Anaerobic Respiration - Anaerobic is without oxygen.

This means there is no oxygen present when ATP is reformed.
There are two methods of Anaerobic Respiration:

The Creatine Phosphate System (20 secs)

We can remake ATP as quickly as we use up our muscle stores of ATP.

To do this we use another chemical compound called **creatine phosphate**.

This is also **stored in our muscles** but is only present in **small amounts**.

Therefore it only provides us with up to another 20 seconds of hard work.

When do your 2 sports use this system

Creatine Phosphate (CP) or The Alactic System.

There is another chemical present in the muscle cell called **Creatine Phosphate** (CP).

When there is a demand, due to muscle contraction, for ATP to be re-built CP breaks down, giving up its P to add to ADP to form ATP + C.
ADP + CP = ATP + C.

Like ADP, the cell has a limited quantity of CP in it, so this method of muscle respiration can only be used when short bursts of energy are required such as in shot-putt or sprint starting.
If further muscle contractions are required then another method of muscle respiration is necessary.

Anaerobic Respiration - Anaerobic is without oxygen.

This means there is no oxygen present when ATP is reformed.
There are two methods of Anaerobic Respiration:

The Lactic Acid System (1 min)

The lactic acid system uses **glycogen** to remake ATP. This is gained from the breakdown of **carbohydrates** in our food and stored in our **liver**.

However, there is **no oxygen** present in this system and we produce **lactic acid** as well as ATP. If this builds up it makes **muscular contractions painful** and we become **tired**.
Therefore, this system can only give a total of about **1 minute** of hard work.

When do your 2 sports use this system

The Lactic Acid System.

Present in all cells of the body is a food substance called **glycogen**, which is made from glucose obtained from digested food.
When glycogen breaks down in the cell, it releases energy. This energy is then used to re-build ATP from ADP and P.
ADP + P + glycogen = ATP + pyruvic acid

As the lactic acid system is anaerobic, there is no oxygen present. Pyruvic acid without the presence of oxygen forms lactic acid.
It is the build-up of lactic acid in the muscle that causes pain, discomfort and fatigue.
Consequently, this method of muscle respiration can only be used for events lasting short periods of time, from between two to two and a half minutes.

Examples of this are the longer sprints or the final part of longer events.
For longer events, the body muscles must work with oxygen present, that is, aerobically.

Aerobic Respiration

Aerobic is with oxygen.

The Aerobic System
(1 min+)

We only use the aerobic system when **oxygen** reaches the working muscles.

Glycogen and oxygen together **re-make** the **ATP**. Lactic acid is not formed as oxygen is now available.

The **waste products** in this system are **carbon dioxide** and **water**. The aerobic system gives us **energy slowly** and therefore is not used for very intensive activity.

However, it can supply energy for a very **long time**.

This pathway begins like the **lactic acid system.**

ADP + P + glycogen = ATP + pyruvic acid.

However, because oxygen is present **pyruvic acid** is not converted into lactic acid but goes on to form another 34 molecules of **ATP.**

34 ADP + lactic acid + oxygen + 34 P = 34 ATP + water + carbon dioxide

When do your 2 sports use this system

Energy systems in sport

The energy we need for different sports varies a great deal.

A **shot putter** uses one huge burst of energy lasting just a few seconds. The energy therefore mainly comes from the **creatine phosphate system**.

A **100m sprint swimmer** needs a longer, but still quite short, burst of energy. The swimmer will therefore rely on the **lactic acid system** to supply the energy needed.

A **marathon runner** needs a continuous supply of energy over a long period. The runner will therefore rely on a well developed **aerobic system**.

In many sports the three energy systems work together at different times to supply the particular type of energy they need.

For example, a hockey player will need the creatine phosphate system when shooting, the lactic acid system when sprinting repeatedly over short distances and the aerobic system when jogging into position.

When would a footballer use each of the 3 systems?

Recovery times

Our **creatine phosphate** and **lactic acid** energy systems are **anaerobic** because they work without oxygen.

Once we have used our creatine phosphate and lactic acid systems we need a **relatively short amount of time to recover** before we can use them again to their full potential.

We can use our **aerobic system** for a **longer** period of time.

However, it also **takes longer for us to recover** fully before it can be used again to its full potential.

E The effects of exercise and sports performance on the energy systems

All movement requires energy. The method by which your body generates energy is determined by the intensity and duration of the activity being undertaken. Activities that require short bursts of effort, such as sprinting or jumping, require the body to produce large amounts of energy over a short period. In contrast, marathon running or cycling require continued energy production over a longer period and at a slower rate.

The body's energy systems facilitate these processes. The energy systems of the body can function aerobically (with oxygen) or anaerobically (without oxygen). Movements that require sudden bursts of effort are powered by energy systems that do not require oxygen – anaerobic systems – whereas prolonged activities are aerobic and require oxygen.

