10.1.2 How an Animal Works[M28, M29]

Single-celled organisms

- Easily obtain food and other raw materials directly from their surroundings;
- Carry out all the functions necessary to keep them alive, within the single cell;
- Get rid of wastes by simple diffusion into the surrounding water.

Multicellular organisms are much larger and overcome the drawbacks of size by having special cells—more correctly collections of cells called organs—to carry out certain tasks for the whole system. The organ systems of the human body (typical of mammals), and their major functions, are identified below.

Organ System[1]		Major Functions
	Integumentary System	Protection from environmental hazards; temperature control
	Skeletal System	Support, protection or soft tissues; mineral storage; blood formation
	Muscular System	Locomotion, support, heat production
	Nervous System	Directing immediate responses to stimuli, usually by coordinating the activities of other organ system
	Endocrine System	Directing long-term changes in the activities of other organ systems
	Cardiovascular System	Internal transport of cells and dissolved materials, including nutrients, wastes and gases
	Lymphatic System	Defence against infection and disease
	Respiratory System	Delivery of air to sites where gas exchange can occur between the air and circulating blood
	Digestive System	Processing of food and absorption of organic nutrients, minerals, vitamins and water
	Urinary System	Elimination of excess water, salts, and waste products; control of pH
	Reproductive System	Production of sex cells and hormones

[1] http://www.iupucanatomy.com/images/anatomy%20slides%20025.jpg

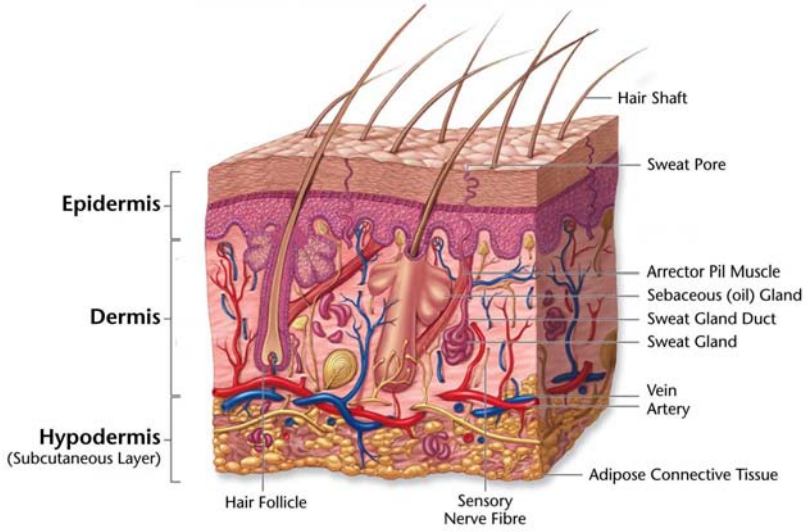
10.1.2.1 Protection from the Environment—The Integumentary System[2]

The integumentary system contains the largest organ in the human body, the skin. It also includes such extensions of the skin as hair and fingernails. The skin, however, is the most important of these.

The integumentary system has a variety of functions. It

- Protects the body's internal living tissues and organs;
- Provides a physical barrier to keep out foreign materials and protect against invasion by infectious organisms;
- Provides a mechanism for the elimination of waste materials;
- Helps to regulate body temperature;
- Acts as a sensory receptor for pain, pressure, and temperature;
- Stores water and fat, protecting the body from dehydration.

The skin comprises three separate layers, the epidermis, dermis, and hypodermis, each with its own particular function.



The Epidermis

The epidermis is the outermost layer of the skin, and has itself several structural layers. The outermost layer of the epidermis, approximately 20–30 cells thick, comprises dead cells containing little more than the keratin that gives the skin its waterproof quality. The innermost layer of the epidermis comprises cells that are mitotically active—*i.e.* they are alive and reproducing. This is where the growth of skin takes place. As the skin grows, cells move towards the outer part of the epidermis. It takes roughly fourteen days for cells to move from the innermost to the outermost layer of the epidermis. Once part of the outer layer, the dead cells remain for another fourteen days or so before slowly and steadily flaking off.

Some cells in the epidermis produce the protein melanin, a pigment that ranges in colour form yellow to brown to black. The amount of melanin produced determines skin colour, which is an hereditary characteristic. Freckles are the result of melanin clumping in one spot.

[2] http://en.wikipedia.org/wiki/Integumentary_system
http://library.thinkquest.org/3007/integumentary.html
http://www.sciencenetlinks.com/interactives/integsystem_resource.html

The Dermis (Cutis)

The dermis is the second, much thicker layer of skin, directly beneath the epidermis. Unlike the epidermis, the dermis has its own blood supply and, as a result, more complex structures are able to exist here. The dermis comprises blood vessels, connective tissue, nerves, lymph vessels, sweat glands and hair shafts. It, in turn, has two main layers:

- The upper layer for touch, pain and heat sensitivity, and which communicate with the central nervous system. It is also responsible for the folds of the fingerprints;
- The lower layer made of dense elastic fibres that house the hair follicles, nerves, gland, and gives the skin most of its elasticity and strength.

Sweat glands collect water and various wastes from the bloodstream, and excrete them through pores in the epidermis. The growth of hair also takes place in the dermis. By the time hair reaches the environment outside of the skin, it is completely dead.

The Hypodermis (Subcutaneous Layer)

Beneath the dermis lies the final layer of skin, the subcutaneous layer. The most notable structures here are the large groupings of adipose tissue (fat deposits). The main function of the subcutaneous layer is therefore to provide a cushion for the delicate organs lying beneath the skin. It also functions to insulate the body to maintain body temperature.

Exercise: Describe the process via which the body regulates its temperature.

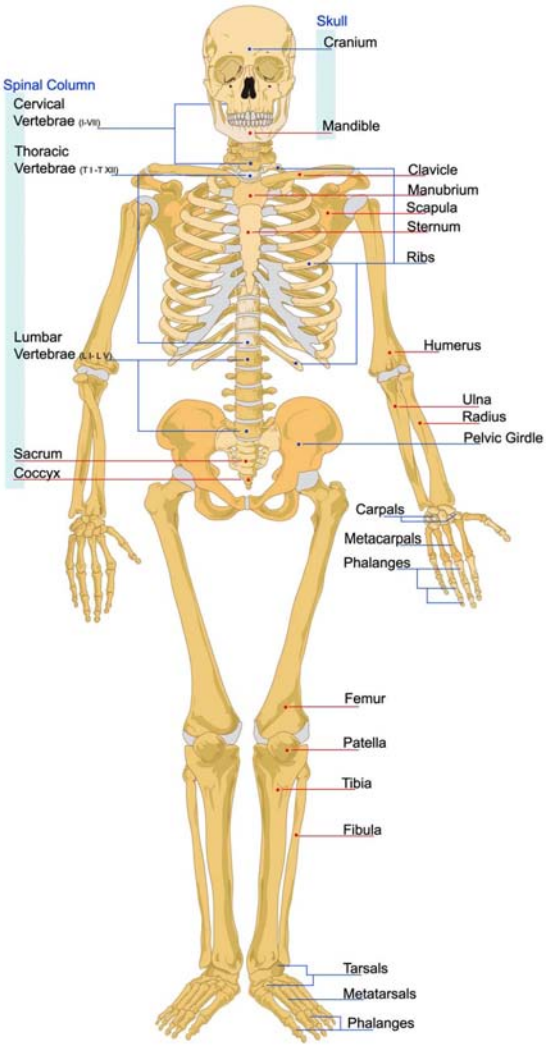
10.1.2.2 Movement

10.1.2.2.1 The Skeleton

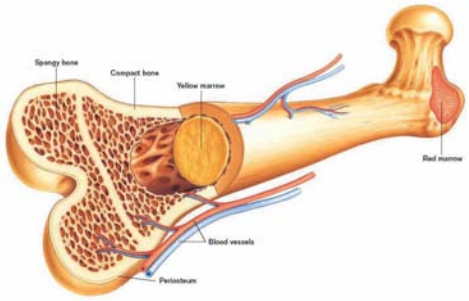
The human skeleton comprises 206 separate bones.

The skeleton[3]:

- Supports and gives shape to the body;
- Protects parts of the body, such as the brain, the heart and the lungs;
- With the aid of muscles attached to the bones, enables the body to move.



Bones comprise two parts[4]:

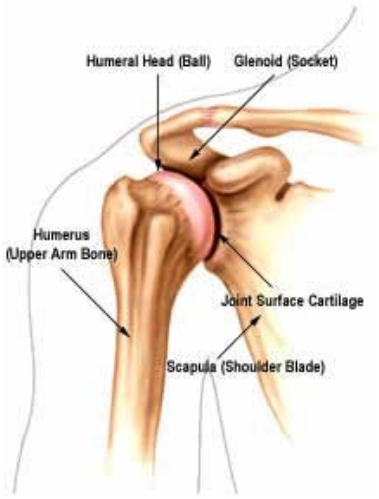


- A **non-living part**, mainly calcium phosphate and calcium carbonate, that makes the bone hard;
- A **living**, **fibrous part** that makes the bone sufficiently flexible to withstand the pull of muscles.

10.1.2.2.2 Joints

The ends of bones fit together at joints. The shapes at a joint are suited to the movement the bones must make:

- **Ball and** socket **joints**, such as the shoulder[5] joint, allow great freedom of movement;
- **Hinge** joints, such as the elbow[6], allow movement in only one plane.



