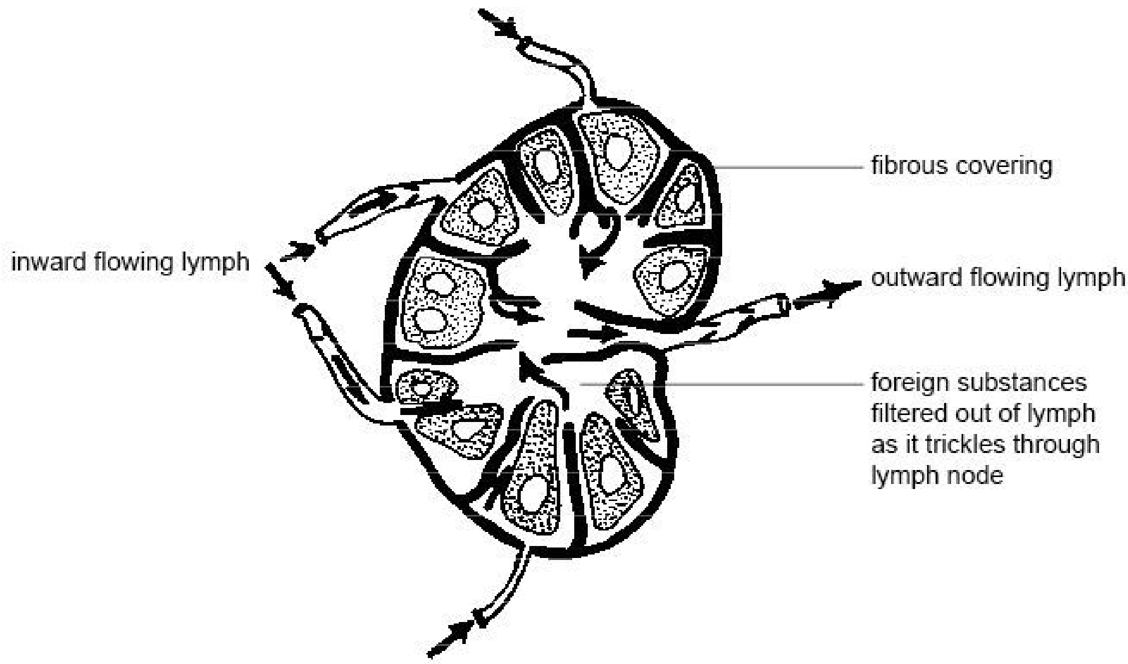

Figure 97

Diagram 10.4 - A lymph node

As well as filtering the lymph, lymph nodes produce the white cells known as **lymphocytes** . Lymphocytes are also produced by the **thymus** , **spleen** and **bone marrow** . There are two kinds of lymphocyte. The first attach invading micro organisms directly while others produce **antibodies** that circulate in the blood and attack them.

The function of the lymphatic system can therefore be summarized as transport and defense. It is important for returning the fluid and proteins that have escaped from the blood capillaries to the blood system and is also responsible for picking up the products of fat digestion in the small intestine. Its other essential function is as part of the immune system, defending the body against infection.

10.2.2 Problems with lymph nodes and the lymphatic system

During infection of the body the lymph nodes often become swollen and tender because of their increased activity. This is what causes the swollen 'glands' in your neck during throat infections, mumps and tonsillitis. Sometimes the bacteria multiply in the lymph node and cause inflammation. Cancer cells may also be carried to the lymph nodes and then transported to other parts of the body where they may multiply to form a secondary growth or **metastasis** . The lymphatic system may therefore contribute to the spread of cancer. Inactivity of the muscles surrounding the lymphatic vessels or blockage of these vessels causes tissue fluid to 'back up' in the tissues resulting in swelling or **oedema** .

10.3 Other Organs Of The Lymphatic System

The **spleen** is an important part of the lymphatic system. It is a deep red organ situated in the abdomen caudal to the stomach (see diagram 10.3). It is composed of two different types of tissue. The first type makes and stores lymphocytes, the cells of the immune system. The second type of tissue destroys worn out red blood cells, breaking down the haemoglobin into iron, which is recycled, and waste products that are excreted. The spleen also stores red blood cells. When severe blood loss occurs, it contracts and releases them into the circulation.

The **thymus** is a large pink organ lying just under the sternum (breastbone) just cranial to the heart (see diagram 10.1). It has an important function processing lymphocytes so they are capable of recognising and attacking foreign invaders like bacteria.

Other lymph organs are the **bone marrow** of the long bones where lymphocytes are produced and **lymph nodules** , which are like tiny lymph nodes. Large clusters of these are found in the wall of the small intestine (called Peyer's Patches) and in the tonsils.

10.4 Summary

- Fluid leaks out of the thin walled capillaries as they pass through the tissues. This is called **tissue fluid** .
- Much of tissue fluid passes back into the capillaries. Some enters the blind-ended lymphatic capillaries that form a network between the cells of the tissues. This fluid is called **lymph** .
- Lymph flows from the **lymphatic capillaries** to **lymph vessels** , passing through **lymph nodes** and along the thoracic duct to join the blood system.
- Lymph nodes filter the lymph and produce **lymphocytes** .
- Other organs of the lymphatic system are the **spleen, thymus, bone marrow** , and **lymph nodules** .

10.5 Worksheets

Lymphatic System Worksheet[1]

10.6 Test Yourself

1. What is the difference between tissue fluid and lymph?
2. By what route does lymph make its way back to join the blood of the circulatory system?
3. As the lymphatic system has no heart to push the lymph along what makes it flow?
4. What happens to the lymph as it passes through a lymph node?

1 http://www.wikieducator.org/Lymphatic_System_Worksheet

5. Where is the spleen located in the body?
6. Where is the thymus located in the body?
7. What is the function of lymphocytes?

/Test Yourself Answers/[2]

10.7 Websites

- http://www.cancerhelp.org.uk/help/default.asp?page=117 Cancerhelp

A nice clear explanation here with great diagrams of the (human) lymphatic system.

- http://www.jdaross.cwc.net/lymphatics2.htm Lymphatic system

Introduction to the Lymphatic System. A good description of lymph circulation with an animation.

- http://en.wikipedia.org/wiki/Lymphatic_system Wikipedia

Good information here on the (human) lymphatic system, lymph circulation and lymphoid organs.

10.8 Glossary

- Link to Glossary[3]

4

2 https://en.wikibooks.org/wiki/%2FTest%20Yourself%20Answers%2F
3 http://en.wikibooks.org/wiki/Anatomy_and_Physiology_of_Animals/Glossary
4 https://en.wikibooks.org/wiki/Category%3A

11 The Gut and Digestion

Figure 98 original image by vnysia[a] cc by

a http://flickr.com/photos/vnysia/521324958/

11.1 Objectives

After completing this section, you should know:

- what is meant by the terms: ingestion, digestion, absorption, assimilation, egestion, peristalsis and chyme
- the characteristics, advantages and disadvantages of a herbivorous, carnivorous and omnivorous diet
- the 4 main functions of the gut
- the parts of the gut in the order in which the food passes down it

11.2 The Gut And Digestion

Plant cells are made of organic molecules using energy from the sun. This process is called **photosynthesis** . Animals rely on these ready-made organic molecules to supply them with their food. Some animals (herbivores) eat plants; some (carnivores) eat the herbivores.

11.3 Herbivores

Herbivores*eat plant material. While no animal produces the digestive enzymes to break down the large* ***cellulose*** *molecules in the plant cell walls, micro-organisms' like bacteria, on the other hand, can break them down. Therefore herbivores employ micro-organisms to do the job for them.*

There are three types of herbivore:

The first, **ruminants** like cattle, sheep and goats, house these bacteria in a special compartment in the enlarged stomach called the **rumen** .

The second group has an enlarged large intestine and caecum, called a **functional caecum** , occupied

by cellulose digesting micro-organisms. These non-ruminant herbivores include the horse, rabbit and rat.

Humans also have a cecum and can be classified as the third type of herbivorous class, along with orangutans and gorillas.

Plants are a primary pure and good source of nutrients, however they are digested very easily and therefore herbivores have to eat large quantities of food to obtain all they require. Herbivores like cows, horses and rabbits typically spend much of their day feeding. To give the micro- organisms access to the cellulose molecules, the plant cell walls need to be broken down. This is why herbivores have teeth that are adapted to crush and grind. Their guts also tend to be lengthy and the food takes a long time to pass through it.

Eating plants have other advantages. Plants are immobile so herbivores normally have to spend little energy collecting them. This contrasts with another main group of animals - the carnivores that often have to chase their prey.

11.4 Carnivores

Carnivorous animals like those in the cat and dog families, polar bears, seals, crocodiles and birds of prey catch and eat other animals. They often have to use large amounts of energy finding, stalking, catching and killing their prey. However, they are rewarded by the fact that meat provides a very concentrated source of nutrients. Carnivores in the wild therefore tend to eat distinct meals often with long and irregular intervals between them. Time after feeding is spent digesting and absorbing the food.

The guts of carnivores are usually shorter and less complex than those of herbivores because meat is easier to digest than plant material. Carnivores usually have teeth that are specialised for dealing with flesh, gristle and bone. They have sleek bodies, strong, sharp claws and keen senses of smell, hearing and sight. They are also often cunning, alert and have an aggressive nature.

11.5 Omnivores

Many animals feed on both animal and vegetable material – they are **omnivorous.** Most primates, including humans, are herbivorous but a few, such as chimpanzees belong to this category as do pigs and rats. Their food is diverse, ranging from plant material to animals they have either killed themselves or scavenged from other carnivores. Omnivores lack the specialised teeth and guts of carnivores and herbivores but are often highly intelligent and adaptable reflecting their varied diet.

11.6 Treatment Of Food

Whether an animal eats plants or flesh, the **carbohydrates** , **fats** and **proteins** in the food it eats are generally giant molecules (see chapter 1). These need to be split up into smaller ones before they can pass into the blood and enter the cells to be used for energy or to make new cell constituents.

For example:

Carbohydrates like cellulose, starch, and glycogen need to be split into **glucose** and other **monosaccharides** ;

Proteins need to be split into **amino acids** ;

Fats or **lipids** need to be split into **fatty acids** and **glycerol** .

11.7 The Gut

The **digestive tract, alimentary canal** or **gut** is a hollow tube stretching from the mouth to the anus. It is the organ system concerned with the treatment of foods.

At the mouth the large food molecules are taken into the gut - this is called **ingestion** . They must then be broken down into smaller ones by digestive enzymes - **digestion** , before they can be taken from the gut into the blood stream - **absorption** . The cells of the body can then use these small molecules - **assimilation** . The indigestible waste products are eliminated from the body by the act of **egestion** (see diagram 11.1).

Figure 99

Diagram 11.1 - From ingestion to egestion

The 4 major functions of the gut are:

1. Transporting the food;
2. Processing the food physically by breaking it up (chewing), mixing, adding fluid etc.
3. Processing the food chemically by adding digestive enzymes to split large food molecules into smaller ones.
4. Absorbing these small molecules into the blood stream so the body can use them.

The regions of a typical mammals gut (for example a cat or dog) are shown in diagram 11.2.

