RS•C

Chemistry NOW

This is a series of four leaflets which present modern aspects of chemistry in a way accessible to school students and directly usable by teachers. Each leaflet consists of four pages of information interspersed with questions to test student's understanding of what they are reading, to help them to link what they have read to the chemistry they already know and to help them to understand the text.

The leaflets could be used to support existing workschemes, to develop comprehension skills or as meaningful exercises to be used in the case of teacher absences (planned or unplanned).

The leaflets are:

•Chemistry and sport

This is aimed at 14–16 year olds and deals with the chemistry of aerobic and anaerboic respiration in the context of athletics and looks at a number of ways in which athletes can manipulate (legally!) the chemistry of this process to their advantage by monitoring the concentration of lactic acid in their blood.

•Chemistry of the atmosphere

This is aimed at 14–16 year olds. This looks at the way that the Earth's present atmosphere has evolved from possible earlier atmospheres. Some of the available evidence for different scenarios is presented and critically discussed.

•Computational chemistry

This is aimed at the post-16 age group. It presents a case study of the development of derivatives of cinnamic acid as a repellent to dissuade birds from eating crops treated with it. It explains how chemists develop relationships between structural features and particular types of activity and how computer modelling programmes are used in this work.

•Combinatorial chemistry

This is also aimed at the post-16 age group. Combinatorial chemistry is a group of techniques for synthesising large arrays of related chemicals. These can be easily automated by the use of robot syringes controlled by computers to carry out repetitive processes. The resulting arrays of chemicals called 'libraries' can then be screened for potential drug activities. Combinatorial chemistry is increasingly being used by pharmaceutical companies in their search for new drugs.

Electron distribution of cinnamamide

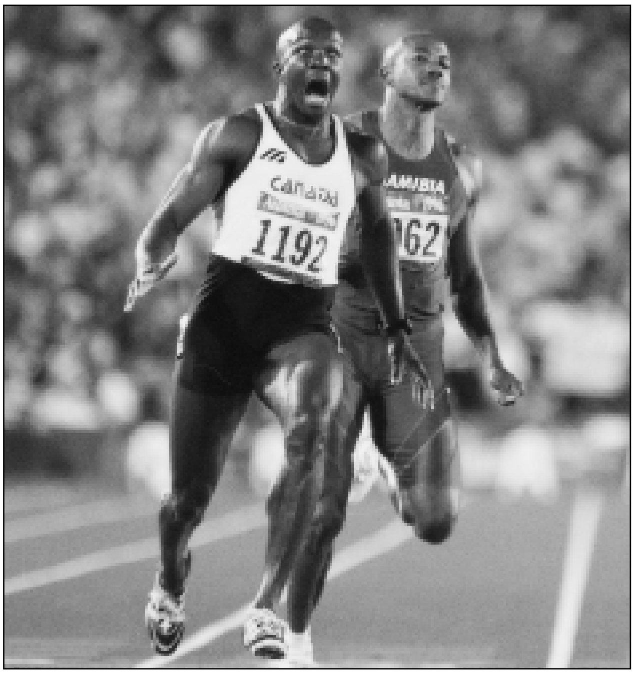
Answers

For the use of teachers, answers to the questions on the leaflets are presented overleaf.

Chemistry and sport

One of the most amazing things about athletics is how World records continue to tumble – performances keep getting better. For example, the World record for the 100 m sprint is 9.79 seconds set by Maurice Greene in June 1999, and the Olympic record – set by Donovan Bailey at the 1996 Olympic Games in Atlanta – is 9.84 seconds. This is over two seconds better than the time of 12 seconds run in the 1896 Games – an improvement of about 20 per cent.

Chemists have contributed to these improvements in a number of ways. For example, the design of improved materials for clothing and equipment – *eg* poles for vaulting, spikes for running and even the track itself. Chemists are also involved in devising and monitoring the best methods of training for particular sports.



▲ ***Donovan Bailey setting the 1996 Olympic100m sprint record***

One example of this is the development of a performance test called the blood lactate threshold which helps endurance athletes – such as marathon runners – to train and prepare for competition and even helps them monitor their performance during an event.