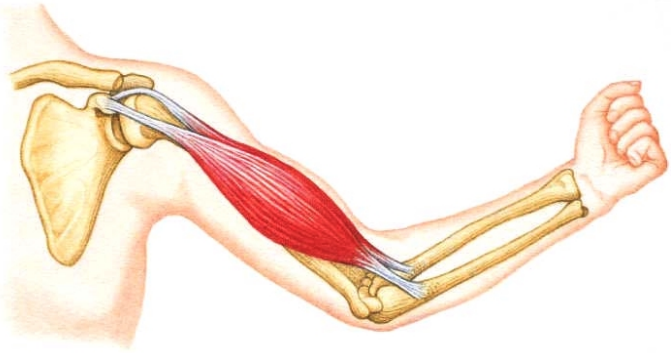
[3] http://commons.wikimedia.org/wiki/image:Human_skeleton_front.svg
[4] http://www.castlefordschools.com/kent/07-08%20lessons/Lessons/Advanced%20Biology%20Lessons/chapter%2037/bone%20structure.jpg
[5] http://www.khandaka-hospital.com/resources(1)_2.jpg
[6] http://orthoinfo.aaos.org/figures/A00029F01b.jpg

10.1.2.2.3 Muscles

Muscles consist of many long, narrow cells—**muscle fibres**—that can contract in length. In contracting, muscles use up much energy, which is, in turn, obtained from food.

Muscles:

- Move limbs, organs and hairs in the skin;
- Hold body structures in position and maintain posture;
- Force liquids through vessels or through the alimentary canal.



Biceps Muscles in the Upper Arm[7]

Muscles are of three types:

- **Striped** or **voluntary muscles** under the control of the will, cause movement of bones. Voluntary muscles provide the effort forces that move bones, which act as levers;
- **Plain** or **involuntary muscles** are not under the control of the will but **contract automatically**. Involuntary muscles are found in the alimentary canal and blood vessels;
- **Heart muscle**, a special form of involuntary muscle, contracts rhythmically throughout life.

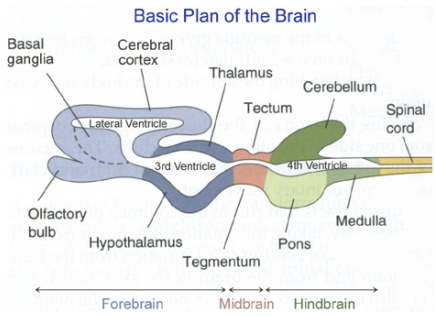
10.1.2.3 Coordination

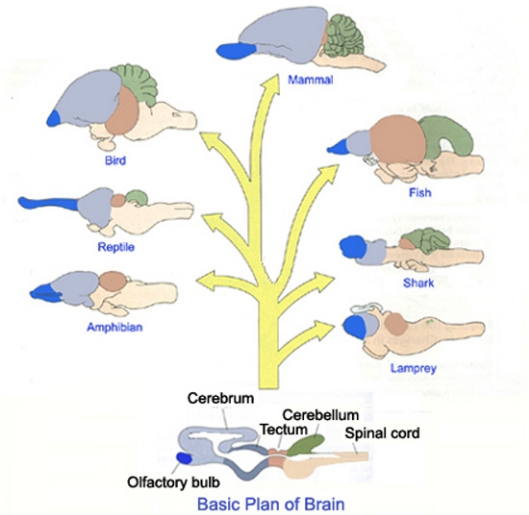
10.1.2.3.1 Nervous Coordination—The Nervous System

The nervous system consists of **neurones**, which communicate information, and **glia**, which support and protect the neurons in various ways. The nervous system is divided in to the **central nervous system**, consisting of the **brain** and **spinal cord**, which are responsible for integration, and the **peripheral nervous system**, which transmits sensory input and executes central commands.

The Central Nervous System

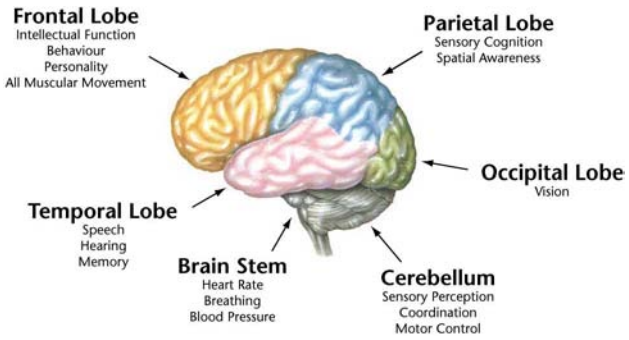
The brains of all vertebrates comprise three basic parts: **forebrain**, **midbrain**, and **hindbrain**.



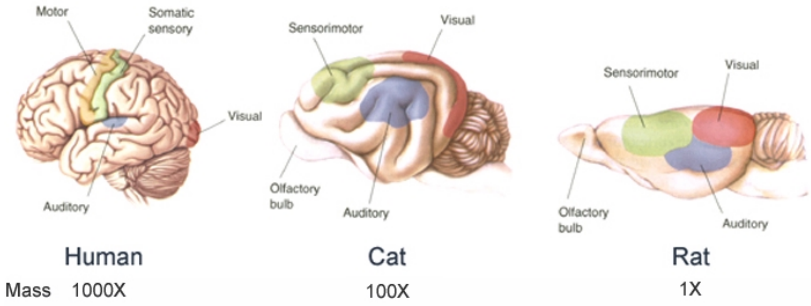


[7] http://www.dkimage.com/discover/previews/740/60417.jpg

Although the general organization of the brain is similar in all vertebrates, the more developed brain structures in the higher vertebrates reflect their more advanced intellectual capabilities. The brain is highly organised with respect to function. The illustration identifies the primary functions of the main parts of the human brain.

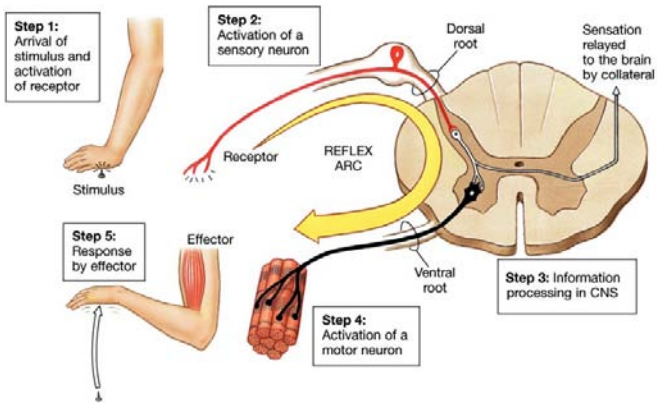


Brains in other vertebrates also show development with respect to functions that contribute to their survival. The human brain is 10 times larger than that of a cat, for example, and 1000 times larger than that of a rat.



The central nervous system is protected by the skull, meninges (the membranes surrounding the brain and spinal chord), and fluid-filled cavities.

The **spinal cord** consists of specific ascending and descending nerve pathways that provide a mechanism for communicating information between the body and the brain. It also controls involuntary responses, the withdrawal reflex for example, to stimuli from the sense organs. Normally, when the central nervous system receives a message from a receptor it becomes **aware** of the stimulus and responds by sending messages through nerves to **effectors**—muscles or glands—which act as a result.



In a **reflex arc**[8], the stimulus may be relayed to the spinal cord, which responds by sending a message directly to an effector without the animal being aware of the happening.

The Peripheral Nervous System

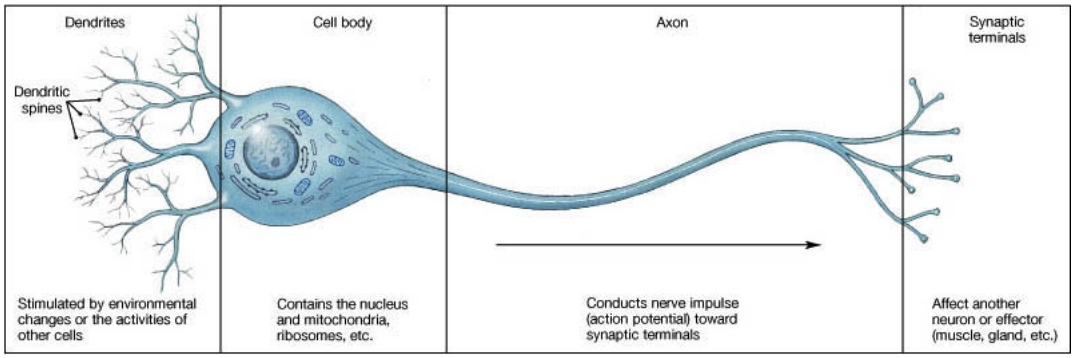
The peripheral nervous system is divided into the **somatic nervous system**, associated with the control of voluntary actions (movement and sensory perception)

[8] http://iupucbio2.iupui.edu/anatomy/images/Chapt14/FG14_15.jpg

and the **autonomic nervous system**, the control system that maintains **homeostasis** in the body (heart beat, digestion, respiration, salivation etc.).

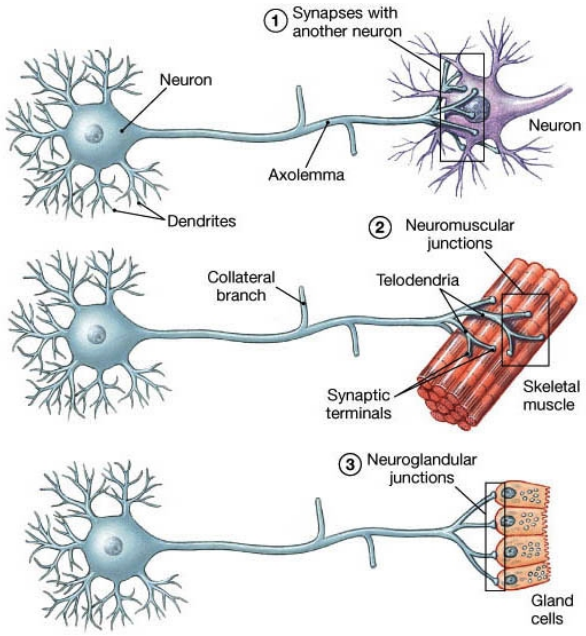
Nerve cells, called **neurones**, make up all parts of the nervous system. Neurones[9] are:

- **Specially adapted** to respond to certain stimuli (various forms of energy);
- Have long extensions called **nerve fibres**;
- **Conduct messages** by means of **electrical pulses** in **one** direction only; from **dendrites**, through the cell body, to **axons**.



