Module 4

The bionic human

Table of contents

Page

Objectives

On successful completion of this module, you should be able to:

- describe the operation of some simple direct current devices
- identify and explain the key components of the human circulatory system
- describe the operation of the human heart
- describe the operation of a pace-maker
- describe the components and operation of the human skeletal and muscular systems.
- describe the technology that is used to repair human bones and joints.

Key concepts

• red blood cells
• plasma
• arterioles
• veins
• white blood cells
• blood type
• capillaries
• voltage
• platelets
• arteries
• veinules
• current

Introduction

Perhaps some of you remember the television series '*The six million dollar man*' which used to be screened in the 1970s. In this series Steve Austin (played by Lee Majors) experiences a near fatal aircraft accident. He is 'repaired' using bionic limbs which are able to provide him with superhuman strength. The ideas expressed in this television series are rapidly becoming a reality. Technology is increasingly being used to repair parts of the human body. In this module we will investigate some of this technology and how it is currently used in the human body.

4.1 Have a heart

Heart disease is one of the most common causes of death in the Western world. Until recently problems with the heart meant almost certain death. Now there are many techniques available that overcome some of the more common physical problems associated with the human heart, some of these include operations on the heart and even entire heart transplants. In this section we will examine some applications of technology that help to address heart problems.

4.1.1 The circulatory system

In section 2.3.1 – The human respiratory system, we discussed its role in the provision of oxygen to cells. We found that all cells require oxygen in order to create the energy needed to undertake their basic functions. This oxygen is absorbed into the blood through the tissues surrounding the alveoli. Our blood is then pumped around the body through a series of tube-like structures and as such is able to deliver the much needed oxygen to the cells and take from the cells wastes including carbon dioxide. Our circulatory system includes those organs that are associated with this delivery of blood throughout the body.

Scientists have not always believed that our blood circulated through the body. In the middle ages, it was believed that our blood did not circulate, but that it was produced by both the heart and the liver. The heart provided 'vital blood' that was sent to the rest of the body through the arteries (the heart was believed to be the 'spiritual centre' of our body), while the liver produced 'nutritive blood' that was sent to vital organs via the veins. William Harvey (1578) was able to dispel this belief through some simple observations and mathematics. Removing the heart from human cadavers he showed that the heart usually contained about 280 ml of blood in its four chambers. Since the average number of heart beats every minute is 72 and each chamber holds approximately 70 ml, Harvey reckoned that the heart would have to produce $72 \times 60 \times 24 \times 70 = 7\ 257\ 600$ ml of blood each day. Such a huge volume (7 257 l) is obviously impossible, and he concluded that in fact the blood circulated around the body and the heart actually pumped the blood.

Scientists now realize that the human circulatory system consists of the following main components:

1. The blood that carries oxygen, food, and hormones to our cells and carries waste products from our cells.
2. The heart, which is actually two pumps in one organ. One part of the heart pumps deoxygenated blood (blood without much oxygen but with a lot of carbon dioxide) to the lungs. The other part of the heart pumps oxygenated blood to the rest of the body.
3. Blood vessels that carry the blood around the body.
4. A number of organs that interact with the blood, putting in or taking out substances.

We will discuss each of these components in more detail below.

The blood

What do you know about blood? When we cut ourselves initially the blood ows and then clots will occur that stop this ow. Blood is normally red. Scientists believe that blood is made up of four main components

1. **Red blood cells** – are necessary for carrying the oxygen around our body. They contain a substance called haemoglobin which is made up of the element iron. Iron is an element that reacts easily with oxygen (e.g. rust) and carbon dioxide and so is ideal for transporting the oxygen and carbon dioxide molecules around our body.

Figure 4.1: Red blood cells

This image has been removed for copyright reasons. By following the reference link below, you may be able to find the original image.

(Source: *Lifeblood*)

2. **White blood cells** – carry antibodies around the body that are used to fight off infection.

Figure 4.2: White blood cells

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(Source: *Lifeblood*)

3. **Platelets** – these are irregular shaped cells that stick together and block cuts in our body.

Figure 4.3: Platelets

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(Source: *Lifeblood*)

4. **Plasma** – this is a straw coloured liquid that makes up about 55% of our blood.

Do you know what your **blood type** is? You might have heard of people who are say O positive, or perhaps B negative. What do these mean? An Austrian scientist, Karl Landsteiner, in the early 20th century found that while human blood contained all of the main components listed above, the red blood cells of people differed slightly. Some people contained a distinct molecule (which he called the A antigen) on the surface of their red blood cells, other people contained another type of molecule (which he called the B antigen), others contained both types of molecules , while still others contained neither of these molecules. Subsequent to this scientists have also found that some people's blood contains a protein which is also found in Rhesus monkeys, while others do not have this protein. Based on the existence of these molecules and proteins, scientists have formed the following eight categories of blood:

Table 4.1: Categories of human blood and the percentage of the population with each type of blood

	Rhesus factor		
	Contains Rhesus protein Rh+	Does not contain Rhesus protein Rh–	Total

A or B molecules	A	Contains A molecule	A+	34%	A–	6%	40%
	B	Contains B molecule	B+	10%	B–	2%	12%
	AB	Contains both A and B molecules	AB+	4%	AB–	1%	5%
	O	Contains neither A nor B molecule	O+	37%	O–	6%	43%
		Total		85%		15%	100%

Of course people with exactly the same type of blood can share their blood; however it is possible for some people to take other types of blood. For example, the blood type 0– can be taken by all people, while the blood type AB+ can only be taken by people with AB+ blood. This is because when our body detects unusual substances in our blood, it tries to destroy these. So a person who has O– blood, has no Rhesus protein nor A and B antigens. If they receive a transfusion of blood that contains some of these substances, their immune system will attempt to destroy this blood.

