SCIENCE OF CYCLING

MWBM Leensen

8th edition, september 2013

Photo's front and back cover by M.Leensen:

Front cover photo: Prologue Olympia's tour 2004, unknown Rabobank cyclist

Back Cover photo:Dutch cyclist Bauke Mollema during the prologue of the Giro d'Italia 2010

Science Syllabus

SCIENCE OF CYCLING

Ing MWBM Leensen MEd

This is the 8th edition of 'Science of Cycling'

The first edition was released in February 2006

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CHAPTER 1 THE HUMAN METABOLISM

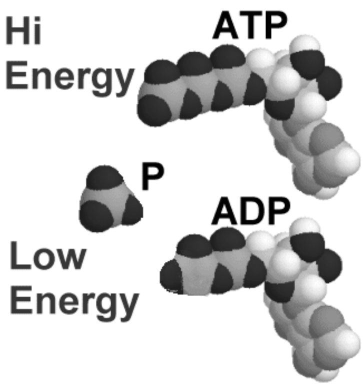
1.1 Why does an athlete train ?

The human body needs energy to 'work'. To get that energy the body has to burn 'fuel' just like a motor in a car burns fuel. And just as cars can use petrol, gas or diesel, the human body has a choice of a couple of different energy production systems. The combination of all energy production systems inside the human body is called the **human metabolism**. In this chapter we will investigate all those different energy production systems in detail.

You will also discover that the different energy production systems in our body all serve a different function. An athlete wants to develop the energy production system(s) that he needs most for his type of sport. When an athlete is training the wrong energy he will not be able to perform the best he can at his sport. That's why a 100 meter sprint training session looks very different from a marathon training session.

1.2 ATP, the basis of the human metabolism

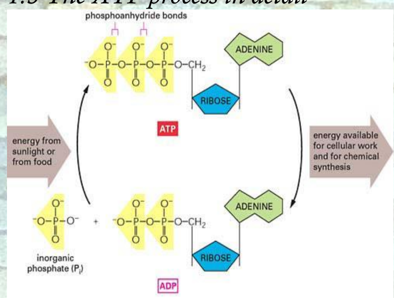
In the human body, one chemical compound, and one compound alone, plays the leading role in our metabolism. This fact is not restricted to the human body, all living creatures on earth use this molecule in their energy systems. This compound is called Adenosine TriPhosphate or **ATP**. The human body needs ATP to power all its physiological processes, for instance the contraction of a muscle cell. Each and every cell in our body needs and uses countless of these ATP molecules every second. And when we are exercising, our ATP demand will increase accordingly.



ATP can be compared with a rechargeable battery. It can store and transport energy inside the body. ATP has the ability to break apart. Breakdown of ATP will create Adenosine DiPhosphate (ADP) and **energy**. This is done by a simple process, in which one of the phosphate parts (also called Pi) is broken off from the ATP molecule, thus reducing the ATP from 3 phosphates to 2, forming ADP . This is commonly written as ADP + Pi. When the bond connecting the phosphate is broken, energy is released.
To keep the system rolling, ADP can be built back up into ATP so that it can be used again and again. To make continuous exercise possible, ATP must be re-synthesised at the same rate as it is utilised. The better your body is able to re-synthesise its ATP, the better trained you are.

1.1 Marathon (↑) and
1.2 100 meter dash (↓)

1.3 The ATP process in detail



Energy and Work
The physical quantity **energy (E)** comes with the unit **J** or Joule**).** One would need 4200 J or 4,2 KJ to heat up 1 litre of water 1˚C.
Also the old unit of **calorie (cal)** is still used, 1 cal = 4,2 J
The quantity **Work (W)** is merely a form of energy and thus has also the unit of Joule. In mechanics the definition of work can be simplified by saying that work is the energy that is used to bring or keep an object in motion.

The chemical equation of this process looks like this:

$$ATP \rightleftarrows ADP + Pi + \textit{energy}$$

Eq.1.1

To make ATP out of ADP one also has to add energy, as can be seen in the equation. But where does that energy comes from?

1.3 Glucose, the energy source of our body

So now that we know we need ATP to use our muscles, and that energy is needed to build up ATP from ADP and Pi, where do we find that energy? Glucose, a sugar that is delivered through the bloodstream, is one of the main ingredients of the food you eat, and glucose is also the molecule that delivers the energy to create ATP out of ADP. This process is called **respiration**. This respiration can occur in two ways in the human body. Aerobic or anaerobic, which means with or without oxygen. Depending on the nature of the activity that is needed, the body chooses from (a combination of) one of the two modes of respiration. Of course you don't go from the anaerobic pathway to the aerobic pathway at once; this is a gradual process. Most sports activities force the human body to use anaerobic as well as aerobic respiration. As an example take a look at the results of measurements on the tracking field (athletics).

Distance/Event	W.R.	% Aerobic	%Anaerobic
200 metres	19,32 s	5	95
400 metres	43,18 s	17	83
800 metres	1:41,11	34	66
1500 metres	3:26,00	55	45
5000 metres	12:37,35	80	20
10,000 metres	26:17,53	90	10
Marathon	2:04:55	98	2

Table 1.1 Aerobic/anaerobic ratio

1.4 Aerobic respiration

Aerobic means 'with oxygen'. Someone with an high **aerobic endurance** is able to generate a lot of energy through aerobic respiration. A sound basis of aerobic endurance is fundamental for almost all sporting events. But what does this mean?
During aerobic respiration the body is working at a level at which the demands for oxygen and fuel can be met by the body. This means that the cells of the body receive enough oxygen and fuel to do their work properly. In the cell a reaction takes place in which glucose reacts with oxygen, thus generating energy. The only waste products formed are carbon dioxide and water.

ATP store
The total amount of ATP at any time in your body is a meagre 50 g. On a per-hour basis, 1 kilogram of ATP is created, processed and then recycled in the average human body.

Classics: The Monuments
Milano-San Remo
Also known as 'La Primavera', the tension of this classic culminates on the last hill, 'il Poggio', less than 10 km from the finish.
To win here, the rider has to have intelligence, patience and a lot of explosive power in his legs. After a steep decline this race often ends in a sprint.

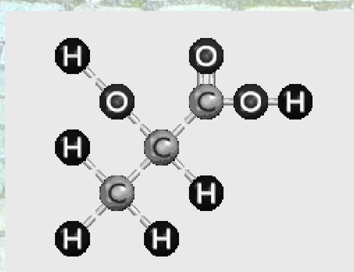
1.4 Milano-San Remo 2012

Definition of Work
Work on an object is defined as :

$$W = F \cdot s \cdot \cos\alpha$$

Where *F* is the net force on the object (in Newton), and *s* is the displacement of the object, in metres.
The angle α is the angle between the directions of force and movement.

1.5 The lactic acid molecule



Written in a chemical equation it reads as follows:

Glucose + oxygen ⟶ carbon dioxide + water

or

$$C_6H_{12}O_6 + ..O_2 \longrightarrow .. CO_2 + .. H_2O$$

Eq. 1.2

There is a maximum to the aerobic power that can be achieved. This level is called the **anaerobic threshold**. If the body needs an even higher energy output, it has to rely heavily on anaerobic respiration.

1.5 Anaerobic respiration

Anaerobic means 'without oxygen'. During anaerobic work the body is working so hard that the demands for oxygen exceed the rate of supply and the muscles have to use another energy process to get their energy demands fulfilled. Now they will have to obtain energy without the use of oxygen. Again, glucose is the fuel. During this process waste products accumulate inside the muscles, the main one being lactic acid. Anaerobic respiration is far less efficient than aerobic respiration. Or, per unit of glucose (for instance 1 gram), anaerobic respiration yields far less energy.
The anaerobic respiration equation looks like this:

Glucose ⟶ lactic acid

Or

………… ⟶ … ………………

Eq. 1.3

As the concentration of lactic acid in your muscle cells increases, you can feel your muscles 'burn' more and more. The muscles, being depleted of oxygen, take the body into a state known as oxygen debt. The body's stored fuel soon runs out, the muscles start cramping due to the high acidity level and at the end activity ceases completely, and painfully. Activity will not be resumed until the lactic acid is removed again and the oxygen debt is gone. Fortunately the body can resume limited activity after even only a small proportion of the oxygen debt has been repaid.

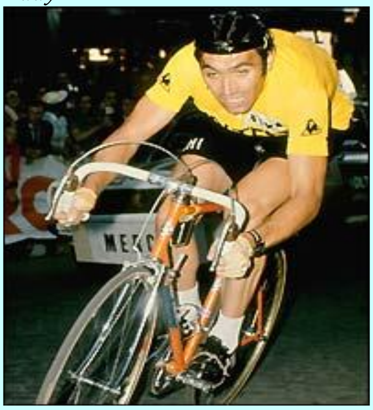
1.6 The anaerobic and aerobic respiration in detail

When we look closer at the anaerobic respiration we can discern three important chemical compounds which all are connected with each other during the process. Each of them plays a part in the anaerobic respiration. Let's see what happens when an athlete starts sprinting at full power:

1 ATP - Adenosine Triphosphate : Only from the energy released by the breakdown of this compound can the cells carry out their work. The breakdown of ATP produces energy and ADP. If no new ATP is formed, the muscles can work up to two seconds before all available ATP is used.

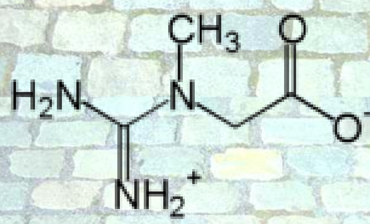
Belgian **Eddy Merckx**, also called 'the cannibal', was an athlete with a very high aerobic endurance. He has won 525 professional races in his career. His world hour record from 1972 was broken only in 2000.

1.6 One of many yellow jerseys of Eddy



1.7 Aerobic or anaerobic respiration?

1.8The ATP molecule



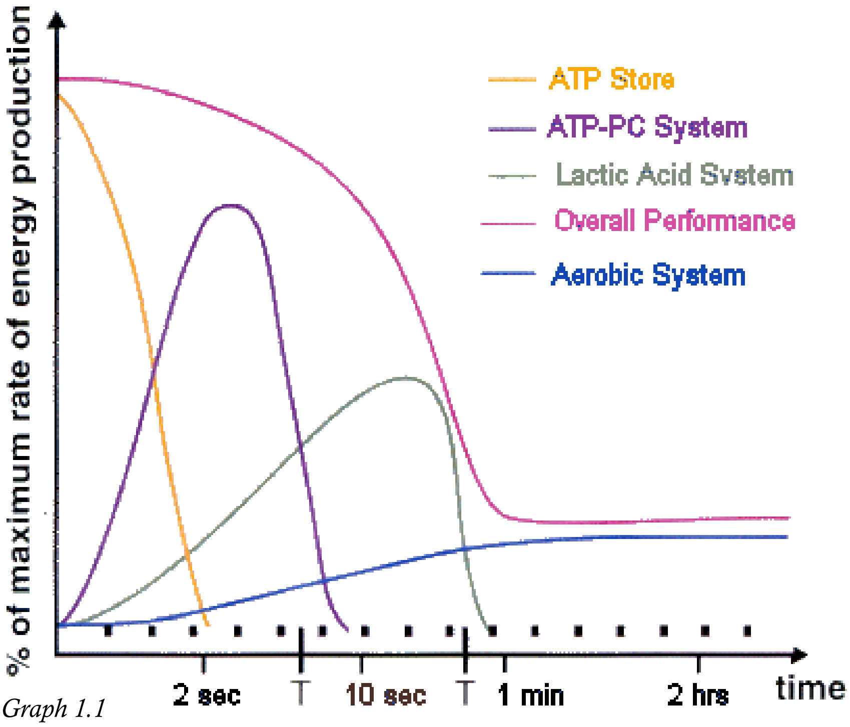
2 PC - Phosphate-creatine : creatine is a chemical compound stored in muscle tissue, which functions as an energy buffer and it transports the energy from the glucose to the ATP cycle. The combination of ADP and PC produces ATP (and C).

$$ADP + PC \rightleftharpoons ATP + C$$

Eq. 1.4

Without PC in your body, ATP could not be formed from ADP and ATP depletion could not be replenished. The PC cycle alone is capable of delivering energy for no more than 10 seconds at most. After that all PC is used and extra energy has to be found in the anaerobic respiration of glucose.

3 LA - Lactic acid : a fatiguing metabolite of the lactic acid system resulting from the incomplete breakdown of glucose. This process of anaerobic respiration can sustain its energy output for one minute at the most.

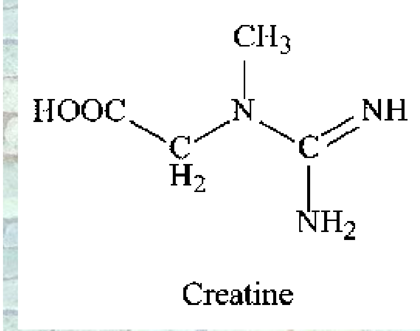


Graph 1.1

After one minute of peak intensity the human body has run out of all sources of extra (anaerobic) energy. What is left is the aerobic respiration system in which ATP is manufactured from food, mainly sugar and fat. During the aerobic activity the human body is able to recover from the peak intensity. The lactic acids will be removed from the muscle cells, and PC and ATP levels in the cells increase to normal levels again. After some time the human body will be able to perform at peak intensity again.

Let us take a closer look at the aerobic respiratory system now. The main energy supplier is the food (and drinks) that we consume daily.

1.9 Creatine molecule



1.10 Creatine, a popular (and allowed!) food supplement for many athletes

Tour de France and food

On a normal Tour de France day, a cyclist burns around 6500 KJ of energy in his body, during a mountain-stage this can go up to 10.000KJ, 5x more than the average human!

That means for all cyclists that they have to eat the whole day through. It starts with a heavy breakfast , with a lot of pasta, cornflakes, beef, bread and other carbohydrates. During the race cakes, sandwiches, bananas, approx. 5 power bars and 5 (liquid) power gels are consumed. Add to that the drinks that are consumed during the race, on a hot day up to 8 liters!

Immediately after the finish a snack, a drink with carbohydrates (coca-cola!) and at dinner again pasta, beef, ham, vegetables, yoghurt, fruit and a slice of cake.

The food is processed in the stomach and intestines. Proteins are first reduced to glucose. Glucose can enter the body and can be transported via the blood to every cell in the human body. After a meal, most of the glucose from the food is stored inside the body in the form of **glycogen**, in muscle cells, and for a large part in the liver. The glycogen reserves act as a temporary storage of the glucose and ensures that we can maintain a constant level of glucose concentration in our blood. Also when dinner happened a few hours ago.

The amount of glucose and glycogen that the body can store is restricted. A well trained athlete can perform at a high level for approx. 90 minutes before the glucose reserves in his body are depleted. If he doesn't eat in that period he will experience a phenomenon referred to as "hitting the wall" or "the man with the hammer". In that case the human body falls back on her last and ultimate energy-producing system, in which **fatty acids** (and in a lesser degree proteins) are used as the energy source, instead of glucose/glycogen. The main drawback of using fatty acids is that this process runs much slower than when using glucose. Thus, the body is not able anymore to maintain a high level performance, which is of course bad news for any athlete. On the other side, this energy source is almost limitless, the stored body fat can supply the human body energy for several days.

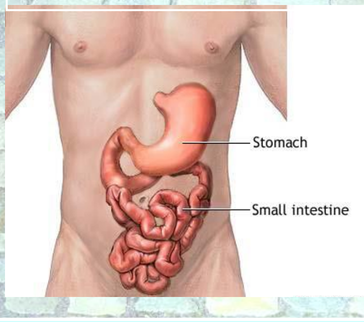
Because of the almost unlimited resources, the human body prefers to burn fatty acids instead of glucose whenever possible. When you are in rest (sitting in a chair for instance) or when you cycle, swim, row or run with a modest intensity, fat provides most of the energy you need to keep on going. Only when the energy-demand increases and the fatty acids cannot generate enough energy, the body will increasingly turn towards glucose as the main source of energy. This threshold point between both ways of aerobic respiration lies around 60-65% of the maximum heart rate (although the change is gradual of course.

As a short summary all the energy systems of the human body are listed in the table below, together with the amount of time that this energy source can deliver a high output of energy when there would not be any refreshing. These durations can be altered, preferably elongated, by specific training. Each different sport aims at a (combination of) different energy source(s). Also important not to forget is that these values are, to a large degree, genetically dependant. A good sprinter is for a large part born as a sprinter!

Type	Energy source	Maximum duration
anaerobic	Stored ATP	1 – 2 s
	ATP-PC system	5 – 10 s
	Lactic acid system	1 min
aerobic	Aerobic, glucose	60 – 90 min
	Aerobic, fatty acid	Several days

Table 1.2 Energy sources and their maximum duration

1.11 Human intestines



Glycogen and diabetes
Under influence of the hormone insulin the human body can form glucose into glycogen and store the latter substance in liver and muscles. People who are having difficulties with this process, due to the absence of insulin in their body, are said to have diabetes. There are a couple of types of diabetes. A lot of times successful treatment consists of the administering of synthetic insulin, with which it is possible for the patient to control the glucose concentration in their blood

World Championships
High on the agenda of the ambitious cyclists are the World Championships, traditionally at the end of the year.
Winning this race earns you a lot of prestige, and the right to wear the jersey of the world champion for a year.