There are three kinds of neurones[10]:

- **Connecting neurones** within the central nervous system, conduct messages from one neurone to another;
- **Motor neurones** conduct messages from the central nervous system to muscles or glands;
- **Sensory neurones** respond to stimuli and conduct messages from sense organs to the central nervous system.



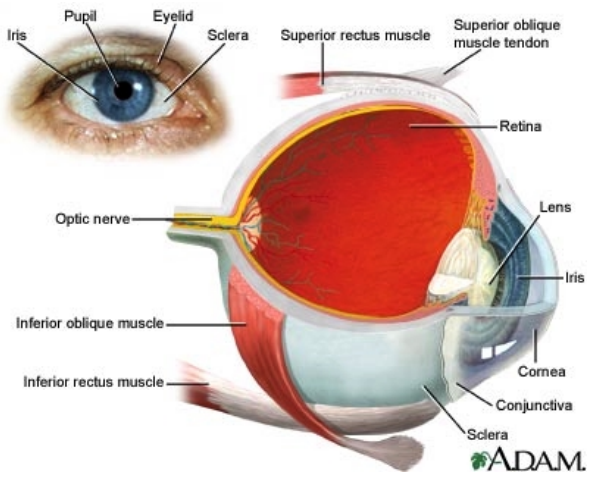
A **nerve** contains a **bundle of nerve cells** that conduct messages along the nerve. As already noted, the spinal cord contains individual nerve pathways for signals travelling to and from the brain.

Stimuli from outside the body are detected by neurones in **organs of special sense**—eye, ear, skin, nose, tongue—which carry messages through nerves to the brain. Neurones in sense organs detecting blood pressure and temperature inside the body also forward messages to the central nervous system. All organs that detect stimuli are called **receptors**.

[9] http://iupucbio2.iupui.edu/anatomy/images/Chapt13/FG13_03.jpg
[10] http://iupucbio2.iupui.edu/anatomy/images/Chapt13/FG13_09b.jpg

10.1.2.3.2 Organs of Special Sense

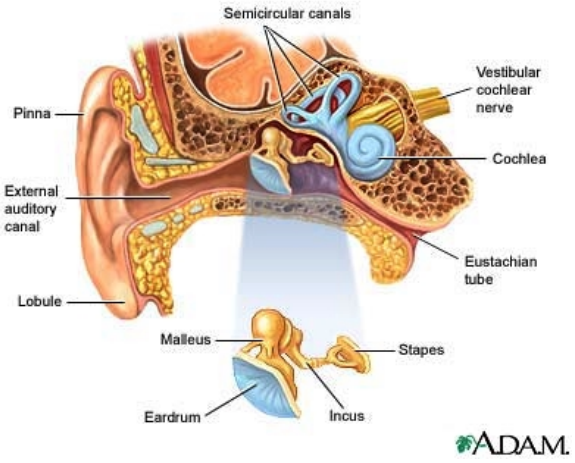
The Eye



The **organ of sight**, the eye[11], which senses light energy, comprises:

- A **tough outer wall**, roughly spherical, lined with black material, filled with transparent jelly and having muscles for movement attached;
- The **transparent cornea** at the front, through which light enters;
- The **iris**, the coloured part behind the cornea, containing involuntary muscles, which controls the amount of light passing through the hole in its centre, called the **pupil**;
- The **lens**, a curved transparent element that provides the mechanism to produce an image of an object, located in front of the eye, on the **retina**. The shape of the lens can be altered, through the action of involuntary **ciliary muscles**, to bring an image into focus;
- The **retina**, lining the inner wall at the back, which contains **light-sensitive nerve fibres**;
- The **optic nerve**, in which nerve fibres from the retina come together and which carries **nervous messages** to the brain.

The Ear

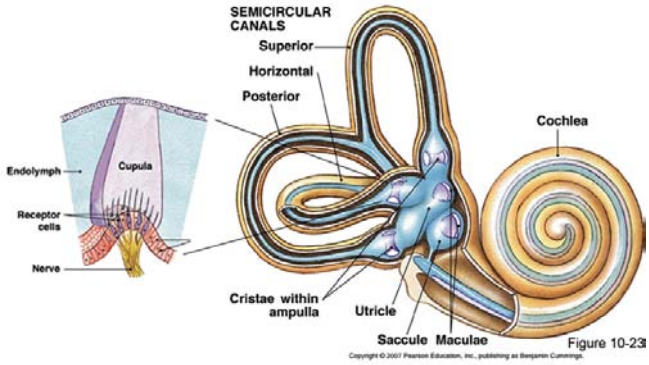


The **organ of hearing**, the ear[12], which detects sound energy, comprises three general parts:

- The **external ear**, which directs **sound waves** to the **eardrum** at its inner end. The eardrum vibrates;
- The **middle ear**. A cavity that contains three small movable bones, the **ear ossicles**. These bones transmit vibrations from the eardrum to an inner oval membrane. The **eustachian tube** joins the middle ear to the back of the throat, to facilitate the equalisation of pressure on both sides of the eardrum to optimise the efficiency of its vibration;

[11] http://www.nlm.nih.gov/medlineplus/ency/images/ency/fullsize/1094.jpg
[12] http://www.nlm.nih.gov/medlineplus/ency/images/ency/fullsize/1092.jpg

- The **inner ear**, containing three centrally located **semi-circular canals**[13], filled with fluid, that are concerned with the sense of body balance and position, and the **cochlea**, a coiled, fluid-filled tube containing nerve-endings that are stimulated by **sound vibrations** transmitted through the **oval membrane**.



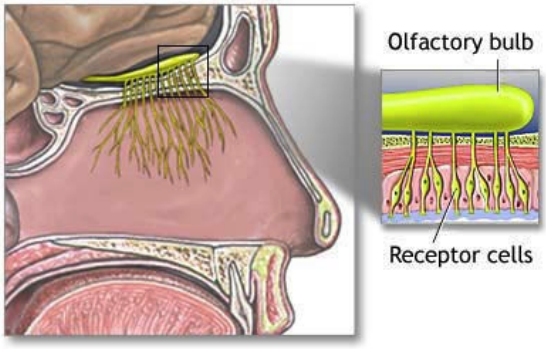
Nerve fibres sensitive to balance and to sound vibrations come together in the **auditory nerve**, which carries messages to the brain.

The Skin

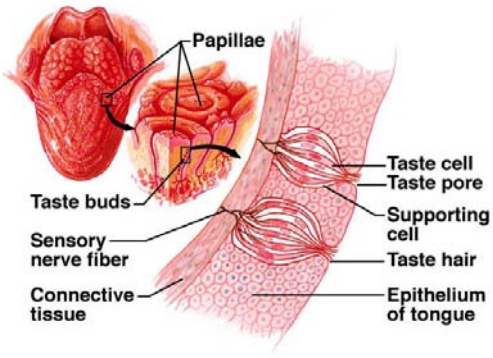
The **organ of touch**, the skin, comprises:

- **Nerve fibres** of different kinds, each of which can be stimulated by various forms of pressure and heat;
- Nerve fibres of each type scattered over the skin in particular spots. Between spots, the skin is not sensitive to a **stimulus**;
- A variation in the numbers of sensitive spots in different parts of the body. There are more nerve fibres sensitive to pressure in the finger-tips than in the upper arm.

The Nasal Cavity and the Tongue



The Nasal Cavity[14]



The Tongue[15]

The **organs of smell**, in the nasal cavity, **and of taste**, in the tongue, are stimulated by chemical substances. Organs of smell detect flavours, which are really **odours**. Organs of taste detect only sweet, sour, bitter and salty taste sensations in solutions of substances.

10.1.2.3.3 Chemical Coordination—The Endocrine System

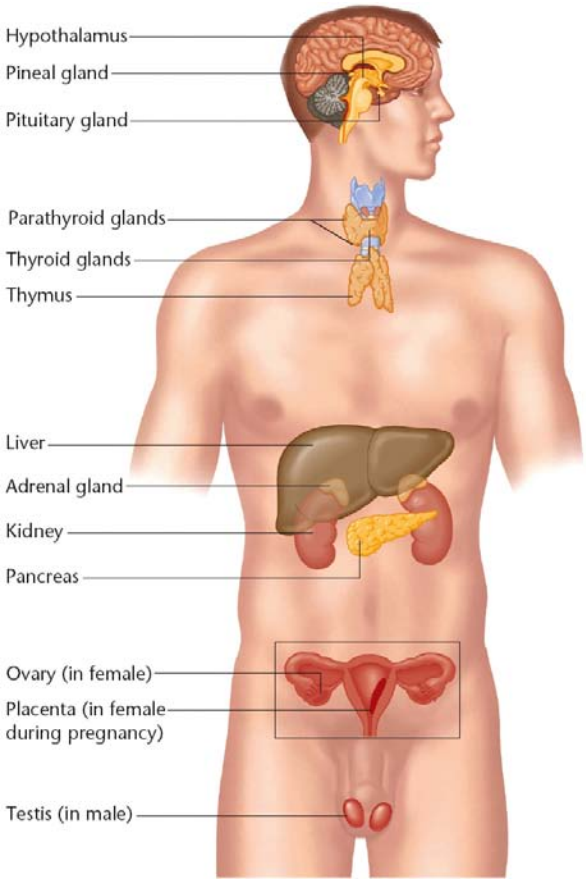
The nervous system sends electrical messages to control and coordinate the body. The endocrine system has a similar job, but uses chemicals to "communicate". These chemicals are known as hormones. In general, the endocrine system is in charge of body processes that happen slowly, such as cell growth and development, tissue

[13] http://www.colorado.edu/intphys/Class/iPHY3430-200/image/10-23.jpg
[14] http://www.nytimes.com/imagepages/2007/08/01/health/adam/8689.jpg
[15] http://classes.midlandstech.com/bio112/taste%20buds.jpg

function, and metabolism, sexual function and reproductive processes. Faster processes like breathing and body movement are controlled by the nervous system. But even though the nervous system and endocrine system are separate systems, they often work together to help the body function properly.