The heart

Did you know that the heart was actually two pumps in one? One on the right hand side that pumps blood to the lungs and one on the left hand side that pumps blood to the body. It is a very efficient pump which beats approximately 100 000 times each day and pumps approximately 9000 l of blood in this time. The heart has a mass of approximately 340 g and is about the size of a clenched fist. It consists of four chambers, the right and left ventricles, and the right and left atria. The flow of blood in the heart is shown in figure 4.4. This figure shows on the right hand side that blood flows into the right atrium of the heart from two major veins (the superior vena cava and the inferior vena cava). A contraction of the muscle on the right hand side will cause this blood to flow through the one-way tricuspid valve into the right ventricle. A further contraction of this muscle will then cause the blood in this chamber to flow out of the pulmonic valve, through the pulmonary arteries and to the lungs. In the lungs it ‘picks up’ oxygen and leaves carbon dioxide. This oxygen rich blood then flows back to the left atrium of the heart via the pulmonary veins. A contraction of the muscle on the left side of the heart will cause the blood in this chamber to flow through the mitral valve into the left ventricle. A further contraction of this muscle will then cause the blood in this chamber to flow through the aortic valve, and into the body’s major artery, the aorta. A more realistic diagram of the heart is shown in figure 4.5.

Figure 4.4: Schematic of blood flow

This image has been removed for copyright reasons. By following the reference link below, you may be able to find the original image.

(Source: Aubuchon 2004)

Figure 4.5: Model of the human heart

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(Source: Aubuchon, *Human heart diagram*)

Blood vessels

Our blood travels around the body in an extensive network of tube like structures. The blood leaves the heart via **arteries**; it then branches into smaller arteries (**arterioles**) and finally runs into the **capillaries**. These capillaries then run into small veins (**veinules**) and then **veins**, which take the blood back to the heart.

Arteries have a smooth inner layer and also contain a strong muscular layer. As the heart beats, the muscles on the walls of our arteries also contract and assist in moving the blood around the body. When we take a pulse, for example, we do so by counting the contractions on our arteries. Our largest artery is the aorta which flows directly out of the heart and takes oxygen rich blood to the body.

All of our tissues contain capillaries. They are extremely narrow, in fact the blood cells travel through capillaries in single file. It is in the capillaries that the cells obtain from the blood their required oxygen and food, and deposit their unwanted carbon dioxide and wastes. Blood from the capillaries then drains into the veins.

Our veins are more elastic than our arteries, allowing them to stretch more as blood flows through them. The internal lining of veins also contains valves, which allow the blood to only flow in the one direction. These serve two purposes, it prevents the blood that now contains wastes and carbon dioxide from mixing with fresh blood and it also assists the heart in moving the blood up against gravity.

Interacting organs

While the major purpose of our circulatory system is the transportation of oxygen to our cells, it also is used to transport food and other substances to the cell; consequently the circulatory system relies on other organs in the body. Apart from the heart, the lungs form an important part of the system, as this is where the gases are taken in and removed from the blood. The food necessary for our cells is absorbed into our blood stream via capillaries within our digestive system. The wastes from our cells are filtered out of the blood stream in the kidneys, so they too form an important part of this system.

4.1.2 Heart disease

In the last section we examined the major components of the human circulatory system. Arguably, the heart is the most important organ in this system, as heart failure rapidly leads to death. In this section we examine two of the many types of heart disease.

Bradycardia

Bradycardia is where the heart beats too slowly. In order for any of our muscles to contract, they must receive small electrical impulses that are sent via our nerve cells. In the heart, such impulses originate in a small part of the right atrium, called the 'sinus node'. These electrical impulses then stimulate the muscles in the atria (plural of atrium) to contract and force out the blood in these chambers. The electrical impulse then travels to another node near the ventricles, called the atrioventricular node (AV) that sends the impulse onto the muscles that surround the ventricles. These too then contract and force the blood from these chambers. When the sinus node is unable to generate these electrical impulses quickly enough, the heart will not beat quickly enough to provide the body with an adequate supply of oxygen.

Heart attack

A heart attack occurs when the heart muscles are unable to receive the blood they need in order to function. All of our tissues and muscles need to be provided with blood in order to operate efficiently. Sometimes the arteries that lead to these muscles can become blocked (due a build up of a fatty substance called cholesterol) or they can instead become hardened and inflexible (due to age). If any of the arteries leading to the muscles of our heart are unable to deliver blood to the heart muscles, the muscle cells can become damaged. The longer the period without blood, the more severe the damage and the greater the risk of death.

Exercise 4.1

1. Why do you think it is that the blood from people with blood type O– can be used by anyone?
2. What are the four chambers of the heart? In what order does blood flow through these chambers?
3. How are veins different from arteries?
4. What is the purpose of the substance haemoglobin that is contained in our red blood cells?
5. What actually happens to the heart during a heart attack?
6. Which types of blood can be successfully transfused into a person with A– blood? What blood types can successfully receive O+ blood?