Amount of energy per g

Fatty acids	39 KJ
Glucose:	
aerobic	17 KJ
anaerobic	0,94 KJ
Protein	17 KJ

Questions Chapter 1

1.1 Look at the different sports below. Which of the two types of endurances (anaerobic/aerobic) do you need (most) when you are doing:


A. Wrestling


B. Skiing


C. Luge

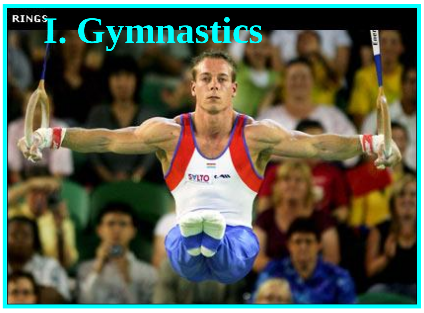

D. Javelin


E. Tennis


F. Tug of war


G. Football


H. Triathlon



I. Gymnastics

1.2 A top male cyclist can generate up to 500 J/s when he is exercising at full aerobic power.

a. How many grams of glucose will this athlete have to use per hour?

In reality you will need to burn more glucose, not all the energy that is released can be used for moving your body. Some energy, for instance, will be lost in the form of heat. The efficiency of the human body is around 20%.

b. How many grams of glucose will this top athlete have to eat each hour to compensate for the amount of glucose that he is using?

1.3 Look at Eq. 1.2. In this equation the oxidation of glucose is depicted. Of course, atoms are not wasted during this process. Before and after the reaction the total amount of atoms of each sort must be equal. Complete the equation by filling in the right numbers on the empty spaces.

Human Efficiency (η)

The efficiency of human muscle has been measured (in the context of rowing and cycling) at 14% to 27%. The efficiency is defined as the ratio of mechanical work output (W_{out}) to the total metabolic cost (Q_{in})

$$\eta = \frac{W_{out}}{Q_{in}}$$

1.4 Look carefully at picture 1.5 of a lactic acid molecule.

a. What is the molecular notation of lactic acid? (Write it down in the form of $C_?H_?O_?$)

b. Complete the anaerobic reaction process in Eq. 1.3.

1.5 Anaerobic burning of glucose leads to lactic acid build up in your muscles. But anaerobic burning has a second disadvantage when comparing it to aerobic burning. Look at table 1.3.

a. What is this second disadvantage?

b. Compare the amounts of energy that can be extracted out of one gram of glucose in both ways of burning. When aerobic burning of glucose would give you 100% of energy, what percentage can be attained through anaerobic burning?

1.6 When you start exercising, it takes some time (1 á 2 minutes) for your aerobic respiration to start up completely. Look at the pictures on the right. Here you see that, before a time trial, professional cyclists first exercise hard on the home trainer. Can you explain why?

1.7 During some of the longer stages of the Tour de France, a cyclist can use up to 10.000 KJ each day. Look at the information of some different foods in the info column, and calculate: how many energy bars would the cyclist have to eat, when energy bars were the only food that he could eat? And how many slices of bread, bananas and plates of spaghetti? (1 plate of cooked spaghetti is 250 g)

***1.8** In graph 1.1 are shown 4 of the 5 different types of energy sources of the human body. Take a second look at the sports of question 1.1. Which of the four energy systems is most important in each of the sports. Also explain your answers. Will these athletes also have to eat during their exercises?

***1.9** In laboratories scientists have been able to 'make' genetic modified mice. These mice cannot make PC (phosphate-creatine) in their bodies. When these mice are placed in a tread-mill how will their performances be, when comparing them with those of normal mice?

***1.10** Some athletes take extra Creatine (C), in the form of a white powder, to enhance their level of performance. How would an extra intake of Creatine lead to a better performance?

(↑)
1.12 Pre-competition exercise, Vincenzo Nibali

1.13 Time trial Fabian Cancellara

High-energy foods

Food	**weight**	**Energy**
Banana	115 g	441 KJ
Energy bar	60 g	877 KJ
Spaghetti	148 g	873 KJ
Slice of bread	25 g	272 KJ

CHAPTER 2 THE CARDIO-VASCULAR SYSTEM

2.1 An overview of the cardio vascular system

In the last chapter we looked closely at the human metabolism. Or, in plain language, we answered the question: how do we get our energy?
The human body obtains its energy mainly by the aerobic respiration of glucose in our cells. This process takes place in almost all of our body cells, in a specific **organelle** named the **mitochondrion**. Most cells have mitochondria, but due to their large energy demand, muscle cells are packed with mitochondria.
To be able to perform optimally, the muscle cells are characterized by a high demand of glucose and oxygen. Also waste products as carbon dioxide (aerobic) and lactic acid (anaerobic) have to be removed quickly. Our blood is able to do all these three tasks (and many more!):

- The red blood cells transport oxygen from the lungs to the cells
- Glucose is secreted by the liver into the bloodstream and transported by the blood fluids
- Carbon dioxide is transported from the cells back to the lungs, also by the red blood cells.

The blood circulation through the blood vessels is maintained by the heart. The total system of heart, vessels and blood is also known as the **cardio vascular system**. The performance of a cyclist or athlete largely depends on the quality of his cardio vascular system. The objective of endurance training is to improve this cardio vascular system. In this chapter we will take a look at the individual components of the cardio vascular system and how we can apply this knowledge in the understanding of sports and training, specifically in relation to the sport of cycling.

2.2 Muscle and muscle fibres

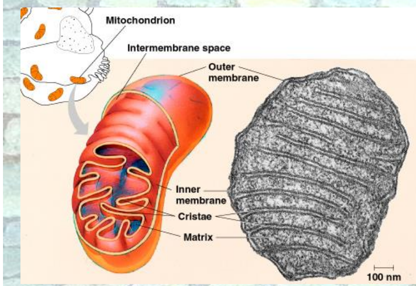
A **muscle fibre** is a single cell of a muscle. Muscle fibres are very long; a single fibre can reach a length of 30 cm. A muscle fibre has the ability to contract (become shorter). In this project we are only interested in skeletal muscle fibres. Human skeletal muscle fibres can be divided into two basic types, type I (slow-twitch fibres) and type IIb (fast-twitch fibres).

Type I

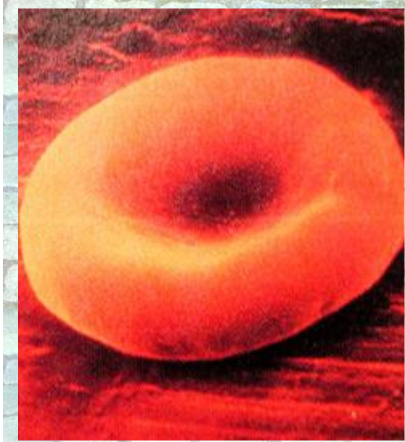
These fibres, also called slow twitch or slow oxidative fibres, contain many mitochondria and many blood capillaries. Type I fibres are red, split ATP at a slow rate, have a slow contraction velocity, are very resistant to fatigue and have a high capacity to generate ATP by aerobic respiration. Type I muscle fibres are typically found in muscles that require endurance, such as chicken leg muscles or the wing muscles of migrating birds (e.g., geese), or in the back muscles of the human neck.

Organelle
In biology, an **organelle** is a discrete structure of a cell having specialized functions. An organelle is to the cell what an organ is to the body. Examples of types of organelles are the cell nucleus, mitochondrion, chloroplast and vacuole.

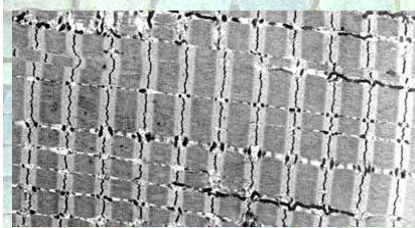
2.1 Mitochondrion



2.2 Red blood cell



2.3 Muscle tissue under the microscope



Type IIb

These fibres, also called fast twitch or fast glycolytic fibres, contain relatively few mitochondria, relatively few blood capillaries and large amounts of glycogen. Type IIb fibres are white, geared to generate ATP by anaerobic respiration, fatigue easily, split ATP at a fast rate and have a fast contraction velocity. Such fibres are found in large numbers in the muscles of the arms.

(Type IIa fibres also exist, but do not play a major role in the human body)

All muscles in the human body contain a mix of the two types of muscle fibre, type I and IIb. Different muscles in the human body have a different ratio of type I/type IIb fibres, according to their (main) function. The muscle fibre ratio is also for a large part genetically determined. That explains (for a part) why some people are more talented for sports like weight lifting and others are better in cycling or long distance running.

Various types of exercises can bring about changes in the fibres in a skeletal muscle. Endurance exercises result in cardiovascular and respiratory changes that cause skeletal muscles to receive better their supplies of oxygen and carbohydrates but do not contribute to muscle mass. On the other hand, exercises that require great strength for short periods of time, such as weight lifting, produce an increase in the size and strength of type II B fibres. The overall result is that the person develops large muscles.

2.3 The Heart, form and function

The heart is nothing more than a muscle. It is located a little to the left of the middle of the chest, and it's about the size of a fist. The heart is basically two pumps in one package. The right side of your heart receives blood from the body and pumps it to the lungs. The left side of the heart does the exact opposite: It receives blood from the lungs and pumps it into the body.

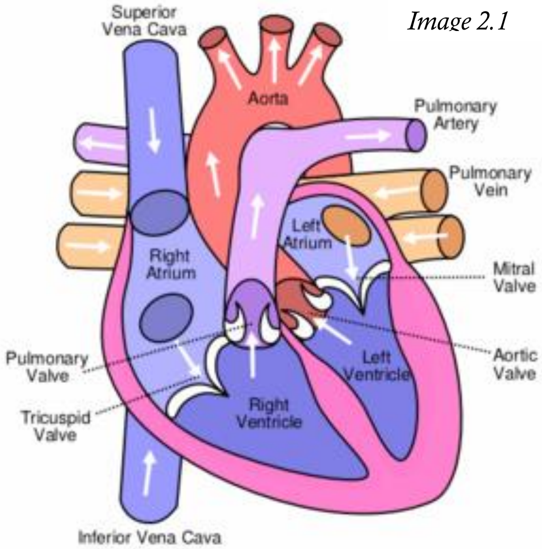


Image 2.1

2.4 Measuring the vital lung capacity with a spirometer

Lungs
Also the lungs play an important role in the aerobic respiration. In the lungs, oxygene is transported from the air to the blood cells, and carbon dioxide is expelled. Lung capacity increases, just like the heart, when you do a lot of aerobic training and is a measure of one's fitness. The average **total lung capacity** for an adult male is 6 litres. In rest about 500 ml of air moves in to and out of the lungs with each breath.
When measuring the lung capacity with a spirometer, it is impossible to exhale all the air out of the lungs. The measured volume of exhaled air is called the **vital capacity** and is 80 % of the total capacity. 4800 ml is a healthy value for the vital capacity for a young male.

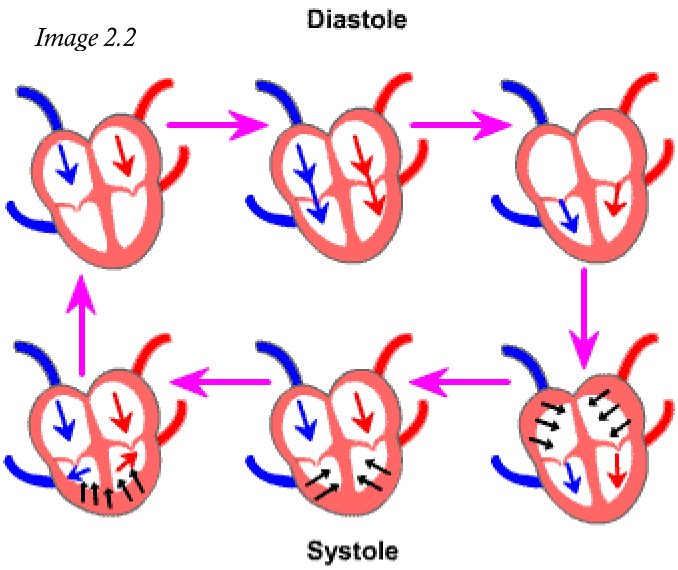
2.4 Image of human lungs made with a CT scan

The heart consists of four different blood-filled areas, and each of these areas is called a **chamber**. There are two chambers on each side of the heart. One chamber is on the top and one chamber is on the bottom. The two chambers on top are called the **atria**. The atria are the chambers that fill with the blood returning to the heart from the body and lungs. The two chambers on the bottom are called the **ventricles**. Their job is to squirt out the blood to the body and lungs.

The atria and ventricles work as a team - the atria fill with blood, then pump it into the ventricles. The ventricles then squeeze, pumping blood out of the heart. While the ventricles are squeezing, the atria refill and get ready for the next contraction. Both atria and both ventricles squeeze as a duo. Four special **valves** inside the heart regulate the blood flow through the chambers.

A ‘single cycle of cardiac activity’, or one heart beat, can be divided into two basic stages. The first stage is **diastole**, during which the cardiac (=heart) muscle is in rest and the ventricles fill themselves with blood. The second stage is called **systole**, which represents the time of contraction of the cardiac muscle.

Image 2.2



In rest, the heart contracts around 70 times per minute. With each contraction 70 ml of blood is pumped into the blood vessels on average (this volume is called the **stroke volume**). That means that the heart is pumping up to 5 litres of blood each minute, when you are in rest.

When the demand of blood increases, the body reacts by increasing the heart rate. Furthermore, also the amount of blood per heart beat increases. A healthy young male can reach up to 22 litre per minute during exercise, with the heart rate increasing to 195 bpm (beats per minute) and a stroke volume of 110 ml.

How can an athlete train his **cardiac output**, the amount of blood that his heart pumps each minute? One might think that one option could be to increase his maximum heart rate by training. This is impossible however. The maximum heart rate a person can reach is not

Volume (V)
Volume is a physical quantity, the unit of volume is the **m³**.
1 m³ = 1000 dm³ = 1.000.000 cm³.
1 dm³ is also called 1 **litre**,
1 cm³ = 1 **cc**.

The human heart
On average a human heart beats 3.000.000.000 times in a lifetime, pumping a total of 150.000 m³ of blood through the arteries. That is the equivalent of 60 olympic swimming pools!

Lance Armstrong’s statistics

Resting heart rate: 32 bpm
Maximum heart rate: 201 bpm
VO_2max: 84 ml/min/kg

2.6Lance Armstrong, Tour de France 2010 trainable. This is a fixed quantity, only depending on your age. On average one could say:

Maximum heart rate = 220 - Age (in years)
Eq.2.1

One aspect that is trainable is the size of the heart. Through training the heart can grow! Top athletes are able to increase their stroke volume to more than 200 ml. Well-trained top athletes can thus reach a cardiac output up to 35-40 l/min. This performance is only reached after years of hard training! A bigger heart also means a lower heart rate when in rest. The heart doesn't have to beat as fast to reach the 5 litre needed each minute. A well-trained athlete will therefore have a lower resting heart rate.

2.4 How does the heart work?

Cardiac muscle is a special and unique type of muscle fibre. A skeletal muscle requires a stimulus from the nervous system to contract. This stimulus can be conscious (when you want to move your hand to grab something) or a reflex (when you touch a hot object and immediately move your hand). The heart does not need a stimulus, but contracts all by itself, although the heart rate can be changed by nervous or hormonal influences. When you exercise or are in a sudden panic situation the heart beat increases.

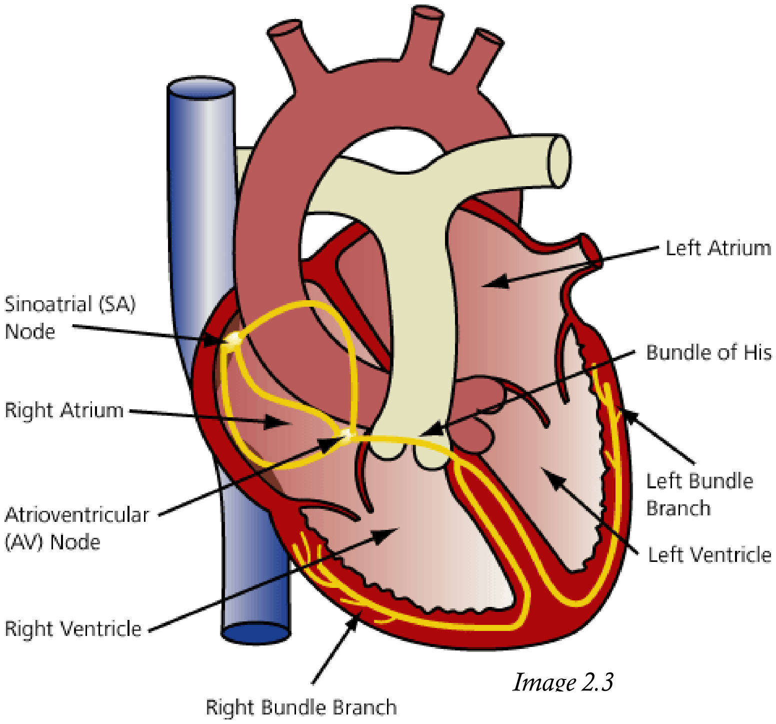
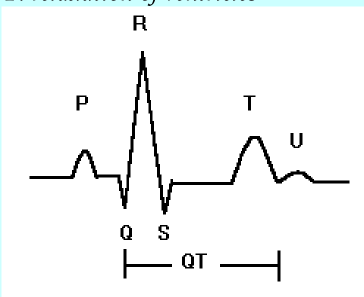


Image 2.3

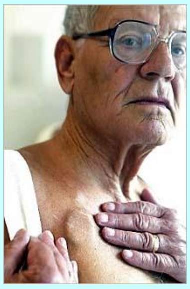
For heart muscle fibres to contract all that is needed is an electric signal. Timing is crucial, all heart muscle fibres must receive their signal with careful timing to make the heart contract in the right way. The rhythmic sequence of contractions is coordinated by the **sinoatrial (**or **SA)** and **atrioventricular** (or **AV**) nodes. The sinoatrial node, often known as the cardiac pacemaker, is located in

ECG
It is possible to measure the electric pulses in the heart from outside the body. This is done using an ECG or electro-cardiograph. With an ECG it is possible to 'see' the contraction of atria and ventricles. A trained doctor can use the ECG to check the heart on diseases and malfunctions.
In television medical dramas, an isoelectric ECG (no cardiac electrical activity or flatline) is often used as a symbol of death or at least extreme medical peril. This is known technically as asystole.