FASTER AND FASTER

Performances in athletics events have steadily improved over the past 100 years as exemplified by the winning times in the Olympic men's 100 m sprint finals.

1896	Thomas Burke (US)	12.0 s
1900	Francis Jarvis (US)	11.0 s
1904	Archie Hahn (US)	11.0 s
1906	Archie Hahn (US)	11.2 s
1908	Reginald Walker (S Africa)	10.8 s
1912	Ralph Craig (US)	10.8 s
1920	Charles Paddock (US)	10.8 s
1924	Harold Abrahams (UK)	10.6 s
1928	Percy Williams (Canada)	10.8 s
1932	Eddie Tolan (US)	10.38 s
1936	Jesse Owens (US)	10.3 s
1948	Harrison Dillard (US)	10.3 s
1952	Lindy Remigino (US)	10.79 s
1956	Bobby Morrow (US)	10.62 s
1960	Armin Hary (FRG*)	10.32 s
1964	Robert Hayes (US)	10.06 s
1968	James Hines (US)	9.95 s
1972	Valeriy Borzov (USSR)	10.14 s
1976	Hasely Crawford (Trinidad)	10.06 s
1980	Allan Wells (UK)	10.25 s
1984	Carl Lewis (US)	9.99 s
1988	Carl Lewis (US)	9.92 s
1992	Linford Christie (UK)	9.96 s
1996	Donovan Bailey (Canada)	9.84 s

** FGR stands for the former Federal Republic of Germany.*

Of course this list will soon be out of date. The internet is a good place to check up on changing information and one place to start with athletics records is

http://www.hkkk.fi/~niininen/athl.html

Q1. What other factors will affect athletic improvement as well as biochemical ones

Q2. Why is there not a steady increase in performance year on year?

Q3. Try plotting a graph of the winning Olympic times against the year.

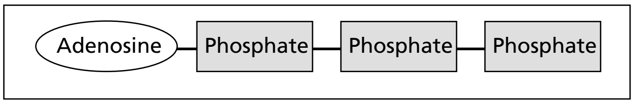
Q4. Suggest why some of the times are recorded to one decimal place and others to two.

• The muscles' energy systems

To understand the blood lactate test, we need to know something about the chemistry of how our bodies convert the chemical energy in our foods into mechanical energy, which makes our muscles contract.

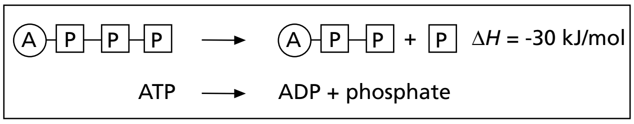
The energy required for muscle contraction comes from a molecule called adenosine triphosphate (ATP, *Fig 1*).

In ATP, an organic (carbon-based) group called adenosine is attached to three



▲ *Figure 1 An ATP molecule*

phosphate groups. The phosphate groups are involved in the energy storage. The loss of one of the phosphate groups produces adenosine diphosphate (ADP) and gives out 30 kJ/mol of energy (*Fig 2*). This reaction



▲ *Figure 2 The loss of a phosphate group from ATP*

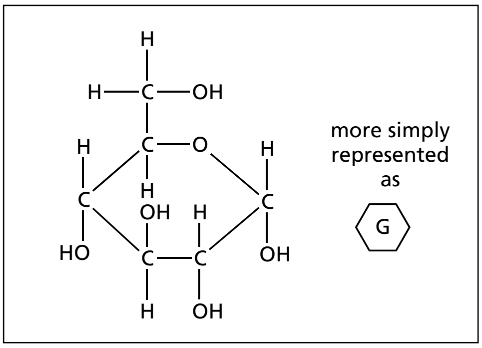
supplies the energy used to make our muscles contract. Surprisingly, we have only a relatively small amount of ATP in our muscles at any one time – even Olympic sprinters have enough for only two or three seconds of effort. So how can a sprinter complete a 10 second 100 m race, never mind a marathon runner keep going for over two hours?