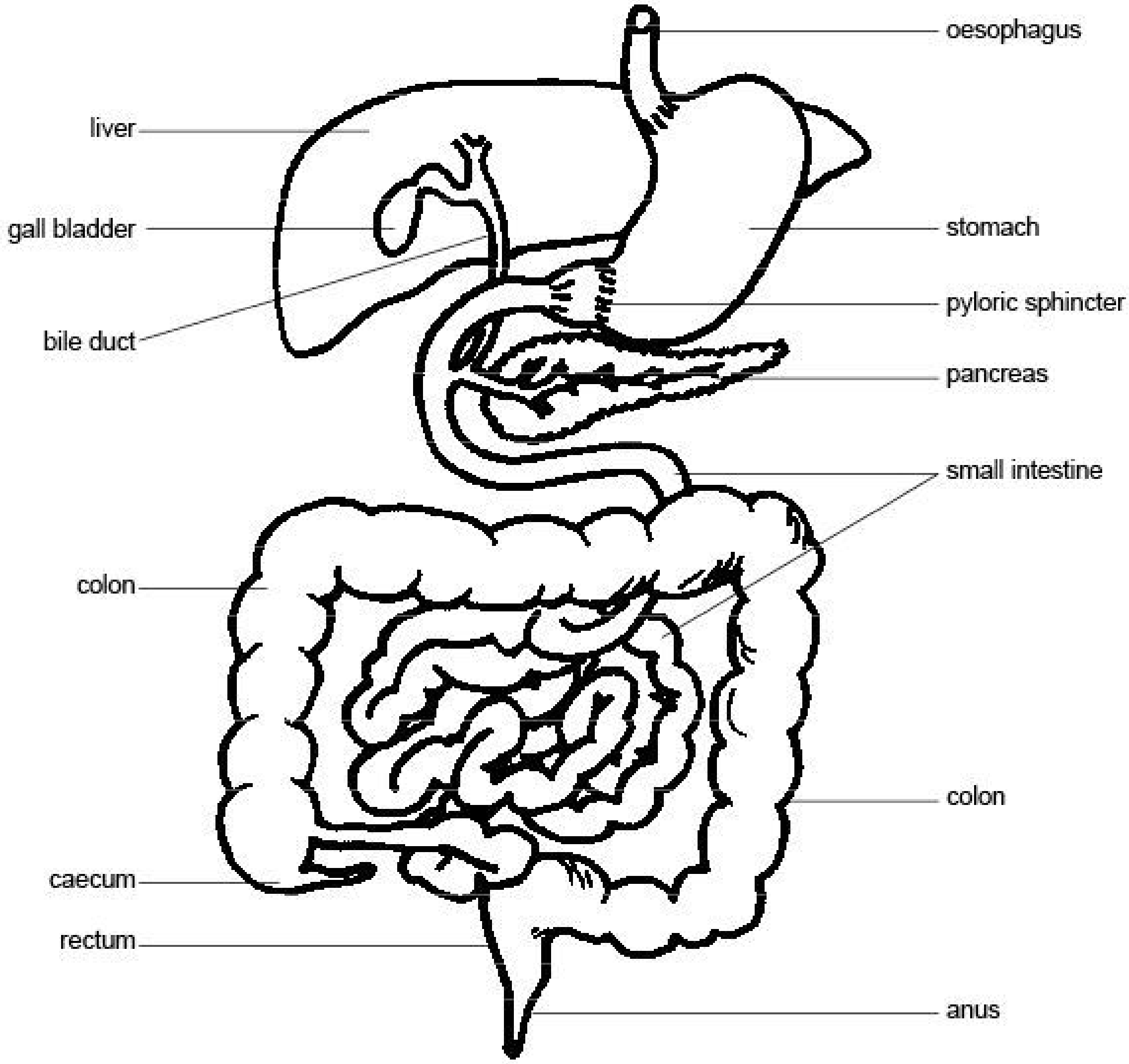

Figure 100

Diagram 11.2 - A typical mammalian gut

The food that enters the **mouth** passes to the **oesophagus** , then to the **stomach** , **small intestine** , **cecum** , **large intestine** , **rectum** and finally undigested material exits at the **anus** . The **liver** and **pancreas** produce secretions that aid digestion and the **gall bladder** stores **bile** . Herbivores have an appendix which they use for the digestion of cellulose. Carnivores have an appendix but is not of any function anymore due to the fact that their diet is not based on cellulose anymore.

11.8 Mouth

The mouth takes food into the body. The lips hold the food inside the mouth during chewing and allow the baby animal to suck on its mother's teat. In elephants the lips (and nose) have developed into the trunk which is the main food collecting tool. Some mammals, e.g. hamsters, have stretchy cheek pouches that they use to carry food or material to make their nests.

The sight or smell of food and its presence in the mouth stimulates the **salivary glands** to secrete **saliva** . There are four pairs of these glands in cats and dogs (see diagram 11.3). The fluid they produce moistens and softens the food making it easier to swallow. It also contains the enzyme, **salivary amylase** , which starts the digestion of starch.

The **tongue** moves food around the mouth and rolls it into a ball for swallowing. **Taste buds** are located on the tongue and in dogs and cats it is covered with spiny projections used for grooming and lapping. The cow's tongue is prehensile and wraps around grass to graze it.

Swallowing is a complex reflex involving 25 different muscles. It pushes food into the oesophagus and at the same time a small flap of tissue called the **epiglottis** closes off the windpipe so food doesn't go 'down the wrong way' and choke the animal (see diagram 11.4).

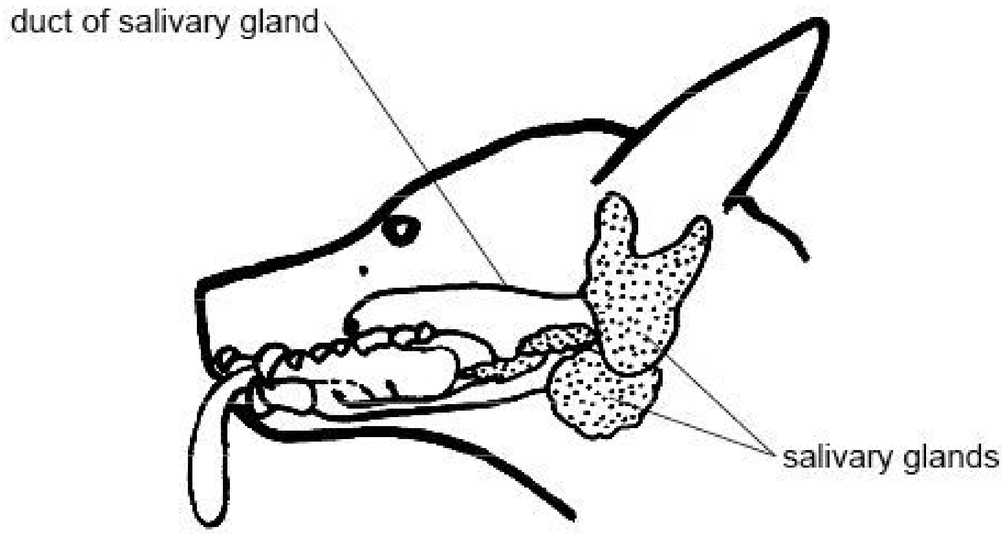

Figure 101

Diagram 11.3 - Salivary glands

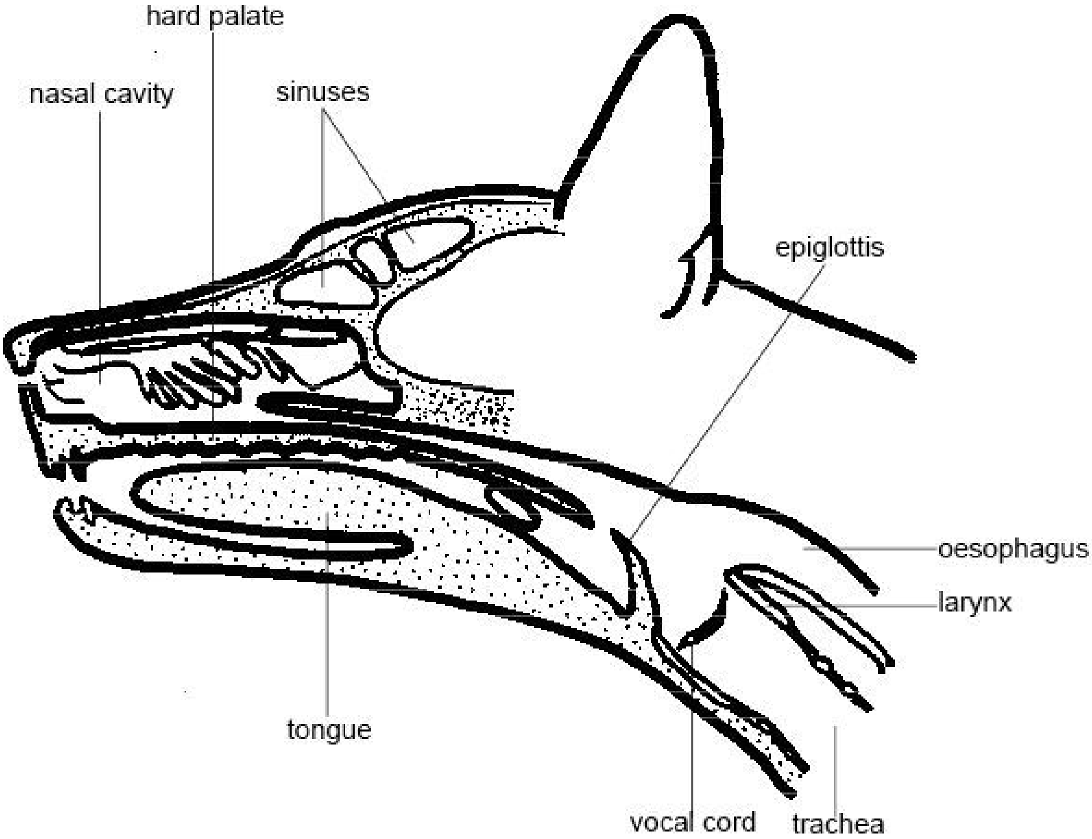

Figure 102

Diagram 11.4 - Section through the head of a dog

11.9 Teeth

Teeth seize, tear and grind food. They are inserted into sockets in the bone and consist of a crown above the gum and root below. The crown is covered with a layer of **enamel** , the hardest substance in the body. Below this is the **dentine** , a softer but tough and shock resistant material. At the centre of the tooth is a space filled with **pulp** which contains blood vessels and nerves. The tooth is cemented into the **socket** and in most teeth the tip of the root is quite narrow with a small opening for the blood vessels and nerves (see diagram 11.5).

In teeth that grow continuously, like the incisors of rodents, the opening remains large and these teeth are called **open rooted teeth** . Mammals have 2 distinct sets of teeth. The first the **milk teeth** are replaced by the **permanent teeth** .