2.7 ***ECG graph***
P: contraction of atria
QRS: contraction of ventricles
T: relaxation of ventricles



Pacemaker
When the heart's natural pacemaker, the SA node, is not working correctly, or when the electrical pulse from the SA node is blocked somewhere in the heart, the function of the SA node is taken over by an **artificial pacemaker.** The pacemaker is placed under the skin near the heart and emits regular electrical pulses to the heart.



the upper wall of the right atrium. This SA node can emit an electrical pulse that makes the atria contract. The electric signal moves as a wave through the muscle tissues of the atria. Once the wave reaches the AV node, situated in the lower right atrium, it is conducted through nerves called the **bundles of His**. The bundles of His distribute the electrical pulse over left and right ventricle and causes contraction of the ventricles. Because it takes some time for the electrical pulse to get from the SA node to the ventricles (the AV node slows down the electrical pulse), the atria contract first, after 0,1 s the ventricles contract. This ensures that the heart functions correctly.

2.5 Measuring the aerobic performance

Until now this chapter focused on the anatomy of the human cardio vascular system. But what does someone needs to become a great endurance athlete?

A good endurance athlete must be able to generate a lot of energy through aerobic respiration. By training he has adapted his body to perform optimal at his sport. He has improved important processes in his body, namely:

- the ability of the muscle cells to extract oxygen from the blood passing through them
- his cardiac output
- his lung capacity

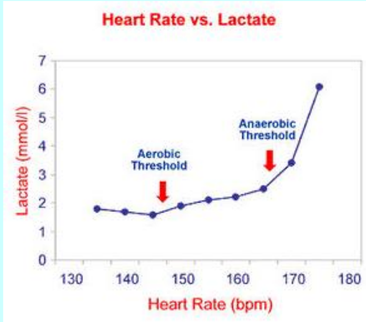
When the athlete is performing at a low level he will get his energy solely from aerobic respiration. When the athlete increases his performance level, at a certain point, the **aerobic threshold**, also anaerobic respiration will occur in his body. This is no problem, as all the lactic acid can be removed from the muscles. The aerobic threshold occurs at around 65% of your maximum heart rate.

As the athlete keeps increasing his performance level, he will reach a point where he won't be able to remove the lactic acid quickly enough from his muscles. The production of lactic acid becomes too large and the lactic acid will accumulate (= increase in concentration). While the lactic acid concentration increases the athlete will feel a increasing burning of the muscles, and after a short while he will have to slow down or stop altogether to give his body the opportunity to remove the lactic acid from the muscles.

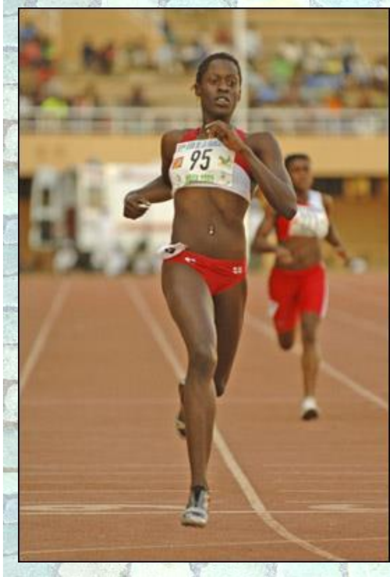
The point where the lactic acid starts rising is called the **anaerobic threshold**, and is mostly at around 85-90% of your maximum heart rate. At this point the cardio vascular system of the athlete is functioning at its peak performance. One can train the ability to go beyond the anaerobic threshold and perform well even at high lactate concentrations, albeit for a short time (end sprint). Lactic acid concentrations of 16 times the normal concentration in rest (1 mmol/l) have been measured.

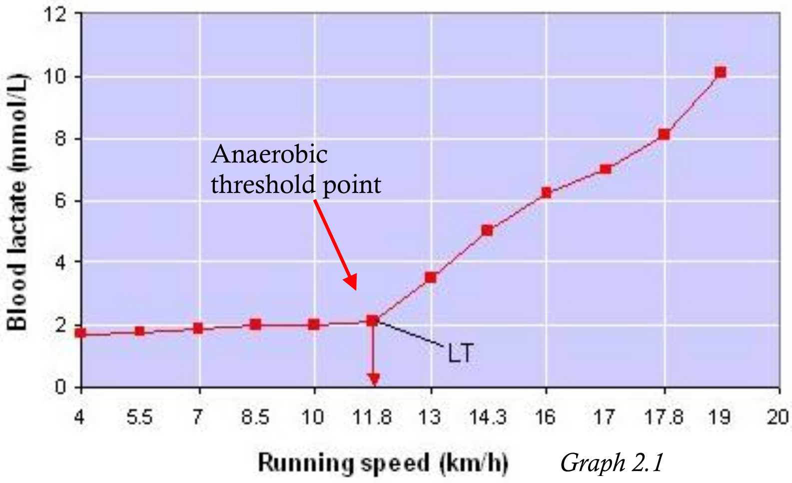
Aerobic & anaerobic threshold
In fig 2.6 test results of an athlete on an ergometer are shown. As the intensity, and also the heart rate, increases there is a point where the lactate concentration in the athlete's blood starts increasing. Here, also anaerobic respiration starts taking place. This is the **aerobic threshold**. At a certain point the intensity is that high that all the lactate can't be removed anymore. The concentration increases steeply. This is the **anaerobic threshold**.

2.8Test results lactate



2.9 800 m dash, final sprint, high lactic acid concentration





Graph 2.1

The anaerobic threshold is a very important value for any endurance athlete. Ideally an athlete wants to perform at that level where he is just under this anaerobic threshold. Look at graph 2.1, where lactic acid concentrations were being measured as an athlete was running harder and harder. Up to a running speed of 11,8 km/h the athlete was able to keep hic lactic acid concentration at a constant level. He can run at a speed of 11,8 km/h for a long time. This is his anaerobic threshold point. During a race he will try to run at this speed.

In laboratories, **ergometers** are used to be able to also measure the power that an athlete is producing. Cyclists mostly use cycling ergometers. During such endurance tests one can measure the maximum speed or maximum **power** that the athlete can produce, when he is performing at his anaerobic threshold. Also the oxygen intake can be measured. A more trained athlete will be able to take in more oxygen per minute, and also will be able to generate a higher power.

As the oxygen intake is such an important parameter, it has its own unit, the **VO_2 max.** The VO_2 max is defined as the highest rate at which oxygen can be taken up and utilized during exercise by a person (when performing at the anaerobic threshold). The VO_2 max has the unit **ml per minute per kg of body weight**. Why per kg of body weight? A large, and heavy, athlete will be able to take in more oxygen than a small, and light, athlete. To be able to compare both athletes, VO_2 max is always given per kg of body weight.

The average young untrained male will have a VO_2 max of approximately 45 ml/min/kg. The average young untrained female will score a VO_2 max of approximately 38 ml/min/kg. Trained endurance athletes can reach values up to 70 ml/min/kg.

The ergometer

The ergometer is designed for the test and training of high performance athletes, especially cyclists. An ergometer measures the amount of energy or work performed by the athlete.

2.10 Ergometer

2.11Oxygen measurement

Power
Power is a physical quantity and describes the amount of (useful) energy that is generated by an apparatus, or a person, per second. The unit of power is the **J/s** or **Watt (W)**.

Another well known unit for power is the **horsepower (hp)**:
1 hp = 746 Watt

Questions Chapter 2

2.1 Look at some average VO_x max values of different well-trained male athletes in the table to the right. These VO_x max values are a good indication of the quality of the cardiovascular system of the athletes.

a. Divide the different sports in two groups: sports where you need a good cardiovascular system, and sports where you don't.

b. Can you explain why some athletes don't have/need a high VO_x max value?

c. What type of muscles do the athletes in each group need the most? Type I or type IIb?

2.2 Read the information on the human lungs in the information column.

a. What lung capacity did you measure during the fitness test?

b. Calculate your total lung capacity. Is it considered healthy?

c. Can you give an explanation why it is impossible to measure directly your total lung capacity?

2.3 On an average, a human body will need approximately 5 litres of blood pumped around each minute, when in rest.

a. You have measured your heart pulse at rest during the fitness test. Calculate how big your heart volume must be to pump 4 litre (when you are a girl)/5 litre (when you are a boy) of blood each minute. Give your answer in cc/mL!

b. Make an estimate of your maximum cardiac output. To do this you will first have to make an estimation of your maximum heart rate. Also use the fact that the heart volume of a healthy young human can increase with 50% when it is performing at its maximum.

Sport	VO_x max (ml/kg.min)
Non-athlete	43-52
Baseball	48-56
Bicycling	62-74
Gymnastics	52-58
Nordic Skiing	65-94
Rowing	60-72
Weightlifting	38-52
Speed skating	56-70

Classics:The Monuments

Tour of Flanders

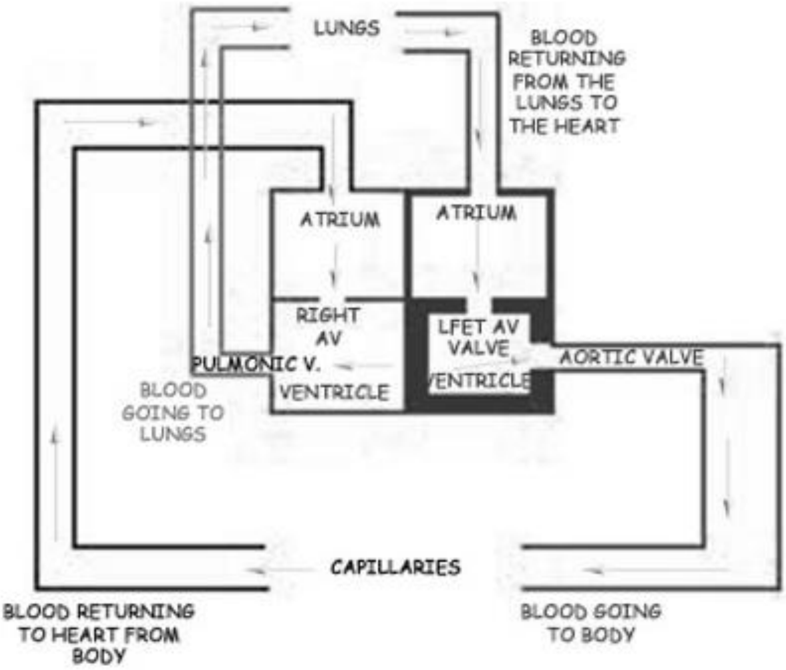
'Vlaanderens mooiste', or 'the best from Flanders' forms the apex in the agenda of many cyclists. The race is situated on small, curvy roads, many of them cobbled.

To win this race, a cyclist must have enormous amounts of stamina, agility and the ability to aggressively attack the succession of steep hills. Also vital for success: being in the front of the peloton at all times. Successful cyclists in these conditions are also known as 'Flandriens'

2.12Tom Boonen, a modern 'Flandrien'

2.4 Look at the image below. Here you can see a schematic view of the cardiovascular system of the human body.

a. Write in this schematic view where we can find the skeletal Give all veins and parts of the heart a colour. Colour it red when the



blood is rich of oxygen, and blue when the blood contains less oxygen.

b. As can be seen in the image, the wall of the left ventricle (chamber) is thicker that that of the right ventricle. The wall consists of strong muscles. Can you give an explanation why the right ventricle is more muscular?

***2.5** In the diagram at the right (2.12) an ECG reading is shown. The electric current that makes the different parts of the heart contract can be measured against time. The graph depicts exactly one heart beat. Read the information on ECG diagrams in the info column on page 15.

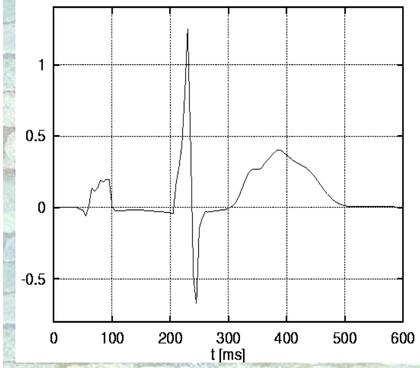
a. Determine the heart rate of this person.

From an ECG some crucial information of the different stages of a heart beat can be measured.

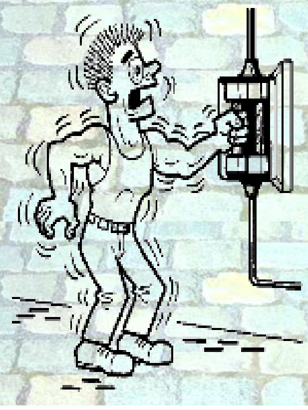
b. Where in this diagram can the P wave be found? How long does it take for the atria to contract?

c. Where in this diagram can the QRS wave be found? How long does it take for the ventricles to contract?

d. When the heart is in asystole (this means that the muscles don't contract anymore, a heart attack), a paramedic can give the patient an electric shock. For the same reason, an accidental powerful electric shock can be deadly. Can you explain why?



2.13 Table of an ECG, exercise 2.5



Classics: The Monuments
Paris-Roubaix

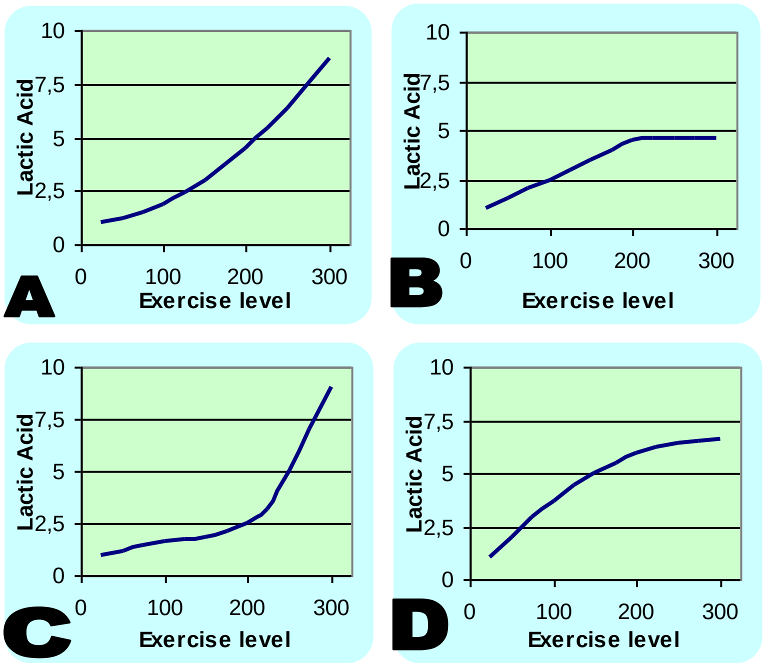
It is the more than 50 km of badly cobbled roads that makes this race 'the Hell of the North'. Falls and flat tires are mishaps that all competitors will encounter. The race ends with a round on the old velodrome of Roubaix.
To win here, a cyclist must be an excellent soloist and moreover a virtuous technical rider. And: no pain, no gain!

2.14 French cobble stones: 'kasseien'

2.6 In this graph you can see the results of a performance test of an athlete. The oxygen consumption has been measured while the exercise level increased in steps.

Graph 2.2

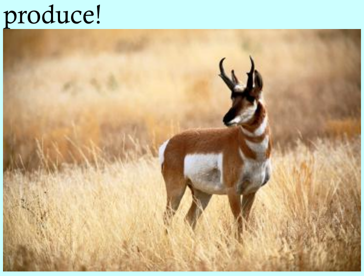
a. How do we call the level of oxygen consumption at the red arrow?
b. Apart from the oxygen consumption, also the lactic acid concentration in the blood of the athlete is measured. Which of the four graphs depicts the right pattern of lactic acid concentration with increasing exercise levels?



Man vs. animal

How does man stack up against other animals?

Measurements on the performances of racing horses revealed values of VO_2max exceeding 180 ml/min/kg. That is twice as much as the best human athletes can produce!



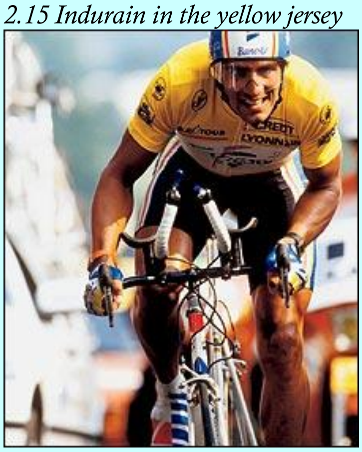
The ultimate endurance champion, the pronghorn antelope, with a VO_2max of 300 ml/min/kg.

The fittest man ever?

Miguel Indurain's statistics

Resting heart rate: 30 bpm
Vital lung capacity: 8 litre
Cardiac output: 50 l/min
VO_2max: 92 ml/min/kg

2.15 Indurain in the yellow jersey



CHAPTER 3 THE PHYSICS OF CYCLING

The first two chapters dealt with the biochemical processes in the human body which enable us to get the energy to move, to grow, in other words to live. In this chapter we will look more closely at how a cyclist can use (a part of) this energy to move as fast as he or she can. This chapter is focused mainly on the physics of cycling.

3.1 The moving cyclist and the laws of Newton

A cyclist is able to generate energy in his muscles which can make the muscles contract. By coordinating these contractions (this is what you learn when you learn how to ride a bike!) he can produce a force on the moving pedals of the bike and in this way he produces an amount of work. The more power that the cyclist generate, the greater the work he produces and the greater the force on the pedals will become. This force is conducted through chain blade, chain, gearwheel and the back wheel to the road surface. What happens next? To answer that question we will take a look at **Newton's Third law** of motion which states:

> ***To every action (force applied) there is an equal but opposite reaction (equal force applied in the opposite direction)***
> *Eq.3.1*

For example, when you put a box on a table, the box will apply a force on the table (due to gravity, red arrow), and the table will apply a force of the same magnitude and opposite direction on the box (blue arrow).