The answer is that ATP is regenerated. The above reaction (*Fig 2*) is reversible and phosphate is re-attached to ADP to make ATP. This requires an input of 30 kJ/mol of energy. The energy for this comes from the breakdown of food molecules – carbohydrates (such as glucose, *Fig 3*), fats and proteins. The primary source is carbohydrates. These molecules store a great deal of energy (a mole of glucose (180 g) can release about 3000 kJ when reacted with oxygen). Our bodies release this energy gradually via the ATP/ADP cycle.

Q 5 a) What word is used to describe a reaction in which energy is; (i) given out; and (ii) taken in?

b) Figure 4 shows an energy level diagram for the formation of ADP and phosphate from ATP. Draw an energy level diagram for the regeneration of ATP from ADP and phosphate

Figure 3 A glucose molecule ▶



Q 6 a) How many molecules of ATP could be regenerated by one molecule of glucose if the process were 100 per cent efficient?

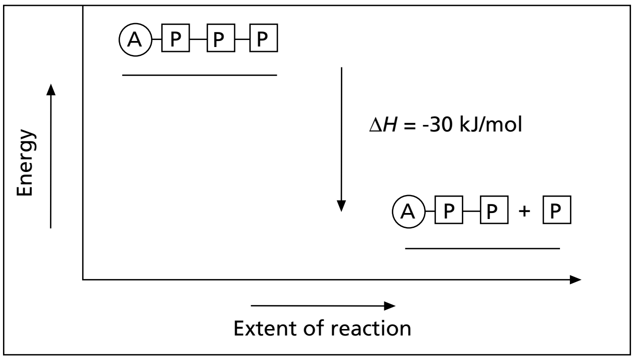
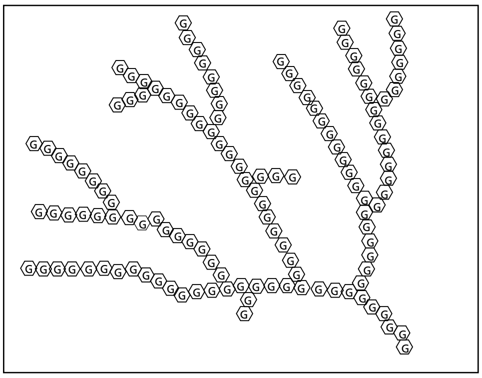


Figure 4 Energy Level Diagram ▲

b) In fact the process is only 40 per cent efficient. How many ATP molecules are actually regenerated by one molecule of glucose?

Glucose is stored in the muscles as a carbohydrate called glycogen, which consists of many glucose molecules linked together (*Fig 5*). Some endurance athletes make sure that they have a good supply of glycogen for an event by 'carbohydrate loading'. They eat a lot of carbohydrate (rice, pasta, bread, potatoes *etc*) for a few days before an event.



◀ *Figure 5 Part of a glycogen molecule*

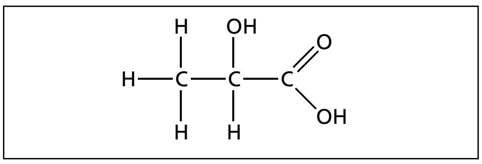
Our bodies have two ways of releasing the energy in glucose molecules – both processes are called respiration.

The first is called aerobic – 'with air' – respiration and uses oxygen to 'burn' the glucose to carbon dioxide and water

glucose + oxygen → carbon dioxide + water
ΔH = - 3000 kJ/mol

Q 7 Write the balanced symbol equation for the aerobic respiration of glucose, $C_6H_{12}O_6$.

The second is called anaerobic ('without air') respiration and involves splitting a glucose molecule into two molecules of lactic acid (*Fig 6*).

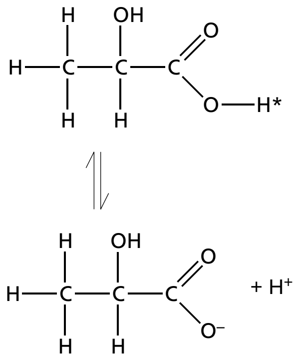


◀ *Figure 6 Lactic acid molecule*

LACTIC ACID AND LACTATE IONS

The chemical properties which we call 'acidity' (sour taste, effect on indicators, reactions with metals, carbonates hydroxides and oxides) are all caused by the $H^+(aq)$ ion. This is a hydrogen atom which has lost its electron so that it consists of just a proton. The substances we call acids dissociate (split up) to release this ion. In lactic acid, just one of the hydrogen atoms, the one marked * can be released to form a $H^+(aq)$ ion and a lactate ion.