The endocrine system and the nervous system are so closely associated that they are collectively called the neuroendocrine system. Neural control centres in the brain control endocrine glands. The main neural control centre is the hypothalamus, also known as the "master switchboard." Suspended from the hypothalamus by a thin stalk is the pituitary gland. The hypothalamus sends messages to the pituitary gland; the pituitary gland, in turn, releases hormones that regulate body functions.

Glands are of two types. Exocrine glands such as the sudoriferous (sweat) glands contain ducts. Ducts are tubes leading from a gland to its target organ. Endocrine glands do not have a duct system and are called ductless glands. These glands release hormones directly into the blood or lymph and influence almost every cell, organ, and function of our bodies. The major glands of the endocrine system are the hypothalamus, pituitary, thyroid, parathyroids, adrenals, pineal body, and the gonads (ovaries and testes). The pancreas is also a part of this system—it has a role in hormone production as well as in digestion. Although the endocrine glands are the body's main hormone producers, some non-endocrine organs—such as the brain, heart, lungs, kidneys, liver, thymus, skin, and placenta—also produce and release hormones.



The endocrine system is regulated by a feedback mechanism in much the same way that a thermostat regulates the temperature in a room. For the hormones that are regulated by the pituitary gland, a signal is sent from the hypothalamus to the pituitary gland in the form of a "releasing hormone," which stimulates the pituitary to secrete a "stimulating hormone" into the circulatory system. The stimulating hormone then signals the target gland to secrete its hormone. As the level of this hormone rises in the circulation, the hypothalamus and the pituitary gland shut down secretion of the releasing hormone and the stimulating hormone, which in turn slows the secretion by the target gland. This system maintains stable blood concentrations of the hormones that are regulated by the pituitary gland.

The Endocrine Glands

Hypothalamus—Located in the lower central part of the brain, the hypothalamus is the primary link between the endocrine and nervous systems. Nerve cells in the hypothalamus control the pituitary gland by producing chemicals that either stimulate or suppress hormone secretions from the pituitary.

Pituitary—Although it is no bigger than a pea, the pituitary gland, located at the base of the brain just beneath the hypothalamus, is considered the most important part of the endocrine system. It's often called the "**master gland**" because it makes hormones that control several other endocrine glands. The production and secretion of pituitary hormones can be influenced by factors such as emotions and seasonal changes. To accomplish this, the hypothalamus relays information sensed by the brain (such as environmental temperature, light exposure patterns, and feelings) to the pituitary.

For example, the pituitary gland may be triggered to release TSH (Thyroid Stimulating Hormone) that subsequently stimulates the thyroid gland to produce thyroid hormones. In turn, thyroid hormones might then inhibit the release of calcium in the blood.

The pituitary gland also secretes **endorphins**, chemicals that act on the nervous system to reduce sensitivity to pain.

Thyroid & parathyroids—The thyroid, located in the front part of the lower neck, is shaped like a bow tie or butterfly and produces the thyroid hormones **thyroxine** and **triiodothyronine**. These hormones control the rate at which cells burn fuel from food to produce energy. As the level of thyroid hormones increases in the bloodstream, so does the speed at which chemical reactions occur in the body.

Attached to the thyroid are four tiny glands that function together called the parathyroids. They release **parathyroid hormone**, which regulates the level of calcium in the blood with the help of **calcitonin**, which is produced in the thyroid.

Adrenals—The body has two triangular adrenal glands, one on top of each kidney. The adrenal glands have two parts, each of which produces a set of hormones and has a different function.

The outer part, the adrenal cortex, produces hormones called **corticosteroids** that influence or regulate salt and water balance in the body, the body's response to stress, metabolism, the immune system, and sexual development and function.

The inner part, the adrenal medulla, produces catecholamines, such as **epinephrine**. Also called **adrenalin**, epinephrine increases blood pressure and heart rate when the body experiences stress. (Epinephrine injections are often used to counteract a severe allergic reaction.)

Pineal body—The pineal body, also called the pineal gland, is located in the middle of the brain. It secretes **melatonin**, a hormone that may help regulate the wake-sleep cycle.

Gonads—The gonads are the main source of sex hormones. In males, they are located in the scrotum. Male gonads, or testes, secrete hormones called androgens, the most important of which is **testosterone**. These hormones regulate body changes associated with sexual development, including enlargement of the penis, the growth spurt that occurs during puberty, and the appearance of other male secondary sex characteristics such as deepening of the voice, growth of facial and pubic hair, and the increase in muscle growth and strength. Working with hormones from the pituitary gland, testosterone also supports the production of sperm by the testes.

The female gonads, the ovaries, are located in the pelvis. They produce eggs and secrete the female hormones **oestrogen** and **progesterone**. Oestrogen is involved in the development of female sexual features such as breast growth, the accumulation of body fat around the hips and thighs, and the growth spurt that

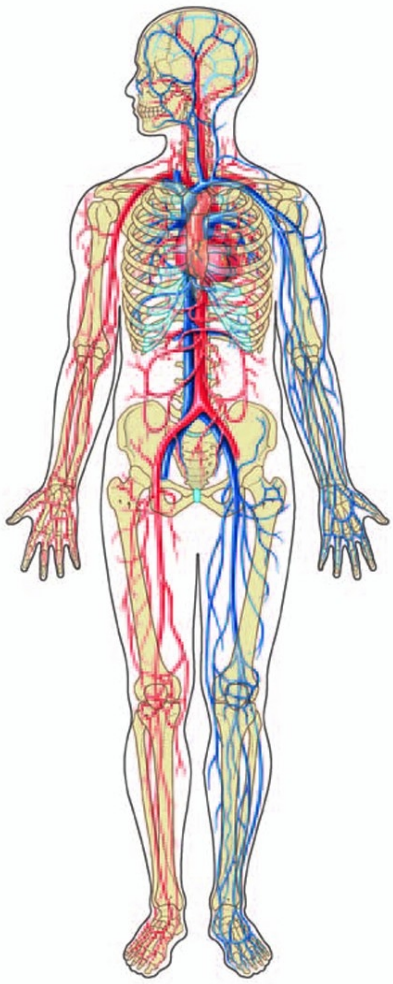
occurs during puberty. Both oestrogen and progesterone are also involved in pregnancy and the regulation of the menstrual cycle.

Pancreas—The pancreas produces (in addition to others) two important hormones, **insulin** and **glucagon**. They work together to maintain a steady level of glucose, or sugar, in the blood and to keep the body supplied with fuel to produce and maintain stores of energy.

10.1.2.4 Transporting Chemicals

The **circulatory system** continuously transports:

- Dissolved, digested food material together with oxygen to every cell in the body;
- Waste substances away from every cell.



The circulatory system comprises both the cardiovascular system and the lymphatic system.

10.1.2.4.1 The Cardiovascular System

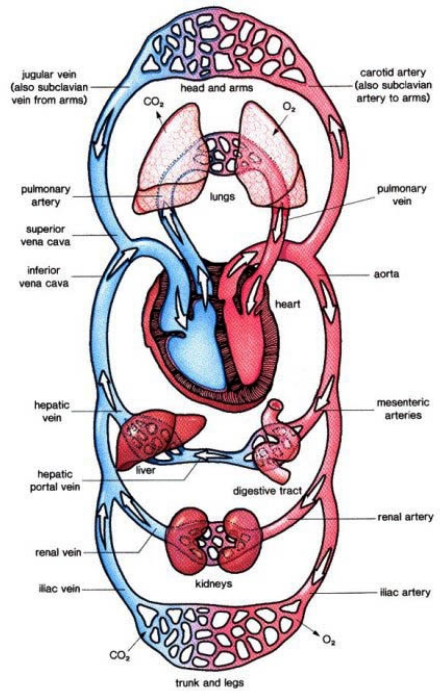
The cardiovascular system[16] forms a closed channel consisting of:

- The **heart**, an enlarged, double blood vessel each part containing inflow and outflow pumping chambers;
- The **arteries**, tubes which lead either directly or indirectly from the heart to the capillaries;
- The **capillaries**, many fine blood vessels which carry blood to every cell of the body and then join the veins;
- The **veins**, tubes which lead from the capillaries back to the heart , with one exception: the hepatic portal vein, which transfers blood from the intestine to the liver.

[16] http://www.dorlingkindersley-uk.co.uk/static/clipart/uk/dk/exp_humanbody/exp_human055.jpg

The heart is the **muscular pumping centre**[17] of the cardiovascular system, circulating the blood through:

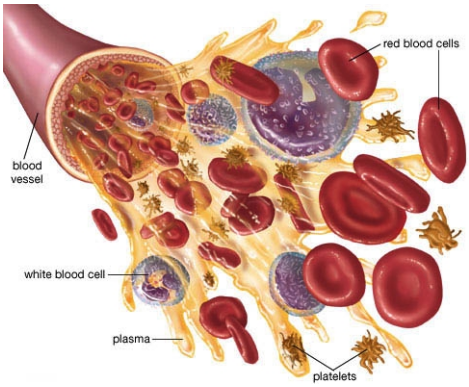
- A circuit from the **right ventricle** of the heart through the **pulmonary arteries** to the lungs and back to the **left atrium** of the heart;
- A circuit from the **left ventricle** of the heart through the **aorta** to all other parts of the body and back again to the **right atrium** of the heart.



Flaps, called valves, in the heart and other blood vessels, prevent **backwards flow of blood**, thus ensuring a one-way flow through the body as the heart beats.

Blood is a **complex mixture**, containing:

- **Red blood cells** (erythrocytes), possessing **haemoglobin**, which carry oxygen from the lungs around the body. A deficiency of healthy red blood cells leads to a condition known as **anemia**;
- A lesser number of **white blood cells** (leukocytes), which play a critical role in defending the body against infectious diseases and foreign materials;
- Plasma, a straw-coloured liquid, mainly water (90% by volume), which carries dissolved food to cells and waste materials away from cells;
- Platelets (thrombocytes), which form a network of fibres, called a clot, when a blood vessel is damaged. The walls of blood vessels contain a substance called **collagen**, which is released if a vessel is damaged.



