Thousands of chemical reactions dictate all of the essential processes within the human body. Electrochemical gradients are responsible for the transmission of nerve impulses and muscle contractions, redox reactions allow the production of ATP, and maintenance of the correct pH is critical for optimal enzyme activity. Maintenance of a relatively stable internal environment for optimal metabolic function is therefore dependent on chemical processes being tightly controlled, much like an industrial setting trying to optimise chemical production. For this reason, the human body provides an excellent opportunity for students to identify the importance of chemical principles in a practical biological setting.

Each Activity has been designed to fit closely with the HSC syllabus points. Whilst there is some consideration given to application of these principles in the human body, the emphasis has been placed on the chemical process itself, with the human body just presenting a real world example. Students will conduct experiments relating to the pH of salt solutions, the role of buffer systems, and the importance of maintaining the correct fluid/electrolyte concentrations for the production of ATP through redox reactions. Students will use pH meters, pulse oximeters, universal indicators, and breath analysis equipment raising an opportunity to discuss the chemical reactions which are occurring on a cellular level.

<table>
<thead>
<tr>
<th>Ref</th>
<th>Students learn about</th>
<th>Science Comes to Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.2.4</td>
<td>Solve problems and analyse information to calculate the potential ($E^\circ$) of named electrochemical processes using tables of standard potentials and half-equations</td>
<td>Conduct a standard redox reaction, and recognise that adenosine triphosphate (ATP) production in the human body is underpinned by a number of processes</td>
</tr>
<tr>
<td>9.3.1</td>
<td>Perform first-hand investigations to use pH meters/probes and indicators to distinguish between acidic, basic and neutral substances</td>
<td>Identify acidic, basic and neutral salts in solution by the use of pH meters</td>
</tr>
<tr>
<td>9.3.2</td>
<td>Describe the solubility of carbon dioxide in water under various conditions as an equilibrium process and explain in terms of Le Chatelier’s principle</td>
<td>Use of bromothymol blue to identify the impact of exhaled air on the acidity of water</td>
</tr>
<tr>
<td>9.3.4</td>
<td>Perform a first-hand investigation to identify the pH of a range of salt solutions</td>
<td>Conduct pH and electrical conductivity testing to identify the importance of fluid/electrolyte balance in the human body</td>
</tr>
<tr>
<td>9.3.4</td>
<td>Qualitatively describe the effect of buffers with reference to a specific example in a natural system</td>
<td>Identify the hydrogen-carbonate buffer system in the human body, and identify its importance during times of increased respiratory demand</td>
</tr>
</tbody>
</table>

**Interesting fact**

Oxygen and carbon dioxide are constantly exchanged in the cells of the body, driving ATP production for muscle contraction. Measuring breath concentration gives exercise biochemists an indication of the chemical reactions which are occurring in cells of the body, in particular whether ATP production is occurring aerobically or anaerobically.
### Activity 1: Acid/base reactions in the human body

Acid-base balance is critical in the human body. Metabolic processes which produce adenosine tri-phosphate (ATP) often produce waste products causing an increase in the number of hydrogen ions in solution and cause the pH of cells and blood to fall. Activity 1 is designed set the scene for the following activities by visually demonstrating to students how metabolic waste products such as carbon dioxide and lactic acid (H+) impact upon the pH of the internal environment. A number of interactive demonstrations using universal pH indicators and acid/base reactions will emphasise the link between blood acidity and breath concentration, in particular to the role of the bicarbonate (HCO₃⁻)/carbonic acid (H₂CO₃) buffer in the natural system. Students will complete chemical equations to represent the observations they make, before reflecting on the following questions:

i) Why is it important that carbon dioxide be removed from the body?
ii) With reference to Le Chatelier’s principle, how would an increase in H+ contribute to breath concentration?
iii) What is the role of a buffer in the human body?
iv) What is the definition of an amphiprotic ion and give one example which is relevant to the human body?
v) Why does the rate of breathing increase during heavy exercise?
vi) Lactic acid is a weak acid produced in the body during high intensity exercise. How do you think lactic acid build up in the body will affect CO₂ concentration of the breath?