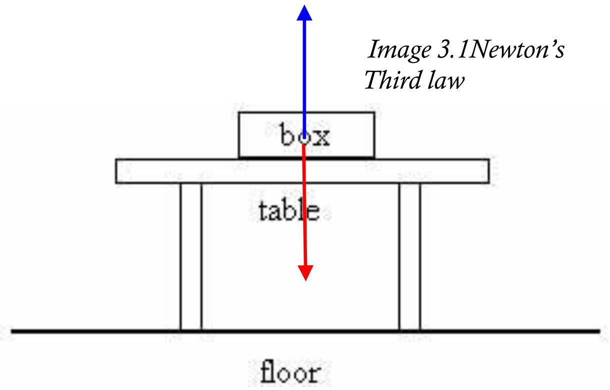


Image 3.1Newton's Third law

Or, in the situation of the cyclist, this law states that when the bike applies a force to the road below, the road will apply an equal force in the opposite direction on the bike that makes the bike move. In other words, how silly this may sound, the bike is being pushed forward by the road surface.

Let us take a look at another of Newton's laws, namely **Newton's first law** of motion:

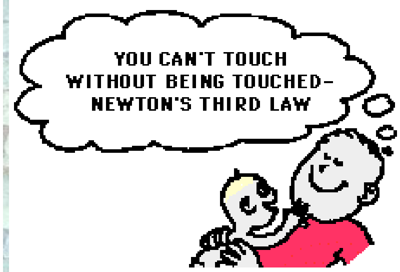
> ***Objects in motion tend to stay in motion, and objects at rest tend to stay at rest unless an outside net force F_n acts upon them***
> *Eq.3.2*

Definitions of some of the SI quantities

Time:
The second is defined as 9192631700 times the period of oscillation of radiation from the cesium atom

Length:
The metre is defined as the distance traveled by light in vacuum during a time interval of 1/299792458 second.

Mass:
The kg is defined as the mass of a specific platinum-iridium alloy cylinder kept at the International Bureau of Weights and Measures at Sevres, France



International System of Units

The **(SI)** base units:

Table 3.1

quantity	**name**	**symbol**
mass	kilogram	kg
time	second	s
length	meter	m
El.current	Ampere	A
Tempe-rature	Kelvin	K
Amount of substance	Mole	mol
Luminous intensity	Candela	cd

Which forces are acting on the cyclist and his bike? As the cyclist is starting to move forwards, he will experience a force called **drag force** or **friction**. The harder he goes, the bigger this friction will become. Thus, two forces are acting on the cyclist, the force of the road pushing the cyclist forwards (the **propelling force**, or also called **thrust**, F_p), and the **resistance force (also called drag** or **friction)** (F_r), pushing the cyclist backwards. Newton's first law of motion says that the bike will move at a constant speed when both forces have the same magnitude. When F_p is as large as F_r both forces cancel each other out, and there is no outside net force F_n working on the cyclist. When the cyclist starts to ride with a constant power, he will go faster and faster until he reaches the point where F_r has become equal to F_p , he will now move at a constant velocity.

When riding, a cyclist is constantly battling the resistance force acting on his bike. The magnitude of his speed is dependent on his continuous power output.

3.2 The resistance force on a moving bike

When riding on a flat road the resistance force has two components:

- **Air friction** or **air drag**
- **Rolling friction** or **rolling drag**

When the road is inclining, when you are climbing up a hill or mountain, a third component is introduced, as the cyclist also has to overcome the **gravitational force**. As the incline of the road becomes quite steep, this gravitational component becomes by far the largest of the three components. That is why climbing a steep mountain is such a hard work for a cyclist. For now we concentrate on riding on a flat road.

Air friction $F_{r,a}$ is, in general, the force that resists the movement of a solid object (like a bike) through a gas. The air friction is made up of friction forces and pressure forces. The theory behind it is quite complicated and is beyond the scope of this project. The air friction can be calculated using the air friction equation:

$$F_{r,a} = -\frac{1}{2} \cdot \rho \cdot v^2 \cdot C_d \cdot A$$

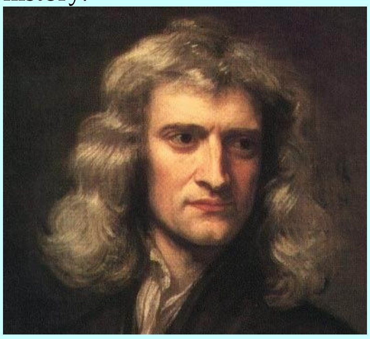
Eq.3.3

Let's look in detail at all the components in this equation:

- $F_{r,a}$ is the **total air friction**, and as it is a force it comes with the unit of Newton (N)
- ρ is the **density** of the gas or liquid where the object is moving through, in kg/m^3. In our case, the cyclist and his bike move through the air, which has a (average) density of 1,226 kg/m^3. The density of water is almost 800 times that of air (1000 kg/m^3). When you ever have tied to run through shallow water, you already know that the friction in water is much, much larger than that in air

Force
Force is a **vector** quantity, this means that force always has a magnitude as well as a direction. The unit of force is the **Newton (N)**. The precise definition of force goes beyond the scope of this project. For now it is enough to know that when you apply a (net) force upon an object, this object will begin change its movement. A mass of 10 kg on the earth's surface feels a gravitational force of approx. 98 N.
A force is often visualised by an arrow.

Sir Isaac Newton
4 January 1643–31 March 1727 was an English physicist, mathematician, astronomer, alchemist, and natural philosopher who is generally regarded as one of the greatest scientists and mathematicians in history.



The Mexico hour records

During the 70's and the 80's Mexico City was a popular location for breaking the cycling world hour record. Due to the height of the track, 2338 m above sea level, the density of the air in Mexico City is significantly lower than at sea level, and therefore also the air friction is smaller.

- ***v*** is the velocity of the bike **relative** to the air, in m/s. This means that when you are riding in the direction of the wind, this velocity is smaller than when you ride against the wind
- ***A*** is the **frontal cross section area**, in m^2. When a cyclist rides at a high velocity, he will automatically bend forward to decrease his frontal cross section area
- C_d is the so-called **drag coefficient**. The drag coefficient depends on the **form** of the object. An aerodynamic formed object will have a lower drag coefficient. The drag coefficient of a cyclist and bike is around 0,9. Professional bikes do have aerodynamic features to decrease the drag coefficient.

The bike is not only in contact with the air, but also with the surface of the road. As the bike moves, there will always be friction between the tyres of the bike and the surface of the road. This friction leads to the rolling friction, $F_{r,r}$. This rolling friction can be calculated with:

$$F_{r,r} = -m \cdot g \cdot \mu_k$$

Eq.3.4

Again we look at the components in this equation:

- $F_{r,r}$ is the **total rolling friction**, and comes with the unit of Newton (N)
- ***m*** is the **mass** of the rolling object, in our case the combined mass of cyclist and bike
- ***g*** is the constant of **gravitational acceleration**, 9,81 m/s^2
- μ_k is called the **coefficient of (kinetic) friction**. Its magnitude depends on the nature of the two surfaces. The combination 'tyre on loose sand' will have a (much) larger μ_k than the combination 'tyre on asphalt'. Also using a small tyre and inflating it to a high pressure decreases the μ_k. Look at the tyres used on a racing bike!

The total resistance force (or drag), F_r is defined as:

$$F_r = F_{r,a} + F_{r,r}$$

Eq.3.5

In normal cycling situations, the air friction will be by far the largest of the two components. The cyclist is mainly battling the air friction.

3.3 Gravitational force

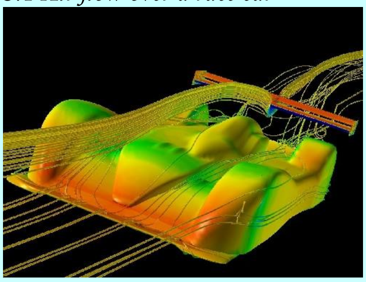
What happens when a cyclist rides up a hill or mountain? From own experience you may well know that climbing a steep hill reduces your velocity enormously. As your power isn't suddenly decreasing, this must mean that riding uphill introduces an extra force.

Look at the illustration in image 3.2. Here, the forces acting on the cyclist are visualised by the red arrows. $F_{r,r}$ and $F_{r,a}$ are the two friction forces, acting in the direction opposite of the direction of movement of the cyclist. There is also a third force, that has, until

Aerodynamics

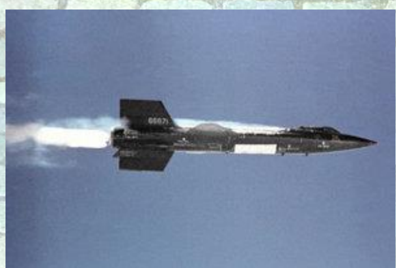
The word aerodynamics comes from two Greek words: aerios, concerning the air, and dynamis, which means force. Aerodynamics is the study of forces and the resulting motion of objects through the air. An aerodynamic object is one that is designed to have a very low resistance when it moves through water or air.

3.1 Air flow over a race car



3.2 Cyclist: Drag coefficient 0,9

3.3 Ferrari Testarossa: Drag coefficient 0,36



3.4 X-15 Rocket airplane Drag coefficient 0,15 now, not been discussed. This force is the **force of gravity**, F_g, that is always directed downwards and pulls the cyclist to the ground. Because the cyclist in image 3.2 moves on a level surface, he is moving **perpendicular** to the force of gravity. In this case the force of gravity is not producing any work on the cyclist.

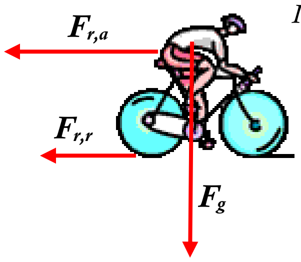


Image 3.2

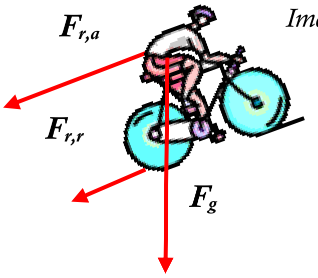


Image 3.3

In image 3.3 the same cyclist is going uphill. The forces of friction are still acting. But in this case, the force of gravity is **not** perpendicular to the direction of movement of the cyclist and is actually doing work on the cyclist. This implies that the cyclist has also to overcome (a part of) the force of gravity. This leads to an increase of the net total of the restricting forces.

Image 3.4 depicts the situation in more detail. We call the angle of inclination of the road α. The force of gravity can be dissected into two forces, $F_{g,x}$,which is directed along the direction of movement, and $F_{g,y}$, which is directed perpendicular to the direction of movement. As $F_{g,y}$ is again perpendicular to the direction of movement, it can be discarded in this calculation. $F_{g,x}$ is the extra force that has to be overcome when the cyclist wants to move up the hill.

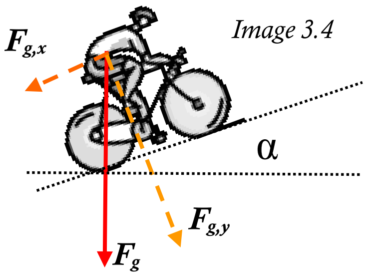


Image 3.4

The magnitude of this force follows from the basic laws of trigonometry and can be calculated as follows:

$$F_{g,x} = F_g \cdot \sin\alpha$$

Eq.3.6

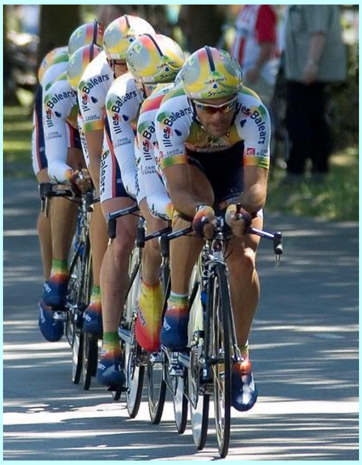
As F_g is only dependent of the total weight of cyclist and bike, equation 3.6 can also be written as:

$$F_{g,x} = m \cdot g \cdot \sin\alpha$$

Eq.3.7

And g is again the constant of gravitational acceleration, 9,81 m/s^2
The total of all resisting forces, F_r , becomes:

Gravity
In physics, **gravitation** or **gravity** is the tendency of objects with mass to attract (to accelerate) each other. Gravitation is one of the four fundamental interactions in nature and also the weakest of them. It acts over great distances and is always attractive.
In 1687 Sir Isaac Newton published the famous book *Principia*, which postulated the law of universal gravitation.



3.5 Drafting:team time trial

Drafting
Drafting is an important technique in road racing. The cyclist, as he moves through the air, produces a turbulent wake behind himself, where the pressure is lower. If you're following another cyclist and can move into the wake behind the front bicyclist, you will have an advantage. The low pressure moves you forward. This can reduce your air resistance up to 40%!

Both images: Time trial championship Eindhoven, 2006
Which team 'drafts' the best?
3.6 Cofidis team

$$F_r = F_{r,a} + F_{r,r} + F_g \cdot \sin\alpha$$

Eq.3.8

Keep in mind that when the road is level and the angle of inclination, α, is zero, also sin α will be zero. In this situation, equation 3.8 transfers into equation 3.5.

3.4 Force, velocity and power

A cyclist is not thinking about forces when he is competing in a race. The only thing he is interested in is his **velocity**. We have looked at the forces that are acting when the cyclist is riding. The cyclist has to work against the resisting forces acting on him. His trained metabolism and cardio vascular system enables the cyclist to put a certain amount of energy per second into his cycling. This amount of energy per second is called the **power** (in Watt) that the cyclist can produce. The better trained the cyclist is, the higher the power that he can generate during a race. A sprinter is able to produce a very high power for a short period of time. A time trial specialist can generate a high power over a longer time.

There is a relationship between the power, the velocity and the propelling force when riding with a **constant velocity**:

$$P = F_p \cdot v \text{ or } P = F_r \cdot v$$

Eq.3.9

With:

- ***P*** the **power** that can be generated (in Watt, or J/s)
- F_p the **propelling force** (in N)
- F_r the total of all **resisting forces** (in N) (= equal to F_p!)
- v the velocity at which the cyclist moves (in m/s)

Now it is possible to calculate the velocity of the cyclist when one knows the power ***P*** of the cyclist and the magnitude of F_r. Equation 3.9 shows that when a cyclist goes uphill, and F_r increases dramatically, the velocity of the cyclist decreases significantly.

Power tells a lot about a cyclist's fitness, but not all. A bigger, and heavier, cyclist will ,on average, be able to generate more power than a smaller cyclist. But that does not have to mean that the bigger cyclist will go at a higher velocity, as also the resisting forces will be larger. To be able to compare cyclists (and athletes in general) of different sizes, the quantity of **power-to-weight ratio** is used, the amount of Watts a cyclist can generate per kg of his bodyweight. Especially world-class climbers have very high values for this ratio, up to more than 6 W/kg.

Power and cycling
Table 3.2

Untrained male	100 W
Amateur cyclist	300 W
Elite cyclist	400 W
World hour record	440 W
1 horsepower	736 W
Road sprint	1500 W
Track sprint	2200 W

3.7 Theo Bos, Dutch world champion track sprint 2004&2006

Marco Pantani
January 13 1970-February 14 2004

Italian Marco Pantani was a gifted climber who excelled in the Giro d'Italia and the Tour de France during the second part of the 90's.Having a power-to-weight ratio of 6,20 W/kg, Pantani was practically unbeatable uphill. Pantani died in 2004 under suspicious circumstances.

3.8 Pantani wins Giro d'Italia 1998

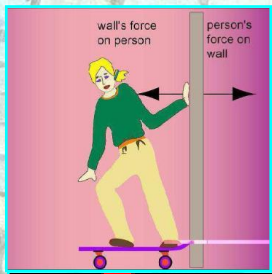
Questions Chapter 3

3.1 In each situation, fill in the right explanations using the laws of Newton. (1st= Newton's first law, 3rd=Newton's third law)

A **Example:**
3rd: The gun acts a force on the bullet as the bullet shoots away, the bullet also acts a force in the opposite direction on the gun
1st: The gun experiences a net force, and will move backwards, towards the shoulder

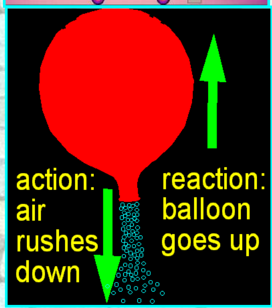
B 3th:……………………………………………………?

1st: The girl will experience an outside net force and moves to the left



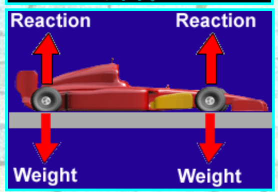
C back 3rd: as the ballon 'pushes' the air downwards, the air pushes upwards

1st:……………………………………………………?



D 3rd:……………………………………………………?

1st: As there is no net force on the car, the car stays at rest



3.2 A mountain bike cyclist is starting his training. The cyclist weighs 76 kg, his bike weighs 11,5 kg. ρ_{air} is 1,226 kg/m^3. The cyclist's frontal cross section is 0,79 m^2 and he has a drag coefficient of 1,0. The cyclist starts riding with a constant velocity of 5,0 m/s. His bike is equipped with tyres with a coefficient of friction of 0,004.
a. Calculate the total resistance force that the cyclist encounters at this velocity.
b. How many percent of the total resistance is formed by the rolling drag, and how many percent by the air drag?

Now the cyclist is accelerating to 10 m/s and moving on with this higher constant velocity.
cWhat percentage of the total resistance is now formed by the rolling drag? What can you conclude?