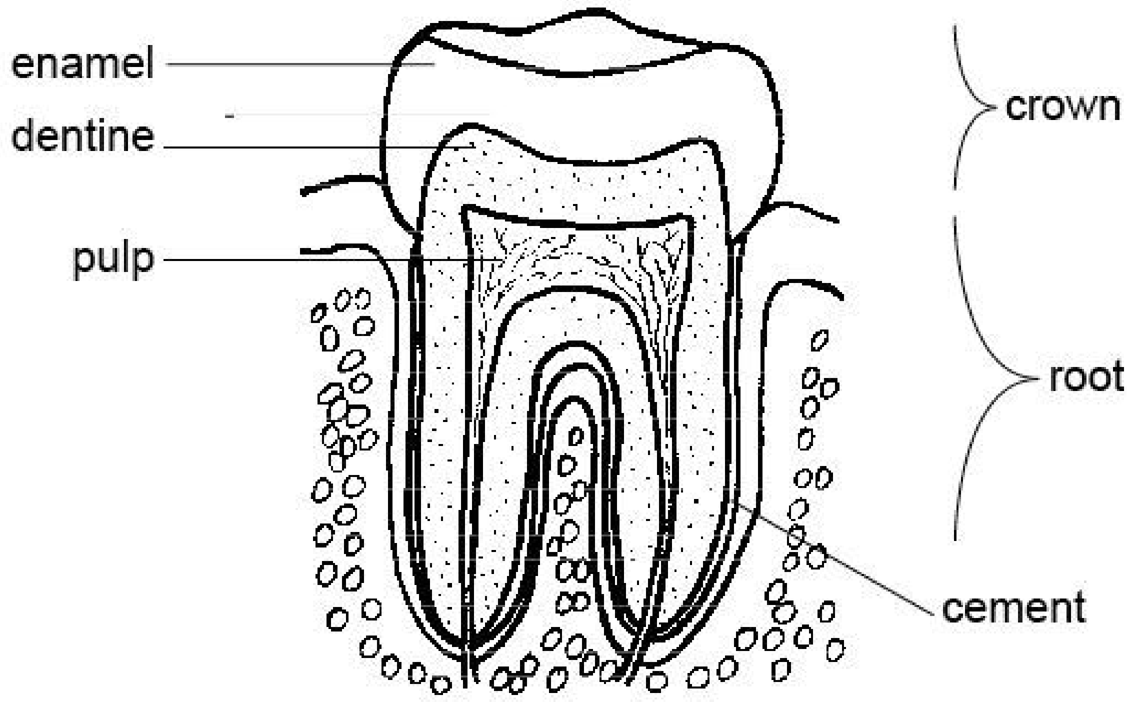

Figure 103

Diagram 11.5 - Structure of a tooth

11.9.1 Types Of Teeth

All the teeth of fish and reptiles are similar but mammals usually have four different types of teeth.

The **incisors** are the chisel-shaped 'biting off' teeth at the front of the mouth. In rodents and rabbits the incisors never stop growing (open-rooted teeth). They must be worn or ground down continuously by gnawing. They have hard enamel on one surface only so they wear unevenly and maintain their sharp cutting edge.

The largest incisors in the animal kingdom are found in elephants, for tusks are actually giant incisors. Sloths have no incisors at all, and sheep have no incisors in the upper jaw (see diagram 11.6). Instead there is a horny pad against which the bottom incisors cut.

The **canines** or 'wolf-teeth' are long, cone-shaped teeth situated just behind the incisors. They are particularly well developed in the dog and cat families where they are used to hold, stab and kill the prey (see diagram 11.7).

The tusks of boars and walruses are large canines while rodents and herbivores like sheep have no (or reduced) canines. In these animals the space where the canines would normally be is called the **diastema** . In rodents like the rat and beaver it allows the debris from gnawing to be expelled easily.

The cheek teeth or **premolars** and **molars** crush and grind the food. They are particularly well developed in herbivores where they have complex ridges that form broad grinding surfaces (see diagram 11.6). These are created from alternating bands of hard enamel and softer dentine that wear at different rates.

In carnivores the premolars and molars slice against each other like scissors and are called **carnassial** teeth see diagram 11.7). They are used for shearing flesh and bone.

11.9.2 Dental Formula

The numbers of the different kinds of teeth can be expressed in a **dental formula** . This gives the numbers of incisors, canines, premolars and molars in **one half** of the mouth. The numbers of these four types of teeth in the left **or** right **half of the upper jaw** are written above a horizontal line and the four types of teeth in the right **or** left **half of the lower jaw** are written below it.

Thus the dental formula for the sheep is:

0.0.3.3

3.1.3.3

It indicates that in the upper right (or left) **half** of the jaw there are no incisors or canines (i.e. there is a **diastema**), three premolars and three molars. In the lower right (or left) **half** of the jaw are three incisors, one canine, three premolars and three molars (see diagram 11.6).

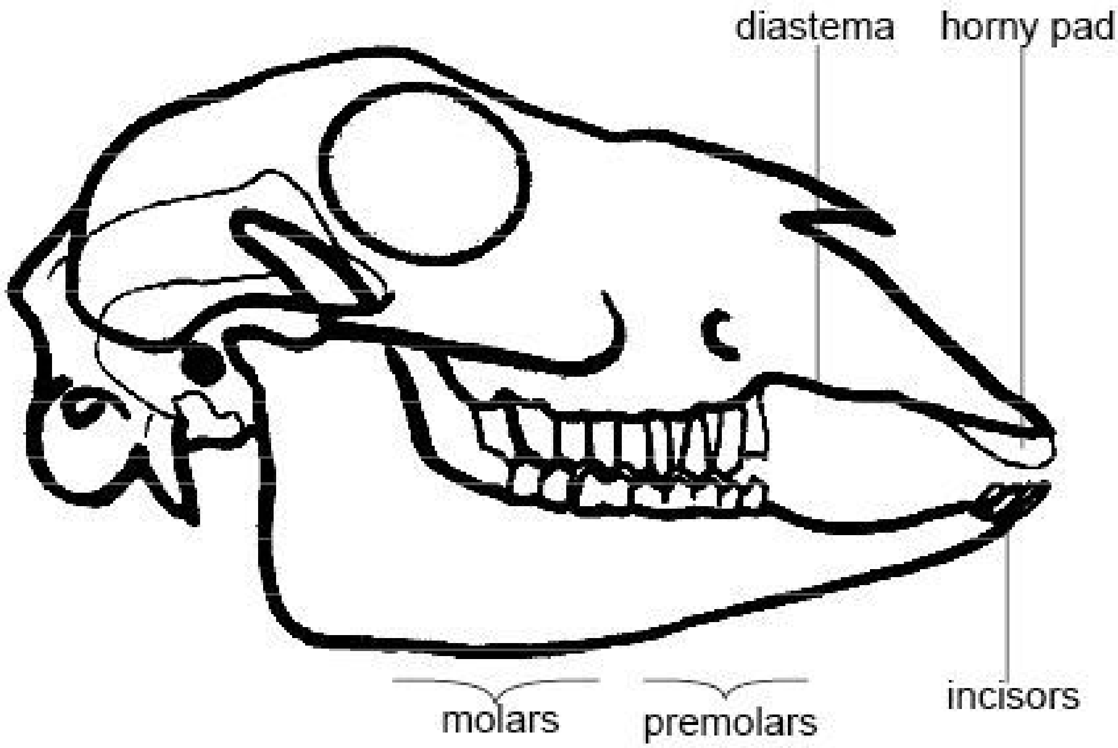

Figure 104

Diagram 11.6 - A sheep's skull

The dental formula for a dog is:

3.1.4.2

3.1.4.3

The formula indicates that in the right (or left) **half** of the upper jaw there are three incisors, one canine, four premolars and two molars. In the right (or left) **half** of the lower jaw there are three incisors, one canine, four premolars and three molars (see diagram 11.7).

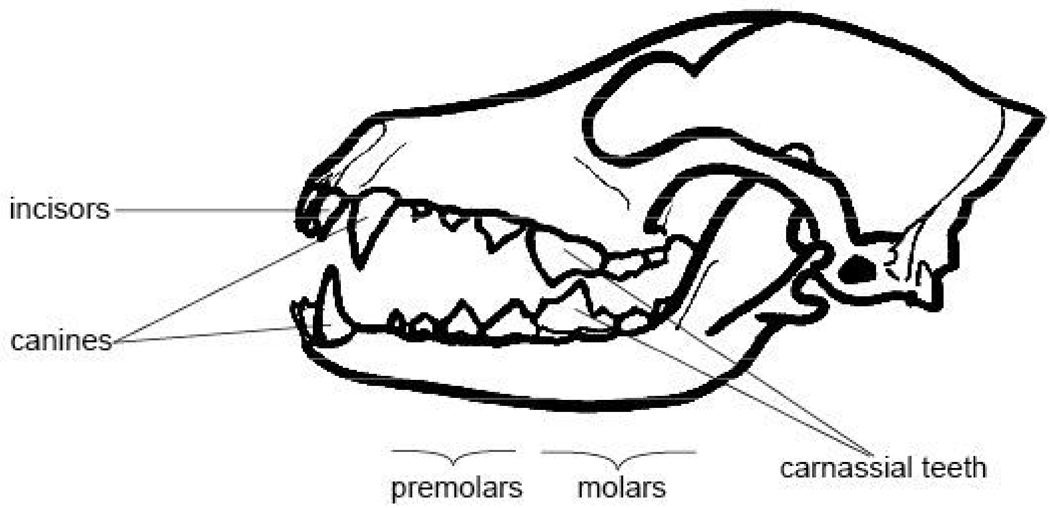

Figure 105

Diagram 11.7 - A dog's skull

11.10 Oesophagus

The **oesophagus** transports food to the stomach. Food is moved along the oesophagus, as it is along the small and large intestines, by contraction of the smooth muscles in the walls that push the food along rather like toothpaste along a tube. This movement is called **peristalsis** (see diagram 11.8).

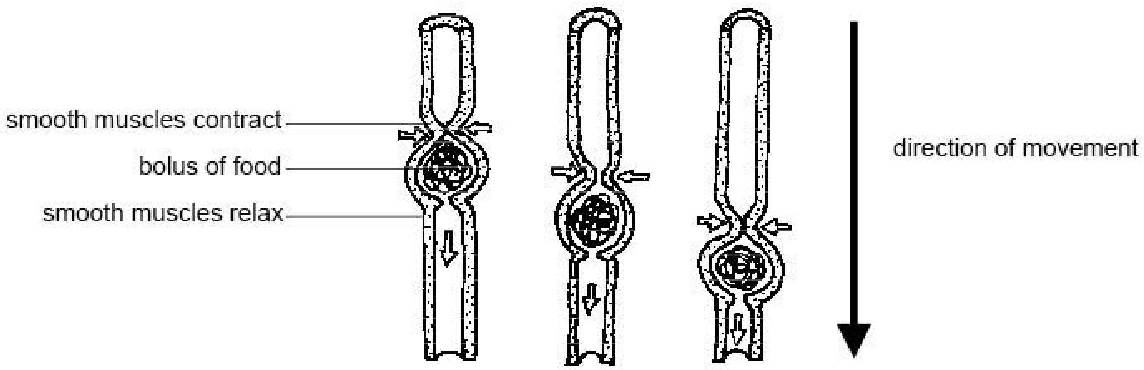

Figure 106

Diagram 11.8 - Peristalsis

11.11 Stomach

The **stomach** stores and mixes the food. Glands in the wall secrete **gastric juice** that contains enzymes to digest protein and fats as well as **hydrochloric acid** to make the contents very acidic. The walls of the stomach are very muscular and churn and mix the food with the gastric juice to form a watery mixture called **chyme** (pronounced kime). Rings of muscle called **sphincters** at the entrance and exit to the stomach control the movement of food into and out of it (see diagram 11.9).