4.2 Technology and the heart

In the last section we examined our circulatory system. You should now appreciate the importance of this system for our health, and the importance of the heart in this system. In the past, the types of heart disease mentioned in the last section invariably led to a certain and usually rapid death. Today, with our amazing technology, it is possible for doctors to treat these types of heart disease; in fact some scientists have even experimented with an artificial heart itself! In this section we will discuss just one type of technology that assists people with heart disease, the electronic pace-maker. In order to fully understand this amazing machine, it is necessary for us to have some understanding of electricity, and we will cover this topic briefly below.

4.2.1 Electricity

How much do you know about electricity? No doubt you use it extensively. How is it created and how is it stored? In this section we will briefly answer some of these questions. We will start with the simplest electricity, the type that you can create yourself.

Static electricity

Have you ever walked across a carpet reached for the door and experienced an electrical shock as your hand made contact? This is an example of static electricity and in this section we shall explain why this happens.

In section 3.2.1 – Building blocks we talked about the basic structure of the atom and how scientists believe that atoms contain charged particles. You might recall that each atom contains a number of positively charged particles called 'protons' and negatively charged particles called 'electrons'. Particles with an opposite charge are attracted to each other. The number of each type of particle in the atom is normally equal. Now when you walk on some carpet, your feet may rub against the carpet and in doing so can lose some electrons onto the carpet. This means that on your body there are now more positively charged particles than negatively charged particles. When you touch a metal door handle, these positively charged particles on your body attract electrons from the door handle and you experience a small zap. This is essentially what happens in lightening, except there is a much bigger zap. During a thunder storm, quite strong upward currents are created in the clouds. These currents push air and water particles upward and as this happens these particles may brush against each other and lose charges. Eventually the air in these storm clouds becomes very charged so that it is able to 'jump' to the earth and equalise this charge.

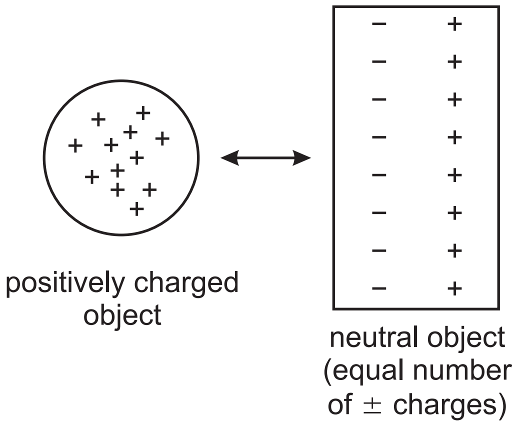
Learning activity 4.1

In order to investigate static electricity, you should try this short experiment.

1. Obtain a balloon, some wool cloth, string and some adhesive tape.
2. Inflate the balloon, tie it off and if possible mark a cross on one side using a permanent marker.
3. Use the tape and string to suspend the balloon from the ceiling.
4. Rub the cross side of the balloon with the wool cloth and then move close to the balloon. The balloon should now be attracted to your face.
5. How far from the balloon do you need to stand before it starts to attract?
6. Will the attraction cease if you place some cardboard between you and the balloon?
7. What happens if you touch the balloon?

8. We said earlier that objects that had an opposite charge attracted. Why is it that the balloon was attracted to your face, when we know that your face will have an equal number of negative and positive charges.

Hopefully after completing the above experiment, you should see that a force exists between two charged objects. When the objects have the same charge (either both positive or both negative) they will repulse each other. When the objects have a different charge (that is one negative and one positive) they will be attracted. In fact an attractive force will often occur when only one object is charged, this is because the charged object tends to attract the free electrons on the other object to one side, making one side of it slightly charged (see diagram below).



You would have also noticed that the attractive force between two opposite charges should not be affected too much when we place cardboard between the objects.

Electrical forces, such as that displayed between your face and the balloon can be quite useful. They are used to run many of our electrical appliances. Unfortunately once we touch the balloon, the charge disappears and so does the force. Being able to create a steady supply of electricity is a useful thing. We will explore, below, how electricity can be created using a chemical cell (or battery).

Chemical electricity

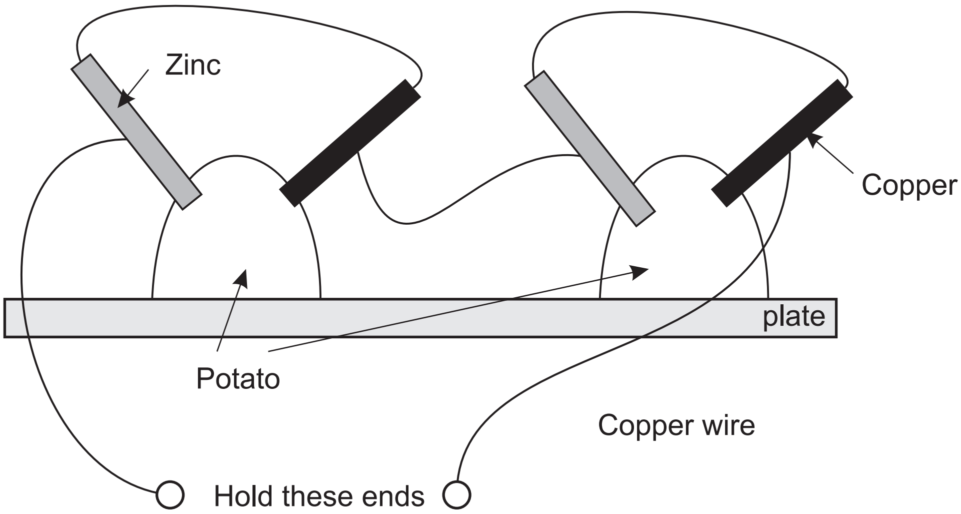
Before we get started in this section, you might like to try the following experiment, which hopefully will produce some electricity for you.