Primary Blood Components[18]

Blood cells, erythrocytes, leukocytes and thrombocytes, are produced in the bone marrow. Production is continuous for the life of an individual, but if a great deal of blood is lost, it must be replaced quickly via a transfusion from another individual. Healthy erythrocytes (red blood cells) have a plasma life of about 120 days before they are broken down, primarily in the spleen but also in parts of the liver. There are many different kinds of leukocytes (white blood cells), with a plasma life ranging from a few of hours to several years. Thrombocytes (platelets) circulate for about a week and are then destroyed in the spleen and parts of the liver.

Blood Groups

The red blood cells, and indeed the blood plasma constituents, in all human beings are not identical. The red blood cells in most human blood, however, belong to one of

[17] http://www.daviddarling.info/images/circulatory_system.jpg
[18] http://cache.eb.com/eb/image?id=91871&rendTypeId=34

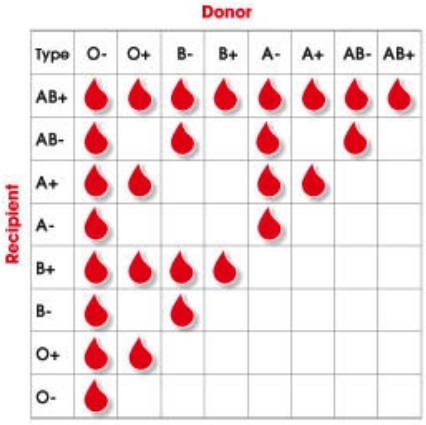
four main groups: **A**, **B**, **AB** or **O**[19]. Each of these groups, or Blood Types, is further divided into those that do or do not possess a **Rhesus factor**. The individual groupings are defined by specific **antigens** (antibody generators) that exist on the surface of the red blood cells, and corresponding antibodies in the blood plasma. Type **A** red blood cells are characterised by the presence of a Type **A** antigen, and the associated plasma contains Type **B** antibodies. Similarly, Type **B** red blood cells are characterised by the presence of a Type **B** antigen, and the associated plasma contains Type **A** antibodies. Type **AB** red blood cells are characterised by the presence of both Type **A** and Type **B** antigens, and the associated plasma contains no Type **A** or Type **B** antibodies. Type **O** red blood cells are free of both Type **A** and Type **B** antigens, but the associated plasma contains both Type **A** and Type **B** antibodies.

Plasma antibodies react with their associated antigens on red blood cells (*e.g.* Type **A** antibodies react with Type **A** antigens), causing the cells to clump together, or agglutinate. The agglutinated red blood cells can clog blood vessels and block circulation. They can also break down completely, with fatal consequences for the individual concerned.

As noted above, individuals also either have (**Rh$^+$**), or do not have (**Rh$^-$**), the **Rhesus factor** (or **Rh D** antigen) on the surface of their red blood cells. The blood plasma of individuals without the **Rh D** antigen on their red blood cells contains the **Rh** antibody, making it incompatible with **Rh$^+$** red blood cells (the plasma of **Rh$^+$** blood contains no such antibodies).

There are, in fact, many antigens on the surface of red blood cells, but only a few, the **ABO** and **Rh** antigens, have a significant impact on blood compatibility (*i.e.* the ability to accept a blood transfusion from another individual) in most people.

Using the **ABO**/**Rh** grouping, the following table[20] illustrates the compatibility of the individual blood groups. The **blood group** of the donor and recipient must be compatible for a satisfactory blood **transfusion**.



Working through the individual combinations of antigens and antibodies, as described above, we can see, for example, that the Type **B** antibodies in Type **A** plasma will react with the Type **B** antigens on either Type **B** or **AB** red blood cells. Type **A** blood will thus be incompatible with either Type **B** or **AB** blood. Similarly, the **Rh** antibodies in any **Rh$^-$** blood group will be incompatible with any **Rh$^+$** red blood cells.

Note that Group **O** is known as the **Universal Donor**, because everyone can receive Group **O** blood, and Group **AB** is known as the **Universal Recipient**, because patients with Group AB blood can receive blood from any donor.

Blood Type is an hereditary trait, passed down to an individual by their parents. The details of this process will be discussed later, when we look at the relationship between genetics and the characteristics of an organism.

[19] There are, in fact, many different blood group definitions in use throughout the world. The ABO system is simply the most commonly used.

[20] http://www.nzblood.co.nz/site_resources/library/images/Blood_Group_Compatibility.gif

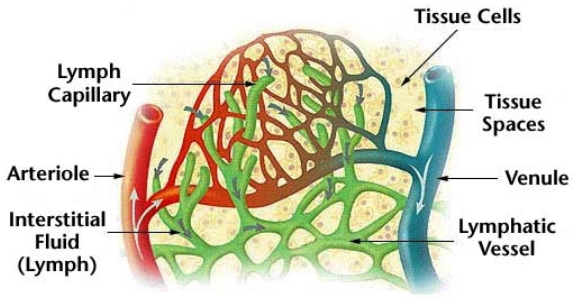
10.1.2.4.2 The Lymphatic System

The lymphatic system and the cardiovascular system, which together comprise the circulatory system, are closely related structures that are joined by a network of capillaries. The lymphatic system is only developed in the higher vertebrates because they require a cardiovascular system that has a relatively high intravascular pressure for the effective transportation of blood. This pressure within the cardiovascular system results in fluid (plasma) seepage (10–20%) from the capillaries into the spaces between tissue cells. In fact, the dissolved constituents of the blood do not directly come in contact with the cells and tissues in the body, but first enter the interstitial fluid, and then the cells of the body. One of the major functions of the lymphatic system is to recover this interstitial fluid, called lymph once it enters the lymphatic system, and return it to the bloodstream.

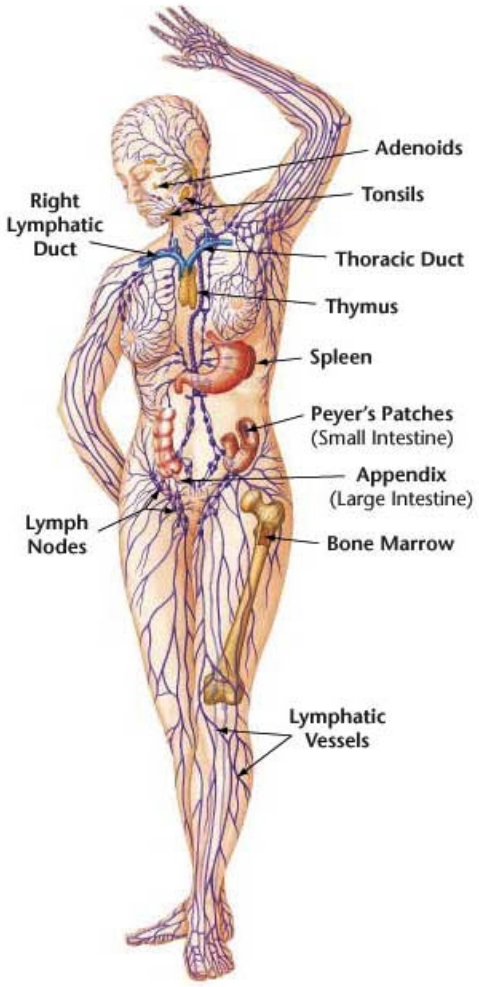
The lymphatic system actually has three interrelated functions:

- As already noted, it is responsible for the collection of interstitial fluid, from body tissue, and its return to the cardiovascular system;
- It absorbs (through lacteals in the small intestine) and transports fatty acids and fats, as chyle, to the cardiovascular system; and
- It produces lymphocytes, special immune cells that fight antigens (viruses, bacteria, etc.) that invade the body.

The lymphatic system comprises ducts, nodes and organs, but can be broadly divided into the conducting system and the lymphoid tissue. The conducting system carries the lymph and consists of tubular vessels that include the lymph capillaries, the lymph vessels and the right and the thoracic (left) ducts.



Arrangement of Lymph Capillaries[21]

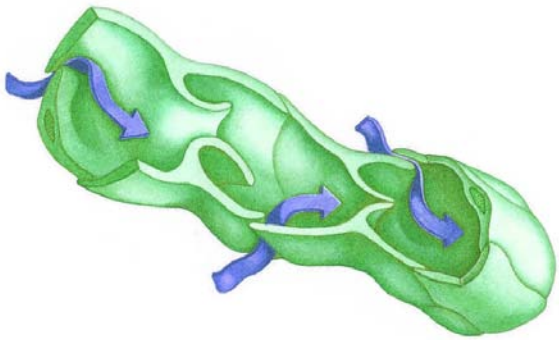


The Lymphatic System[22]

The lymphoid tissue is primarily involved in immune response, and consists of lymphocytes and other white blood cells enmeshed in connective tissue through which the lymph passes. Regions of the lymphoid tissue that are densely packed with lymphocytes are known as lymphoid follicles. Lymphoid tissue can either be structurally well organized as lymph nodes or may consist of loosely organized

[21] http://en.wikipedia.org/wiki/image:illu_lymph_capillary.png
[22] http://www.dkimages.com/discover/previews/770/80538.jpg

lymphoid follicles known as the mucosa-associated lymphoid tissue, or MALT (*e.g.* Peyer's patches, in the small intestine).



Flow of Interstitial Fluid (Lymph) into a Lymph Capillary[23]

The lymph capillaries are very permeable, and because they are not pressurised the lymph fluid can drain easily from the tissue into the lymph capillaries. Lymph is then 'pumped' through the lymphatic system via a peristaltic action that is maintained through the normal movement of skeletal muscles. A series of valves in each lymphatic vessel, similar to those in veins, ensures that lymph only flows in one direction, away from the tissue. As it passes though the system, lymph is filtered through a series of lymph nodes, usually 8–10, before returning to the blood stream. These nodes destroy and filter out toxins and potentially harmful bacteria, in this way forming an essential part of the body's immune system. You will often notice that your lymph nodes (concentrated in your neck, armpits and groin) are swollen after you have suffered from an infection—this is a normal consequence of their immune system function.