The cyclist now changes his mountain bike for a racing bike (which weighs 8,0 kg). Due to the differences in geometry of both bikes, his frontal cross section decreases to 0,62 m^2 and his drag coefficient becomes 0,88.
d. What velocity will the cyclist go on his racing bike, when his propelling force stays the same as in question 3.2c?

Velocity (*v*)
Velocity is a vector quantity, this means that velocity always has a magnitude (also called **speed**) and a direction.
Velocity is defined as:

$$\text{Velocity} = \frac{\text{distance travelled}}{\text{the time it took}}$$

or mathematically: $v = \dfrac{\Delta x}{\Delta t}$

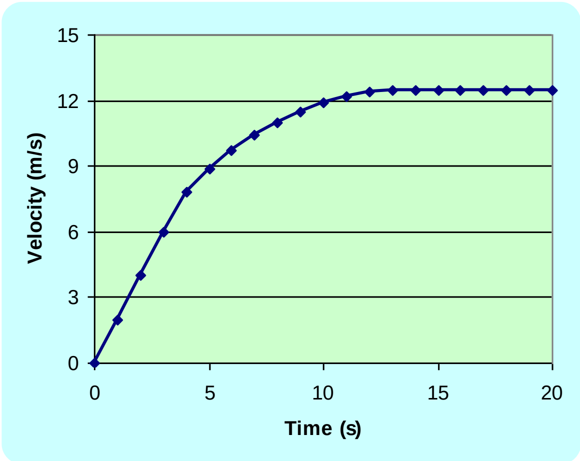
The unit of velocity is **m/s**.

1 m/s = 3,6 km/h
1 km/h = 0,28 m/s

3.3 In the info column on the right you can read about the world record of Fred Rompelberg.
a. What velocity did Rompelberg reach during his record run (in km/h)?

Look also carefully at the picture.
b. Explain, using your knowledge of the different forces on a cyclist, how Rompelberg was able to go at that incredible high velocity.

***3.4** A cyclist is on her bike, on the top of a hill. She decides to roll downhill, without cycling herself. In the graph you can see her velocity in the first 20 seconds of her movement.
a. Explain, by using forces, why the girl starts to move. Where does the propelling force comes from?
b. As can be seen in the graph, the girl reaches a constant velocity after some seconds. Explain why she is, after a while, going at a constant velocity.
c. After 20 seconds the girl bends over her steering bar as much as she can, making herself as small as possible. Explain what will happen with her velocity (she still is not cycling!)



3.5 Dutch cyclist Theo Bos was, at one moment, the fastest cyclist in the world. In 2006 Bos clocked a stunning world record of **9,772** seconds over 200 m.
a. Calculate the average velocity of theo Bos in his record-setting race.

Lets presume that Bos generated around 2000 W on average during is record breaking race.
b. Calculate the average resistance force that Bos encountered during his race.

Super-fast Fred 

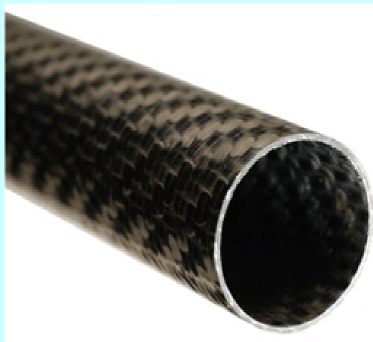
Dutch Fred Rompelberg did something that was thought to be impossible. In 1995 he timed an **absolute speed world record** of 13,39 seconds over 1 km. During this race Rompelberg made good use of a windscreen on a F1-car, as can be seen on the picture below. Fred Rompelberg was 50 years of age at the time of this record and he broke the world record on a dry salt lake in the USA.

3.9 Rompelberg in action

Carbon

The last decades carbon has become a much-loved material for building racing bike frames and other parts of the bike. Carbon has two main advantages:
1. It is extremely strong for its density, so you can build a light ánd strong frame.
2. Unlike metals, carbon parts are built using a mould. This enables the frame makers to build frames in more exotic forms.

3.10 Carbon tube



***3.6** The famous l'Alpe d'Huez has an average inclination of 5°.
a. Calculate the resisting force that **you** would have to overcome when you would try to climb that mountain. To make life easier you may forget about air friction and rolling friction. Gravity is your main opponent during this climb!
b. Look up your maximum aerobic power from the fitness tests. Use Eq. 3.9 and make an estimate about the velocity you would develop when climbing this mountain.

The climb of the l'Alpe d'Huez has a total length of 13,8 km.
c. How much time would it take you to climb the l'Alpe?

Marco Pantani did it in 37 minutes and 35 seconds!

Angle or percentage?

There are different ways to describe the pitch of the slope of a road. One is to measure the angle of the slope with the horizon. Another common way is to use a percentage.

The percentage is defined as

$$\% = \frac{\text{difference in altitude}}{\text{horizontal difference}} \cdot 100$$

To calculate the percentage out of the angle:

$$\% = \tan(\text{angle}) \cdot 100$$

3.11 Liege-Bastogne-Liege, the famous Redoute climb, 23%!(13°)

3.7 A cyclist has to overcome three different forces during a race: the air resistance, the rolling friction and gravity. Technology helps the professional cyclist whenever possible. Take a good look at the three forces and try to explain the advantages of using the following cycling attributes:

triathlon bar

22 mm super thin race tyres

high rimmed carbon wheels with flat spokes

tight fitting clothes

closed wheel

thin carbon front fork

carbon streamlined frame

streamlined helmet

CHAPTER 4 FOOD AND DOPING

4.1 Osmosis

Without food, a human is able to survive up to a couple of weeks. Without water, only a couple of days. Water is essential for the human body to function. It is the main component of all drinks we drink, and water is also a main component of our food. Water transportation in and out the human cells is accomplished through a physical phenomenon called **osmosis**.

To explain osmosis, look at image 4.1.

For osmosis to happen two things are needed:

- Two volumes of water (or another solution) that contain different concentrations of solvents (salts etc.)
- A membrane that separates the two volumes of water, with special characteristics, all water can go through, but the salts are blocked. Such a membrane is called a **semipermeable** membrane

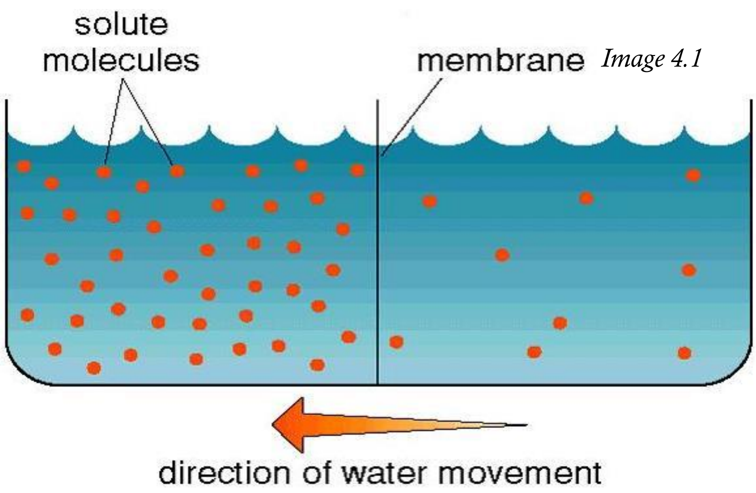


Image 4.1

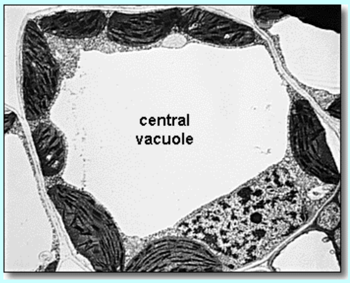
What happens in such a situation is that the water molecules will **diffuse or flow from an area of low salt concentration (right in the picture) to an area of high salt concentration** across a semi permeable membrane. This phenomenon is called **osmosis**. The osmosis stops when the concentrations left and right are equal, or when the osmosis is opposed by an increase in the pressure in the region of high solute concentration.
The pressure required to prevent the passage of water through a selectively-permeable membrane and into a solution of greater concentration is called the **osmotic pressure** of the solution, or **turgor**. Whether the solute molecules are all of the same kind of molecule or from different molecules is not important at all for the process of osmosis.

To be able to calculate the solvent concentration or **Molarity** (**moles/L** or **M**) one needs two parameters:

- The volume of solution, in litres
- The total amount of solvents in the solutions, in **moles**

Turgor pressure
Most mature plant cells have a **central vacuole** which often takes up more than 80% of the cell interior. When this vacuole is **hypertonic**, compared to the intercellular solution, water will go inside the vacuole through osmosis, until the vacuole is full and under pressure. The cell wall prevents the cell from bursting, resulting in pressure on the cell wall from within, also called **turgor pressure**. The pressure of each cell wall against its neighbour results in stiffness that allows the plant to stay upright. Cells not adapted to hypotonic environments, like animal cells, will burst due to the inflow of water.

4.1 Plant cell with central vacuole



Mole
The mole (or mol) is one of the 7 base SI units and describes the amount of substance. One mole of a certain substance contains $6{,}0221415 \cdot 10^{23}$ molecules. This number is known as **Avogadro's number**. One mole of a substance is also that quantity of a substance whose mass in grams is the same as its **atomic weight**. For instance: one mole of Carbon - 12 (with an atomic weight of 12) weighs exactly 12 g.

Example: When you have 2 L of water, with in it dissolved a total of 4 moles of glucose, the molarity of the solution is

$$\text{Molarity} = \frac{\text{moles of solvent}}{\text{liters of solution}} = \frac{4}{2} = 2\ M$$

Eq.4.1

Note: When you would dissolve 4 moles of NaCl salt into two 2 L of water, the molarity would become $\frac{8}{2} = 4\ M$, because the salt would dissolve into 4 moles of Na^{+} ánd 4 moles of Cl^{-} ions in the water!

4.2 Osmosis in the human body

Why is osmosis such an important process in our human body? The cell membranes of all living cells have the characteristics of a semipermeable membrane. Water can pass through unhindered, but the solvents in it can't.

The human cells in our body are surrounded by a liquid, the so-called **intercellular fluid**. This intercellular fluid contains a lot of salts and other solvents. Interaction by means of osmosis can take place between the intercellular fluid outside the cell membrane and the cell fluid inside the cell membrane.

(Salt is also a solute, and when it is concentrated inside or outside the cell, it will draw the water in its direction. As a rule of thumb:
Salt Sucks!)

There are three possibilities:

- The intercellular solution is **isotonic**. **Iso** means 'the same': if the concentration of solute, or molarity, is equal on both sides (inside and outside of the cell), there will be **no net flow** of water going in our out the cells .
- The intercellular solution is **hypotonic**. **Hypo** means 'less': in this case the concentration of (salt) molecules outside the cell is lower, and the molarity inside the cell is greater, water will **flow into** the cell. The cell will gain water and grow larger. In plant cells, the central vacuoles will fill and the plant becomes stiff and rigid, the cell wall keeps the plant from bursting. In animal cells, the cell may be in danger of bursting, special organelles called contractile vacuoles will pump water out of the cell to prevent this.
- The intercellular solution is **hypertonic**. **Hyper** means 'more': in this case the concentration of (salt) molecules outside the cell is higher, which causes the water to be **sucked from** the cells to the intercellular solution. In plant cells, the central vacuole loses water and the cells shrink. In animal cells, the cells also shrink. In both cases, the cell may die. This is why it is dangerous to drink sea water. It is a myth that drinking sea water will cause you to go insane, but people shipwrecked at sea will speed up dehydration (and death) by drinking sea water.

Pressure (P)
Pressure is a physical quantity that describes the force per unit area applied on a surface (in a direction perpendicular to that surface).

$$P = \frac{F}{A}$$

Pressure comes with the unit of **Pascal** (**Pa**). one **Pa** equals a pressure of one Newton of force per m^3 of surface.
Other used units:
1 **bar** = 100.000 Pa
1 **atm**. = 101 325 Pa

Fish, salt or freshwater?
Most fishes release their nitrogenous wastes as ammonia. Some of the wastes diffuse through the gills into the surrounding water. Others are removed by the kidneys. Kidneys help fishes control the amount of ammonia in their bodies. Saltwater fish tend to lose water because of osmosis., they are **hypotonic**. In saltwater fish, the kidneys concentrate wastes and return as much water as possible back to the body. The reverse happens in freshwater fish, which are **hypertonic**. They tend to gain water continuously. The kidneys of freshwater fish are specially adapted to pump out large amounts of dilute urine. Some fishes have specially adapted kidneys that change their function, allowing them to move from freshwater to saltwater.

4.2 The Salmon, salt ánd freshwater

4.3 Osmosis and sports drinks

When an athlete is training or in competition, he will use a large amount of sugar and other nutrients. By means of sweating, the athlete will also lose a lot of water. This water loss can eventually lead to **dehydration**, an unhealthy shortage of water inside the body. When he does not replenish nutrients and water, he will eventually not be able to perform at a high level. It is very important to eat and drink during exercise.

Plain water is said to be good for your health. But it can actually be toxic if consumed in large amounts. The salts in the human body (in the intercellular solution) will in such a case be diluted to a dangerously low level and the intercellular solution will become strongly hypotonic. On the other hand, a shortage of water is also unhealthy. Symptoms of dehydration are headache, dizziness, unconsciousness and in very severe case death. Just plain water does not do the trick for endurance athletes. They have to use **sport drinks**.

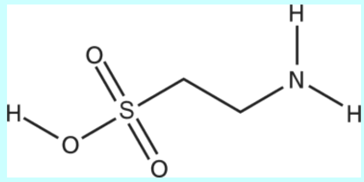
Sports drinks are on the market for around 35 years. The first sports drinks consisted of water, sugars (glucose) and salts. Later, also other stimulating components like taurine and caffeine were added to the sport drinks. Depending on the molarity of the drink, sports drinks can be divided in two categories:

- **Isotonic** sports drink. This drink has a molarity that is equal to that of the human blood (and the intercellular fluid). An isotonic drink contains around 6-8 g of sugars per 100 ml of water. The stomach and intestines are able to take up an isotonic fluid very swiftly. An isotonic drink is ideal for **rehydration** of the body. The infuses used at the hospitals, when someone is dehydrated and is in dire need of water, are always isotonic.
- When there are (a lot) more sugars and other substances in the sports drink, it is called an **hypertonic** sports drink. A disadvantage is that the stomach is not able to take in a hypertonic fluid as quickly as an isotonic fluid. The hypertonic drink stays longer in the stomach. The advantage lies in the fact that a hypertonic drink contains more sugars, and thus more energy, the athlete can replenish his energy supplies. Hypertonic drinks are also called **energy drinks**. Is has become quite popular to add prestation enhancing stimulants to the energy drinks (caffeine, taurine, guarana and other herbs).
- Of course you could also drink a **hypotonic** drink, like pure water. Hypotonic fluids don't stay long in the stomach, and the intestines are not able to take in a hypotonic fluid very swiftly. A symptom of drinking hypotonic drinks can therefore be a 'full' belly. So, drinking hypotonic drinks is not as advantagous as drinking an isotonic or hypertonic drink. In severe cases, drinking large quantities of hypotonic drinks can lead to dangerous situations.

Water poisonous?
"A London hospital recently treated a 23-year-old man who had slipped into a coma following a drastic detox diet which caused his brain to swell.
The patient was found to be suffering from **hyponatraemia**, or **water intoxication**, in which levels of sodium in the blood became dangerously diluted.
The fruit and vegetables he was eating did not contain enough sodium to counter the loss of minerals."
Belfast Telegraph 17 may 2005

Taurine, the myth?
Taurine was first isolated from the bile of the ox, and this is where its name is derived from: the Latin word for ox, Bos taurus.
Taurine is the most frequently occurring free amino acid in the human. A 70-kg human contains up to 70g of taurine. Taurine-containing energy drinks are sold with a lot of hype suggesting that taurine is responsible for a wide variety of positive mental effects, but this has, until now, never been proved. The fact that drinks that contain taurine sell at such a premium is more likely due to marketing than the intrinsic value of the substance.

4.3 Taurine-molecule



4.4 Cycling and doping

> *"The 1998 Tour de France in was hit by the worst drugs scandal in its history. The Festina team was thrown out of the Tour after the team masseur Willy Voet was arrested when performance-enhancing drugs where found in his team car. In the end, one third of all teams in the race either withdrew or were expelled because of illegal drug abuse."*

Also 2006 became a notorious 'dope-year' with the Spanish **'operaçion Puerte'** leading to 50+ names of cyclists which were using blood-doping, and the disqualification of the winner of the Tour de France, Landis, after he was tested positive on the use of synthetic testosterone.

In sports, **doping** refers to the use of performance-enhancing drugs such as anabolic steroids, particularly those that are forbidden by the organizations that regulate competitions. The use of doping in the sport of cycling is as old as the sport itself. Not until the dramatic death of Tommy Simpson during the Tour de France of 1967 did this use of stimulants rise any eyebrows. After Simpsons death also the UCI (Union Cycliste Internationale) joined the fight against drugs in their sport.

But what is considered doping, when is a certain drug prohibited for athletes ? Simply said: all drugs that are mentioned on the so-called **doping list** are considered doping and are illegal.

A handful of commentators maintain that 100% prevention of doping is an impossibility, and that all doping should be legalised. However, most disagree with this assertion, pointing out the **harmful** long-term effects of many doping products.

An example: **Anabolic Steroids**, a popular and dangerous drug

Steroids are drugs that have been derived from hormones. Anabolic Steroids are synthetic derivatives of testosterone, a natural male hormone. The hormone's anabolic effects help the body in retaining dietary proteins, thus aiding **growth of muscles**, bones, and skin.

Those who choose to take steroids put themselves at risk to more than 70 side effects ranging in from acne to liver cancer. They can have both psychological and physical reactions to the steroids. The liver, cardiovascular and reproductive systems are most at risk for steroid use.