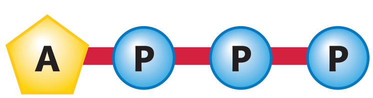
All energy systems work together, but the type of activity and its intensity will determine which system is predominant.

The role of ATP in exercise

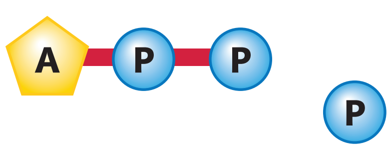
Energy is required in order to make the muscle fibres contract. This energy is obtained from the breakdown of foods in the diet, particularly carbohydrate and fat. The body maintains a continuous supply of energy through the use of **adenosine triphosphate (ATP)**, which is often referred to as the energy currency of the body.

ATP is a molecule that stores and releases chemical energy for use in body cells. When ATP is broken down, it gives energy for immediate muscle contractions. It is the only molecule that can supply the energy used in the contraction of muscle fibres (see Figure 1.20).

ATP consists of a base (adenine) and three phosphate groups. It is formed by a reaction between an **adenosine diphosphate (ADP)** molecule and a phosphate. Energy is stored in the chemical bonds in the molecules; when a bond is broken, energy is released.



(a) ATP is formed when adenosine diphosphate (ADP) binds with a phosphate



(b) When a cell needs energy, it breaks the bond between the phosphate groups to form ADP and a free phosphate molecule

Figure 1.20: ATP and energy released from the breakdown of ATP

ATP works like a rechargeable battery. Energy is released by converting ATP to ADP, which is the 'uncharged' form. By binding a phosphate back with the ADP to resynthesise ATP, the 'battery' is charged again and ready to be used for immediate and powerful muscular contractions.

However, your muscles have only very small amounts of ATP stored in them, so to replenish ATP quickly, the body has to use a number of other systems as well.

The ATP–PC (alactic) system in exercise and sports performance

The ATP–PC (alactic) system is **anaerobic**, which means that it does not require oxygen to produce energy. This is important in sports where sudden and powerful movements are required, such as shot put or sprinting, as the muscles can use ATP to produce energy and movement without having to 'wait' for oxygen to be delivered.

A muscle cell has a small amount of ATP in it that it can use immediately, but there is only enough to last for about three seconds. To replenish the ATP levels quickly, muscle cells also contain a high-energy phosphate compound called creatine phosphate (or phosphocreatine, or PCr). When the high-energy bond in PCr is broken, the energy it releases is transferred to ADP to resynthesise ATP.

The ATP–PC system only supports high-intensity exercise for short periods of time (approximately 10 seconds) as the PC store runs down quickly. If exercise continues at a high intensity these stores will only partially replenish, as there will not be enough energy available for creatine and phosphate to reform phosphocreatine. A ratio called the 'work-to-rest ratio' can be used to determine how quickly a system will replenish. For the ATP–PC system this ratio is 1 : 10–12. This means that for every second of work you need to allow 10–12 seconds for recovery.

The lactate system in exercise and sports performance

The lactate system is a short-term energy system and is used to meet energy requirements of higher intensity over a longer period, such as during a 400-metre race. It is an **anaerobic** process that does not require oxygen and therefore is not sustainable over a long duration.

The body breaks down most carbohydrates from the foods we eat and converts them to a type of sugar known as glucose. When the body does not need to use the glucose for energy, it stores some of it in the liver and muscles where it is easily accessible for energy production and is known as **glycogen.**

In the lactate energy system, ATP is made by the partial breakdown of glucose and glycogen through the process of **anaerobic glycolysis**. Around 60–90 seconds of maximal work are possible using this system.

Anaerobic glycolysis

When the ATP–PC system begins to fade at around 10 seconds, the process of anaerobic glycolysis begins. This system breaks down liver and muscle glycogen stores without needing the presence of oxygen. The breakdown of glucose and glycogen releases energy which can be used to resynthesise ATP; the breakdown of glucose produces two molecules of ATP, whereas the breakdown of glycogen can produce three molecules of ATP.

Lactic acid production

Unfortunately, anaerobic glycolysis produces lactic acid as a by-product. Lactic acid is the limiting factor of the anaerobic system. It accumulates and diffuses into the tissue fluid and blood. If this substance is not removed quickly enough by the circulatory system, it builds up to impede muscle contraction and cause fatigue. You may have experienced this as an uncomfortable burning sensation and soreness in your muscles during intense exercise.

A recovery time of approximately eight minutes will aid the removal of lactic acid from the muscles as well as the storage of glycogen in your muscles.

The aerobic system in exercise and sports performance

The **aerobic** energy system is the long-term energy system. If plenty of oxygen is available, as it is during everyday movements and light exercise, glycogen and fatty acids break down to yield the largest amounts of ATP. This produces carbon dioxide and water, which do not affect the ability of muscles to contract, unlike the lactic acid produced by the lactate system.