### Activity 2: Salts in solution and the human body

When in aqueous solution, salts dissociate into their ions thereby giving the solution the capacity to conduct electricity. Depending on the properties of the ions in solution, this may also influence the pH of the solution. Maintaining the correct balance of fluids and electrolytes is critical to many electrochemical processes in the body including nerve conduction, muscle contraction and ATP production. Activity 2 is designed to give students the opportunity to test a range of salt solutions for acidity/alkalinity, and electrical conductivity using a range of equipment including digital pH meters. They will develop a link between electrical conductivity and the capacity of the body to produce ATP through redox reactions, whilst also recognising the link that certain waste products have on blood pH. Students will be given the opportunity to discuss the following questions:

i) The acidic/basic nature of a range of salts, and how these may contribute to the pH of blood in the human body
ii) Why does sodium chloride show electrical conductivity when in aqueous solution?
iii) Why is electrical conductivity important in the human body and what is the importance of maintaining the correct fluid electrolyte concentration to electrochemical processes?
iv) What is the difference between a strong and a weak acid?

### Activity 3: REDOX reactions in the human body

Redox reactions are characterised by the transfer of an electron (or hydrogen ion) from one species to another. In the human body, redox reactions occur as a transfer of hydrogen ions (H⁺), and are critical in the process of ATP production. Every time a hydrogen atom leaves a compound, it does so with an electron attached. This exothermic reaction drives the production of a high energy compound called ATP, which can later be used to support muscle contractions. Activity 3 is designed to demonstrate to students how a common redox reaction (Cu²⁺/Cu / Fe / Fe²⁺) relates to the process in the human body which produces ATP, the energy currency for all cells. Students will complete half-cell equations to demonstrate the relevant reactions occurring, and consider how this translates to ATP production in the human body under electrolytic conditions. Using standard reduction potentials students will predict whether the reaction will occur spontaneously or non-spontaneously. Students will consider the answers to the following questions:

i) What process within the human body is underpinned by REDOX reactions?
ii) Given the importance of ATP production for muscle contraction in the human body, why is it critical that the body maintains the correct balance between fluids and electrolytes?

### Interesting Facts:

i) Altitude training has been shown to improve performance due to an improved blood buffering capacity, along with an increase in lactate exchange and removal. These all contribute to a stable blood pH, thereby promoting effective function of enzymes contributing to ATP production

ii) Sodium bi-carbonate and sodium citrate have been used to enhance athlete performance by improving buffering capacity of the blood against acidic conditions caused by lactate and carbon dioxide build up. An improvement in performance of 1-2% was demonstrated during a 30km cycling test, with the ingestion of bicarbonate prior
Activity 4: Breath concentration and ATP production

The oxygen and carbon dioxide used and produced in cells as a result of ATP production are inhaled and exhaled through the air that we breathe. For this reason, breath analysis is commonly used to reflect the processes occurring on a cellular level. The balance between oxygen uptake and carbon dioxide exhaled from the body is used to reflect whether ATP production is occurring aerobically or anaerobically. This is possible because a higher concentration of carbon dioxide is reflective of higher contributions from anaerobic pathways. Activity 4 allows students to monitor physiological markers such as heart rate, oxygen usage, oxygen saturation and carbon dioxide production before and after a brief bout of high-intensity exercise. Students will consider the impact of the exercise on blood pH, and consider how buffers contribute to production of carbon dioxide, whilst answering the following questions:

i) Why did oxygen usage increase during exercise? How can this be attributed to redox reactions occurring in the cells?

ii) How did the bicarbonate/carbonic acid buffer system contribute to carbon dioxide concentration of the breath?

iii) Why is blood pH important to the function of the human body?

iv) Given the increase in carbon dioxide concentration, what do you think was happening to the pH of blood at the end of the vertical jump testing? What might this be attributed to?

v) How might a change in blood pH have contributed to vertical jump performance towards the end of the testing?

vi) What is the role of oxygen in ATP production?

ANSWERS

Thousands of chemical reactions dictate the essential processes within the human body. With such a large number of reactions occurring, the maintenance of a stable internal environment is therefore dependent on chemical processes being tightly controlled. Your job is to conduct a number of experiments to reflect these chemical processes.

Interesting Fact:

Oxygen and carbon dioxide are constantly exchanged between cells in the body during ATP production. Measuring the concentration of breathe gives exercise biochemists an indication of the chemical reactions occurring in cells.