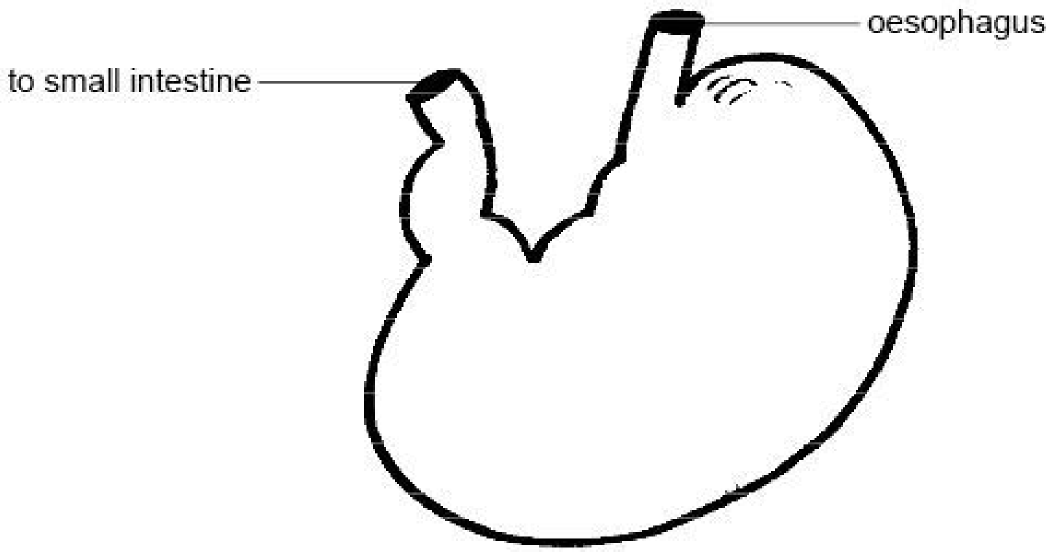

Figure 107

Diagram 11.9 - The stomach

11.12 Small Intestine

Most of the breakdown of the large food molecules and absorption of the smaller molecules take place in the long and narrow small intestine. The total length varies but it is about 6.5 metres in humans, 21 metres in the horse, 40 metres in the ox and over 150 metres in the blue whale.

It is divided into 3 sections: the duodenum (after the stomach), jejunum and ileum. The duodenum receives 3 different secretions:

1) **Bile** from the liver;

2) **Pancreatic juice** from the pancreas and

3) **Intestinal juice** from glands in the intestinal wall.

These complete the digestion of starch, fats and protein. The products of digestion are absorbed into the blood and lymphatic system through the wall of the intestine, which is lined with tiny finger-like projections called **villi** that increase the surface area for more efficient absorption (see diagram 11.10).

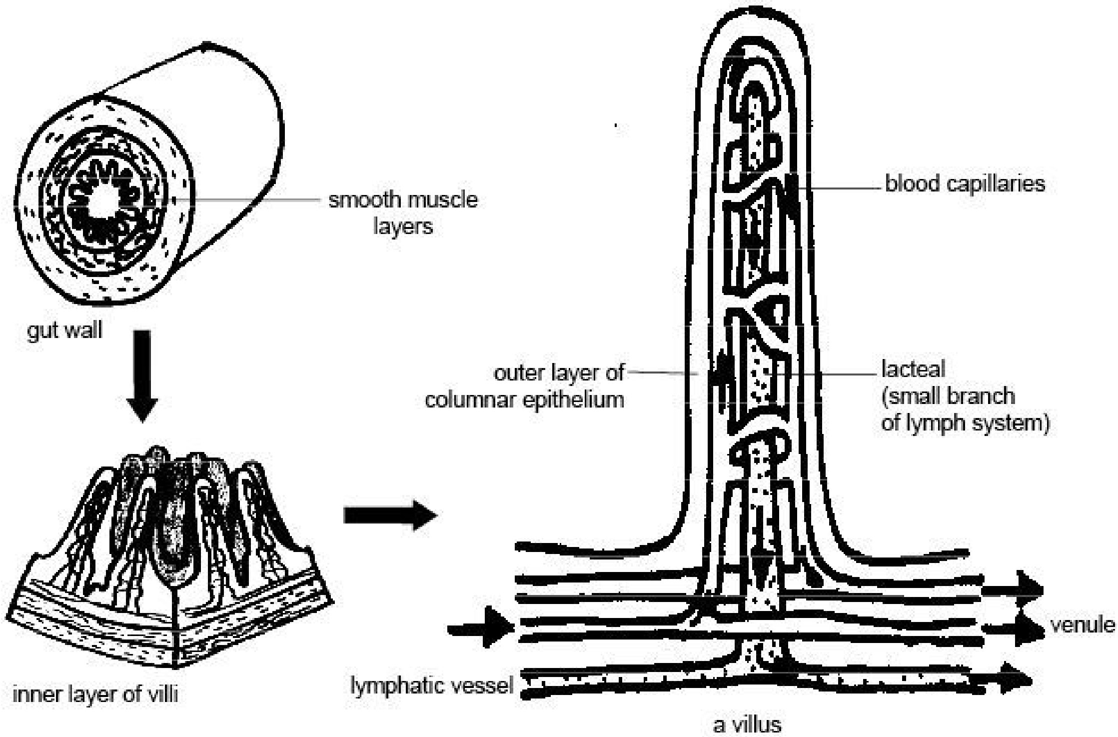

Figure 108

Diagram 11.10 - The wall of the small intestine showing villi

11.13 The Rumen

In ruminant herbivores like cows, sheep and antelopes the stomach is highly modified to act as a "fermentation vat". It is divided into four parts. The largest part is called the **rumen** . In the cow it occupies the entire left half of the abdominal cavity and can hold up to 270 litres. The **reticulum** is much smaller and has a honeycomb of raised folds on its inner surface. In the camel the reticulum is further modified to store water. The next part is called the **omasum** with a folded inner surface. Camels have no omasum. The final compartment is called the **abomasum** . This is the 'true' stomach where muscular walls churn the food and gastric juice is secreted (see diagram 11.11).

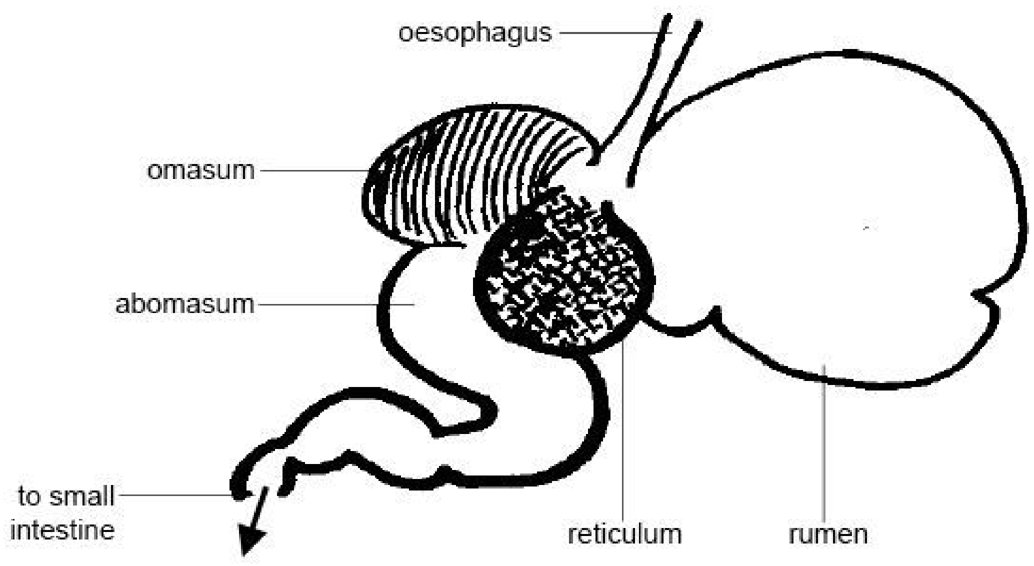

Figure 109

Diagram 11.11 - The rumen

Ruminants swallow the grass they graze almost without chewing and it passes down the oesophagus to the rumen and reticulum. Here liquid is added and the muscular walls churn the food. These chambers provide the main fermentation vat of the ruminant stomach. Here bacteria and single-celled animals start to act on the cellulose plant cell walls. These organisms break down the cellulose to smaller molecules that are absorbed to provide the cow or sheep with energy. In the process, the gases methane and carbon dioxide are produced. These cause the “burps” you may hear cows and sheep making.

Not only do the micro-organisms break down the cellulose but they also produce the **vitamins E, B and K** for use by the animal. Their digested bodies provide the ruminant with the majority of its protein requirements.

In the wild grazing is a dangerous activity as it exposes the herbivore to predators. They crop the grass as quickly as possible and then when the animal is in a safer place the food in the rumen can be regurgitated to be chewed at the animal’s leisure. This is ‘chewing the cud’ or **rumination** . The finely ground food may be returned to the rumen for further work by the microorganisms or, if the particles are small enough, it will pass down a special groove in the wall of the oesophagus straight into the omasum. Here the contents are kneaded and water is absorbed before they pass to the abomasum. The abomasum acts as a “proper” stomach and gastric juice is secreted to digest the protein.

11.14 Large Intestine

The **large intestine** consists of the **caecum** , **colon** and **rectum** . The chyme from the small intestine that enters the colon consists mainly of water and undigested material such as cellulose (fibre or roughage). In omnivores like the pig and humans the main function of the colon is absorption of water to give solid faeces. Bacteria in this part of the gut produce vitamins B and K.

The caecum, which forms a dead-end pouch where the small intestine joins the large intestine, is small in pigs and humans and helps water absorption. However, in rabbits, rodents and horses, the caecum is very large and called the **functional caecum** . It is here that cellulose is digested by micro-organisms. The **appendix** , a narrow dead end tube at the end of the caecum, is particularly large in primates but seems to have no digestive function.

11.15 Functional Caecum

The caecum in the rabbit, rat and guinea pig is greatly enlarged to provide a "fermentation vat" for micro-organisms to break down the cellulose plant cell walls. This is called a **functional caecum** (see diagram 11.12). In the horse both the caecum and the colon are enlarged. As in the rumen, the large cellulose molecules are broken down to smaller molecules that can be absorbed. However, the position of the functional caecum after the main areas of digestion and absorption, means it is potentially less effective than the rumen. This means that the small molecules that are produced there can not be absorbed by the gut but pass out in the faeces. The rabbit and rodents (and foals) solve this problem by eating their own faeces so that they pass through the gut a second time and the products of cellulose digestion can be absorbed in the small intestine. Rabbits produce two kinds of faeces. Softer night-time faeces are eaten directly from the anus and the harder pellets you are probably familiar with, that have passed through the gut twice.