Aerobic energy production occurs in the mitochondria of the muscle cells. The aerobic system relies on the breakdown of carbohydrates and stored fats to produce energy, and improved aerobic fitness makes it easier for the body to convert these food sources.

The production of energy within the aerobic system is slow to engage because it takes a few minutes for the heart to deliver oxygenated blood to working muscles. Long, continuous and moderate exercise, such as long-distance running, produces energy using this system.

The aerobic energy system can be broken down into three processes.

1. **Aerobic glycolysis** – this is the first stage of **aerobic metabolism** (the breakdown of foods into energy). It converts carbohydrates (in the form of either glucose or glycogen) into pyruvic acid using oxygen. This breakdown requires 10 chemical reactions: another reason why the aerobic system is slower to deliver energy and is suited to steady sports performance. The process of aerobic glycolysis produces two molecules of ATP.
2. **Krebs cycle** – sometimes known as the **citric acid cycle**, this is the second phase in the process of anaerobic metabolism. It takes place in the mitochondria. The pyruvic acid that was produced during aerobic glycolysis enters the mitochondria and is converted to citric acid. This results in two molecules of ATP being produced, with carbon dioxide and hydrogen being produced as waste products. The carbon dioxide will be exhaled by the lungs and the hydrogen will be used in the next phase of energy production, the electron transport chain.
3. **Electron transport chain** – the hydrogen that was released as part of the Krebs cycle is vital in the production of energy. The electron transport chain is the most important step in energy production and is where the majority of ATP is created. This process will create 34 molecules of ATP from glucose. The hydrogen created as part of the Krebs cycle is accepted by the hydrogen acceptor found in the mitochondria where, in the presence of oxygen, ATP can be produced.

In total the aerobic energy system will produce 38 molecules of ATP from one molecule of glucose. Depending on the duration and intensity of the exercise, as well as your level of fitness, recovery of the aerobic energy systems can range from a few hours to 2–3 days.

The energy systems in combination

During exercise the body does not switch from one system to another – energy at any time is derived from all three systems. However, the emphasis changes depending on the intensity of the activity relative to the efficiency of your aerobic fitness, i.e. your ability to deliver and utilise oxygen. Table 1.6 shows different types of sport and the relative contributions made by the different energy systems. Figure 1.21 illustrates the contribution of different energy systems during exercise.

When you start running, the following process takes place.

- The muscle cells burn off the ATP they already contain in about three seconds.
- The creatine phosphate system kicks in and supplies energy for 8–10 seconds. This would be the major energy system used by the muscles of a 100-metre sprinter or a weightlifter, where rapid acceleration, short-duration exercise occurs.
- If exercise continues, the lactic acid energy system kicks in. This occurs in short-distance exercises such as a 200- or 400-metre run or a 100-metre swim.
- If exercise continues, the aerobic energy system takes over. This occurs in endurance events such as an 800-metre run, a marathon run, rowing, cross-country skiing and distance skating.

Table 1.6: The different lengths of time for each energy system, with sport examples

Duration	Classification	Energy supplied by	Sport example
1–3 seconds	Anaerobic	ATP (in muscles)	A punch in boxing
3–10 seconds	Anaerobic	ATP + PC	100-metre sprint
10–45 seconds	Anaerobic	ATP + PC + muscle glycogen	200-metre run
45 seconds–2 minutes	Anaerobic, Lactic	Muscle glycogen	400-metre run
2 minutes–4 minutes	Aerobic + Anaerobic	Muscle glycogen + lactic acid	1500-metre run
Over 4 minutes	Aerobic	Muscle glycogen + fatty acids	Marathon running

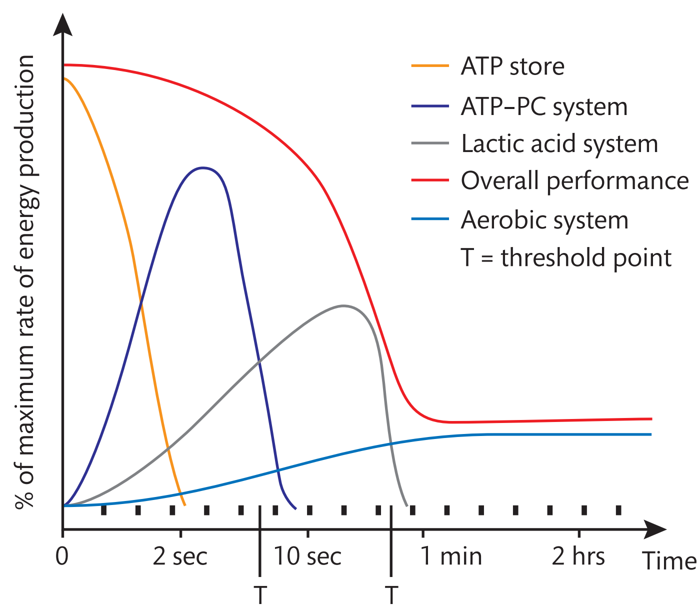


Figure 1.21: The contribution of different energy systems during exercise

PAUSE POINT Why do different sports use different energy systems?