Activity 1: Indicators and Acid/Base Reactions in the Human body

Waste products such as CO₂ need to be removed from the body. Exhaling air from our lungs, into a water solution can be used to demonstrate the impact of metabolic waste products on pH within the human body.

Write your observations from the demonstration in the table provided:

<table>
<thead>
<tr>
<th>Solution</th>
<th>Observations</th>
<th>pH of solution</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure water (with Bromothymol Blue)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Addition of Hydrochloric Acid (HCl) to Bromothymol Blue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breathing into Bromothymol Blue solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breathing through Lime Water (No Indicator)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breathing Into Buffer Solution (With Indicator)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixing HCl with sodium bicarbonate buffer (NaHCO₃) through limewater</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
i) Which chemical process contributes to the production of carbon dioxide in the human body?
ATP production from glucose contributes to the production of carbon dioxide according to the reaction on page 1. In addition to this, the bicarbonate/carbonic acid buffer system also causes carbon dioxide to be exhaled in breath in order to stabilise blood pH levels.

ii) Why is it important that carbon dioxide be removed from the body?
If not removed from the body, carbon dioxide causes the pH of cells and blood to fall. This in turn has a negative impact on enzymes involved in all processes within the body, of particular importance relating to the production of ATP.

iii) By completing the chemical reaction, can you identify why carbon dioxide causes a fall in pH when in a water solution?

\[
\text{CO}_2 (g) + \text{H}_2\text{O} (l) \rightarrow \text{H}_2\text{CO}_3 (aq) \rightarrow \text{HCO}_3^- (aq) + \text{H}^+ (aq)
\]

iv) Le Chatelier’s principle states that if a system is at equilibrium and is disturbed by a change to the conditions, the system will tend to re-establish equilibrium by forming either more reactants or more products. In the above equation, how would the addition of more acid (H\(^+\)) affect CO\(_2\) production?

Addition of H\(^+\) would cause the reaction to be driven to the left, contributing to an increase in the production of CO\(_2\) (g) and H\(_2\)O (l). This demonstrates the role of the bicarbonate/carbonic acid system in the human body; i.e. increasing the concentration of H\(^+\) causes an increase in the carbon dioxide concentration of exhaled breath.

v) When added to bicarb soda (NaHCO\(_3\)), HCl caused a basic neutralisation reaction to occur. Can you complete the equation to represent this reaction, and recognise how the bicarbonate buffer system works to neutralise the acidic products of metabolic reactions in the body?

\[
\text{HCl(aq)} + \text{NaHCO}_3 (aq) \rightarrow \text{NaCl(aq)} + \text{H}_2\text{CO}_3 (aq) \rightarrow \text{H}_2\text{O}(l) + \text{CO}_2 (g)
\]

vi) What is the role of a buffer in the human body?
A buffer is a solution which resists the change to pH despite the addition of small amounts of acids or bases. Buffers are very important in the human body, with many metabolic activities producing acids or bases as waste products. Buffer systems in the human body allow the pH of blood to be maintained around a constant pH of 7.4 despite the addition of acids and bases from metabolic activities. If blood pH falls below 6.8, death may occur thus emphasising how important buffers are to the body.

vii) What are the two components of a buffer?
A buffer consists of a weak acid, and its conjugate base. An example of a buffer in the human body is the bicarbonate (HCO\(_3^-\))/ carbonic acid (H\(_2\)CO\(_3\)) system; in which the carbonic acid component is the acid, and the bicarbonate ion is the conjugate base. Addition of an acid is neutralised by the HCO\(_3^-\), whilst addition of a base is neutralised by the H\(_2\)CO\(_3\). There are multiple other buffer systems in the human body including the phosphate and the haemoglobin buffer.

viii) What is the definition of an amphiprotic ion and give one example which is relevant to the human body?
An amphiprotic substance is able to be an acid or a base by either donating or accepting a hydrogen ion. Both water and the bicarbonate ion (HCO\(_3^-\)) are examples of amphiprotic substances.

\[
\text{HCO}_3^- (aq) + \text{H}_2\text{O} (l) \rightarrow \text{H}_2\text{CO}_3 (aq) + \text{OH}^- (aq)
\]

