the phosphofructokinase.
- When the ATP is low again, the enzyme works as normal, speeding up glycolysis.

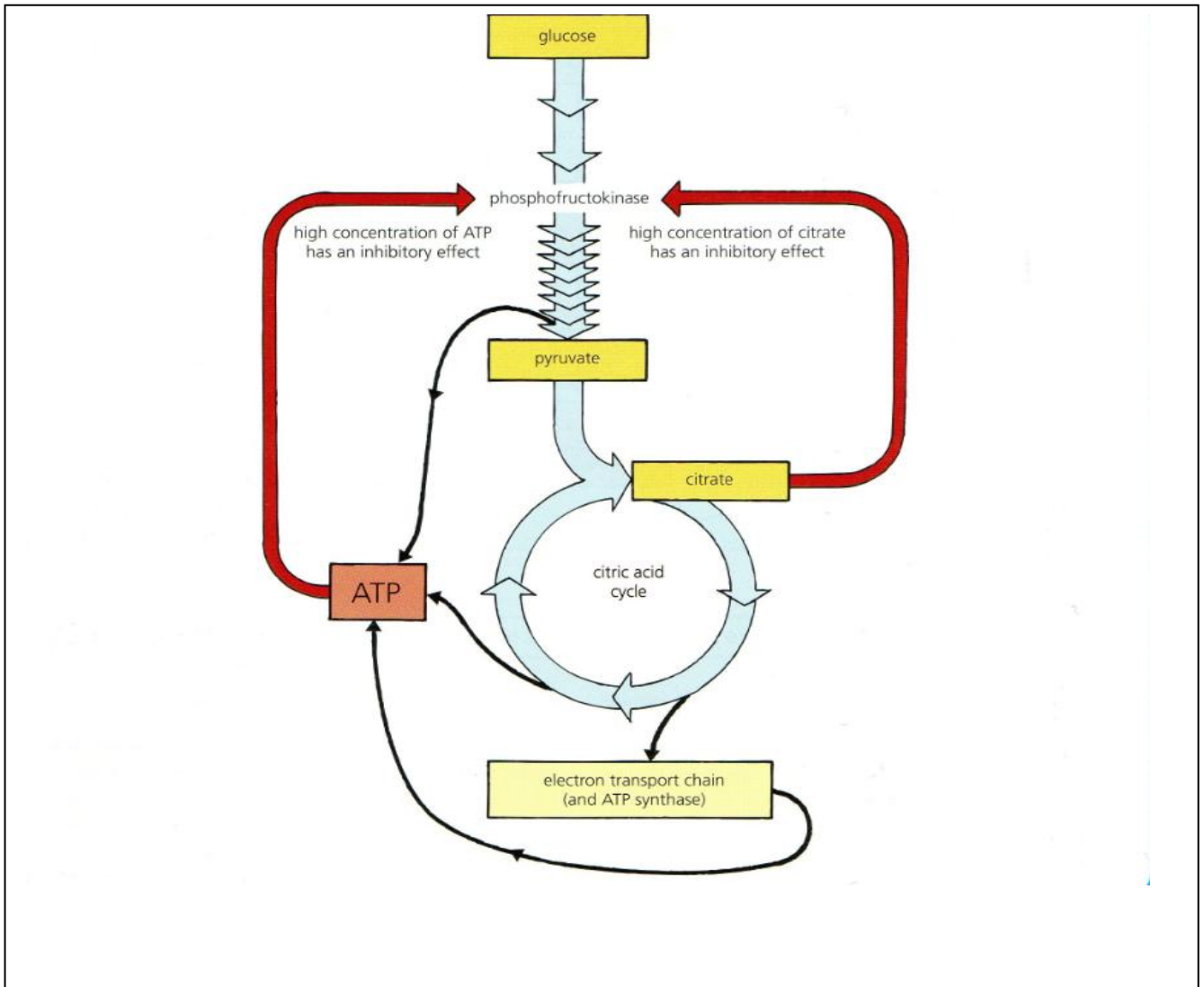
The citric acid cycle can also be controlled through inhibition

- Inhibition also occurs when there is a high concentration of citrate.
- When the levels of citrate drop, the enzyme is no longer inhibited, speeding up the rate of glycolysis

The importance of Feedback inhibition

This process is important because:

- It prevents the build up of an intermediate which is not needed
- ATP is only produced when required
- Resources are conserved



Energy systems in muscle cells

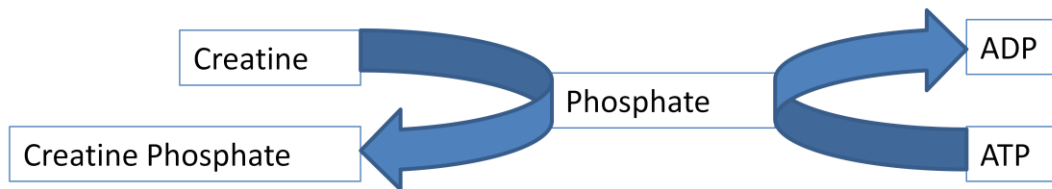
During strenuous muscle activity the cell rapidly breaks down its reserves of ATP to release energy.