Lymphoid tissue is concentrated in the bone marrow, lymph nodes, spleen, thymus, adenoids and tonsils, so-called Peyer's patches in the small intestine, and the appendix (large intestine).

Function of the Spleen

One of the main functions of the spleen, the largest of the lymph organs, is to bring blood into contact with lymphocytes. As blood flows slowly through the spleen, any disease organisms within it are likely to come into contact with lymphocytes in the spleen tissue. This contact activates the lymphocytes, which can then attack the foreign invaders. As blood flows through the spleen, macrophages remove worn-out red and white blood cells and platelets. These macrophages produce the pigment bilirubin from the breakdown of haemoglobin and release it into the blood plasma. Bilirubin is removed from the blood by the liver and kidneys and is excreted in the bile and to a lesser extent in the urine. Because a great deal of blood circulates through the spleen, this organ also serves as a kind of reservoir for blood. Adrenalin and sympathetic nerve discharge stimulate the spleen to contract, releasing much of its blood into the circulation. This function is important especially during haemorrhage, but it is not considered essential in humans. (The reservoir function of the spleen is considered especially important in dogs and other carnivores.) The spleen appears to store platelets in humans, and a large percentage of the body's platelets are normally found there. If the spleen is surgically removed, some of its functions are taken over by the bone marrow and liver; other functions are simply absent, and the body manages without them.

[23] http://www.dkimages.com/discover/previews/740/80644.jpg

Function of the Thymus

Lymphocytes originate from haemocytoblasts (stem cells) in red bone marrow. Those that enter the thymus mature and develop into activated T-lymphocytes *i.e.* able to respond to antigens encountered elsewhere in the body. They then divide into two groups:

- those that enter the blood, some of which remain in circulation and some of which lodge in other lymphoid tissue
- those that remain in the thymus gland and are the source of future generations of T-lymphocytes.

The maturation of the thymus and other lymphoid tissue is stimulated by thymosin, a hormone secreted by the epithelial cells that form the framework of the thymus gland. Involution of the gland begins in adolescence and, with increasing age the effectiveness of T- lymphocyte response to antigens declines.

Function of the fatty acid transport system

Lymph vessels called lacteals are present in the lining of the gastrointestinal tract, predominantly in the small intestine. While most other nutrients absorbed by the small intestine are passed on to the portal venous system to drain, via the hepatic portal vein, into the liver for processing, fats (lipids) are passed on to the lymphatic system, to be transported to the blood circulation via the thoracic duct. The enriched lymph originating in the lymphatics of the small intestine is called chyle.

Immune Response

Lymph nodules are small masses of lymph tissue (up to a millimetre or so in diameter) in which lymphocytes are produced. Lymph nodules are scattered throughout loose connective tissue, especially beneath moist epithelial membranes such as those that line the upper respiratory tract, intestine, and urinary tract. Lymph nodules appear to be strategically distributed to defend the body against disease organisms that penetrate the lining of passageways that communicate with the outside of the body. A lymph nodule consists mainly of large numbers of lymphocytes enmeshed within reticular fibres. Lymph nodules do not have vessels bringing lymph to them. The periphery of the nodule is not sharply defined. Some lymph nodules develop germinal centres, central areas filled with immature lymphocytes. Here new lymphocytes proliferate from stem cells that originate in the bone marrow.

Most lymphatic nodules are small and solitary. However, some are found in large clusters. For example large aggregates of lymph nodules occur in the wall of the lower portion (ileum) of the small intestine. These large masses of lymph nodules are known as Peyer's patches. Tonsils are also aggregates of lymph nodules. They are located strategically to defend against invading bacteria. The tonsils produce lymphocytes. They are located under the epithelial lining of the oral cavity and pharynx. The lingual tonsils are located at the base of the tongue. The single pharyngeal tonsil is located in the posterior wall of the nasal portion of the pharynx above the soft palate and is often referred to as the adenoids.

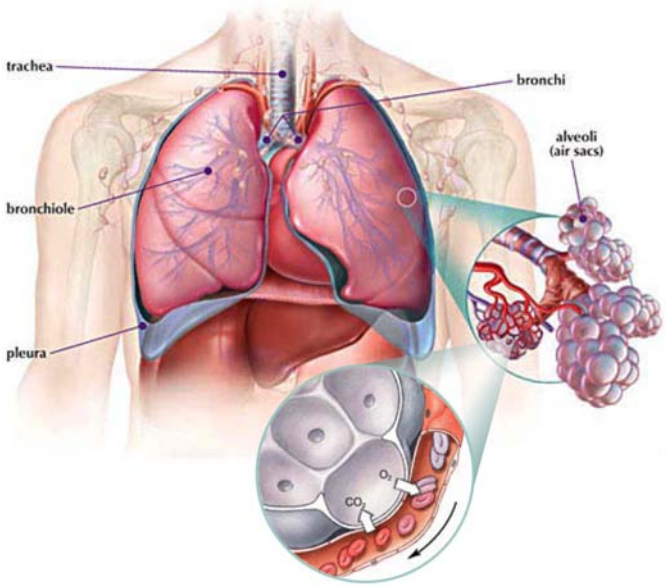
10.1.2.5 Respiration

Cells absorb food and oxygen from the blood and, as a result of a series of complex chemical changes, controlled by **respiratory enzymes**, are able to use these materials to supply energy for their various activities. In this process, called respiration, carbon dioxide and water are released as waste products.

$$\text{glucose} + \text{oxygen} + \text{water} \xrightarrow[\text{enzymes}]{\text{respiratory}} \text{energy} + \text{carbon dioxide} + \text{water}$$

Metabolic processes like respiration, in which complex molecules such as glucose are broken down into more simple compounds, with the release of energy, are known as **katabolic** processes. Energy so generated is often used to produce the compound **adenosine triphosphate** (**ATP**). This substance provides a regulated supply of energy as it is needed by the activity of the cell for the many chemical reactions that occur therein.

The organs concerned with breathing—the **lungs**—are located in the cavity of the **thorax**[24]. Movements of the rib basket and the diaphragm by means of muscles cause air to be drawn into and forced out of the lungs. Oxygen and carbon dioxide are absorbed into red blood cells and released from the blood plasma respectively through **alveoli**, tiny air sacs that populate the ends of the bronchioles within the lungs.



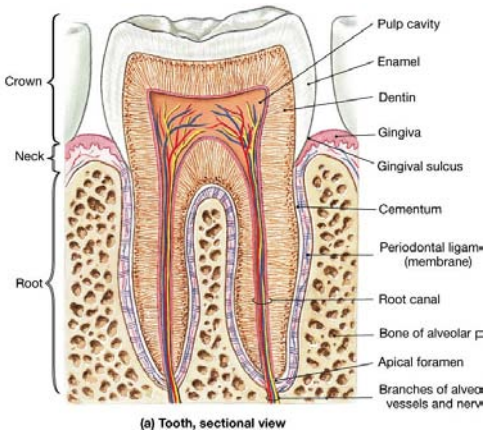
[24] http://www.avastin.com/avastin/images/figures/how-nsclc-develops.jpg

10.1.2.6 Food an Nutrition

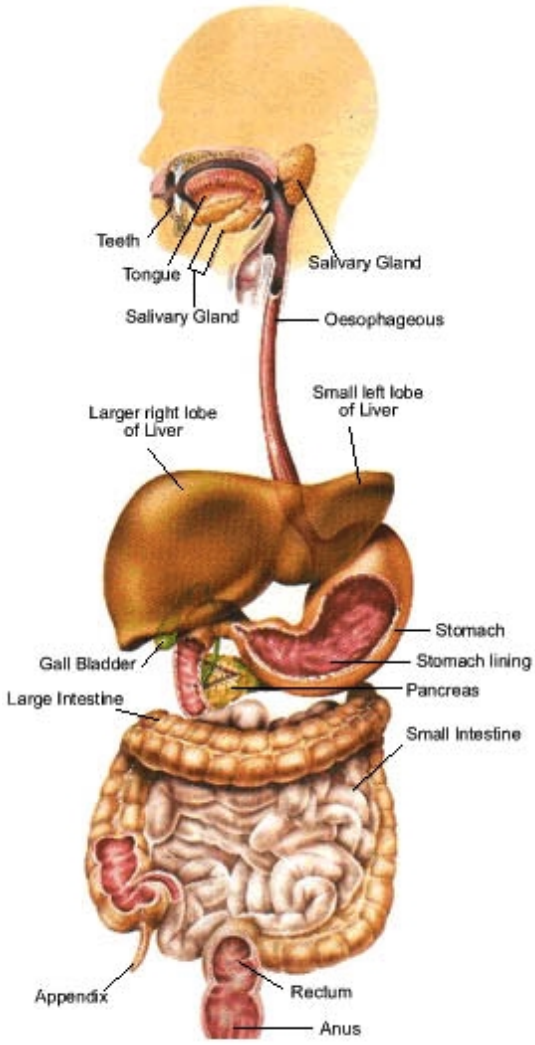
10.1.2.6.1 Digestion

Solid food must be converted to **soluble material** in order to be used by the living cells of the body. This conversion takes place in the **alimentary canal**[25] as follows:

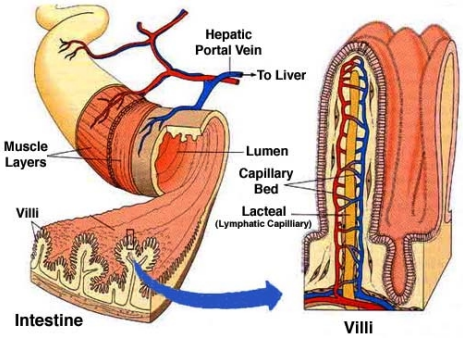
- Solid food, together with water, salts and vitamins, is **ingested** through the mouth where it is chopped and ground by teeth[26];



(a) Tooth, sectional view



- **Digestion**—the conversion to soluble material—begins in the **mouth** where an **enzyme**—**ptyalin**—in saliva converts starch to maltose sugar;
- Food is swallowed, passing down the **oesophagus** to the stomach where enzymes, including **pepsin**, begin changing proteins to peptones;
- Food passes through a **muscular valve** into the intestine, which is long and coiled, where:
  - *(a)* It mixes with **digestive juices**, from the **pancreas** and the wall of the small intestine, and **bile**, from the **liver**;
  - *(b)* Digestion is completed; proteins are converted to amino acids, carbohydrates are converted to glucose, and some fats are converted to fatty acids and glycerol while others are emulsified by bile;
  - *(c)* Soluble materials are absorbed through the **villi**[27], which line the intestine, passing into blood capillaries and lymph vessels;



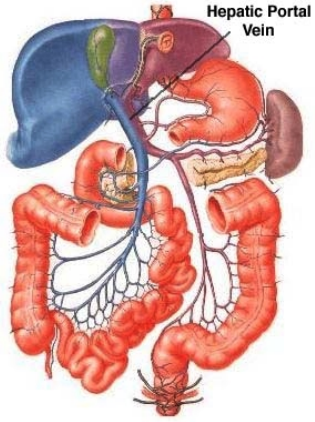
[25] http://www.neximumresearch.com
[26] http://www.iupucanatomy.com/images/Picture%20251g.jpg
[27] http://incostress1.files.wordpress.com/2007/10/villi.jpg

- **Undigested material**—roughage—and water pass into the large intestine to be stored temporarily before being expelled as faeces from the anus. This is the process of **egestion**.