OR

\[
\text{HCO}_3^- (aq) + \text{H}_2\text{O} (l) \rightarrow \text{CO}_3^{2-} (aq) + \text{H}_3\text{O}^+ (aq)
\]

ix) The bicarbonate (HCO\(_3^-\))/ carbonic acid (H\(_2\)CO\(_3\)) buffer system is critical to maintaining a relatively constant pH in the blood. What is an example of when H\(^+\) may increase in the human body?
Metabolic processes in the human body are more likely to produce acids as waste products. Two examples include the production of carbon dioxide, which forms weak carbonic acid when in aqueous solution, whilst lactic acid (2-hydroxypropanoic acid) also causes an increase in the concentration of H\(^+\) ions in the body. The most notable example of this occurring is during exercise, requiring ATP to be produced anaerobically. This is an incomplete chemical reaction, leading to the production of lactic acid and consequent reduction in pH of the internal environment.

x) How does the bicarbonate / carbonic acid buffer system respond to the addition of H\(^+\) ions in the body? Write an equation to demonstrate this reaction?

\[
\text{H}^+ (aq) + \text{HCO}_3^- (aq) \rightarrow \text{H}_2\text{CO}_3 (aq) \rightarrow \text{H}_2\text{O}(l) + \text{CO}_2 (g)
\]
xi) Why does the rate of breathing increase during heavy exercise?
Exercising muscles require an increase in the availability of ATP. As a result, more oxygen needs to be transported to the muscles and more carbon dioxide must also be removed in order to maintain pH at a constant level. The concentration of carbon dioxide also increases during high intensity exercise as a result of the bicarbonate buffer mechanism. Each of these contribute to an increase in the rate of breathing during exercise.

xii) Complete the equations to demonstrate how the bicarbonate/carbonic acid buffer system would respond under basic and acidic conditions?

Acidic: \( H^+(aq) + HCO_3^-(aq) \rightarrow H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(l) \)

Basic: \( H_2CO_3(aq) + OH^-(aq) \rightarrow HCO_3^-(aq) + H_2O(l) \)

xiii) Lactic acid is a weak acid produced in the body during high intensity exercise. How do you think lactic acid build up in the body will affect \( CO_2 \) concentration of the breath?

Lactic acid (2-hydroxypropanoic) is produced as a result of ATP production through anaerobic conditions. As an acid, it causes a fall in the pH of blood. When lactic acid increases in the blood, the bicarbonate buffer system will increase the production of carbon dioxide in order to remove "acid" from the body (remember that carbon dioxide in the blood causes acidic conditions). Therefore removal of carbon dioxide from blood will attempt to maintain blood pH at a stable level of 7.4.

Activity 2: Salts in Solution and the Human Body

In water, salts dissociate into their ions and give the solution electrical conductivity. Electrolyte solutions are critical to most processes within the human body.

Using the equipment provided, determine the pH and electrical conductivity of the solutions.

<table>
<thead>
<tr>
<th>Solution</th>
<th>pH</th>
<th>Light Performance (0-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1M NH4Cl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2M NH4Cl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1M NaCl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2M NaCl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1M Na2CO3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2M Na2CO3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

i) Using the information from the table, complete the equation to demonstrate the acidic/basic characteristics of ammonium (\( NH_4^+ \)) salts?

\( NH_4^+(aq) + H_2O(l) \rightarrow NH_3(aq) + H_3O^+(aq) \)

ii) Ammonia (\( NH_3 \)) is basic when in aqueous solution. Can you write an equation to demonstrate the basic nature of ammonia?

\( NH_3(aq) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq) \)

iii) Nitrogenous waste is produced from the breakdown of proteins in muscle, this process increasing during high intensity exercise due to mechanical breakdown of muscles. Ammonium ions (\( NH_4^+ \)) which are toxic in the human body combine with carbon dioxide to produce urea which is less toxic and can be stored in the kidney. Why is it important that ammonium ions (\( NH_4^+ \)) are removed from the body?

According to the above reaction, ammonium ions must be removed from the body because when in aqueous solution they dissociate into \( H^+ \) ions, resulting in the blood pH falling. This will in turn affect the capacity of enzymes to function correctly.

iv) Using the information from the table, complete the equation to demonstrate the acidic/basic characteristics of sodium carbonate (\( Na_2CO_3 \))?