Muscle cells have an additional source of energy in **creatine phosphate** that can be used to replenish ATP pools during rigorous bouts of exercise.

This system can only support strenuous muscle activity for around 10 seconds, when the creatine phosphate supply runs out.

When muscle energy demand is low, ATP from cellular respiration is used to restore the levels of creatine phosphate.

During Rest Period



When the demand for energy is low during rest, little ATP is required.

Therefore any ATP is broken down to release energy and phosphate to regenerate creatine phosphate (acts as a high energy reserve).

During vigorous exercise, the muscle cells do not get sufficient oxygen to support the electron transport chain.

Under these conditions, pyruvate is converted to **lactic acid**.

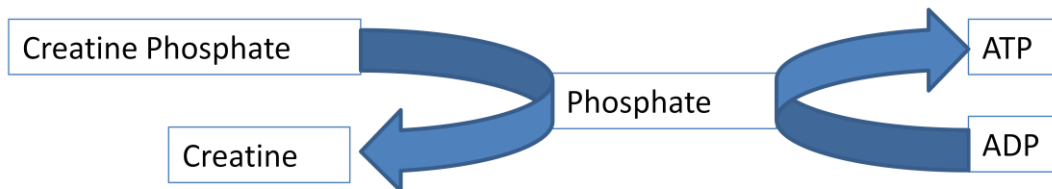
This conversion involves the transfer of hydrogen from the NADH produced during glycolysis to pyruvic acid to produce lactic acid.

This regenerates the NAD needed to maintain ATP production through glycolysis.

Lactic acid accumulates in muscle causing **fatigue**.

The **oxygen debt** is repaid when exercise is complete; this allows respiration to provide the energy to convert lactic acid back to pyruvic acid and glucose in the liver.

During Strenuous Activity



The breakdown of the creatine phosphate releases the phosphate which can then convert ADP into ATP by phosphorylation.

This ATP can then be used for muscular contraction for a few more seconds

Sufficient energy is generated for short bursts of exercise

There are different types of skeletal muscle fibres:

Slow twitch (Type 1) muscle fibres contract more slowly, but can sustain contractions for longer and so are good for endurance activities.

These muscle fibres are good for endurance activities like long distance running, cycling or cross-country skiing.

Slow twitch muscle fibres rely on aerobic respiration to generate ATP and have :-

- many mitochondria
- a large blood supply
- a high concentration of the oxygen storing protein **myoglobin**.

The **major storage fuel** of slow twitch muscles fibres is **fats**.

Fast twitch (Type 2) muscle fibres contract more quickly, over short periods, so are good for bursts of activity.

These muscle fibres are good for activities like sprinting or weightlifting.

Fast twitch muscle fibres :-

- generate ATP through glycolysis
- only and have few mitochondria
- have a lower blood supply than slow twitch muscle fibres.

The **major storage fuels** of fast twitch muscles fibres are **glycogen** and **creatine phosphate**.

Most human muscle tissue contains a mixture of both slow and fast twitch muscle fibres.

Athletes show distinct patterns of muscle fibres that reflect their sporting activities.

Feature	Type of skeletal muscle fibre	
	1 (slow-twitch)	2 (fast-twitch)
Speed of contraction	Slow	Fast
Length of time for which contraction is sustained	Long	Short
Speed at which fibre becomes fatigued	Slow	Fast
Respiratory pathway(s) normally used to generate ATP	Glycolysis and aerobic pathways	Glycolysis only
Number of mitochondria present	Large	Small
Density of blood capillaries associated with fibre	High	Low
Concentration of myoglobin in cells	High	Low
Major storage fuels used	Fats	Glycogen and creatine phosphate

Slow-twitch fibres rely on aerobic respiration to generate most of the ATP and are effective during endurance exercise such as rowing and cycling.

Fast-twitch muscle fibres depend on glycolysis to generate ATP for power events such as sprinting