Learning activity 4.2

Experiment

1. To do this experiment you will need a potato, 2 galvanized nails, 2 pieces of copper (perhaps two old pennies, or 2 cent coins that have been cleaned) and three lengths of insulated copper wire (perhaps a very small light globe if you want to 'see' the electricity).
2. Cut the potato into two halves and place on a plate.
3. Place in each potato a nail and a piece of copper so that they are fairly close but not touching (say 5 cm apart).

4. Remove some of the insulation from each of the copper wires and connect the potatoes as in the diagram below:



5. Hold the ends of the two wires. Do you feel any shock? (It won't be big). Perhaps try to attach the two wires to either side of a very small torch batter. Does it glow?

With some luck, you should have been able to produce a very small amount of electricity from one potato and some bits of metal. You have made a very simple electro-chemical cell (similar to the batteries that we use to power our small appliances).

But how does this work (if indeed you were able to get it to work)?

The potato contains a mild acid (see table 3.6) that reacts with the two metals. As it turns out, the metal zinc tends to lose electrons more easily than copper and the mild phosphoric acid (H_2PO_4) that is contained in the potato helps this to occur.

At the zinc (galvanized nail) the following reaction occurs:

Zn . $Zn^{2+} + 2e^-$

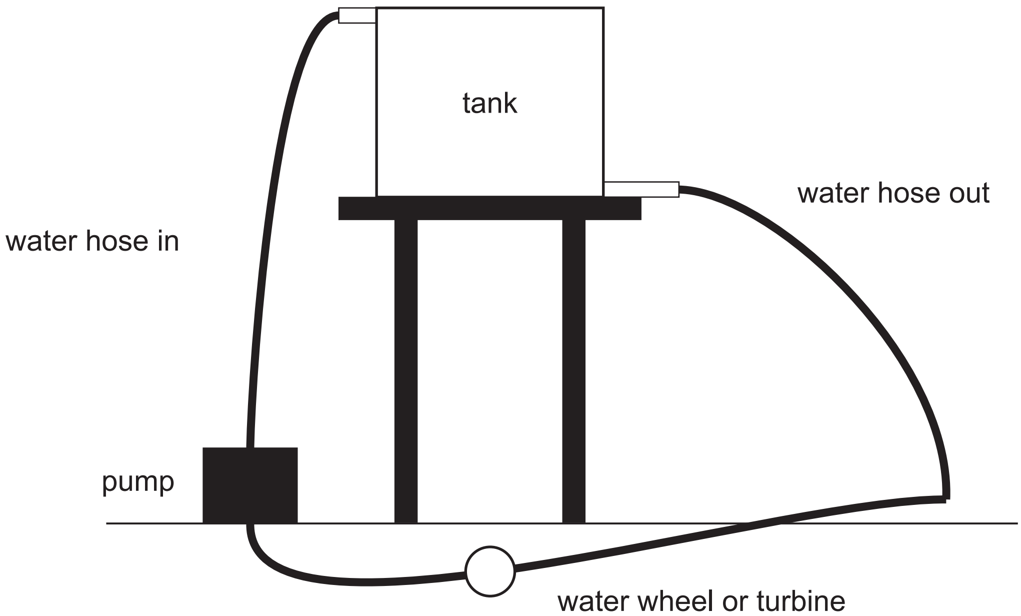
In other words zinc ions are created and in doing so electrons are released. At the same time at the copper, electrons are combining with hydrogen ions (that have been released by the acid) to produce hydrogen gas. In this way a shortage of electrons occurs at one end and an excess at the other end, consequently a flow of electricity occurs. That is negative electrons flow through the copper wires (and your fingers) and positive ions flow through the potato.

This is essentially how most batteries work. Some, like car batteries have metal plates in an acid solution, and others like torch batteries have metal plates in a dry porous substance. Chemical reactions in these batteries produce a flow of electricity and will do so until all of the substances have been depleted.

Electrical circuits

Electricity will not continue to flow unless there is an unbroken circuit. In the case of our potato battery, we wouldn't feel any electricity unless we touched both wires. Even when we have a complete circuit, we might not detect any electricity unless it has a sufficient **voltage** and **current**. We will discuss these two concepts in this section.

A useful analogy for electricity is the concept of water in a tank (see the diagram below). Imagine that we have some water in a tank which is placed high above the ground. A tap on the right hand side allows water to move from the tank, through a hose to a water wheel (or perhaps an electrical turbine). After the water passes through the wheel it goes to a pump where it is lifted up to the tank again, ready to start again (a bit like a fountain in a garden, where water runs out of the fountain, is collected, and then pumped back into the fountain).

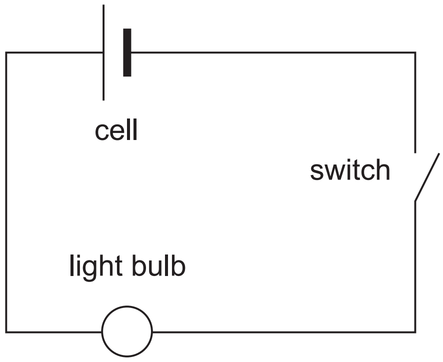


What would happen to the speed of the water wheel if we were to lower the tank, so that it was only just above the ground? What would happen if we made the hose longer and narrower?

