Teacher Notes:

400 m running, Acids and Bases

These notes are designed as a guide on how to lead the session and are written in a script format. If you wish to lead the session in a different way please feel free to do so.

The **red text** indicates what each slide includes, while the **blue text** highlights the key points being discussed in each slide. The **owl symbol** demonstrates where students are required to perform a task (e.g. questions, experiment, etc.). These are used to help you observe the students learning and recap any information which the students have found difficult to understand.

Slide 1

Opening slide containing title of session.

The first slide provides the title of the session and a picture of an athletics track visually introducing the topic.

Slides 2 & 3 – Introduction to the 400m and its relation to chemistry

A brief introduction to the sport of 400 m running and how the sport relates to chemistry.

The 400 m race, an athletics event that is recognised as being one of the toughest speed endurance races it is possible to compete in, dates back to the Ancient Olympics of 724 BC (the 14th Ancient Olympic Games). Here the Diaulos Race was introduced, consisting of a single lap of the stadium approximately 400 m long. The event was repeated at all subsequent Ancient Olympic Games and every Modern Olympic Games since their reintroduction in 1896.

The 400 m race is considered to be so tough because a sprint is required over a distance which is too long to be a sprint, due to the nature of the energy system athletes employ for sprinting. For a 400 m race, the most predominant energy system used by elite athletes is anaerobic glycolysis. This energy system can last from 30 to 40 s when trained, almost long enough to complete the entire race which takes the very best athletes between 44 to 50 s to complete.

Anaerobic means produced without oxygen. As a by-product of the manufacturing of energy through anaerobic glycolysis, lactate is produced from the breakdown of glucose without oxygen. Over the initial few 100 m's the concentration of lactate builds up in the muscle cells of the athletes. This build up can give a sensation of pain, known as a stitch, to the runner. Lactate is sometimes, although incorrectly, interchanged with the term lactic acid, however this does simplify the concept and therefore lactate can be considered to be lactic acid for the purpose of this module.

Acids and alkalis are very important in chemistry and through the examination of lactic acid, produced by the runners of a 400 m race, acid and pH (a measurement of acidity) will be explored.

Slides 4 – 7 – Energy provision in the body

These slides explore the different processes employed by the human body to produce energy.

Key Point
Aerobic glycolysis is the most efficient form of energy production in the body completely breaking down glucose into water and carbon dioxide. It is however a comparably slow process to other forms of energy production.

A simple description of lactic acid is that it is a waste product from creating energy for exercise when insufficient amounts of oxygen are available. Effectively, the body has a small store of energy for exercise (known as its ATP store). Once this store has dissipated, there needs to be a way of re-synthesizing it so the body can carry on exercising.

There are three ways that the body can replenish its ATP stores. These are through ATP PC, anaerobic glycolysis and aerobic glycolysis. The body can reproduce ATP which is the fuel for exercise at varying rates for varying amounts of time depending on intensity of exercise. Briefly:

ATP PC can create ATP very quickly but only for a short space of time (6-10 s).

Anaerobic glycolysis produces more ATP per molecule of glucose but more slowly than ATP PC and it can be produced for a longer period of time (30 – 40 s). An unfortunate by-product is lactic acid but this can be removed after it has been produced by providing oxygen to the areas affected. A cool down exercise helps to increase oxygenated blood flow to the area.

Finally aerobically, ATP is produced most efficiently, for the longest period of time and is produced using oxygen.

Slides 8 - 9

Acids and bases are examined in these two slides using lactic acid to link back to the 400 m.

Key Point
An acid is a proton or H^+ ion donator.
A base accepts H^+ ions.

Although anaerobic glycolysis is a fast way of releasing energy, which a runner can use to move their muscles, the lactic acid produced as a by-product has effects on the muscle performance and must be removed. Another by-product also includes the release of hydrogen ions (H^+) through the hydrolysation of ATP. It is widely debated amongst exercise physiologists as to what causes the acidosis (an increase in acidity) of muscle cells through anaerobic glycolysis and is why you may often hear the term lactic acid build up. In this module, for simplification, lactic acid is attributed to being the cause of the acidosis.

Lactic acid, as it states in its name is an acid.

An acid is a proton or H^+ donator, i.e. it will donate a hydrogen ion to another compound.

The compound which accepts this hydrogen ion is a base.

If a solution has a greater number of hydrogen ions than there are acceptors for these ions, the solution is known to be acidic. If there are more hydrogen ion accepting compounds in the solution than there are hydrogen ions, the solution is known to be a base. Most solutions will reach a natural balance leaving the solution either acidic or base and this is especially common in solutions found in the body.