In the body, lactic acid exists as both the acid itself and the lactate ion. For simplicity we will refer to them both as lactic acid.



Not all the molecules in a solution of lactic acid split up in this way – in fact only about four in every 100 split up in a dilute solution. Acids in which only a small percentage of the molecules are dissociated are called **weak acids**. This is in contrast with **strong acids** where all of the molecules in a solution are split up to release $H^+(aq)$. A good example is hydrochloric acid; in a solution of this acid, no H-Cl molecules remain undissociated.

Anaerobic respiration releases less energy than aerobic respiration.

Glucose → lactic acid ΔH = - 150 kJ/mol

Q 8 Glucose has the molecular formula $C_6H_{12}O_6$. What is the molecular formula of lactic acid? What other product is there (if any) of the anaerobic respiration of glucose?

Aerobic respiration is our main source of energy supply. It relies on a continuous supply of oxygen being provided through the bloodstream. In short-term, high-intensity activities, such as sprinting – 'oxygen debt' activities – the bloodstream cannot supply oxygen fast enough for aerobic respiration, and the body resorts to anaerobic respiration as well. Lactic acid builds up in the muscles which may be a factor in fatigue. It then takes around 30–40 mins for the lactic acid to be cleared from the body after a period of high intensity exercise.

Some athletes attempt to delay the onset of fatigue caused by lactic acid by so-called 'bicarb loading'. Before an event, they take large quantities of sodium hydrogencarbonate ($NaHCO_3$), also called bicarbonate of soda or sodium bicarbonate. This is a base. It makes the blood more alkaline and reacts with the lactic acid, clearing it from the muscles faster. Some beneficial effects have been reported, but the side effects of this practice (which is quite legal) include diarrhoea, stomach cramps, bloating and nausea - not the best conditions in which to do competitive sport!

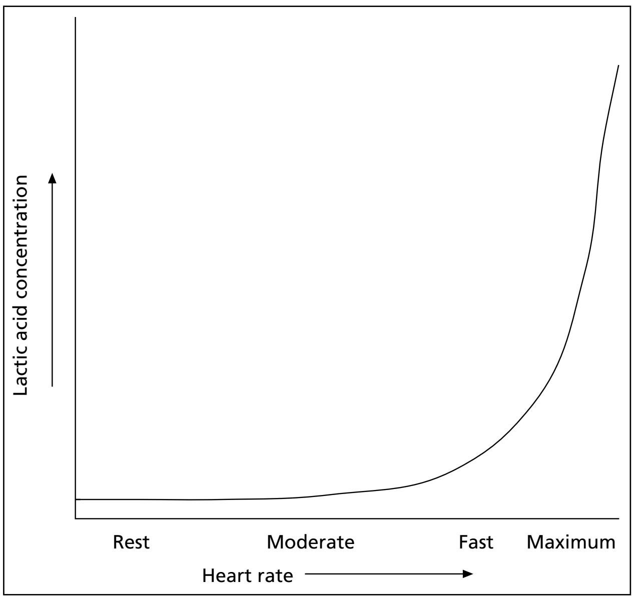
Q 9 Hydrogencarbonates and carbonates react in a similar way with acids. What gas might cause the bloated feeling in 'bicarb loading' when sodium hydrogencarbonate reacts with lactic acid?