Hopefully you have answered that lowering the tank will slow the water, because it doesn't have the same pressure as it did before. Similarly using a longer and narrower hose will also slow the wheel, as the water will lose pressure as it travels through the hose. Perhaps you can try this at home. Connect one hose to the tap and see how much pressure you can obtain, then connect a second hose to the first (so that it's twice as long) and see how much pressure you obtain.

But what does all of this have to do with electricity? The chemical cell discussed in the last section is a bit like the pump (and the tank) in the above analogy. Electrons in the cell are given energy through the chemical reaction that occurs (which we call voltage) in much the same way as the pump lifts the water. The electrons are then stored with this energy in the battery (in much the same way as the water is stored in the tank). When we connect the two ends of the battery, the electrons pour out of one end and into the other; so that when we put our finger in the way we should 'feel' a small shock. This flow of electrons is called the electrical current. The 'speed' of the current will depend on how much energy is lost in the circuit and will be adversely affected by long and thin wires (just like the water is slowed by long thin hoses). The factors that 'slow' (or reduce the energy of) our electrons are collectively called the **resistance** of the circuit.

Let's look at how scientists might represent the electrical circuit in a torch. The cell (or battery) is depicted by two vertical lines, all of the connecting wires by straight lines, the switch by a break in the circuit and the bulb by a circle. When the switch is closed, electrons will move through the circuit and light the bulb. You don't need to draw circuit diagrams in this course, but it is useful to understand what they are about and some are much more complicated than the one below.



What happens if we put a more powerful battery in our torch (assuming that we can fit it in there)?

Hopefully you would have said that the light bulb will shine more brightly (or blow). This is because batteries with a larger voltage will produce electricity with more energy. This extra energy will either make the bulb shine more brightly or else burn out the small filament in the bulb.

If we used wire in our circuit which had a low resistance (like copper) the current of electrons will flow through the circuit with out losing too much energy except in the light. If however, we use wire which had a higher resistance, the current will use up energy moving through the wires and won't have enough to run the light.

In the above discussion we have talked about the terms voltage, current and resistance. Hopefully you can see that they are all related. For example using a more powerful battery (that is one with more voltage) will increase the current, in other words it will allow more electrons to flow. However using wires which have a high resistance will slow the current (reduce the number of electrons flowing). The exact relationship between the three is given by Ohm's law, which you may have heard of before. This law says that the current flowing in a circuit is equal to the voltage divided by the resistance. In symbols this is written:

$$I = \frac{V}{R} \text{ or more commonly } V = IR$$

where I is the current measured in amperes (A)

V is the voltage measured in volts (V), and

R is the resistance of the wire measured in Ohms (Ω)

Let's look at an example of how this law works.

Example

A torch runs from a 1.5 V battery and the total resistance in the circuit is 300 O. Calculate the current that will flow through the torch circuit.

Solution

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{1.5}{300} \\ &= 0.005 \text{ A} \end{aligned}$$

So in this case we will have a very small current of 0.005 A or 5 mA (milliamps). You might feel such a small current if you placed your fingers in the circuit, but it certainly would not do you any harm. A larger current of say 10 to 20 mA can cause our muscles to spasm and even lead to instances where a person cannot release the electrical wire. A current of 200 mA (only 0.2 A) can be fatal, causing our heart to beat irregularly or even stop (remember our heart muscles beat because of the small electrical signals that they receive from the sinus node).

Exercise 4.2

1 What do we mean by the term voltage?

2 What do we mean by the term current as it applies to electricity?

3 Why do we sometimes get a shock when we get out of a car?

4 What factors will influence the amount of current that will flow in an electrical circuit?

5 If a circuit has a 6 V battery and has a total resistance of 120 O, what current should flow?

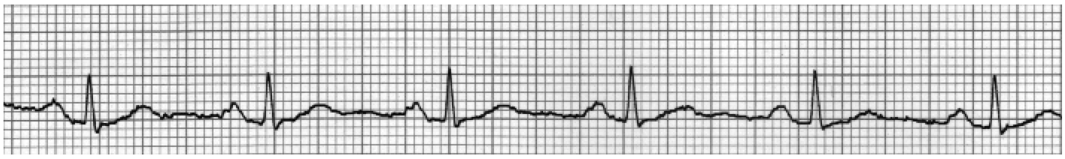
6 What sized battery (that is its voltage) would be needed to move a current of 20 mA through a circuit with a resistance of 350 O?

7 Some people can be electrocuted from electricity with quite small currents and voltage, while others can survive quite large lightning strikes. Why do you think this is the case? What other factors might influence whether the electricity is fatal?

4.2.2 The pacemaker

In the last section we mentioned that the beating of our heart is a result of electrical signals that are generated in the sinus node (a small part of the heart). In the last section we have discussed some basic facts relating to electricity. Scientists have developed a machine that is able to measure and record the electrical voltage in the heart. This machine is called the electrocardiograph and it produces a graph which is called the electrocardiogram (ECG). For a normal person an ECG might look like the one shown in figure 4.6. On this graph changes in the voltage in our heart are represented by changes in the vertical scale of the graph. The horizontal dimension of this graph represents changes in time. Each ‘spike’ in the ECG shows a normal heart beat.

Figure 4.6: Electrocardiogram for a normal person



(Source: *Electrocardiogram*)

You can see from this graph that unlike the voltage that might flow through a torch battery circuit (which is quite constant) the voltage in our heart will vary in size.

(If you want more information regarding the interpretation of an ECG, see the online reference at Wikipedia page on *Electrocardiogram*.)