Hint Choose a sport. What is the main energy system that is used?

Extend Now consider a team sport and a specific position. Are different energy systems used during a performance? If so, why?

Case study

Mo Farah versus Usain Bolt

As part of his charity, the Mo Farah Foundation, Mo Farah has challenged the world 100-metre champion, Usain Bolt, to race over a distance that would not suit either runner. Mo Farah is the current Olympic champion over 5000 metres and 10,000 metres, while Usain Bolt is the Olympic champion over 100 metres and 200 metres. Farah has suggested that they race between 600–800 metres.

1. Suggest an optimum distance that would be fair for both athletes.
2. Why do you think that one athlete is better suited to one distance than another distance?

Adaptations of the energy systems to exercise

Long-term exercise will allow the body's energy systems to adapt to the physical demands of exercise. This means that by following an exercise programme it is possible to train each energy system so that you can perform for longer and at increasingly harder intensities.

Increased creatine stores

Short-duration, interval training sessions using high-intensity exercises will improve your ability to produce anaerobic energy. Your body will adapt and be able to store more creatine in the muscles which will improve the ATP–PC system. This will result in you being able to exercise anaerobically for longer using fast and powerful movements.

Increased tolerance to lactic acid

Anaerobic training stimulates the muscles to become better able to tolerate lactic acid and to clear it away more efficiently. With endurance training the capillary network extends, allowing greater volumes of blood to supply the muscles with oxygen and nutrients. The muscles are able to use more fat as a fuel source and become more efficient at using oxygen, increasing the body's ability to work harder for longer without fatiguing. The net result is an increase in the body's maximal oxygen consumption.

Aerobic energy system

Long-term exercise will improve the ability of the aerobic energy system to produce energy, as improvements in the cardiovascular system will allow for increased oxygen to be delivered which is needed to produce ATP aerobically. Likewise, adaptations of the cardiovascular system will aid the removal of lactic acid through oxidisation.

Increased use of fats as an energy source

Fat is the primary energy source during low-intensity exercise. Fat combustion powers almost all exercise at approximately 25 per cent of **aerobic capacity** (which is approximately 60–70 per cent of your maximum heart rate). Fat oxidation increases if exercise extends to long periods, as glycogen levels deplete. When considering the effects of long-term exercise, the trained athlete has a greater opportunity to burn fat as a fuel than the non-trained athlete because they have a more efficient system of delivering oxygen to the working muscle, as well as a greater number of mitochondria.

Key term

Aerobic capacity – the maximum amount of oxygen that can be consumed during maximal exercise.

Increased storage of glycogen and increased numbers of mitochondria

Muscles increase their oxidative capacity with regular training. This is achieved by an increase in the number of mitochondria within the muscle cells, an increase in the supply of ATP and an increase in the quantity of enzymes involved in respiration. The ability of the muscles to store more glycogen is also increased, meaning that anaerobic glycolysis can last for longer.

Link

You can find more information on this topic in *Unit 5: Application of Fitness Testing*.

Additional factors affecting the energy systems

There are two main additional factors that must be considered when examining the energy systems and their impact on sport and exercise performance.

Diabetes and hypoglycaemic attack

Diabetes is a condition where the amount of glucose in your blood is too high. This is known as type I diabetes. It develops when glucose cannot enter the body's cells to be used as fuel. **Insulin** is the hormone produced by the pancreas that allows glucose to enter the body's cells, where it is used as fuel for energy. If you have diabetes, your body cannot make proper use of this glucose so it builds up in the blood and cannot be used.

Hypoglycaemia is an abnormally low level of glucose in your blood. When your glucose (sugar) level is too low, your body does not have enough energy to carry out its activities. Hypoglycaemia mainly occurs if someone with diabetes takes too much insulin, misses a meal or exercises too hard. Typical early warning signs are feeling hungry, trembling or shakiness, and sweating. Additional symptoms include confusion, and you may have difficulty concentrating. In severe cases, a person experiencing hypoglycaemia can lose consciousness.

Children's lack of lactate system

Although we all possess the same body systems, a child's body systems are still growing and developing, with significant changes occuring during puberty. One such area is the lactate energy system, which is not fully developed in children. During high-intensity exercise, lactic acid will build up in the muscles and, due to their developing cardiovascular system, it is more difficult for children to remove this waste product. Therefore it is generally recommended that children exercise aerobically.