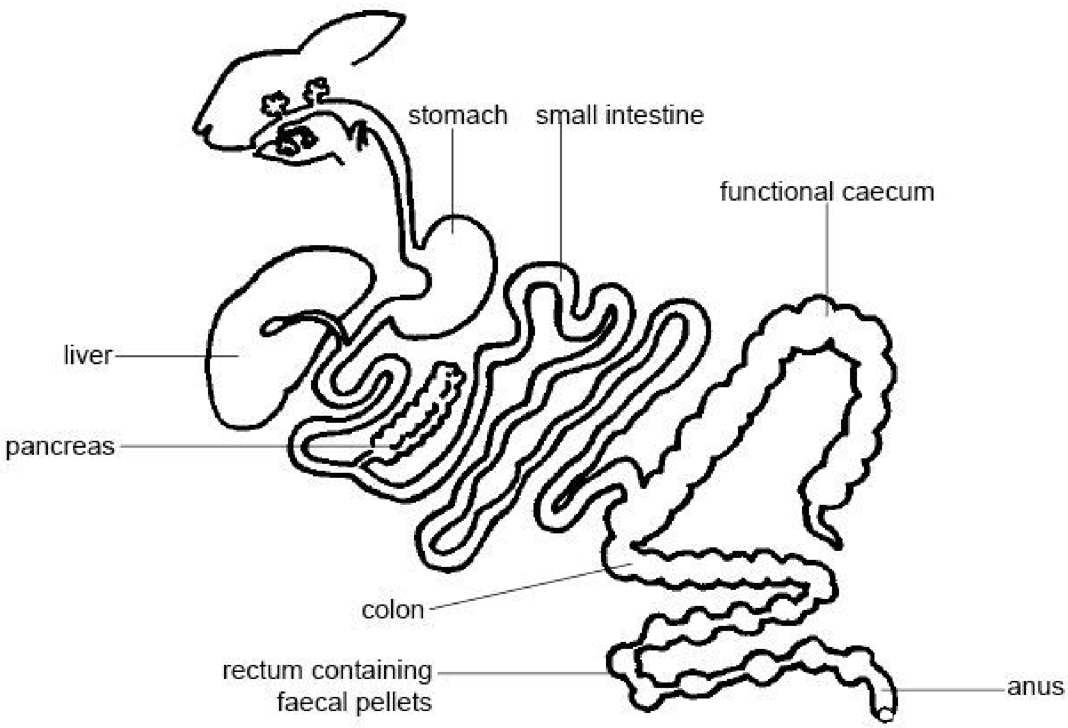

Figure 110

Diagram 11.12 - The gut of a rabbit

11.16 The Gut Of Birds

Birds' guts have important differences from mammals' guts. Most obviously, birds have a **beak** instead of teeth. Beaks are much lighter than teeth and are an adaptation for flight. Imagine a bird trying to take off and fly with a whole set of teeth in its head! At the base of the oesophagus birds have a bag-like structure called a **crop** . In many birds the crop stores food before it enters the stomach, while in pigeons and doves glands in the crop secretes a special fluid called **crop-milk** which parent birds regurgitate to feed their young. The stomach is also modified and consists of two compartments. The first is the true stomach with muscular walls and enzyme secreting glands. The second compartment is the **gizzard** . In seed eating birds this has very muscular walls and contains pebbles swallowed by the bird to help grind the food. This is the reason why you must always supply a caged bird with grit. In birds of prey like the falcon the walls of the gizzard are much thinner and expand to accommodate large meals (see diagram 11.13).

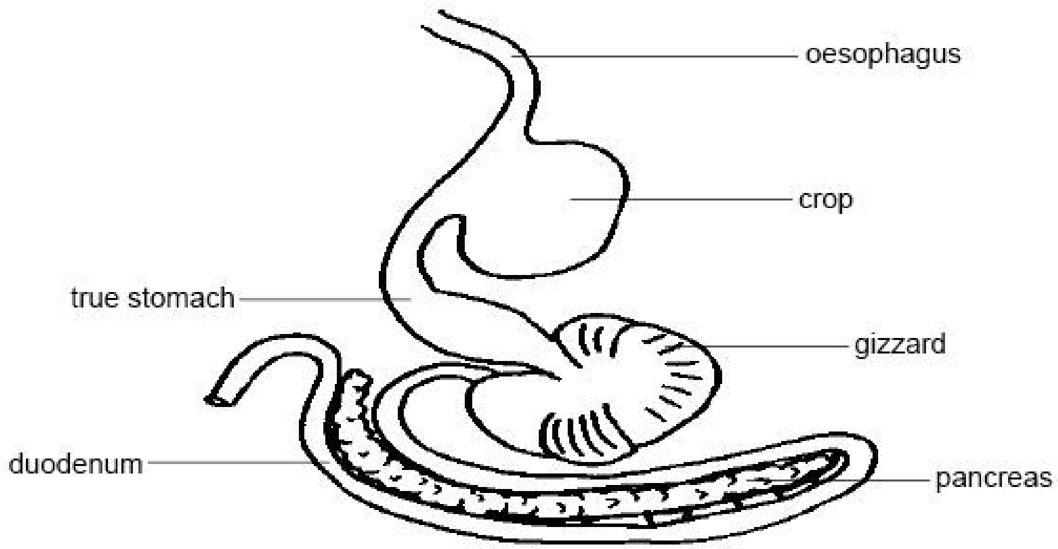

Figure 111

Diagram 11.13 - The stomach and small intestine of a hen

11.17 Digestion

During digestion the large food molecules are broken down into smaller molecules by **enzymes** . The three most important groups of enzymes secreted into the gut are:

1. **Amylases** that split carbohydrates like starch and glycogen into monosaccharides like glucose.

2. **Proteases** that split proteins into amino acids.
3. **Lipases** that split lipids or fats into fatty acids and glycerol.

Glands produce various secretions which mix with the food as it passes along the gut.

These secretions include:

1. **Saliva** secreted into the mouth from several pairs of **salivary glands** (see diagram 11.3). Saliva consists mainly of water but contains salts, mucous and salivary amylase. The function of saliva is to lubricate food as it is chewed and swallowed and salivary amylase begins the digestion of starch.
2. **Gastric juice** secreted into the stomach from glands in its walls. Gastric juice contains **pepsin** that breaks down protein and hydrochloric acid to produce the acidic conditions under which this enzyme works best. In baby animals rennin to digest milk is also produced in the stomach.
3. **Bile** produced by the liver. It is stored in the **gall bladder** and secreted into the duodenum via the **bile duct** (see diagram 11.14). (Note that the horse, deer, parrot and rat have no gall bladder). Bile is not a digestive enzyme. Its function is to break up large globules of fat into smaller ones so the fat splitting enzymes can gain access the fat molecules.

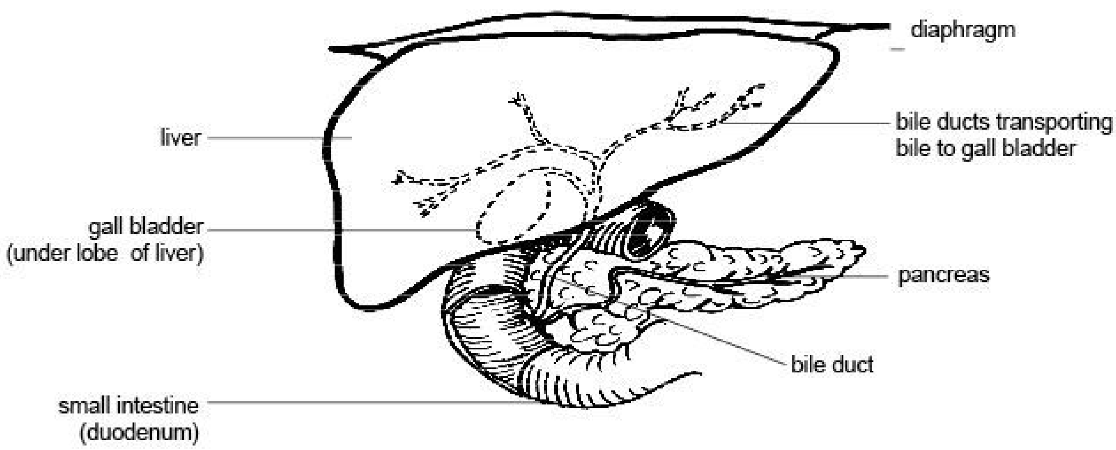

Figure 112

Diagram 11.14 - The liver, gall bladder and pancreas

11.18 Pancreatic juice

The **pancreas** is a gland located near the beginning of the duodenum (see diagram 11.14). In most animals it is large and easily seen but in rodents and rabbits it lies within the membrane linking the loops of the intestine (the **mesentery**) and is quite difficult to find. **Pancreatic juice** is produced in the pancreas. It flows into the duodenum and contains **amylase** for digesting starch, **lipase** for digesting fats and **protease** for digesting proteins.

11.19 Intestinal juice

Intestinal juice is produced by glands in the lining of the small intestine. It contains enzymes for digesting disaccharides and proteins as well as mucus and salts to make the contents of the small intestine more alkaline so the enzymes can work.

11.20 Absorption

The small molecules produced by digestion are absorbed into the **villi** of the wall of the **small intestine** . The tiny finger-like projections of the villi increase the surface area for absorption. Glucose and amino acids pass directly through the wall into the blood stream by diffusion or active transport. Fatty acids and glycerol enter vessels of the lymphatic system (**lacteals**) that run up the centre of each villus.

11.21 The Liver

The liver is situated in the abdominal cavity adjacent to the diaphragm (see diagrams 2 and 14). It is the largest single organ of the body and has over 100 known functions. Its most important digestive functions are:

1. the production of **bile** to help the digestion of fats (described above) and
2. the control of **blood sugar** levels

Glucose is absorbed into the capillaries of the villi of the intestine. The blood stream takes it directly to the liver via a blood vessel known as the **hepatic portal vessel** or **vein** (see diagram 11.15).

The liver converts this glucose into glycogen which it stores. When glucose levels are low the liver can convert the glycogen back into glucose. It releases this back into the blood to keep the level of glucose constant. The hormone **insulin** , produced by special cells in the **pancreas** , controls this process.