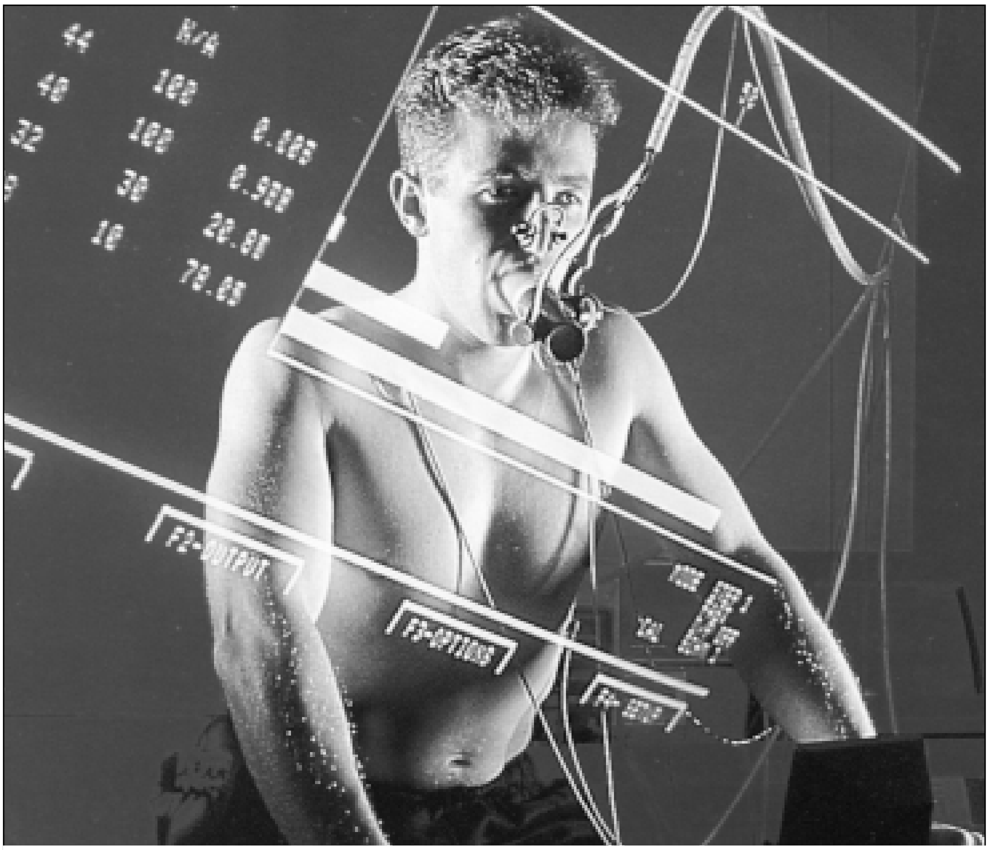
• The blood lactate threshhold

The lactic acid concentration in the blood can be measured using a test strip – rather like indicator paper – and a blood sample of no more than a single drop. The normal level of lactic acid in the blood is between 0.0045–0.09 g/dm^3 but this can rise to as much as 2.25 g/dm^3 after high intensity exercise such as a 400 m sprint.

Figure 7 shows a graph of lactic acid concentration in the blood against heart rate – a measure of the intensity of exercise. The **blood lactate threshold** is the heart rate at which lactic acid begins to build up in the

Figure 7* *Blood lactic acid concentration





Measuring oxygen intake

blood. It is therefore the point at which anaerobic respiration kicks in. For endurance athletes, such as long distance runners, this threshhold is very important. They rely on aerobic energy production to maintain their ATP level for long periods of time. If lactic acid builds up, they have moved into anaerobic energy production which can continue only for a short time. They must keep their heart rate (and therefore their exercise intensity) below this threshhold to maintain their activity for a long period of time. If athletes know their blood lactate threshholds, they can keep their heart rates below them during an event. Many athletes monitor their heart rates during training and competition to do just this.

Suitable training can increase the blood lactate threshhold – an untrained person's threshhold is around 65 per cent of their maximum heart rate while a trained endurance athlete can achieve up to 90 per cent of their maximum heart rate.

Q10 On a copy of Fig 7; (a) mark the blood lactate threshold; and (b) sketch the graph you would expect for a trained endurance athlete.

At the moment, athletes can only measure their heart rate – not their lactic acid level – during competition. However, on-line sensors that measure lactic acid concentration in the blood directly may soon be available. These will probably work by shining a beam of infrared radiation through the skin and through blood in the blood vessels. The radiation will be of a wavelength that is absorbed by lactic acid. The less intense the beam when it emerges, the more lactic acid there is in the blood. Such sensors might look like wrist watches. Sensors are currently being developed to measure blood glucose levels in people with diabetes, and lactic acid sensors will use similar technology.