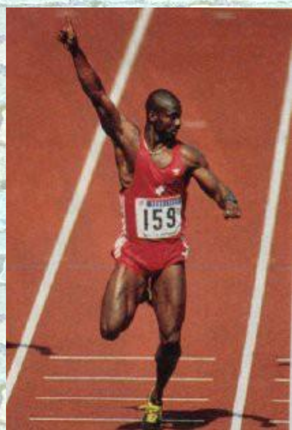
Steroids used by males can cause withered testicles, sterility, and impotence. Females risk acquiring irreversible masculine traits, breast reduction, and sterility. The psychological effects in both sexes include aggressive, combative behaviour and depression. Some of side effects will not show up for years, such as heart attacks and strokes. When used during adolescence steroids could cause arrested bone development.

Tommy Simpson

During the 1967 Tour de France, the English rider Tom Simpson collapsed whilst climbing the Mont Ventoux. Despite mouth-to-mouth resuscitation and the administration of oxygen, plus a helicopter airlift to a nearby hospital, Simpson died of a heart stroke. The combination of doping, extreme heat and alcohol were fatal to him. Two tubes of amphetamines and a further empty tube were found in the rear pocket of his racing jersey.

4.4 Simpson in the yellow jersey

4.5 Ben Johnson, caught using steroids after his victory at the 1988 Olympics



Questions Chapter 4

4.1 Look at the table on the left. In summer your body can sweat up to 1,5 litres per hour. Look up your weight in the fitness results and answer the following question:
a. How long could you exercise in summer before your performance starts to decrease?
To prevent a decrease in performance, you may decide to drink 1,5 litre of water each hour that you exercise.
b. Explain why this is not the best action that you can take.
c. What would be the best strategy when exercising in the heat of summer?

4.2 The average molarity of the human extra cellular and intracellular fluids is around 0,300 M, or 300 mM.
Let's make a sport drink by ourselves. The body needs glucose, so we will add glucose to our drink. The body also needs a bit of salt, especially when it is very hot. One can calculate how many grams we would need to have one mole of glucose. When we would dissolve 180,2 grams of glucose in one litre of water we would get a solution with a molarity of exactly 1,0 M . 29,72 grams of salt in one litre of water also leads to a molarity of 1,0 M.

We take a bottle with a volume of 0,500 L. We add 20,0 grams of glucose and 1,00 gram of salt.
a. Calculate whether this sport drink is isotonic, hypotonic or hypertonic.
b. When we would like to make an isotonic sport drink with only glucose in it, how many grams would we have to add to our 0,50 L bottle?

% body weight lost as sweat	**Physiological effect**
2%	Less performance
4%	Capacity muscles decline
5%	Heat exhaustion
7%	hallucinations
10%	Heat stroke
> 10%	coma

4.6 Pure glucose

4.7  *Floyd Landis, caught after the Tour de France of 2006. 4 years later, Landis admits that he used doping on a large scale during the last decade.*

4.3 Take a look at some different views on the doping problems in our sports. Read them carefully, and choose 2 opinions that you agree with, and two opinions that you disagree with. Write them down, and also write down why you agree or disagree with these opinions. What is your opinion?

"Doping is damaging for the athletes' health, but that is a choice that the athlete has to make, not some doping committee"

"Doping leads to unfair situations for the athletes and the sport itself"

"Doping is essentially contrary to the spirit of sport"

"There is nothing that really can be done to doping, so we better allow it"

"Doping leads to spectacular achievements. Without doping sport would be less exciting"

"The media expect too much from the athletes. The athletes have to use doping to be able to perform to our wishes"

"An athlete can be under very high pressure by sponsors to perform"

"As an athlete always wants to perform better than ever, the use of doping is a logical choice, but wrong"

"Sport plays a too important role in our world. It is logical that this over-valuation leads to doping usage"

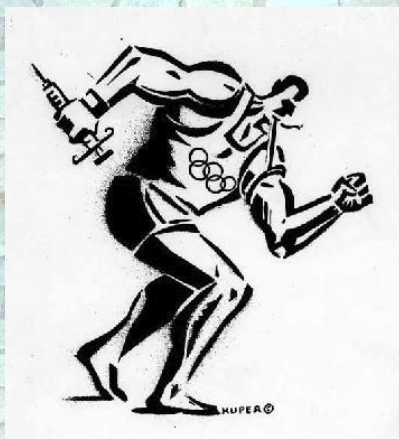
"When all athletes are allowed to use doping, nobody is 'cheating' anymore. So allow it"

"Professional athletes depend on their performances. Don't pay the athletes anymore, and doping usage will decrease immensely"

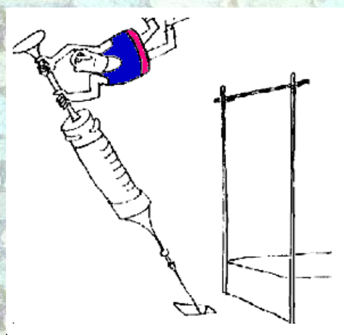
"Athletes who are caught using doping never may perform in competition, ever!"

"Top athletes are role-models. When they use doping, kids will be easier persuaded to use doping too someday"

4.8 Riccardo Ricco on his way to the doping control, Tour de France 2008 (he was found guilty and immediately disqualified)



Doping and youths
Is doping only used by the top athletes of this world?
In the USA one million US citizen already took hormone preparations without medical indication. Of them ***700,000*** between the age of 14 and 18 years!



RESEARCH PROJECT 1 GLUCOSE AND STARCH DETERMINATION

You already have learnt that glucose, a common type of sugar, is the main energy source of the cells in our body,. We obtain glucose through digesting, or in simpler terms: eating. A high percentage of the glucose that we consume comes disguised as starch. Starch is a complex carbohydrate which is insoluble in water; it is used by plants as a way to store excess glucose. The energy that is contained in starch is not directly available for the human cells. Our body is able to divide the large starch molecules into the smaller glucose molecules, which can then be transported to all cells in our body. This process takes place in the small intestine, under influence of enzymes. It takes time for the human body to extract glucose from starch. Depending on the type of starch this cutting process can take between 30 en 120 minutes. On the other hand, glucose is able find its way into the blood stream in no more than 6 minutes after eating or drinking it!

In this experiment you will determine if there is glucose or starch in six different articles of food. To demonstrate the presence of glucose and starch in each of the foods, you will use respectively iodine and Fehling A+B as **indicators**. Iodine together with starch leads to a purple-black colour. When Fehling A+B is added to glucose, the solution will change to a brown-orange colour after warming.

You will need:

- 16 test tubes
- a solution of iodine and water
- Fehling A + B
- hot water bath
- knife and plate
- milk
- sport drink
- meat
- banana
- apple
- bread
- muesli bar
- pasta

RP1.1 Fehling A+B ↑ and Iodine ↓

Procedure:

First you will do a test run to test the indicators. The teacher will give you 4 test tubes, 2 are filled with glucose, and 2 are filled with starch. Put some drops in a test tube with glucose, and some drops in a test tube with starch. What do you see? Write down your observations. After the iodine, you do the same with the fehling indicator. Put some drops of fehling in each of the solutions and put the test tubes in a warm water bath for exact **one minute**. Write down your observations. What is the effect of each of the two indicators?

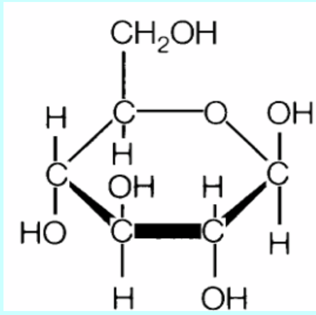
Divide the six different articles of food over the 12 test tubes. Cut all the food in very small particles and use enough of each to see the effect clearly! Don't forget to wash the plate after each cutting to prevent contamination! Add a couple of drops of Fehling A+B to the first group of six test tubes and put the test tubes in the hot water bath for exact **one minute**. The other six test tubes will be tested for starch. Add a couple of drops of the iodine solution to each of these test tubes.

Results:

Present your results in a clear **table**. Can you also make an estimation of the amount of glucose and starch in the different tubes? If so, also work out these data in your table. Answer the following questions:

- which of the tested articles of food are useful to consume during sport activities? And why?
- Which of the tested articles are better consumed after, or well before, the sport activities? And why?
- Which articles are not that useful for an athlete? And why?

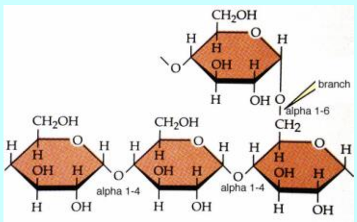
Glucose and starch



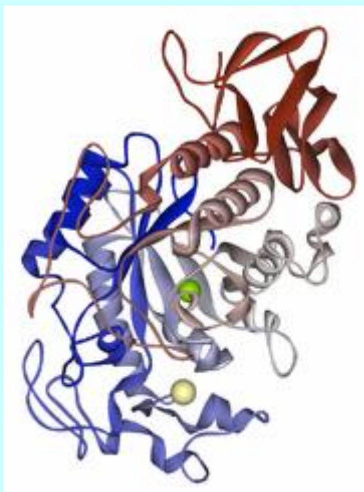
RP1.2 Glucose

A starch molecule is far too big to be digested in the human intestines. Therefore, it has to be 'cut' into smaller pieces by a substance called **amylase**. Thus, starch is reduced to glucose and maltose (another type of sugar).

RP1.3 Starch



RP1.4 Alpha-amylase enzyme



RESEARCH PROJECT 2 MEASURING YOUR HEART BEAT

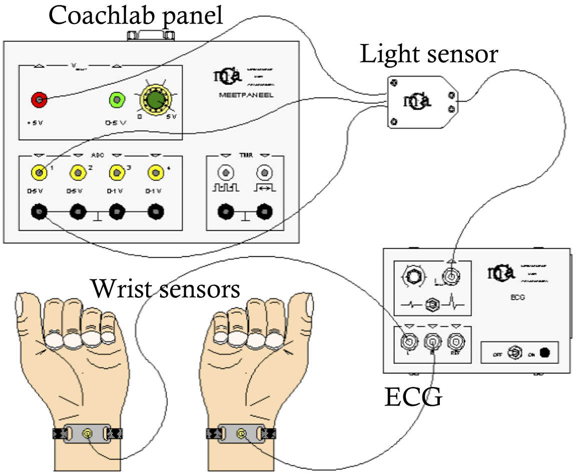
During each heart beat an electric current propagates through the human heart. It is possible to measure these electric signals. One way is to make an electro cardiogram or ECG. In this research project you will make an ECG of your own heart, and determine your heart rate in rest and during activity. What differences can you detect between these two ECG's?

You will need:

- ECG analyser with sensors
- CMA light sensor
- Coachlab II panel
- PC with IPCoach
- ECG gel
- Home trainer (optional!)

Procedure:

The test set-up is prepared for you by the teacher or an assistant. The test person has to sit on a chair. The two sensors are placed and fastened on his wrists. Use ECG gel to make a good contact between sensor and wrist.



The test set up

Now you are ready to make a read-out of the heart beat of the test person. Save the read-out in Excel, so that you can analyse it later.

Let the test person do some hard activity. Running up and down the stairs, doing a number of deep knee bends or doing a sprint on a home trainer. Immediately after the work-out, do a second ECG reading of the test person.

All three students in the group have to make these 2 ECG's!

Results:

Determine the heart rates, using the excel readings, in rest and after a work-out. Present the ECG's of all the team members in graphs. Also examine the shape of the ECG's. Can you see any difference between the ECG's? What are the differences between an ECG in rest and one after activity?

RP2.1 Coachlab II panel

RP2.2 ECG analyser with 2 electrodes

ECG measurement

Electrocardiography (ECG) measures, over time, the electrical activity of the heart. The etymology of the word is derived from the Greek *electro*, because it is related to electrical activity, *cardio*, Greek for heart, and *graph*, a Greek root meaning "to write".
The ECG works mostly by detecting and amplifying the tiny electrical changes on the skin (by using skin electrodes) that are caused when the heart muscle "depolarises" during each heart beat.

RP2.3 ECG test

RESEARCH PROJECT 3 CONCONI TEST USING THE ERGOMETER

The famous Conconi test gives the athlete insight in his energy consumption and his abilitiy to perform. Energy consumption and O_2-consumption have a clear and direct relationship. An increase in energy consumption during aerobic exercise will result in extra O_2-consumption. The intake of oxygen takes place in the lungs, subsequently the blood transports it to all parts of the body.
During exercise there will be a change in both the respiratory (lungs) as well as the cardiovascular system. We will have a closer look at these processes during the following research project.

RP3.1 Also the professional athletes rely on Concoti tests to check their condition.

You will need:

- Sport clothes (shorts, preferably cycling bibshorts, and T-shirt, sturdy shoes)
- Towel
- Heart rate monitor
- Ergometer
- Stopwatch
- Weight scale
- Bottle of water

Procedure

As it is almost impossible to do the test ánd simultaneously write down all the results, you will have to do this test in duo‘s. One rides the bike (rider), and one writes down (experimenter), looks at the time and adjust the power level at the right moments. It is very important that you read carefully what you have to do in this test. It would be very awkward when you find out during the test that you don‘t know what to do next. You would have to start all over again! The test will take approximately 20-30 minutes per student.

RP3.2 Lance Armstrong, doing the Conconi test

The test
A duo of students, consisting of a test rider and an exerimenter, will go to the bike-ergometer which has been set up at school.
During this experiment the rider will have to breathe through a cap. This way different parameters can be measured:

- The oxygen concentration of the exhaled air,
- The volumes of the inhaled and exhaled air,
- The heart beat frequency,
- The power.

With these parameters you can calculate the exercise efficiency of the rider. An average result (adult) can be seen in Table P3.1. Which of your parameters are different and how much they are different determines whether you can perform above or below normal.

		Exercise		
	Rest	Light	Medium	Heavy
Oxygen consumption(ml min^{-1})	250	1500	2800	3500
Oxygen consumption of muscles (ml min^{-1})	50	1250	2200	3150
Cardiac output (L min^{-1})	5	13	16	21
Arterio venous oxygen difference (ml L^{-1})	50	100	127	130
$P_{\bar{v}}O_2$(mmHg)	40	26	23	20
Heart rate (beats min^{-1})	72	144	160	190
Diastolic filling time (ms)	500	200	170	150
Stroke volume (ml)	70	90	100	110
Mean blood pressure (mmHg)	85	90	95	100
Pulse pressure (mmHg)	40	60	90	120
Systolic/diastolic pressure (mmHg)	110/70	130/70	155/65	180/60

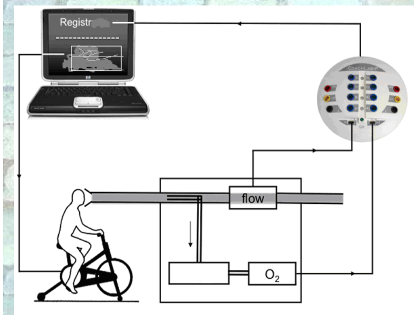
Table RP3.1. Cardiovascular and respiratory adjustments during light, middle and heavy exercise.
(J.J. Bray, Lecture Notes on Human Physiology, Blackwell Scientific Publications, Cambridge, GB, 1994 3ed, pg 691).

Test rider
The test rider will exercise on the bike-ergo meter and breath through the cap. He must try to keep on going as long as possible, al the while cycling at a constant rhythm.

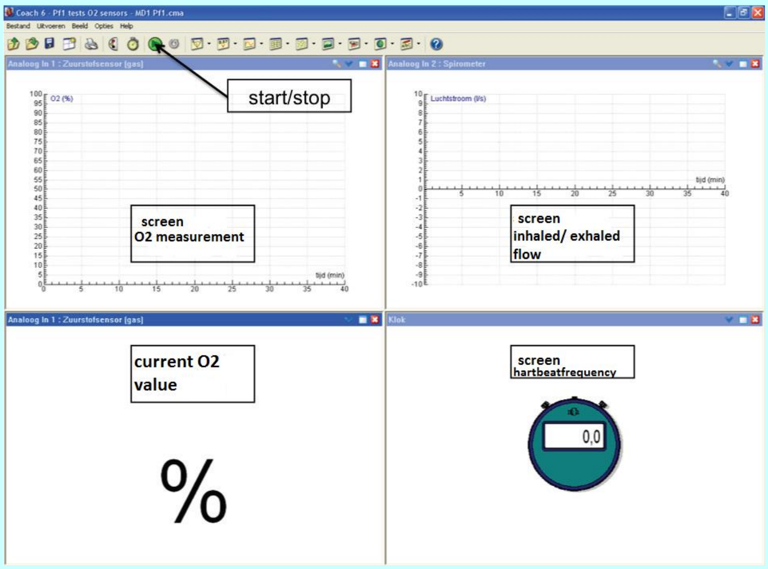
Experimenter
The experimenter has to control the protocol of the test the rider is doing. This means he will have to gradually increase the resistance of the ergo meter.

On the ergo meter you can read the time and produced power in watts and this has to be managed by the experiment leader according to the schedule further on.

The measurement of the oxygen consumption.
The exhaled air of the test rider goes to the flow meter and further on to the oxygen sensor.
The flow meter will measure the volume of the inhaled and exhaled air (litres/second) and the oxygen sensor will measure the oxygen concentration (%) in the exhaled air. Reading of the results of these sensors will be done with the help of the program 'IPCoach'.During the test the screen on the computer will look like this.



RP3.3 Schematic view of the oxygen consumption test setup



RP3.4 IPCoach screen layout

<u>How to work.</u>

1) 0-4 minutes: The measurement is started in which we measure the O_2% in the surrounding air. The test person puts on the mask without the hose.
2) 4-8 minutes: The hose is connected to the mask of the test person who remains still. (measurement at rest).
3) 8-±28 minutes: The test person starts cycling and we will begin the Conconitest (see later on) in which the resistance will be increased during the test. During the test the gears of the bike must continually be adapted to ensure that the test person continues cycling as comfortable as possible.
   Also note the heartbeat frequency during the test.
4) When the test rider cannot continue anymore, the measurement is stopped by clicking the STOP button in the coach programme
5) Save the coach registration bij clicking: "Bestand --> Opslaan als".