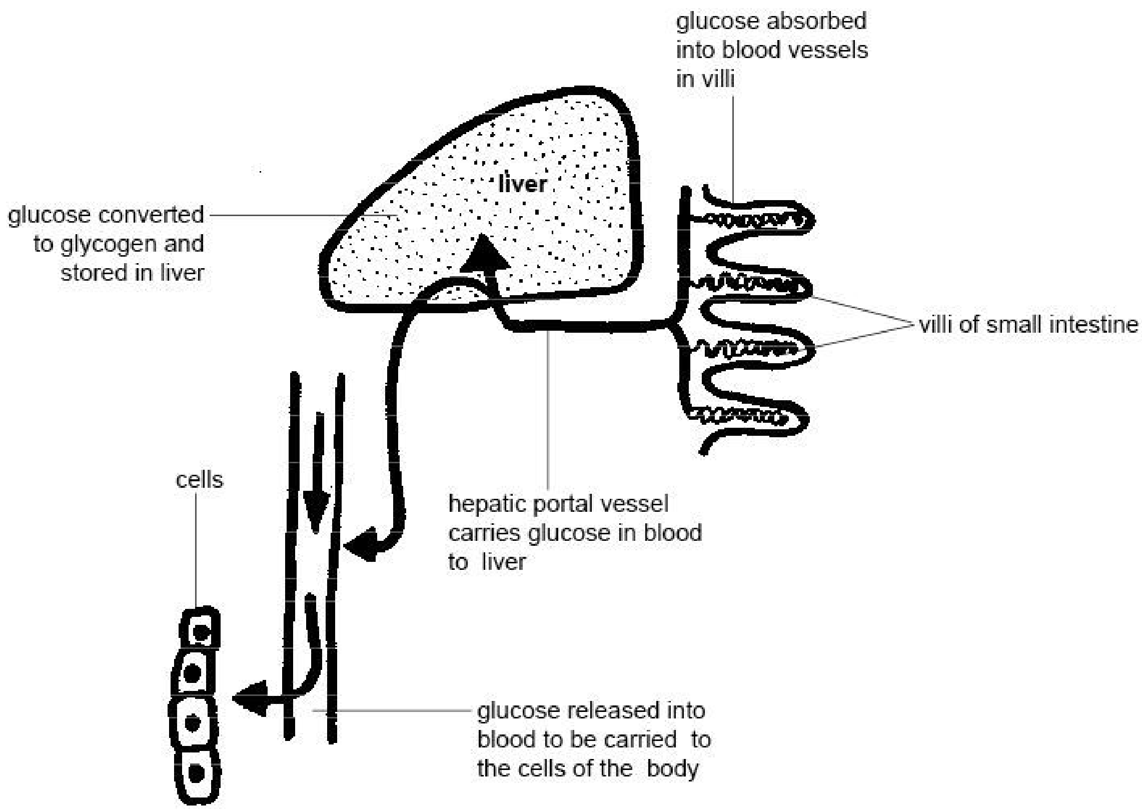

Figure 113

Diagram 11.15 - The control of blood glucose by the liver

Other functions of the liver include:

3. making **vitamin A** ,

4. making the **proteins** that are found in the **blood plasma** (**albumin, globulin** and **fibrinogen**),

5. storing **iron** ,

6. removing **toxic substances** like alcohol and poisons from the blood and converting them to safer substances,

7. producing **heat** to help maintain the temperature of the body.

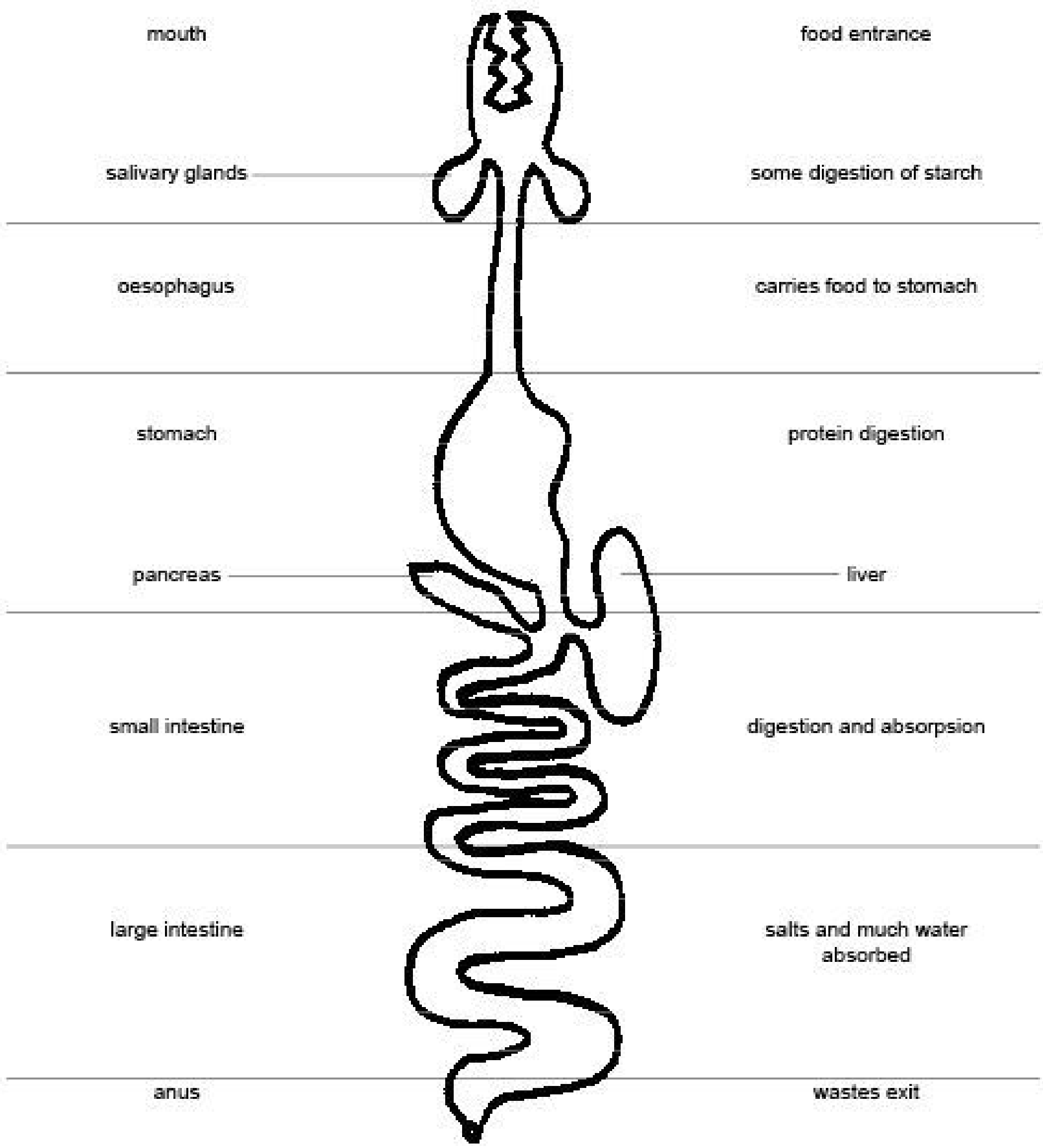

Figure 114

Diagram 11.16 - Summary of the main functions of the different regions of the gut

11.22 Summary

- The **gut** breaks down plant and animal materials into nutrients that can be used by animals' bodies.
- Plant material is more difficult to break down than animal tissue. The gut of **herbivores** is therefore longer and more complex than that of **carnivores** . Herbivores usually have a compartment (the **rumen** or **functional caecum**) housing micro-organisms to break down the **cellulose** wall of plants.

- Chewing by the teeth begins the food processing. There are 4 main types of teeth: **incisors, canines, premolars** and **molars** . In dogs and cats the premolars and molars are adapted to slice against each other and are called **carnassial** teeth.
- **Saliva** is secreted in the mouth. It lubricates the food for swallowing and contains an enzyme to break down starch.
- Chewed food is swallowed and passes down the **oesophagus** by waves of contraction of the wall called **peristalsis.** The food passes to the stomach where it is churned and mixed with acidic **gastric juice** that begins the digestion of protein.
- The resulting **chyme** passes down the small intestine where enzymes that digest fats, proteins and carbohydrates are secreted. **Bile** produced by the liver is also secreted here. It helps in the breakdown of fats. **Villi** provide the large surface area necessary for the absorption of the products of digestion.
- In the **colon** and **caecum** water is absorbed and micro organisms produce some **vitamin B and K** . In rabbits, horses and rodents the caecum is enlarged as a **functional caecum** and micro-organisms break down cellulose cell walls to simpler carbohydrates. Waste products exit the body via the **rectum** and **anus** .
- The **pancreas** produces **pancreatic juice** that contains many of the enzymes secreted into the small intestine.
- In addition to producing bile the liver regulates blood sugar levels by converting glucose absorbed by the villi into glycogen and storing it. The liver also removes toxic substances from the blood, stores iron, makes vitamin A and produces heat.

11.23 Worksheet

Use the Digestive System Worksheet[1] to help you learn the different parts of the digestive system and their functions.

11.24 Test Yourself

Then work through the Test Yourself below to see if you have understood and remembered what you learned.

1. Name the four different kinds of teeth
2. Give 2 facts about how the teeth of cats and dogs are adapted for a carnivorous diet:
   1.
   2.
3. What does saliva do to the food?
4. What is peristalsis?
5. What happens to the food in the stomach?
6. What is chyme?

1 http://www.wikieducator.org/Digestive_System_Worksheet

7. Where does the chyme go after leaving the stomach?
8. What are villi and what do they do?
9. What happens in the small intestine?
10. Where is the pancreas and what does it do?
11. How does the caecum of rabbits differ from that of cats?
12. How does the liver help control the glucose levels in the blood?
13. Give 2 other functions of the liver:
   1.
   2.

/Test Yourself Answers/[2]

11.25 Websites

- http://www.second-opinions.co.uk/carn_herb_comparison.html Second opinion. A good comparison of the guts of carnivores and herbivores
- http://www.chu.cam.ac.uk/~ALRF/giintro.htm The gastrointestinal system. A good comparison of the guts of carnivores and herbivores with more advanced information than in the previous site.
- http://www.westga.edu/~lkral/peristalsis/index.html Peristalsis animation.
- http://en.wikipedia.org/wiki/Digestion Wikipedia on digestion with links to further information on most aspects. Like most websites this is mainly about human digestion but much is applicable to animals.

11.26 Glossary

- Link to Glossary[3]

Gut and Digestion[4]

2 https://en.wikibooks.org/wiki/%2FTest%20Yourself%20Answers%2F
3 http://en.wikibooks.org/wiki/Anatomy_and_Physiology_of_Animals/Glossary
4 https://en.wikibooks.org/wiki/Category%3A

12 Urinary System

Figure 115 original image by fazen[a] cc by

a http://flickr.com/photos/fazen/2615416/

12.1 Objectives

After completing this section, you should know:

- the parts of the urinary system
- the structure and function of a kidney
- the structure and function of a kidney tubule or nephron
- the processes of filtration, reabsorption, secretion and concentration that convert blood to urine in the kidney tubule
- the function of antidiuretic hormone in producing concentrated urine
- the composition, storage and voiding of normal urine
- abnormal constituents of urine and their significance
- the functions of the kidney in excreting nitrogenous waste, controlling water levels and regulating salt concentrations and acid-base balance
- that birds do not have a bladder

12.2 Homeostasis

The cells of an animal can only remain healthy if the conditions are just right. The processes that take place in them are upset if the temperature is too high or too low, or if the fluid around or inside them is too acid or alkaline. **Homeostasis** is the name given to the processes that help keep the internal conditions constant even when external conditions change. The word means, "staying the same".

There are a number of organs in the body that play a part in maintaining homeostasis. For example, the skin helps keep the internal temperature of bird and mammals bodies within a narrow range even when the outside temperatures change (see Chapters 5 and 16); the lungs control the amount of carbon dioxide in the blood (see Chapters 8 and 16); the liver and pancreas work together to keep the amount of glucose in the blood within narrow limits (see Chapter 5) and the kidneys regulate the acidity and the concentration of water and salt in the blood (also see Chapter 16). How the kidneys do this will be described later in this chapter.