People who have irregular heart beats, such as those who suffer from bradycardia, may have an ECG that resembles the one shown in figure 4.7. The downward peaks in this graph indicate that the direction of the heart beat has changed. Such irregularities can be rectified if an artificial device can provide small electrical pulses when the heart begins to 'miss a beat'. A pacemaker is such a device.

Figure 4.7: ECG for a person suffering from sinus bradycardia

This image has been removed for copyright reasons. By following the reference link below, you may be able to find the original image.

(Source: *ECG library – sinus bradycardia*)

Early heart pacemakers consisted of a battery, and some sophisticated electronic circuitry that could change the constant voltage produced by the battery into one that contained a series of regular peaks (such an electronic device is called an oscillator and you might like to check out the online references on this device). The early pacemaker was worn outside the person and contained a lead that was actually placed on the heart itself. A picture of this early pacemaker is shown in figure 4.8, which also shows a metronome (an object that musicians use to help keep the beat, and which served as the inspiration for the invention) and the circuit diagram for the pacemaker (which you can see is quite complex).

Figure 4.8: Early pacemaker together with a metronome

This image has been removed for copyright reasons. By following the reference link below, you may be able to find the original image.

(Source: *The Bakken library and museum*)

Modern pacemakers are similar except that they are actually inserted into the patient and their electronic equipment also includes a small 'computer chip' that is able to sense when the heart has ceased beating. So unlike older pacemakers that produced a series of regular pulses, new pacemakers will only do so when they detect that there is a need for this.

Reading activity 4.1

Study Selected reading 4.1: 2005, *Pacemaker* <http://www.nlm.nih.gov/medlineplus/tutorials/pacemakers/ct159102.pdf> and then answer the following questions.

1. Describe the flow of electricity in a normal heart beat. That is, where does the electricity start and where does it finish? How does it move from one point to the next? What happens as it moves?
2. What is meant by the term 'Arrhythmias'?
3. Where about in the body are artificial pacemakers normally placed? How are they connected to the heart?
4. What are some risks associated with using an artificial pacemaker? What sorts of things and equipment should you avoid? Why?

4.3 Picking a bone

Due to the wear and tear of our skeletal system and in many cases, accidents, our ability to walk and move around can become severely impaired. At one time (and indeed in many countries still) people with no limbs were relegated to a miserable life, now technology has greatly improved the ability of these people to lead a normal life. In this section you will undertake some research on current technology that is used to repair and even replace parts of our skeleton.

This research will be based, in part, on a number of reading activities (see below) and will be presented for assessment in the last assignment (see the Introductory book for more details). Before you commence the reading activities, you should carefully revise the section 2.2.1 that deals with our skeletal and muscular systems.

Reading activity 4.2

Study Selected reading 4.2: 2006, *Bone fractures* <http://www.stayinginshape.com/3osfcorp/libv/r04.shtml> that deals with bone fractures and common methods for repairing these. This technology is quite old, but it is a good starting point. As you study this reading, think about how the technology described in the reading has been used to repair our skeletal system. Then try to answer the following questions:

1. What are the different types of fractures?
2. What different technology has been used to repair fractures?

Reading activity 4.3

Study Selected reading 4.3: 2001, *Hip implants* <http://orthoinfo.aaos.org/fact/thr_report.cfm?Thread_ID=271> that deals with hip implants. There are many reasons why our hips might fail us, one in particular is arthritis. As you study this reading think about the technology that has been used to repair and indeed replace our hips. Then try the following questions:

1 What materials are used in hip replacements? How are these chosen?

2 The reading describes three types of hip replacements, what are they? How do they differ from each other?

Reading activity 4.4

Study Selected reading 4.4: 2006, *Hip replacement* <http://en.wikipedia.org/wiki/Hip_replacement> that deals with the history of hip replacement technology. As you study this reading, think about how the materials for this technology have been chosen.

Reading activity 4.5

Study Selected reading 4.5: Dailami, J 2002, 'The myoelectric arm: It's electrifying', *A Review of Engineering in Everyday Life* <http://illumin.usc.edu/article.php?articleID=6> that deals with the Myoelectric Arm. This reading studies the exciting use of technology in the development of artificial limbs. As you study this reading, think about the technology that has been used in this artificial arm and why it has been used. Then try to answer the following questions:

1 Artificial arms have been in existence for some time (remember the fictitious pirate Captain Hook). What has been the problem with these earlier models?

2 The myoelectric arm cannot be used by all amputees, as they need to produce a sufficiently strong enough EMG. What is an EMG and how strong must it be in order to operate the myoelectric arm?

3 What are the advantages and disadvantages of the myoelectric arm over other types of prosthetic limbs.

Reading activity 4.6

Study Selected reading 4.6: 2005, 'A toast to the bionic man', *Popular Science* <http://www.popsci.com/popsci/medicine/6123dc8a25076010vgnvcm1000004eecbccdrcrd.html> that deals with a prosthetic shoulder and arm. This reading gives some useful background into how a person may lose their limbs and then describes the technical details of the bionic shoulder, even including a diagram. As you study this reading make a note of the particular technological enhancements that this prosthetic device contains.

Conclusion

In this module we have examined instances where technology has been used to repair parts of the human body. The first part of the module examined our circulatory system and the important role that the heart has in this system. Unfortunately, like all parts of our body, the heart can become damaged. At one time heart damage was usually fatal, now technology can avoid this certain death. In this module we looked at one aspect of heart technology, that was the electronic pace maker. In order to understand how this operated we also examined some important concepts that relate to electricity, that is voltage and current.