Q 11 What is the advantage of measuring blood lactic acid levels during the race with an infra-red sensor? Are there any possible objections to this?

•Acknowledgements

This article is adapted by Ted Lister, with permission, from Mark Holmes, *On track to the Olympic games: Chemistry Giving the Winning Edge* in Australian chemistry Resource Book, Charles L. Fogliani (ed), p. 226. Queensland: Royal Australian Chemical Institute, 1998.

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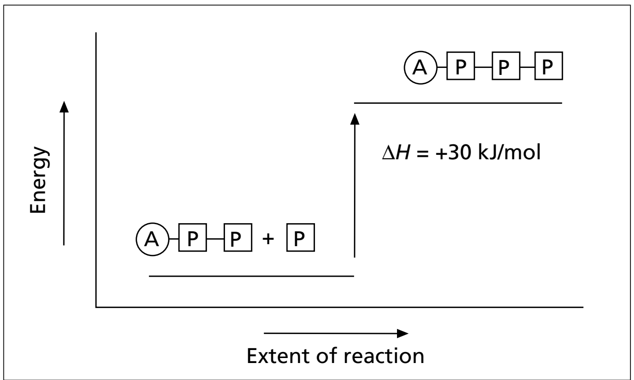
Answers...

•Chemistry and sport

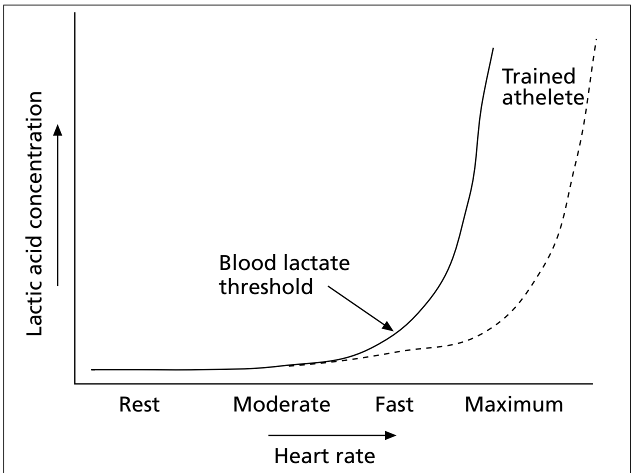
1. **Many factors including weather, health of competitors, psychological state of competitors, equipment.**
2. **Some of the above factors vary from competition to competition plus natural variation amongst competitors.**
3. **Graph plotted by students.**
4. **Improvement in timing methods from hand-operated stop-watches to electronic methods brings about greater accuracy.**
5. **a) (i) exothermic, (ii) endothermic**

   b)



6. **a) 100**

   b) 40
7. **$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_20$**
8. **$C_3H_6O_3$. None – all the atoms are accounted for.**
9. **Carbon dioxide.**
10. **Note:**
    The blood lacatate threshold is a heart rate not a lactic acid concentration.



11. **Athletes will be able to respond faster to the information they get. Some athletes may not be able to afford the sensors and could be put at a disadvantage. Some might think that such reliance on technology is 'not sporting'.**

Note for teachers

Lactic acid is, of course, a weak acid and at the pHs of blood and muscle it exists predominantly as lactate ions. It has not been thought appropriate to stress this point in an article aimed principally at pre-16 students. Teachers using the article with older students might wish to refer to this.

•Chemistry of the atmosphere

1. a) 32, 28, 44;

b) 8, 7, 11

2. **There is more oxygen and nitrogen and less carbon dioxide and water vapour in the modern atmosphere.**
3. **Fossils are the remains of once-living creatures preserved in rocks. Certain fossils are associated with certain eras.**

4. a) Rust

b) $4FeO + O_2 \longrightarrow 2Fe_2O_3$

5. **Lightning might have ignited them - especially in the high level of oxygen present at the time.**
6. **The carbon was originally in the atmosphere as carbon dioxide and was converted into carbohydrate by photosynthesis and later into coal or oil.**
7. **Add acid and test any gas given off with limewater (aqueous calcium hydroxide). If a carbonate is present, carbon dioxide will be given off which will turn limewater milky.**