Hormones are chemicals that carry messages around the body in the blood and are central to many of the homeostatic processes mentioned above. Their role will be described in more detail in Chapter 16.

12.3 Water In The Body

Water is essential for living things to survive because all the chemical reactions within a body take place in a solution of water. An animal's body consists of up to 80% water. The exact proportion depends on the type of animal, its age, sex, health and whether or not it has had sufficient to drink. Generally animals do not survive a loss of more than 15% of their body water.

In vertebrates almost 2/3rd of this water is in the cells (**intracellular fluid**). The rest is outside the cells (**extracellular fluid**) where it is found in the spaces around the cells (**tissue fluid**), as well as in the blood and lymph.

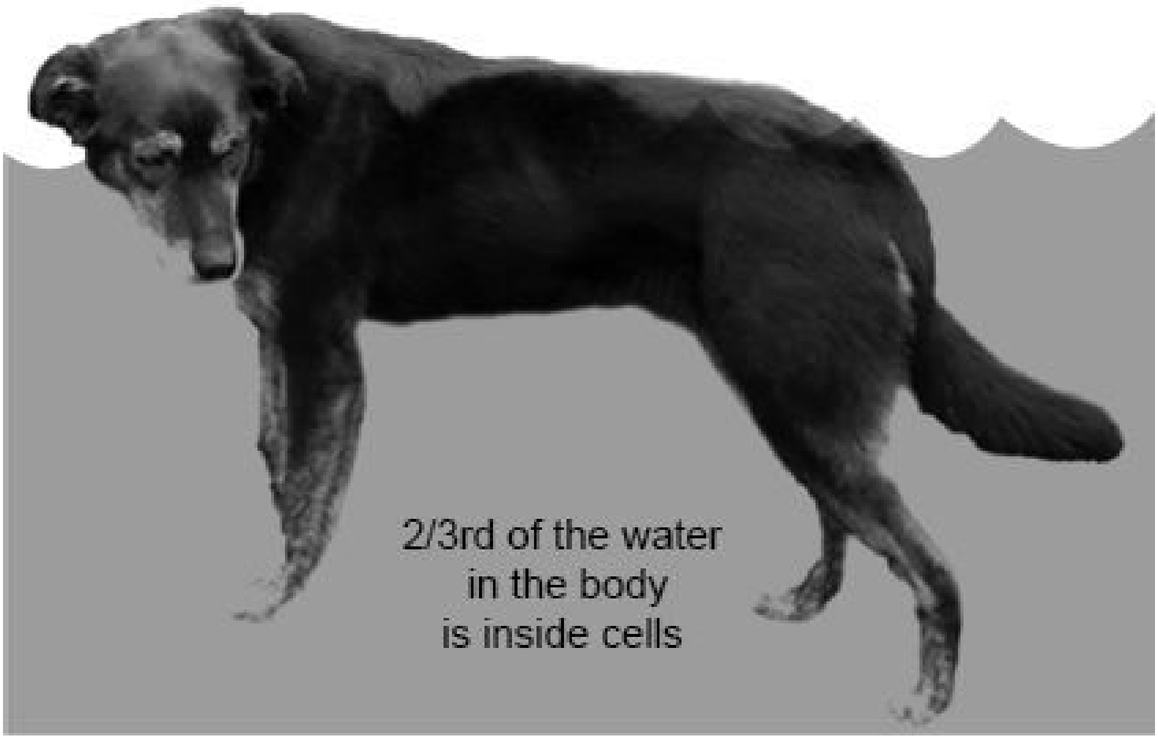

Figure 116

Diagram 12.1 - Water in the body

12.4 Maintaining Water Balance

Animals lose water through their skin and lungs, in the faeces and urine. These losses must be made up by water in food and drink and from the water that is a by-product of chemical reactions. If the animal does not manage to compensate for water loss the dissolved substances in the blood may become so concentrated they become lethal. To prevent this happening various mechanisms come into play as soon as the concentration of the blood increases. A part of the brain called the **hypothalamus** is in charge of these homeostatic processes. The most important is the feeling of thirst that is triggered by an increase in blood concentration. This stimulates an animal to find water and drink it.

The kidneys are also involved in maintaining water balance as various hormones instruct them to produce more concentrated urine and so retain some of the water that would otherwise be lost (see later in this Chapter and Chapter 16).

12.4.1 Desert Animals

Coping with water loss is a particular problem for animals that live in dry conditions. Some, like the camel, have developed great tolerance for dehydration. For example, under some conditions, camels can withstand the loss of one third of their body mass as water. They can also survive wide daily changes in temperature. This means they do not have to use large quantities of water in sweat to cool the body by evaporation.

Smaller animals are more able than large ones to avoid extremes of temperature or dry conditions by resting in sheltered more humid situations during the day and being active only at night.

The kangaroo rat is able to survive without access to any drinking water at all because it does not sweat and produces extremely concentrated urine. Water from its food and from chemical processes is sufficient to supply all its requirements.

12.5 Excretion

Animals need to excrete because they take in substances that are excess to the body's requirements and many of the chemical reactions in the body produce waste products. If these substances were not removed they would poison cells or slow down metabolism. All animals therefore have some means of getting rid of these wastes.

The major waste products in mammals are carbon dioxide that is removed by the lungs, and urea that is produced when excess amino acids (from proteins) are broken down. Urea is filtered from the blood by the kidneys.

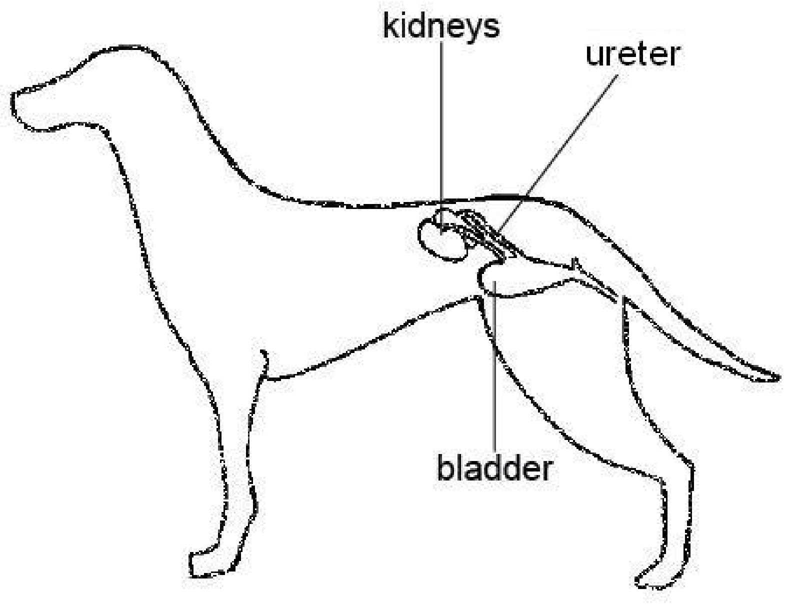

Figure 117

Diagram 12.2 - The position of the organs of the urinary system in a dog

12.6 The Kidneys And Urinary System

The **kidneys** in mammals are bean-shaped organs that lie in the abdominal cavity attached to the dorsal wall on either side of the spine (see diagram 12.2). An artery from the dorsal aorta called the **renal artery** supplies blood to them and the **renal vein** drains them.

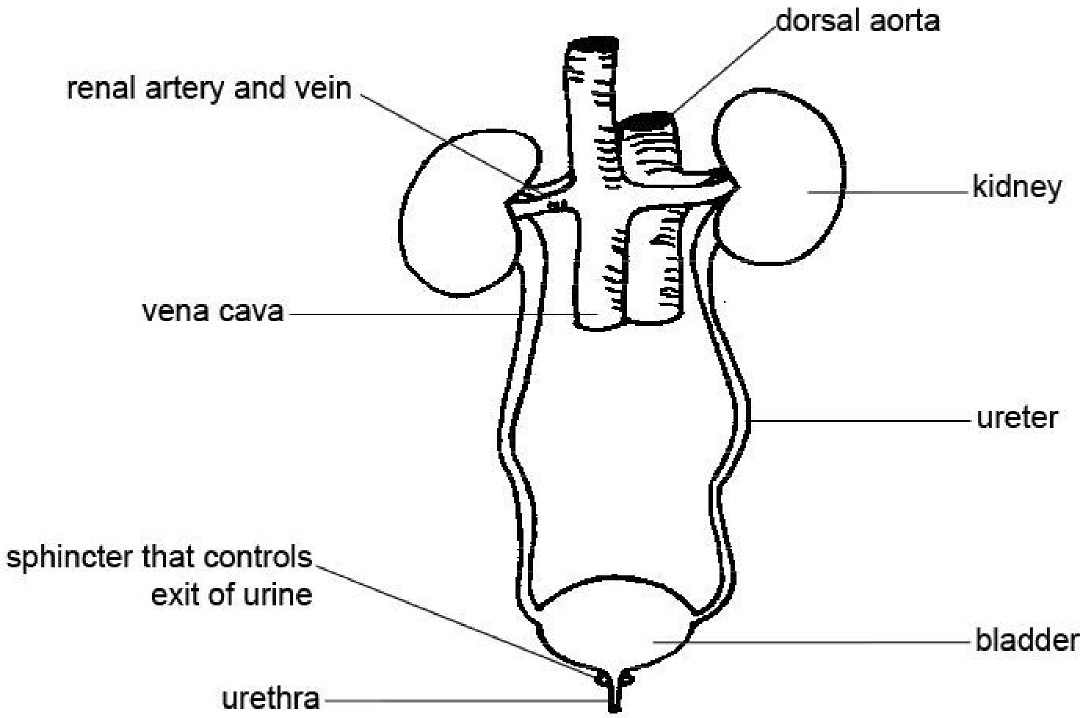

Figure 118

Diagram 12.3 - The urinary system

To the naked eye kidneys seem simple enough organs. They are covered by a fibrous coat or capsule and if cut in half lengthways (longitudinally) two distinct regions can be seen - an inner region or **medulla** and the outer **cortex** . A cavity within the kidney called the **pelvis** collects the urine and carries it to the **ureter** , which connects with the **bladder** where the urine is stored temporarily. Rings of muscle (**sphincters**) control the release of urine from the bladder and the urine leaves the body through the **urethra** (see diagrams 12.3 and 12.4).