10.1.2.6.2 Absorption of Food

After absorption through the villi:

- Digested foods pass along the **capillaries** via the **hepatic portal vein**[28], to the liver. Some is stored and some is changed chemically before passing on to body cells;
- Some fatty acids and glycerol travel via the **lymph vessels** to **fat deposits**.



Continued growth and good health depend upon a **balanced diet** which supplies for absorption into the body all requirements of proteins, carbohydrates, fats, vitamins, mineral salts, water and roughage.

10.1.2.7 Excretion

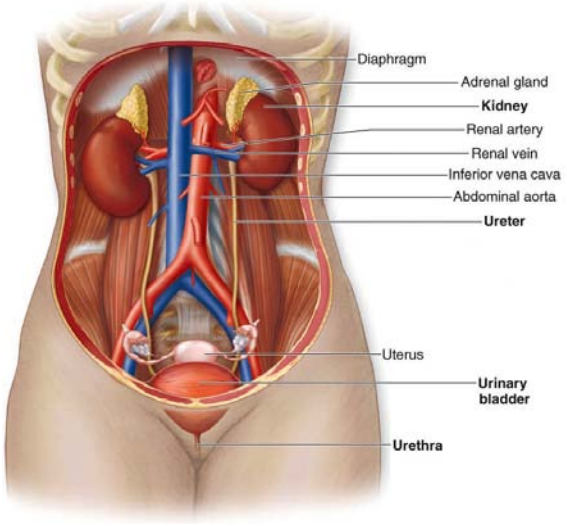
Unwanted substances formed in the cells are called excretory products and their removal is called excretion.

The main waste products formed in the body are:

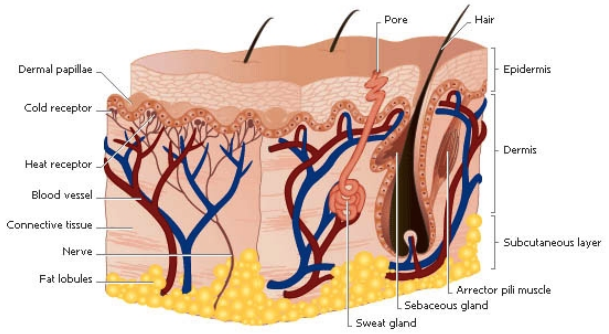
- **Water**, mainly from respiration;
- **Carbon dioxide**, from respiration;
- **Urea**, from the breakdown of amino acids.

The organs in which excretion takes place are:

- **Lungs**, which excrete the carbon dioxide and some water;
- **Kidneys**, which excrete urea and water as urine;
- **Skin**, which excretes some water and salts.



Urinary System (Female)[29]



Cross-Section of Human Skin[30]

[28] http://www.heartweb.net/uploadfile/200701/20070127062826913.jpg
[29] http://blog.lib.umn.edu/trite001/studyinghumananatomyandphysiology/f27-1al_urinary_system_c.jpg
[30] http://www.naturalrussia.com

10.1.2.8 Reproduction

Reproduction is the process of separating part of a living body to form a new organism—an offspring that resembles the parent in most characteristics.

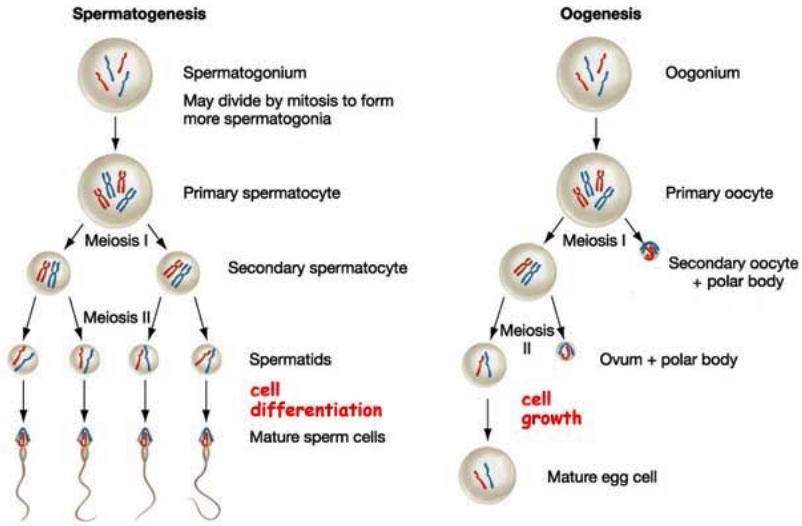
Heredity, the **transmission of characteristics** from one generation to the next, is brought about by reproduction. All living bodies grow from cells that were formerly parts of other living bodies.

There are two types of reproduction:

- **Asexual reproduction**, in which a s**ingle parent** divides into **two parts**, each growing into a complete organism;
- **Sexual reproduction**, in which a **sperm** or reproductive cell from a male parent unites with an **ovum** or reproductive cell from a female parent to form a single cell, a **zygote**, which grows into a **complete offspring** or the **two parents**.

Sexual reproduction takes place as follows:

- Special cells in the reproductive organs of males and females divide by a process called **meiosis** to produce **sperm** (spermatogenesis) and **ova** (oogenesis) respectively[31];



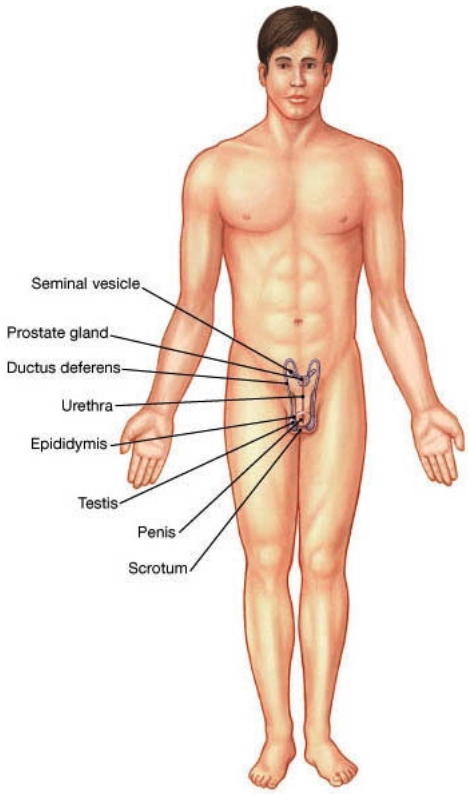
- Sperm and ova each contain **half the number of chromosomes** of the body cells of the organism;
- When a **sperm** and an **ovum** unite, the chromosomes add together in the **nucleus of the zygote**;
- The zygote thus receives **half** its **inherited characteristics** from each parent;
- The zygote cell then divides by **mitosis**[32] into **two identical cells** and as the organism grows, **inherited characteristics** from **each parent** are carried to every part of the offspring.

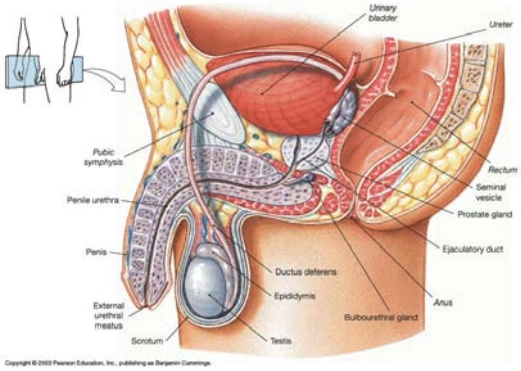
[31] http://fig.cox.miami.edu/~cmallery/150/devel/sf45x3.jpg
[32] http://kvhs.nbed.nb.ca/gallant/biology/mitosis_meiosis.html

The **reproductive system of a mammal**, including a human being, consists of:

In the **male**[33,34]

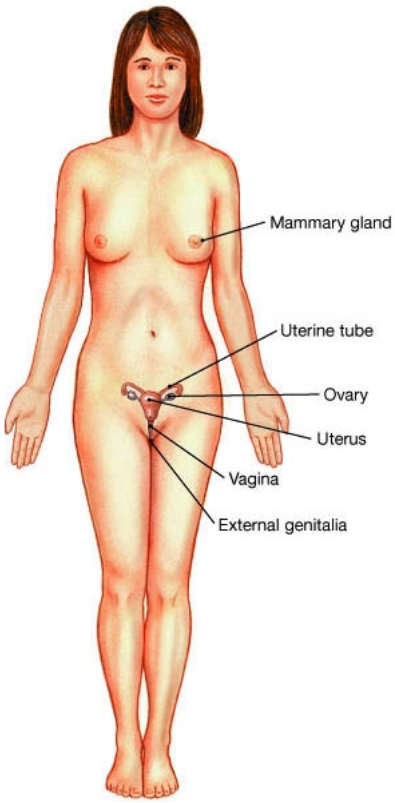
- **Testes** to produce sperm
- Tubes to discharge these through the penis