In the second part of this module, we examined how technology has been used to repair damage to our skeletal and muscular system. You should have found that technology for repairing bone fractures has been with us for some time, but more advanced technology now allows for replacement of bone joints and even entire limbs. As you studied the readings in this section you should have noted some of the factors that scientists have needed to consider, in their choice of technology. For example, in the development of artificial limbs they have had to consider the weight of the limb and its mobility. Similarly, in the choice of materials for artificial hips, they need to consider whether the material will react with the human body and whether it will be strong enough. These considerations in turn will then need knowledge of chemical reactions (we studied these in section 3.4) and forces (we studied these in section 2.2.2).

Post test

1 How was William Harvey able to prove that our blood actually circulated around the body?

2 What are the four main components of our blood.

3 What is the name of the blood cell that is used to create clots and hence prevent us from bleeding to death?

4 A person has a blood type of AB+. Explain what this means. What type of blood could this person safely receive in a transfusion?

5 The heart has four chambers. From which chambers does blood flow out of the heart? In each instance, state where the blood will go to after leaving the chamber.

6 What is the name of the largest artery in the body? What about the largest vein?

7 Describe the symptoms of the heart disease bradycardia.

8 Electricity can be produced in batteries from chemical reactions. What needs to be produced in these reactions in order to create electricity? Give an example of such a reaction.

9 If a torch battery is connected to a light bulb, how much electrical current should flow in the circuit if the battery used was 6 V and the total resistance in the wires and bulb was 200 O?

10 What is an ECG and what is it used for?

11 Briefly describe how a pacemaker operates.

12 What are the names of the two bones that join at our hip?

13 What type of joint is our hip?

14 How are the bones in our joints kept together?

15 What is the purpose of cartilage in our skeletal system?

16 What factors do scientists need to consider when they choose materials for artificial hips?

17 How do users operate the new electric prosthetic arms ?

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Glossary

Hopefully you are maintaining the glossary of new terms that was suggested for each module. Some of these are listed below (you should be able to look up their meaning). Your glossary may be different to this and include other terms also.

- red blood cells
- white blood cells
- platelets
- plasma
- blood type
- arteries
- arterioles
- veinules
- veins
- capillaries
- voltage
- current
- resistance

Feedback

Exercise 4.1

1 A blood type of O– means that the blood does NOT contain the A molecule, the B molecule nor the Rhesus protein. It is only when transfused blood contains substances that are not in our blood, that antibodies are introduced by our body to fight these substances. Since the O– type blood contains no foreign substances, it can be used by all people.

2 The four chambers are the left and right atriums, and the left and right ventricles. Blood flows from our body, through the largest vein (the vena cava) into the right atrium of our heart. From there it is pumped into the right ventricle. From the right ventricle, the blood is pumped to the lungs where it picks up oxygen. It then flows through the pulmonary veins to the left atrium. From there it is pumped into the right ventricle, and from there to the body, via our main artery, the aorta.

3 Veins carry blood back to the heart. They are usually more flexible than arteries and contain valves that prevent the blood from flowing the wrong way. Arteries, on the other hand, carry blood from the heart. They are usually much stronger than veins, and contain a muscular layer that assists in moving the blood around.

4 Haemoglobin contains the element iron. We know from the section on Oxidation, that iron will react easily with oxygen (producing rust). So haemoglobin is able to ‘carry’ the oxygen while it is in the blood.

5 During a heart attack, it is often the case that the heart’s muscles do not receive enough oxygen to function. When this happens they may cramp or cease to work, often with fatal consequences.

6 A– blood contains the A molecule but does not contain the Rhesus protein. Therefore a person with this blood can receive more A– blood, but can also receive O– blood.

O+ blood does not contain the A or B molecule, but does contain the Rhesus protein. Consequently it can be received by people with the following types of blood: O+, A+, B+ and AB+ (that is anyone who has the Rhesus protein).

Exercise 4.2

1 Voltage is a measure of the amount of energy carried by the electrical current. So electrical current with 240 V has a lot more energy than electrical current with 12 V.

2 Current is a measure of how much electricity is flowing. Essentially it is how many electrons are flowing in the electrical circuit in a given time. In circuits with high currents, more electrons will flow.

3 As the car moves along, it continually collides with particles in the air. Sometimes these collisions will result in electrons being removed from the outer shell of the car. As a result, the car will gain a slight positive charge. As the tyres on the car do not conduct electricity,

the car will stay charged until there is some way for electrons to flow from the earth to the car. This occurs when we first step out of the car, as during this process we are holding onto the car and also touching the earth. Our body, therefore, conducts the electrons from the earth to the car and we experience a small electrical shock.

4 The amount of electrical current that will flow in a circuit will depend on how much energy the electrons in the current had in the first place (their voltage) and how much resistance the electrons encounter in the circuit as they flow (the resistance).

5 We know that $V = 6$ V, and $R = 120$ O.

If we substitute these values into Ohm’s law, we obtain:

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{6}{120} \\ &= 0.05 \text{ A} \end{aligned}$$

6 We know in this question that $I = 20$ mA = 0.02 A, and $R = 350$ O.

If we substitute these into the common form of Ohm’s law we obtain:

$$\begin{aligned} V &= IR \\ &= 0.02 \times 350 \\ &= 7 \text{ V} \end{aligned}$$

7 Whether electricity is fatal or not will depend on a number of factors. If the electricity strikes near the heart, than it may cause the heart muscles to stop beating and therefore be fatal. If we receive a strike elsewhere on our body, the current may bypass the heart on its way to the earth. The type of clothes worn, might also effect the severity of any electrical current. If we are wearing clothes that may be reasonable conductors of electricity, then the current might flow over our body to the earth, rather than through our body.