Classics: The Monuments
Liège-Bastogne-Liège

Also called 'La Doyenne', or 'the old lady', as the first L-B-L was organized in 1892! Being the last of the spring classics, this race is an excellent test for those cyclists who are focusing on the Giro d'Italia or the Tour de France.
The profile of this classic is filled with long climbs, which favors the climbers in the peloton. The hill 'La Redoute' is an excellent point to place a splitting acceleration. But the finish line is still a long way from there.
Living legend Bernard Hinault, 'the badger', won the snowy edition of 1980 with an impressive solo, finishing almost 10 min ahead of his competitors.

RP3.4 Bernard Hinault in action

Calculations:

6) For each stage of the Conconitest you should determine what the oxygen consumption was during that period. (in L/min.)

The Principle of the measurement of your oxygen usage

While the test person sits on the bicycle, he breathes through a mouth cap, which sends exhaled air to the flow meter and the oxygen sensor. The flow meter measures the flow in l/min and the oxygen sensor measures the absolute oxygen concentration in the exhaled air in %. The principle of measuring relies on measuring:

1. The flow of the exhaled air:

The flow measures the exhaled air in L/s. To determine the absolute volume, the surface under the graph is calculated. The result is a value with the entity: L/s*min. The quantity exhaled air per minute is now calculated as follows:

$$Flow = \frac{graph\ area \cdot 60}{total\ time},$$

with the *flow* in L/min, the *graph area* in Ls/min, and the *total time*, being the time that it took you to do the test, in min

2.**The fall of O_2-level** of the exhaled air with respect to the base O_2-level (O_2ref):

Due to the O_2-consumption of the test person the O_2-concentration of the exhaled air will be lower than that of the surrounding air. The difference will be: ΔO_2 (%).

The VO_2 in L/min can be calculated as followed:

1) The surface under the graph will be divided by the number of minutes as followed:

$$O_2 concentration = \frac{graph\ area}{total\ time},$$

with the *O_2-concentration* in %, the *graph area* in %min and the *total time* in min.

2) Because the air is dried for the O_2-measurement it has to be corrected for the change in O_2-tension with a factor 0,94:

$$\Delta O_2 = (O_2 ref \cdot 0,94) - O_2 concentration,$$

with ΔO_2 in %, *O_2ref* in% and *O_2concentration* in %

The quantity of O_2 consumed by the test person (VO_2 in L/min) can be calculated from the flow (L/s) and the difference in oxygen content, ΔO_2 (%):

$$VO_2 = \frac{DO_2 \cdot Flow}{100}$$

with VO_2 in L/min, ΔO_2 in % and the *flow* in L/min

Force and Power

Cycling and triathlon are sports where the parameters force and power have a clearly different meaning. When we talk about endurance training the most important fact is the power you can generate during for instance one hour.
For a male person of 75 kg, one can generally state power as follows:

non sporters	*150 W*
Sportive person	*225 W*
Well trained cylist	*300W*
Amateur-cyclist	*375 W*
Top Amateur	*425 W*
pro-cyclist	*500 W*

For women, these values are approximately 10-15% lower. Especially in mountainous terrain the relative power (W / kg) is much more important than the absolute power (Watts). On the other hand, in flat areas the absolute power and aerodynamics of the cyclist will form much more decisive factors

Professor Francesco Conconi

This Italian sports doctor and scientist gained fame in the 80's when he prepared the Italian cyclist Francesco Moser in his, successful attempt, to break the world hour record, partly by introducing new training techniques. During the 90's his name was frequently mentioned in relation with cyclists which were using the, then, unknown doping EPO.

7) Then derive from this number the produced energy. (Joules)
   - You can use the IPCoach program to do this by calculating the surface of the area beneath the graph. Then determine the oxygen consumption and from this you can determine the energy production if you know that 1 litre of oxygen will produce 20 kJ of energy.
8) Draw the graph of the relationship between the power and the produced energy in the figure beneath. Determine your efficiency at each stage. (%)
9) After a good shower and some well deserved rest you are now ready to work out the data. Make, in Excel, a graph with the power on the x-axis, and the heart rates on the y-axis. If all went well you are able to draw a nice straight line through the data points. Except for the last couple of points, which bend from the straight line. Try to determine the point at which these last measuring points start to deviate from the straight line. That point of deflection is called the anaerobic threshold.

From all the data you have obtained in this experiment you must determine your own statistics :

	My results (choose the correct unit)
I. What was your VO_2max?	
II. What was your maximum heartbeat	
III. What was your maximum power?	
IV. What was your heart rate at your VO_2max?	
V. What is your anaerobic threshold?	
VI. Determine your heart rate at your anaerobic threshold	
VII. At what value does the line in the graph you made cross the X-axis? What does this point mean?	
VIII. What is the efficiency of your respiration at your maximum heart rate?	
IX. What is the efficiency of your respiration at your anaerobic threshold point?	

RP3.5
World record 100 m dash:
 *Usain Bolt 9.59 s*

World record marathon
 *Patrick Makau 2:03:38*
RP3.6

The author

Martijn Leensen (27-5-1972) studied Applied Physics and Environmental technology before embarking on a teaching career.
Cycling is one of his most valued hobby's. In an active way (he competed in amateur races in his early adulthood) and passively, as a spectator.

RP3.8 The author with another ass

RESEARCH PROJECT 4 MEASURING THE DRAG RESISTANCE

When you are riding a bike, you are constantly battling the resistance forces on you and the bike. In this experiment you will measure the magnitude of these forces. To do that you will use the **second law of Newton**, in which a relation is described between the force acting on an object (bike + rider), the mass of the object and the acceleration of this object:

$$F = m \cdot a$$

Eq RP3.1

In other words, when there is acting a **net force** on an object, this object will accelerate!

The (average) **acceleration** of an object is defined as:

$$a_{avg} = \frac{\Delta v}{\Delta t}$$

Eq RP3.2

Or in words: the acceleration is equal to the difference in velocity of an object in a certain period of time, divided by the amount of time. You will try to answer one or more of the following research questions:

- What is the relation between the resistance force and the size and weight of the cyclist?
- What is the relation between the resistance force and the posture of the cyclist?
- What is the relation between the resistance force and type of bike?
- What is the relation between the pressure in the tires and the total resistance?

Before you start your experiment you will have to discuss with your teacher about which research question(s) you will try to answer!

You will need:

To do this experiment you will need:

- At least one bike with a digital speed meter
- One or more test driver(s)
- A weight scale
- A stopwatch
- A test circuit of 50 metres of undisturbed road

Procedure:

The test driver is cycling with a constant velocity. The moment he enters the test circuit, the cyclist **stops cycling**, and he looks at the speed meter to read of his speed. At the end, the cyclist is again reading the speed of his bike. At the same time, a team member is

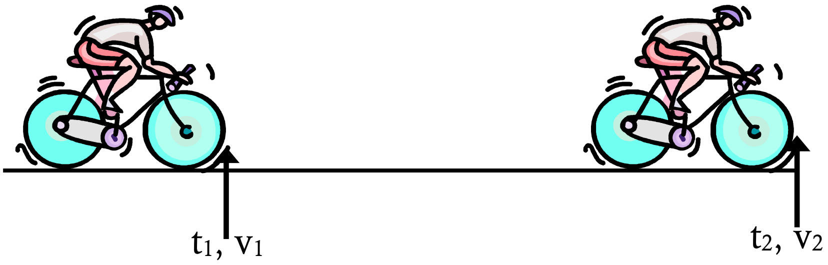
Acceleration

Acceleration, or **a,** is a **vector** quantity, this means that force always has a magnitude and a direction. A negative acceleration is also called a deceleration.
The unit of acceleration is **m/s^2**. When you are falling, your acceleration will be around 9,81 m/s^2, meaning that every second you are falling, your velocity will increase with 9,81 m/s (disregarding any air resistance!).

RP4.1 Minimising drag resistance: By using a very low steer with long handle bars (triathlon bars) …

… André Greipel is reducing his frontal area and thus his drag resistance.

recording the time that it takes the test cyclist to do the 50 meters on the test circuit.



To calculate the average acceleration of the test rider, use this equation:

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{v_2 - v_1}{t_{stopwatch}}$$

Eq RP3.3

A couple of important notes when doing the test runs:

- **Repeat** your measurements. It is better to measure each situation 3 times, and afterwards average your results
- Change the length of your test run, when needed. When the run is chosen too short, you will hardly measure a difference in the velocity. When the run is too long, the acceleration will probably vary too much, and it will be harder to get nice results.
- Don't forget that wind can have a profound effect on your results. For better results, perform the tests with the wind in your face, if possible.
- All measured accelerations must be negative, as the rider is decelerating when he is not cycling.

When you have calculated a_{avg} from your measurements, you are ready to calculate the resistance force. Don't forget to also weigh the test driver with bicycle! Your resulting forces will have a negative sign, which is quite logical. The resistance force is always directed in the opposite direction of the velocity, so it will always be a negative sign.

Results

The result is in the form of a proper research rapport that includes:

- What is your research question?
- How did you do the tests? What decisions did you make, and why?
- Present your results in clear tables (Word) and graphs (Excel). Show **all** your measurement results in the tables. Also investigate the relations that you have found in the graphs. Is the function a linear function, an exponential function, etc? Can you maybe give an equation of the found relation?
- Conclude with a clear answer on the research question(s).

RP4.2 High rolling resistance

RP4.3 Low drag resistance

Classics: The Monuments
Giro di Lombardia

Being the only autumn classic of the big 5, its nick name is 'la classica delle foglie morte', or 'the race of the falling leaves'.
A heavy route with hills and mountains often leads to a drastic selection in the peloton. Those cyclists who aspire to end their season with a victory will have to possess all-round qualities. The route also leads over the 'Ghisallo' hill, past the church of the 'Madonna del Ghisallo', the patron saint of all cyclists

RP4.4 Madonna del Ghisallo

RESEARCH PROJECT 5 MATHEMATICAL CYCLING MODEL

In this research project you will use a mathematical model to investigate the relations between different physical parameters during cycling. The calculator that you will use can be found at:
http://bikecalculator.com/veloMetric.html

We will use the metric units. Always select 'metric units' at the top. Furthermore we will concentrate on riding a racing bike only. In this project you will answer three research questions:

Research question 1: what is the relation between the power and the velocity of a cyclist?

To answer this question, fill in **your** length and weight as the length and weight of the cyclist. Work with a bicycle weight of 9,0 kg, an air temperature of 20º C and a height of 1 meter above sea level. There is no slope in the road, and no wind. Choose 'hands on the drops' and 'narrow racing tire' for frond and rear wheel. Now you are ready to do some measurements! Fill in a value of 25 W as the cyclist's power. By pressing 'calculate' you can read the velocity of the cyclist (that is you) when he is generating 25 W of power.

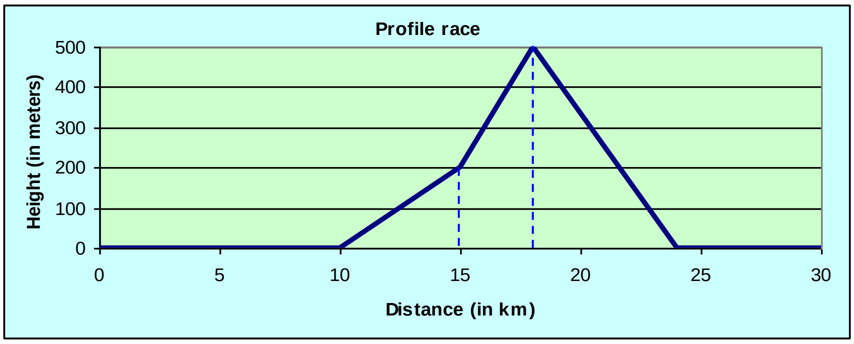
Increase the power in steps and calculate the velocity at each power level. Present your results in a table and a graph. Investigate the relation that you have found in the graph. Is the function a linear function, an exponential function, etc? Can you give an equation of the found relation?

Research question 2: Which of the two riders will win the race?

Look at the table of two cyclists and the graph showing the profile of the stage. Both riders will give their 100% over the 30 km track. Make a **distance-time graph** with both riders in it. Use this graph to answer these questions:
Who of the two cyclists will win the race?
Who will be the first at the top of the hill?

	Ben 'the bull'	Eddy 'the eagle'
weight	82 kg	60 kg
length	1,90	1,65
Power-to-weight ratio	5,0 W/kg	6,0 W/kg
Weight bike	8,0 kg	7,5 kg

Table RP4.1

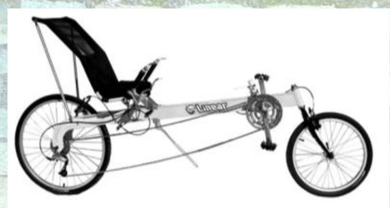


Graph RP4.1

RP5.1 Roadster

RP5.2 MTB

RP5.3 Tandem



RP5.4 Recumbent

Research question 3:

Now that you know how this calculator works, you are able to do a research by yourself. Make a research plan: formulate a question that you can answer using this calculator. Write down your research question, a hypothesis (what do you think will be the answer) and how you are going to do this research (what relationship(s) will you try to look at). How will you present your results?

Before you start your research, you will first discuss your research plan with the teacher.

Some ideas for a research:

- What is the effect of the choice of tires on the velocity?
- What is the relation between air friction and rolling friction at different speeds
- Greg Lemond won the 1989 Tour de France by 8 seconds. During the last time trial of 24 km he was the only one using a triathlon bar. Was this triathlon bar decisive for Lemond?
- What is the effect of doing a 1 hour record try in Mexico City, at 2338m above sea level, compared to sea level?
- Will you achieve higher speeds on a tandem, on a recumbent or on a racing bike? Can you also explain why?
- Etc…

Present your results in clear tables and graphs. Give a quantitative conclusion (that is: with numbers and relationships) based on your measurements.

RP5.5 Francesco Moser, beating the World hour record in Mexico City, 1984

RP5.6 Greg Lemond, in the Tour de France time trial in1989, using a triathlon bar for the first time and in this way winning the Tour de France by only 8 seconds.

RP5.7 World championships tandem race, 1970

RESEARCH PROJECT 6 OSMOSIS AND SPORT DRINKS

Are sport drinks what they say they are? Ideally, sport drinks should be isotonic to have the biggest effect. Isotonic fluids are quickly taken up by the human intestines. In this test you will test three sport drinks. Are they really isotonic drinks? We will use blood cells from a cow, as the fluids inside these cells have the same molarity as the human cells. We will use cow blood cells as a **model** of human tissue. When red blood cells are left in a fluid the cells will stays the same, decreases in size or increase in volume depending on the concentration of the fluid.

What will happen to the red bloodcells when:

- it is put in an isotonic solution?
- it is put in a hypotonic solution?
- it is put in a hypertonic solution?

First check your answers on these questions before you can proceed!

You will need:

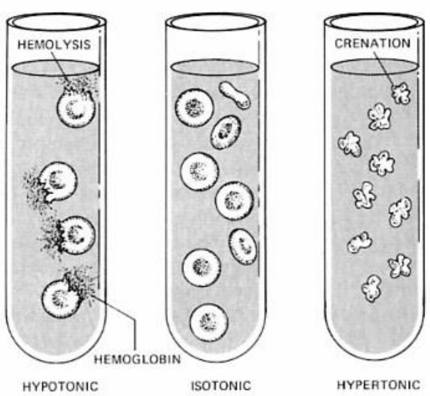
- blood from a cow
- salt solutions (0,0 %, 0,9%, 4%)
- three different brands of sport drinks
- 7 test tubes
- Pincer
- Set square
- microscope

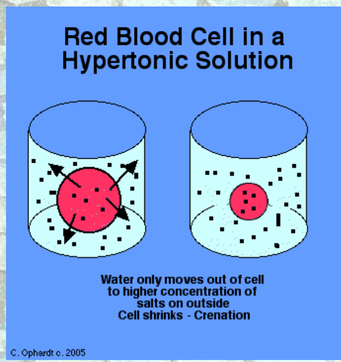
Procedure

First put 3 cc of the different salt solutions in a different test tube and also fill three test tubes with 3 cc of each of the 3 sport drinks. Don‘t forget to mark your tubes! Then add to the 6 test tubes 2 cc of the cow blood. Let the tubes rest for 24 hours.
After that time investigate the results. Take a microscope and compare the red blood cells of the three salt solutions using a magnification of 400x. First look at normal red blood cells.
Then you look at the red blood cells in the other salt solution. Make a drawing. Also write near each of the drawings what your drawing is representing, the magnification and the date and your name.

What will the red blood cells in the sport drinks look like? Compare the results of the different test tubes and draw your conclusions. Are all three sport drinks indeed isotonic?

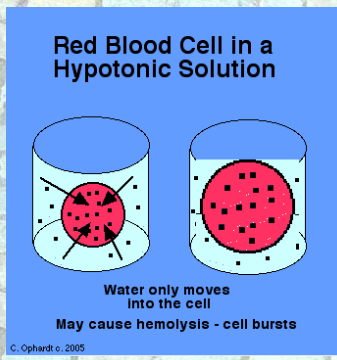
RP6.4 Blood cells and osmosis



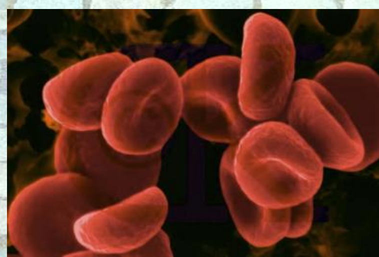


RP6.1 Crenation ↑

RP6.2 Hemolysis ↓



RP6.3 Human red blood cells



Results

Present your measurements in the form of a scientific report.
In the results section you should present the drawing of the tubes after 24hours and the drawing of the red blood cells of interest.
Make a conclusion based on your findings. In the evaluation you can point out:

- Which salt solutions were hypertonic, isotonic and hypotonic.
- What does this result mean for your total body and what does it mean for your sporting capacity?
- What will the red blood cells in the three isotonic drinks look like?
- Which of the sport drinks are isotonic, and which are hyper- or hypotonic according to the label.
- Are the sport drinks what they claim they are?