The chemical reactions which happen in the body, that are necessary for life, must take place under the right acidic or alkaline conditions. This means that if excess acids or bases are fed into blood or muscle fluids, the chemical reactions which need to take place can be affected. That is why if too much lactic acid is produced through anaerobic glycolysis, and not removed, the solutions in and around the muscle cells become too acidic for further chemical reactions to take place. These reactions are needed to produce the energy required for the cells and muscles to continue functioning as they should. This can be seen in runners when they ‘tie up’ towards the end of a 400 m race.

Slide 10 – pH – the measurement of acidity levels

The pH scale and what is considered to be pH neutral.

Key Point
A neutral pH has the value of 7.0 on the pH scale.

Acidity levels of a solution can be measured using the pH scale. Most solutions will fall between 2 and 12 on the scale, where 2 would be a very strong acid and 12 a very strong base. In pure water, at 25 °C, the concentration of hydrogen ions (H^+) equals the concentration of hydroxide ions (OH^-). This is defined as 'neutral' on the pH scale and corresponds to pH 7.0. If the concentration of H^+ ions in the solution exceeds that of OH^- ions, then the solution will have a pH value less than 7.0 and is acidic. If the OH^- ion concentration in the solution exceeds that of the H^+ ions then the solution will have a pH greater than 7.0 and is basic or alkaline.

Slide 11 – Changing pH levels in muscle cells due to the buildup of H^+ ions

The change of pH in muscle cells during intense exercise.

The normal level of a muscle cell is pH 7.1. The increased concentration of lactic acid and free hydrogen ions from the hydrolysation of ATP, produced by anaerobic glycolysis, disrupts the normal pH level of the muscle cells. The increase in the concentration of H^+ ions changes the muscle cell pH level to less than 7.0. It can change it to as low as around pH 6.5. This reduction in pH can affect muscle contraction, as the reduction stimulates the nerve endings, resulting in pain. The effect to muscle contraction is dependent on the tolerance of each individual to withstand the 'pain' felt from the reduction of pH. The body must therefore try and neutralise this change in pH.

Slides 12 – 14 – Balancing of pH levels in muscle cells

The return of muscle cell pH levels back to normal after intense exercise

Neutralising pH level means bringing the pH level back to its neutral or natural state, which in the muscle cell is 7.1. If the muscle cell pH level has been reduced and become acidic due to an increase in lactic acid concentration this can be neutralised in a number of ways. Primarily to neutralise the pH in this instance the lactic acid, or actually the lactate, must be removed. Alternatively the prevention of buildup of lactate in the first place is also a method used by the body to ensure the pH stays at its neutral state in the muscle cells.

The removal of the lactate formed through anaerobic exercise is facilitated in two ways. Some of the lactate formed is taken *via* the blood to the liver. The liver converts the lactate back into glucose which can be used as the fuel to create the ATP, the energy source used for exercise.

The remaining lactate diffuses into the blood and is taken or spread out to the surrounding body. This option will reduce the local concentration of lactate which will prevent the pH of the localised muscle cell from reducing as much.

The prevention of the buildup of lactate can also be facilitated in a number of ways. Getting plenty of well oxygenated blood to the muscle cells quickly can provide oxygen for the breakdown of lactate to pyruvate which can be used as a fuel in a separate energy system employed by the body. A cool down will ensure a continuous supply of oxygenated blood is transported to the localised muscle cell for this purpose.

The concentration of lactate can also be prevented from building up by reducing the intensity of exercise and hence using the aerobic energy system which uses oxygen to produce ATP.

Distribute the 'student handout worksheet' and allocate 15 mins for the students to attempt the questions on the worksheet. The questions are related to the all of the slides.

Slides 15 – 17 - Questions & answers from worksheet

Go through the answers to the worksheet, with the students, with the use of these slides. Recap any areas where students have particularly struggled, to ensure learning takes place.

The slides can be used to cover the answers to the questions in a group situation or can be printed off and kept by the students for revision purposes.

1. What is the energy system employed by the body that produces lactic acid as a by-product?

The energy system that produces lactic acid as a by-product is anaerobic glycolysis.

2. Define the terms acid and base.

An acid is: An acid is a proton or hydrogen ion (H^+) donator.

A base is: A base is a hydrogen ion (H^+) acceptor, most commonly a hydroxide ion (OH^-).

3. What is the scale used to measure acidity? What value is considered to be neutral on this scale and how is this neutral value determined?

The scale used to measure acidity is known as the pH scale. The value 7.0 on this scale is considered to be neutral. This is determined by the fact that at 25 °C pure water has a concentration of H^+ ions equal to that of OH^- ions and has a value of 7.0 on the pH scale.

4. The pH value of a muscle cell under normal conditions is 7.1. This can drop to a pH value of 6.5 if extensive amounts of anaerobic glycolysis has taken place. If this happens would the muscle cell be experiencing acidic or alkaline conditions? (Explain your answer).

If the muscle cell pH value dropped to 6.5 on the scale the muscle cell would be experiencing acidic conditions. This is because any value under the neutral value of 7.0 on the pH scale is considered to be acidic.