Reading activity 4.1

1 The electrical signal starts from an area on the right atrium called the sinus node. From there it travels to another area of the heart, called the atrio-ventricular node. It then spreads to the ventricles of the heart, causing them to contract and pump blood. The electrical signal moves through small fibres that conduct electricity.

2 Arrhythmias is a term that refers to any change in the normal rhythm of the heart.

3 Artificial pacemakers are usually placed in a ‘pocket’ of skin in the upper chest. The leads are connected to the heart through veins.

4 The pacemaker could fail or the leads attaching it to the heart could come loose. In such an instance surgery would be needed to either replace the pacemaker or the leads. Since artificial pacemakers are electronic devices, they are affected by strong magnetic fields. A person with an artificial pacemaker should avoid Magnetic Resonance Imaging and also power generators and welders, as these all produce strong magnetic fields.

Reading activity 4.2

1 The types of fractures listed in this reading are: the simple fracture, the compound fracture, the transverse fracture, the greenstick fracture and the comminuted fracture. Make sure you can understand the differences between these.

2 Traditionally plaster casts have been used to support fractures during the mending process. Other technology used includes: wires, metal plates, nails or rods and screws.

Reading activity 4.3

1 The ball part of the joint is made from cobalt/chromium-based alloys. The socket is made of metal, a type of polyethylene, or a combination of the two. Materials used need to be: biocompatible (they cannot react with the chemicals in our body); strong (its no use having something that wears away quickly); and, they need to have similar properties to our bones (eg; strong and flexible).

2 The three types of hip replacements cited are cemented, cementless, and a mixture of the two. In cemented hip replacements, a type of cement is used to hold the artificial parts to the existing bones. In cementless replacements, materials are used so that the existing bone will actually combine with the artificial substances and hold them in place. In the hybrid replacement, the socket is usually attached without cement and the ball attached with cement.

Reading activity 4.5

1 the problem cited in this article is user discomfort (although for a pirate, that probably would not be an issue). Other problems with early artificial arms would have included a loss of mobility, as in most cases the person could not do much with them.

2 The reading incorrectly says that the EMG is a small electrical signal created by our body to move muscles. In fact EMG stands for electromyogram, an instrument that is used to measure these signals. In order to operate the myoelectric arm a person needs to be able to generate signals in the range of 5 to 20 microvolts. Now a microvolt is a millionth of a volt, so 5 microvolts is 0.000 005 volts (a pretty small voltage).

3 The advantages include its greater mobility (it can be used over the head, down by the feet, etc). Also plastic coverings can be applied to the myoelectric arm so that it resembles the real thing (see the photo provided).

The disadvantages include the fact that it is heavier than other types of artificial arms, and since it operates on electricity, the user needs to be very careful around water (a bit of a problem when you have a shower).

Post test

1 Given the volume contained in a heart and the number of times it would beat every day, he was able to show that if the blood was not circulated, then the body would have to create about 7000 litres of blood each day (which was obviously impossible).

2 The four main components of our blood are: the red blood cells, the white blood cells, the platelets and the blood plasma.

3 Platelets

4 A blood type of AB+ means that the blood in question contains the A and B molecules and the Rhesus protein.

A person with AB+ blood can take all types of blood.

5 Blood flows out of the ventricles. From the right ventricle it goes to the lungs and from the left ventricle it goes to the body.

6 The largest artery is the aorta which flows from the heart to the body. The largest vein is called the Superior Vena Cava and flows into the heart from the body.

7 Bradycardia is when the heart has an irregular beat. So its symptoms would be an irregular heart beat.

8 Electrons need to be produced so that they can flow out of the battery and create an electrical current. An example of such a reaction is where zinc reacts with acid and produces electrons. This is written:

Zn . $Zn^{2+} + 2e^-$

9 We can use Ohm's law to calculate this:

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{6}{200} \\ &= 0.03 \text{ A} \end{aligned}$$

10 An ECG is an electrocardiogram, it is a graph produced by a machine that is used to measure the electrical signals produced by the heart. It can accurately show if the heart has irregular beats.

11 A pacemaker consists of a small electronic device called an oscillator, that is able to produce regular electrical signals. In some cases it can produce signals for the heart, ensuring that it will beat with regularity. More sophisticated pacemakers actually monitor the heart's natural beat and send electrical signals to the heart when there is a break in the heart's natural beat.

12 One of the bones is the femur (which is the bone in our upper leg), the other is the ox coxa (which is our hip itself).

13 The joint at our hip is a ball and socket joint. It is a type of synovial joint.

14 It depends on the joints, but in our hip the two bones are help in place by ligaments. The bones in our spine are held together with cartilage. Muscles also help keep our bones together.

15 Cartilage grows at the end of bones and often serves to cushion them. It can eventually grow into bone itself. Cartilage is also used to join some bones, such as those in our spine.

16 They need to consider whether the materials they use will react with the chemicals in our body. They also need to consider whether the materials they use will be as strong and as flexible as our bones.

17 The myoelectric arm operates from small currents that are given off by the person's muscles. So in order for this to happen, the person must flex muscles near the stump of the artificial arm. Such flexing of the muscles will produce small currents (this is what causes the muscle to move) and these in turn are used to operate the arm.