Alberto Contador

Without doubt, the Spanish Alberto Contador is the best stage racer of this time. At an age of 27, he already won the Tour the France 3 times, ánd the Vuelta and the Giro d'Italia. He is the only cyclist to win all three 'Grand Tours' within a time span of just 14 months.

RP6.4 Contador during the prologue of the Tour de France 2010

RESEARCH PROJECT 7 CO_2 USAGE DURING ACTIVITY

In this project we will take a look at the CO_2 (carbon dioxide) concentrations in the air we breathe out. To examine this we need to know a little bit more about the chemistry behind this all.

For this examination we will use **phenolphthalein.** Phenolphthalein has been used for over a century as a laxative, but is now being removed from the market because it is carcinogenic.

Phenolphthalein is a sensitive acidity (pH) indicator with the formula $C_{20}H_{14}O_4$. It can change into different colours, depending on the acidity of the solution. Phenolphthalein can thus act as an indicator, it can tell us something about the solution we want to investigate. First, what is meant by the 'acidity' of a solution?

The pH scale is a measure of the acidity, it is derived from the hydrogen (H+) ion concentration. It spans from 0 to 14 with the middle point (pH 7) being neutral (neither acidic or basic). Tap water has a pH of 7.

Any solution with a pH number **greater than 7** is considered a **base** **a**nd any pH number **less than 7** is considered an **acid**. 0 is the strongest acid and 14 is the strongest base.

In this test we are using Phenolphthalein as an acid-base indicator. It changes colour in solutions of different pH values. There are many possible acid-base indicators. For example; Bromophenol blue is an acid- base indicator whose useful range as an indicator lies between pH 6.2 and 7.6. It changes from yellow at pH 6.2 to blue at pH 7.6, and this reaction is reversible.

Question:
What colour will Bromophenol blue have when the acidity is 6.8? (green)

Question:
Why is it important that the reaction of Bromophenol blue is reversible?

Look up in the table which 2 colours a fenolftalein-solution can have and in which circumstances these colours will appear.

Question:
Does phenolphthalein change colour in a acid or a base solution?

Indicator	pH Range	Quantity per 10 ml	Acid	Base
Methyl yellow	2.9-4.0	1 drop 0.1% soln. in 90% alc.	red	yellow
Methyl orange	3.1-4.4	1 drop 0.1% aq. soln.	red	orange
Chlorphenol red	5.4-6.8	1 drop 0.1% aq. soln.	yellow	red
Bromphenol blue	6.2-7.6	1 drop 0.1% aq. soln.	yellow	blue
Neutral red	6.8-8.0	1 drop 0.1% soln. in 70% alc.	red	yellow
Phenolphthalein	8.0-10.0	1-5 drops 0.1% soln. in 70% alc.	colorless	red
Nile blue	10.1-11.1	1 drop 0.1% aq. soln.	blue	red
Tropeolin O	11.0-13.0	1 drop 0.1% aq. soln.	yellow	orange-brown
Trinitrobenzoic acid	12.0-13.4	1 drop 0.1% aq. soln.	colorless	orange-red

RP7.1 Alkanine detergents

What does pH mean?

Acidic and basic are two extremes that describe chemicals, just like hot and cold are two extremes that describe temperature. Mixing acids and bases can cancel out their extreme effects; much like mixing hot and cold water can even out the water temperature. A substance that is neither acidic nor basic is neutral.

The pH scale measures how acidic or basic a substance is. It ranges from 0 to 14. A pH of 7 is neutral. A pH less than 7 is acidic, and a pH greater than 7 is basic. Each whole pH value below 7 is ten times more acidic than the next higher value. The same holds true for pH values above 7, each of which is ten times more alkaline—another way to say basic—than the next lower whole value.

RP7.2 A car battery, very acidic!

In the following experiment we will use Phenolphthalein as an indicator. The CO_2 in the air reacts in water to H_2CO_3 and this can split in H^+ and HCO_3, this way increasing the amount of H^+ in the solution. As the amount of H^+ is increasing (and thus the solution becoming more acidic), the colour of the Phenolphthalein will change. This reaction we will use to determine the amount of CO_2 that is present in a solution.

CO2-production during physical exercises

Introduction

During physical exercises the body uses a part of its energy reserves in the muscle cells, in the form of monosaccharides. Someone who wants to lose weight can do this by eating less or one can exercise more. You can already measure this weight loss after a few weeks of exercising. In this assignment you will measure the amount of energy that is created by measuring the carbon dioxide in the air that exits your mouth. Remember, carbon dioxide is a waste product of the human aerobic respiration!

Using a sodium hydroxide-solution and a Phenolphthalein solution the concentration of carbon dioxide can be measured. A sodium hydroxide-solution is basic and will make the Phenolphthalein in the solution to become pink or purple-red. Carbon dioxide reacts with sodium hydroxide in the solution and will make the solution more acidic. The Phenolphthalein will become colourless.

To test our results you will also measure the CO_2 concentration using a CO_2 sensor.

You will need

- plastic bag with sealable tube
- Erlenmeyer (250 ml) with matching drilled fuse and matching tube
- syringe (10 ml)
- measuring cylinder (100 ml)
- dripping bottle with Phenolphthalein solution
- 0,001 M sodium hydroxide-solution (keep the solution inside the closed bottle as much as possible)
- white paper
- watch or stopwatch

Procedure

With use of the following method, you will measure the difference of the concentration of carbon dioxide during exhalation between a test person in rest and a test person after he has carried out 30 squats (kneebends). First the amount of carbondioxide in rest will be determined.

- Put 50 ml from a 0,001 M sodium hydroxide-solution in a erlenmeyer
- flask of 250 ml.
- Add to this solution in the erlenmeyer flask three drops of
- Phenolphthalein solution. Put the erlenmeyer flask on a white paper so that the colour of the solution can be well observed.

Concentration of hydrogen ions compared to distilled water		Examples of solutions at this pH
10,000,000	pH = 0	Battery acid, strong hydrofluoric acid
1,000,000	pH = 1	Hydrochloric acid secerted by stomach lining
100,000	pH = 2	Lemon juice, gastric acid, vinegar
10,000	pH = 3	Grapefruit, orange juice, soda
1,000	pH = 4	Tomato juice, acid rain
100	pH = 5	Soft drinking water, black coffee
10	pH = 6	Urine, saliva
1	pH = 7	"Pure" water
1/10	pH = 8	Seawater
1/100	pH = 9	Baking soda
1/1,000	pH = 10	Great Salt Lake, milk of magnesia
1/10,000	pH = 11	Ammonia solution
1/100,000	pH = 12	Soapy water
1/1,000,000	pH = 13	Bleach, oven cleaner
1/10,000,000	pH = 14	Liquid drain cleaner

RP7.3 The pH scale

The 'Grand Tours'

There are cyclists who excel in 1-day competitions, the classics. But the most famous personalities in cycling's rich history are those who were able to win one or more of the three 'Grand Tours':

la Vuelta,
il Giro and of course
la Tour de France.

All three competitions have a duration of three weeks and a rich history. Cyclists will be heavily tested on their time trial skills, their climbing skills and their ability to swiftly recover from the agonies of each racing day.
Eddy Mercks was able to win a staggering total of 11 Grand Tours.

Giro d'Italia centoanni

- Close the erlenmeyer flask with a drilled fuse with a tube. Take care that the plastic bag contains no air.
- Collect some exhaled air from the test person in the plastic bag. Take care that only the last half of the volume of exhaled air is blown into the plastic bag. The first half is of no use. Do not breath in too deep before you exhale. Take a normal breath, otherwise the result cannot be used for the experiment.
- Push a bit of the collected air from the plastic bag and quickly
- connect the syringe with the tube on the bag.
- Fill the syringe with 10 ml of air from the bag. Keep the tube on the bag as much closed as possible.
- Connect the syringe with the erlenmeyer flask and squirt 5 ml of airfrom the syringe into the erlenmeyer flask. Keep from now on a count of the total volume of injected air.
- Vigorously shake the content of the erlenmeyer flask for 10 seconds.
- Leave the syringe attached to the erlenmeyer flask.
- Squirt another 5 ml of air into the erlenmeyer flask and again shake it forcefully for 10 seconds.
- Repeat this procedure until the solution in the erlenmeyer-flask is starting to de-colour. Now decrease the amount of air-intake in each cycle to only 2ml. Stop with injecting when the solution has lost all its colour.
- Calculate the amount of injected air and use the table below to determine the total amount of carbon dioxide.
- Clean all tools and repeat this determination with exhaled air after exercise.

ml sodium-hydroxide used	Amount of CO_2 that has reacted	Volume of gas CO_2
5	0,005 mmol	0,112 ml
10	0,010 mmol	0,224 ml
15	0,015 mmol	0,336 ml
20	0,020 mmol	0,448 ml
25	0,025 mmol	0,560 ml
30	0,030 mmol	0,672 ml
35	0,035 mmol	0,784 ml
40	0,040 mmol	0,896 ml
45	0,045 mmol	1,006 ml
50	0,050 mmol	1,118 ml

Also determine the CO_2 concentration both in exhaled air after the Coconi (research project 3) exercise and in exhaled air in a normal situation by using the CO_2-sensor.

Acid rain

RP7.4 Eroded statue due to acid rain

Acid rain is one of the most dangerous and widespread forms of pollution. Technically, acid rain is rain that has a larger amount of acid in it than what is considered as normal. In many places in Europe and Northern America the rain can be ten to seventy times more acid than unpolluted rain. Many living and non-living systems are harmed as a result of acid rain. Whole forests die, and architecture can be severely damaged by it.

Acid rain is caused by smoke and gases that are given off by factories and cars that run on fossil fuels. The sulfur that is present in the fuel combines with oxygen and becomes sulfur dioxide. Some of the nitrogen in the air becomes nitrogen oxide. These pollutants go into the atmosphere, and become acids (see also *RP7.5* on page 53).

Singing in the Acid Rain.

Results

Make a report of this investigation according to the scientific method. The way such a report should be build up is as follows; Define the question – Hypothesis – Materials and Method – Results – conclusion

TIP1: Put the results off the experiment in a table.

TIP2: Put the answers to the following questions in the correct section of your scientific report.

1. Calculate the increase or decrease (percentual) in the total amount of carbon dioxide between the exhaled air in rest and after some heavy exercise.
2. Explain why the sodium hydroxide-solution has to be kept in a sealed bottle.
3. Explain why the exhaled air in both cases has to come from the same person.
4. Presume that this experiment was performed with two persons from the same weight and age. One is a trained athlete and the other, which does not do in sports at al, is living a sitting, inactive life. How will the carbon dioxide amount in the exhaled air after exercise relate between these two persons? Explain your answer.
5. Compare the results of the chemical measurement and the CO2 sensor measurement.

$SO_2 + ½O_2 + H_2O \rightarrow H2SO4$

$H_2SO_2 \rightarrow 2H^+ + SO_4^{2-}$

similarly

$2NO_2 + ½ O_2 + H_2O \rightarrow 2 HNO_3$

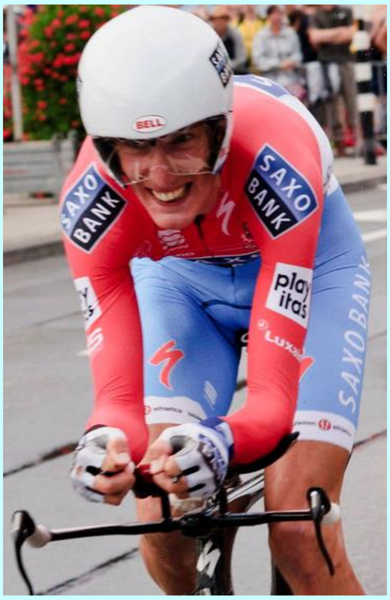
$HNO_3 \rightarrow H^+ + NO_3^-$

RP7.5 Reactions in the atmosphere, leading to acid rain

Andy Schleck

The flamboyant Luxembourgian Andy Schleck is considered to be one of the most talented young riders at this moment. Only a good Contador can compete with Schleck in the 'Great Tours'. After 3 second places in the 'Grand Tours' it can only be a matter of time before Schleck will win one of them.

RP7.6 Prologue Tour de France, 2010



APPENDIX: HOW TO MAKE A SCIENTIFIC REPORT

An important part of an investigation is the report. The meaning of this report is that:

- The reader gets a clear and fast impression of what has happened
- The maker of the report knows exactly what he has done, in which way and in which order.
- Another researcher can repeat this experiment in exactly the same way, so that he is able to double check the results

Make the scientific report always according to a standard set-up.

Reports will be checked on neatness, language and content

1. Titlepage
- Title (possibly with subtitels)
- Name of the researchers
- Date
- Class

2. Research question
- A research question is formulated
- Here you put down the question which you want to answer in this experiment
- Preferably not more than one sentence

3. Introduction
- First you start reading about the subject of your experiment, to know more about your subject.
- The important data which apply to your research question are worked out into a nice introduction.

4. Hypothesis
- Before you start the experiment you normally have some expectations about what will occur (from the literature, or just gut feeling).
- Here you write down a probable answer on the research question
- The hypothesis will help you to construct a good experiment

5. The experiment
- Start with putting down a list of essentials
- Then think of how you will perform the experiment.
- Add a drawing of your set-up to clarify things
- How have you performed the experiment. (Write it down in such a way that someone who does not know this experiment can perform the experiment in the exact same way as you did, by means of this report)
- Always perform a double blind experiment, if possible!!!

Vincenzo Nibali

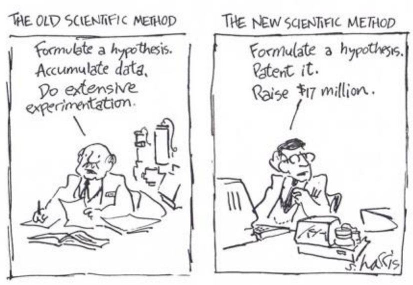
Nicknamed ‘the shark’, Sicilian Vincenzo Nibali is the hope of all Italian tifosi. He is expected to fill the gap left by Marco Pantani, Italy’s last winner of the Tour de France (1998).

In 2010 he was called at the last moment, whilst he was relaxing on the beach, to substitute another cyclist in the Giro d’Italia. Nevertheless he finished with a very respectable 3th place.

Since then he has won the Giro, as well as the Vuelta.

A1 Vincenzo Nibali, concentrating before the Giro time trial, 2010

A2 The Scientific Method explained…



6. Results

This part of the report delivers the results of your experiment. Some points of attention are:

- Put down only facts, not your interpretation. So keep the results and your conclusion strictly divided.
- Preferably use tables and/or graphs, wherever possible.

7. Conclusions

Here you answer your research question, based on your experiment.

8. Evaluation

This is the most important part of the scientific report because it contains your interpretation on the whole subject.

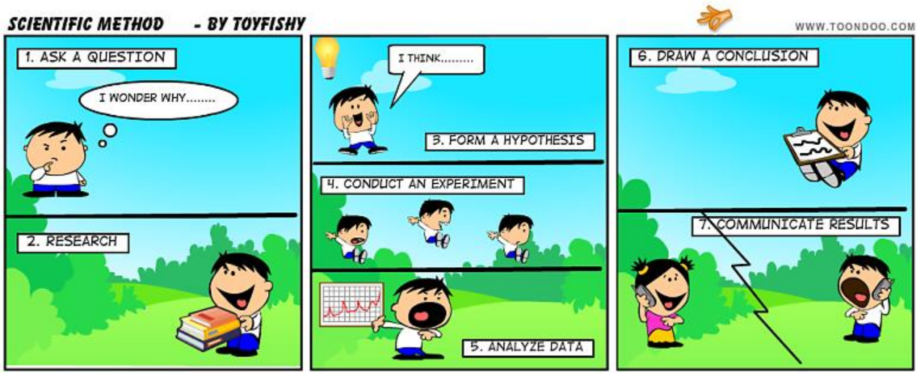
- You discuss your hypothesis.
- Should the experiment have failed in a way or does it look to be incorrect, try to tell what might have gone wrong.
- Make suggestions for possible further researchers

9.Literature

Make the literature list as follows:

Surname writer, initials, name book or article, Publisher, year, print.
Example:
Janssen P.J. ,
Wonderful life, Wolters Noordhoff, 1995, 4th print.

Websites as follows: address, maker, title, date
Example: http://www.biology.arizona.edu/ D.Brown, Biology Site, okt 1997



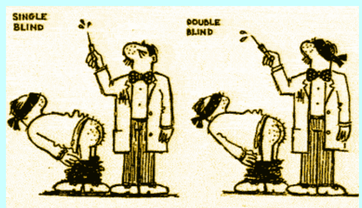
"You are completely free to carry out whatever research you want, so long as you come to these conclusions."

Double blind experiments

In a double-blind experiment, neither the individuals (that are tested) nor the researchers know who belongs to the control group and the experimental group. Only after all the data have been recorded do the researchers learn which individuals are which.

Performing an experiment in double-blind fashion is a way to lessen the influence of the prejudices and unintentional physical cues on the results. The key that identifies the subjects and which group they belonged to is kept by a third party (the teacher) and not given to the researchers until the study is over.

Double-blind methods can be applied to any experimental situation where there is the possibility that the results will be affected by conscious or unconscious bias on the part of the experimenter.



NOTES:

NOTES:


Rabobank
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Skoda
GIANT