\( CO_3^{2-}(aq) + H_2O(l) \rightarrow HCO_3^-(aq) + OH^-(aq) \)
v) Why does sodium chloride show neutral characteristics when in aqueous solution?
Sodium chloride is neutral when in solution due to the fact that Na\(^+\) and Cl\(^-\) ions do not hydrolyse with water.

vi) Why is electrical conductivity important in the human body?
Electrical conductivity is critical in a number of processes within the human body including nerve transmission, muscle contraction and also in the process of ATP production.

vii) What is the difference between a strong and a weak acid? Use the space provided to draw a diagram to represent the differences between the two (HA = acid; A\(^-\) = Conjugate base).

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Activity 3: REDOX Reactions in the Human Body

In the human body, every muscle contraction requires ATP. Redox reactions are responsible for the production of ATP, with oxygen being the terminal electron acceptor.

i) Oxidation is ________________ of electrons/or hydrogen; Reduction is ________________ of electrons/or hydrogen.

ii) What process within the human body is dependent on REDOX reactions?
ATP production in the human body is dependent on a number of redox reactions. This process, known as oxidative phosphorylation occurs via the transfer of electrons along the inner cell membrane. The final (terminal) electron acceptor is oxygen, emphasising the importance of oxygen in aerobic ATP production.

iii) Standard reduction potentials (E\(^0\) volts) give an indication of the tendency for one species to gain electrons. Reduction potentials of half cells can be added together to give an overall cell potential (E\(^0\) cell). Spontaneous reactions occur when E\(^0\) cell is positive. Use the table of Standard Reduction Potentials to identify whether a spontaneous reaction will occur between the following two species under electrolytic conditions:

\[
\begin{align*}
\text{Cu}^{2+} (aq) + 2e^- &\rightarrow \text{Cu}(s) \quad E^0 = 0.34 \text{ V} \\
\text{Fe} (s) &\rightarrow \text{Fe}^{2+} + 2e^- \quad E^0 = 0.44 \text{ V} \\
E^0 (\text{cell}) &= 0.78 \text{ V}
\end{align*}
\]

iv) The species with the most positive reduction potential has the greatest tendency to be reduced, therefore gaining electrons. Which of the above two species will be reduced, and which will be oxidised?
In the equations above, copper (Cu) had the highest reduction potential meaning that it had the greatest tendency to gain electrons and be reduced. Therefore we know that iron (Fe\(^{2+}\)) will be oxidised and lose electrons in the redox reaction. On the basis that iron will be oxidised, the E\(^0\) is reversed giving it a positive value of 0.44 V.

v) Will the reaction occur spontaneously?
Yes, due to the E\(^0\)(cell) being greater than zero.

vi) What did you observe when you placed the iron nail in the Copper Sulfate (CuSO\(_4\)) solution. Can you explain this in terms of the redox reaction taking place?
When placed in the solution, the surface of the iron nail took on a reddish-brown deposit which is copper, produced from the reduction of Cu\(^{2+}\) ions. If allowed to proceed for up to a couple of hours, the copper will continue to be displaced from the CuSO\(_4\) solution, and the iron takes its place in solution as Fe(SO\(_4\)) turning the solution to a green colour.

vii) Redox reactions in the human body occur in order to produce ATP for muscle contraction. This process occurs by way of a transfer of hydrogen ions between species. Understanding that each H\(^+\) contains one electron; can you identify the following as either oxidation or reduction?

\[
\begin{align*}
\text{NADH} &\rightarrow \text{NAD}^- + \text{H}^+ \quad \text{Oxidised} \\
\text{NAD}^- + \text{H}^+ &\rightarrow \text{NADH} \quad \text{Reduced}
\end{align*}
\]

viii) The overall reaction releasing energy for the production of ATP is:

\[
\text{O}_2 + 4\text{e}^- + 4\text{H}^+ \rightarrow 2 \text{H}_2\text{O}
\]
Oxygen is termed the "terminal electron acceptor". With this in mind, has oxygen been reduced or oxidised?

Reduced: \(\text{O} (0) + 2\text{e}^- \rightarrow \text{O} (2)\)
Activity 4: Breath Concentration and ATP Production

Oxygen is important for ATP production and the removal of carbon dioxide in breath is important to maintain the pH of blood within a small range. By monitoring breath concentration for oxygen and carbon dioxide content, biochemists can identify what is happening at the level of the cell.