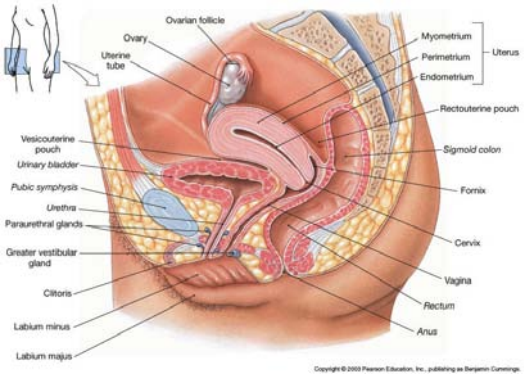




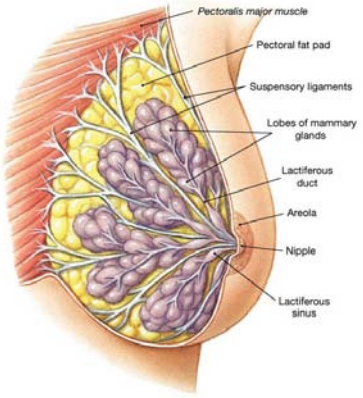
In the **female**[35,36]

- **Ovaries** to produce ova
- Tubes to carry the ova through the uterus, to be discharged through the vagina





[33] http://iupucbio2.iupui.edu/anatomy/images/Chapt01/FG01_06k.jpg
[34] http://www.iupucanatomy.com/images/Picture%20636.jpg
[35] http://iupucbio2.iupui.edu/anatomy/images/Chapt01/FG01_06l.jpg
[36] http://www.iupucanatomy.com/images/Picture%20674.jpg

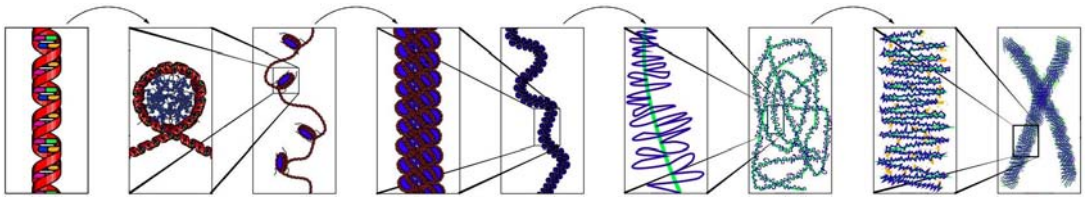


If the ovum of a mammal is fertilised by a sperm cell to produce a zygote, however, the zygote is not discharged, but implants itself in the wall of the uterus and commences to grow as an embryo. A placenta is formed, enabling food, oxygen, carbon dioxide and wastes to pass between the mother and embryo. After a period of gestation when the offspring has sufficiently developed to need no further protection it is forced out from the mother's body. For a time afterwards it is fed by milk produced from the mammary glands[37] of the mother.

10.1.2.9 Inheritance and Growth

Heredity is the process by which traits are passed from parents to their offspring. The study of heredity in biology is called **genetics**, since the fundamental unit within a cell that defines its individual characteristics is a **gene**.

Genes are grouped together in molecules of DNA (deoxyribonucleic acid), which form the basis of the chromosomes that exist in the nucleus of plant, animal and fungi cells[38]. In the case of animals, these chromosomes are inherited from the parents of the individual, through the ovum and sperm that created the initial zygote from which the individual developed. Through the process of mitosis, this genetic material was replicated in every cell as the zygote grew into a fully functioning individual.



The process of DNA folding into a Chromosome[39]

Alternative versions of individual genes, known as **alleles**, account for variations in inherited characteristics. Thus, for each gene, an organism inherits two alleles, one from each parent. In the simplest case, where a specific characteristic is determined by a single gene, if the alleles associated with that characteristic differ, then one, the **dominant allele**, determines the organism's appearance—the other, the **recessive allele**, has no noticeable effect on the organism's appearance. In practice, individual characteristics of an organism are often determined by more than one gene, and most genes have more than two alleles, so that the interplay between individual alleles is more complex than this simple example. Nonetheless, an organism having a pair of identical alleles for a characteristic is said to be **homozygous** for the gene controlling that characteristic. An organism that has two different alleles for a gene is said to be **heterozygous** for that gene. When an allele appears only on the female sex (X) chromosome, with no associated allele on the male sex (Y) chromosome, the males are said to be **hemizygous** (females may be either homozygous or heterozygous).

10.1.2.9.1 Genotype vs Phenotype

Genotype is the characteristic of an individual defined by its genetic code while **phenotype** is the characteristic expressed in the physical appearance of that individual,

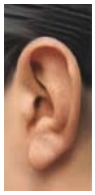
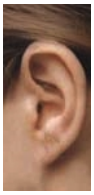
[37] http://iupucbio2.iupui.edu/anatomy/images/Chapt27/FG27_21.jpg
[38] Some DNA also exists in the mitochondria of cells.
[39] http://upload.wikimedia.org/wikipedia/commons/4/4b/Chromatin_Structures.png

as dictated by the dominant or recessive nature of the alleles that determine the expression of individual characteristics.

We will look more deeply into the relationship between genotype and phenotype later, when we study genetics in its own right. For the present, some simple examples will serve to illustrate the distinction between the two.

Free/Attached Earlobes

Simple or complete dominance results when a heterozygous genotype yields a phenotype that expresses only the dominant allele. In human beings, the trait of free or attached earlobes is believed to be determined by a single gene, with a dominant *free* allele. If the dominant *free* allele is represented by the letter F, and the recessive *attached* allele by the letter f, then we may illustrate the relationship between genotype and phenotype as follows:

Genotype	FF or Ff	ff
Phenotype	 Free Earlobe	 Attached Earlobe

Eye Colour

Partial or incomplete dominance results from a heterozygous genotype that yields an intermediate phenotype. In the case of human eye colour, the situation is further complicated by the fact that eye colour is not determined by just one gene. While it is not clear how many genes do contribute to eye colour, the **Punnett square**[40] below illustrates the diversity of phenotype (shown above the respective genotype) that could occur if just two, partially dominant genes were involved.

Father
Aa Bb

Mother
Aa Bb

	AB	Ab	aB	ab
AB	AA BB	AABb	Aa BB	Aa Bb
Ab	AA Bb	AA bb	Aa Bb	Aa bb
aB	Aa BB	Aa Bb	aa BB	aa Bb
ab	AaBb	Aa bb	aa Bb	aa bb

AA BB

AA Bb

Aa Bb

Aa bb

aa bb

[40] Named after British geneticist Reginald C. Punnett (1875–1967)

Blood group

The ABO blood group in humans is determined by multiple alleles of a single gene. There are four phenotypes for this characteristic: a person's blood group may be either **A**, **B**, **AB** or **O**. These letters refer to two carbohydrates—A and B—that may be found on the surface of red blood cells. A person's blood cells may have carbohydrate A (Type **A** blood), carbohydrate B (Type **B**), both (Type **AB**), or none (Type **O**), as illustrated schematically below.

Genotype	**Phenotype** (Blood Group)	**Red Blood Cells**
$I^A I^A$ or $I^A i$	**A**	
$I^B I^B$ or $I^B i$	**B**	
$I^A I^B$	**AB**	
ii	**O**	

The four blood groups result from various combinations of three different alleles for the enzyme (I) that attaches the A or B carbohydrate to red blood cells. The enzyme encoded by the I^A allele adds the A carbohydrate, whereas the enzyme encoded by I^B adds the B carbohydrate (the superscripts indicate the carbohydrate). The enzyme encoded by the *i* allele adds neither A nor B. Because each person carries two alleles, six genotypes are possible, resulting in four phenotypes (see Table above). Both the I^A and the I^B alleles are dominant to the *i* allele. Thus, $I^A I^A$ and $I^A i$ individuals have Type A blood, and $I^B I^B$ and $I^B i$ individuals have Type B blood. Recessive homozygotes, *ii*, have type O blood, because their red blood cells have neither the A nor the B carbohydrate. The I^A and I^B alleles are **codominant**—both are expressed in the phenotype of $I^A I^B$ heterozygotes, who have type AB blood.

As mentioned in Section 10.1.2.4 above, matching compatible blood groups is critical for safe blood transfusions. For example, if a Type A person receives blood from a Type B or Type AB donor, the recipient's immune system recognizes the "foreign" B substance on the donated blood cells and attacks them. This response causes the donated blood cells to clump together, potentially killing the recipient.

Assignment: Examine the genetic basis for eye colour in fruit fly.

10.1.2.9.2 Growth.

Growth is the increase in size of an organism and is brought about by **each existing cell dividing into two**, then each of these into two more, and so on. All new cells originate from the first cell by the process of mitosis. **Mitosis** takes place as every cell of the body divides during growth, thus carrying full **biological information** from the first zygote cell to every new cell.

This biological information, passed from one generation to the next, controls the development of the organism, causing cells to change or **differentiate** during growth to form various tissues and organs that are similar to those of their parents.

References

Biology (7th Ed., Australian Version), Campbell, N. A., Reece, J. B. and Myers, N.. (Pearson Education Australia, 2006) [ISBN 1-74103-386-1]

Human Anatomy (5th Ed), Martini, F. H., Tallitsch, R. B. and Timmons, M. J.. (Benjamin Cummings, 2005) [ISBN 0-80537-211-3]

Many of the images from this text are available from the Indiana University/Perdue University at Columbus Web site:
http://www.iupucanatomy.com

Ultimate Visual Dictionary of Science, Maiklem, L. (Ed.) (Dorling Kindersley, 2000) [ISBN 1-86466-162-3] pp 178–255 Human Anatomy

Wikipedia
(http://en.wikipedia.org)

All images credited to third parties modified and/or used without permission.