Complete 15-25 vertical jumps consecutively, recording every fifth jump score and monitoring breath concentration throughout:

<table>
<thead>
<tr>
<th>Measure</th>
<th>BEFORE EXERCISE</th>
<th>AFTER EXERCISE</th>
<th>Jump #</th>
<th>Jump performance (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen % (Breath)</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Dioxide %</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breath</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart Rate (bpm)</td>
<td></td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen Saturation (Finger)</td>
<td></td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPE</td>
<td></td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

i) What happened to oxygen levels in breath during and after exercise? What is the role of oxygen in the redox reaction in producing ATP?

Oxygen levels in the breath decreased following the exercise, suggesting that oxygen was utilised in the body. Oxygen is taken from the breath into cells of the body in order to produce ATP allowing muscle contraction. Oxygen is reduced to water, in an exothermic reaction which drives the production of ATP.

\[ \text{O}_2 + 4e^- + 4H^+ \rightarrow 2 \text{H}_2\text{O} \]

ii) Carbon dioxide concentration of breath increased during exercise. What do you think was the role of the bicarbonate/carbonic acid buffer system in this observation?

Carbon dioxide concentration of breath during high-intensity exercise will rise as a result of the bicarbonate (HCO\(_3^-\)) buffer system trying to maintain blood and cell pH, despite the accumulation of metabolic products which would otherwise cause pH to fall.

iii) What is the pH of blood maintained at under normal circumstances?

Approximately 7.4,

iv) Why is blood pH important to the function of the human body?

Failure to maintain this correct pH contributes to enzymes becoming less effective in catalysing metabolic reactions.

v) Given the increase in carbon dioxide concentration, what do you think was happening to the pH of blood at the end of the vertical jump testing?

Increased production of carbon dioxide suggests that the pH of blood was falling below 7.4. On the basis that carbon dioxide is acidic in solution, the body's removal of carbon dioxide is essentially removing acid, consequently controlling blood pH.

vi) What do you think may have contributed to this change in pH?

Accumulation of lactic acid, produced as a result of anaerobic ATP production. Lactic acid causes a fall in blood pH.

vii) How might a change in blood pH have contributed to vertical jump performance towards the end of the testing?

Enzymes work best to catalyse reactions under specific conditions (temperature, pH and electrolyte concentration). When pH falls below optimal, the chemical reactions which produce ATP are less effective, thus may not keep up with the ATP demand of the exercising muscles. As a result, force production in muscles may decline and leads to performance also being negatively affected.

Interesting Fact:
When mixed with the bicarbonate ion (HCO\(_3^-\)), hydrogen ions (H\(^+\)) from the acetic acid cause the production of carbonic acid (H\(_2\)CO\(_3\)), before forming water (H\(_2\)O) and carbon dioxide (CO\(_2\)). This is the same mechanism allowing our bodies to remove hydrogen ions from our bodies by controlling the concentration of CO\(_2\) in our breath. If the concentration of hydrogen ions in our body increases, this drives the equation to the right causing a greater production of CO\(_2\) to occur, which can be identified in the air we breathe.

\[ \text{H}^+(aq) + \text{HCO}_3^-(aq) \rightarrow \text{H}_2\text{CO}_3(aq) \rightarrow \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
Glossary

**Adenosine triphosphate (ATP)** - the fuel source for all muscle contractions in the human body. ATP production is a typical example of a redox reaction, which occurs in cells.

ATP is produced in cells by the breakdown of food, in this case glucose (C₆H₁₂O₆) :

\[ \text{C}_6\text{H}_{12}\text{O}_6(s) \ + \ 6\text{O}_2(g) \ \rightarrow \ 6\text{CO}_2(g) \ + \ 6\text{H}_2\text{O}(l) \ + \ 34\text{ATP} \]

**Exercise** - as the intensity of exercise increases, the rate at which ATP must be produced from glucose also increases.

**Cells** - the body is made up of millions of cells each with a specific role. ATP production occurs in cells according to the chemical reaction above.

**Carbon dioxide (CO₂)** - produced during the production of ATP from glucose, must be removed from the body.

**Oxygen (O₂)** - important requirement for cells to produce ATP from glucose.

**Breath concentration** - by monitoring oxygen and CO₂ concentration we can gain insight into what is happening on a cellular level.

**Sports drinks** - contain glucose, electrolyte and water allowing athletes to perform for longer.

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