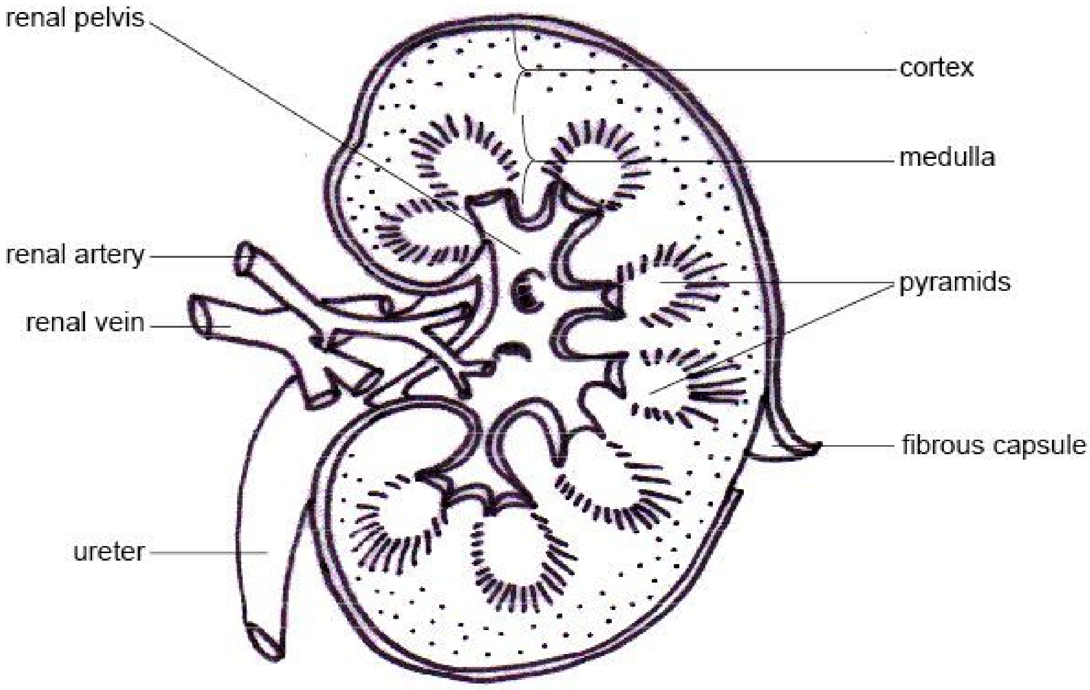

Figure 119

Diagram 12.4 - The dissected kidney

12.7 Kidney Tubules Or Nephrons

It is only when you examine kidneys under the microscope that you find that their structure is not simple at all. The cortex and medulla are seen to be composed of masses of tiny tubes. These are called **kidney tubules** or **nephrons** (see diagrams 12.5 and 12.6). A human kidney consists of over a million of them.

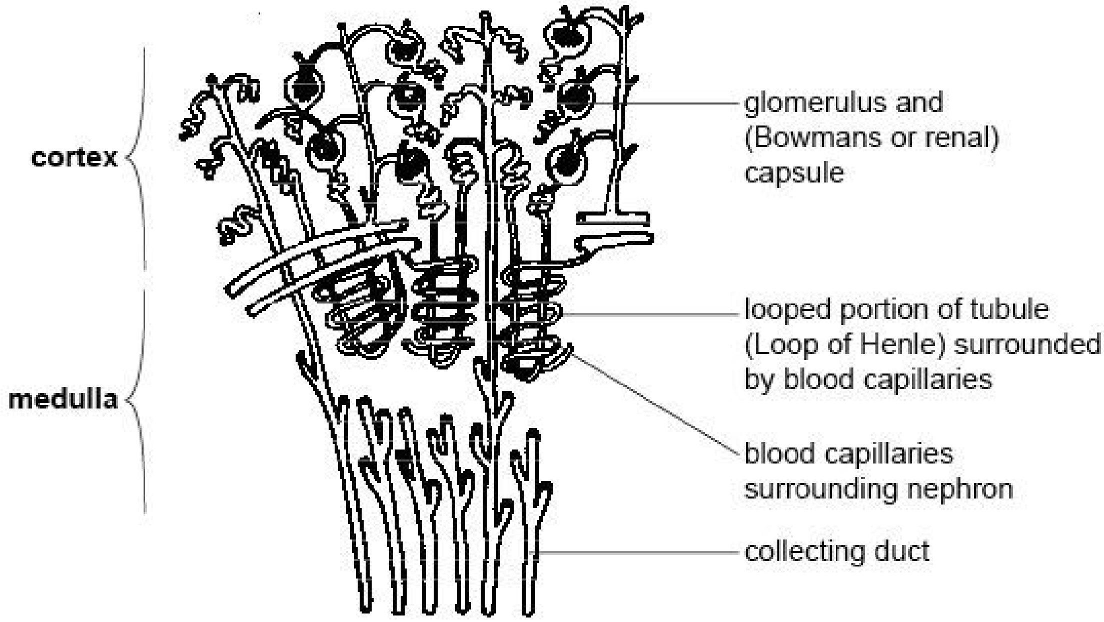

Figure 120

Diagram 12.5 - Several kidney tubules or nephrons

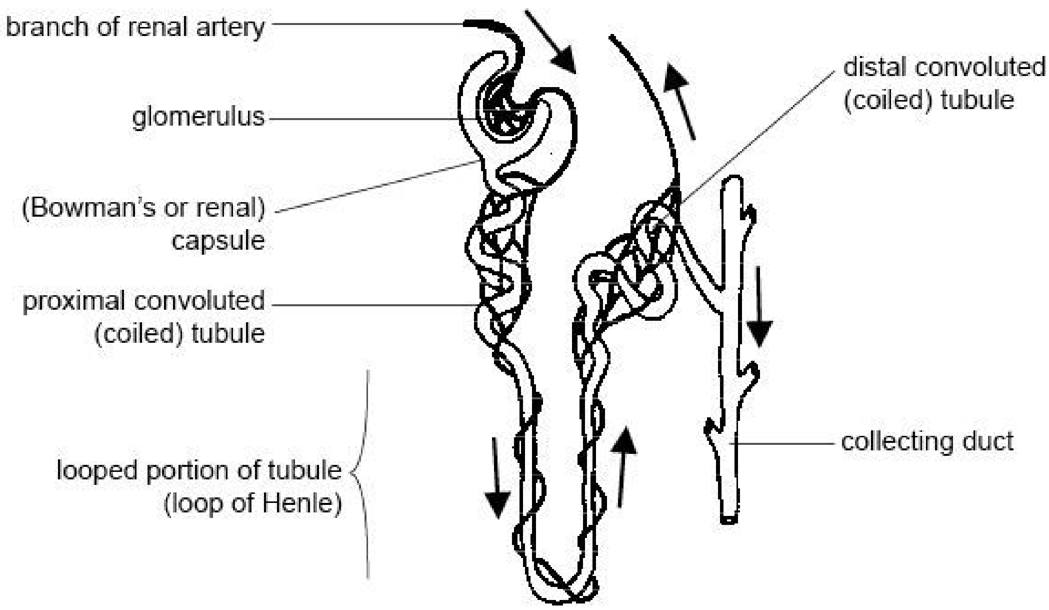

Figure 121

Diagram 12.6 - A kidney tubule or nephron

At one end of each nephron, in the cortex of the kidney, is a cup shaped structure called the (**Bowman's** or **renal**) **capsule** . It surrounds a tuft of capillaries called the **glomerulus** that carries high-pressure blood. Together the glomerulus and capsule act as a blood-filtering device (see diagram 12.7). The holes in the filter allow most of the contents of the blood through except the red and white cells and large protein molecules. The fluid flowing from the capsule into the rest of the kidney tubule is therefore very similar to blood plasma and contains many useful substances like water, glucose, salt and amino acids. It also contains waste products like **urea** .

12.7.1 Processes Occurring In The Nephron

After entering the glomerulus the filtered fluid flows along a coiled part of the tubule (the **proximal convoluted tubule**) to a looped portion (the **Loop of Henle**) and then to the **collecting tube** via a second length of coiled tube (the **distal convoluted tubule**) (see diagram 12.6). From the collecting ducts the urine flows into the **renal pelvis** and enters the **ureter** .

Note that the glomerulus, capsule and both coiled parts of the tubule are all situated in the cortex of the kidney while the loops of Henle and collecting ducts make up the medulla (see diagram 12.5).

As the fluid flows along the proximal convoluted tubule useful substances like glucose, water, salts, potassium ions, calcium ions and amino acids are **reabsorbed** into the blood capillaries that form a network around the tubules. Many of these substances are transported by active transport and energy is required.

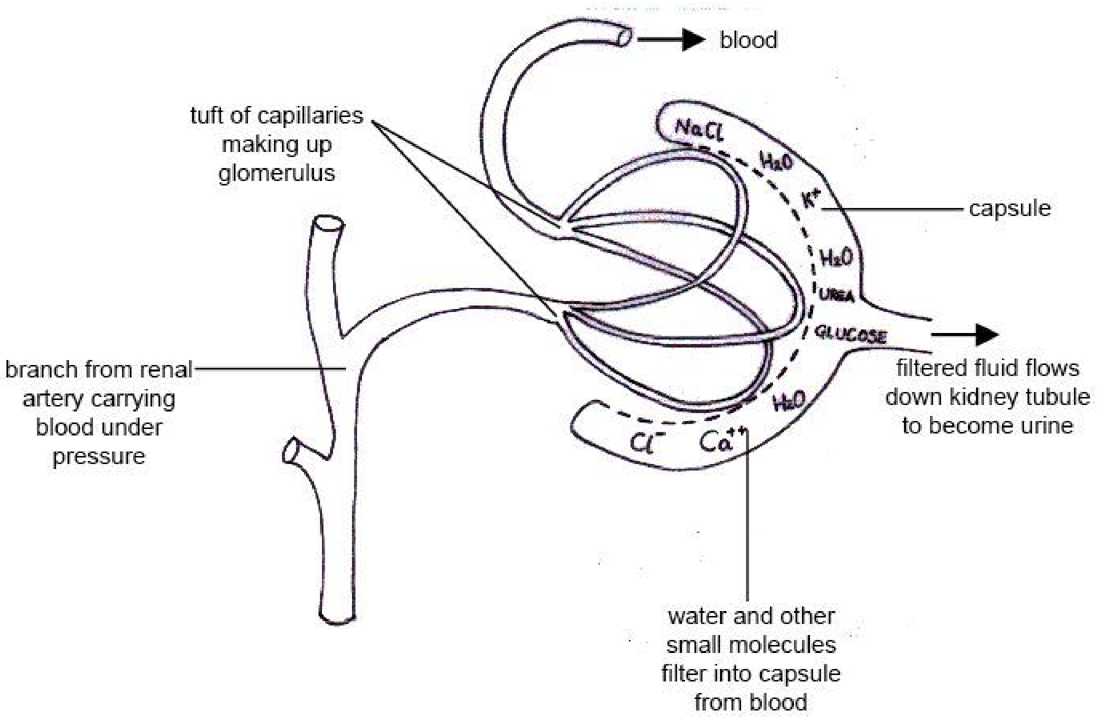

Figure 122

Diagram 12.7 - Filtration in the glomerulus and capsule

In a separate process, some substances, particularly potassium, ammonium and hydrogen ions, and drugs like penicillin, are actively **secreted** into the distal convoluted tubule.

By the time the fluid has reached the collecting ducts these processes of absorption and secretion have changed the fluid originally filtered into the Bowman's capsule into urine. The main function of the collecting ducts is then to remove more water from the urine if necessary. These processes are summarised in diagram 12.8.

Normal urine consists of water, in which waste products such as urea and salts such as sodium chloride are dissolved. Pigments from the breakdown of red blood cells give urine its yellow colour.

12.7.2 The Production Of Concentrated Urine

Because of the high pressure of the blood in the glomerulus and the large size of the pores in the glomerulus/capsule-filtering device, an enormous volume of fluid passes into the kidney tubules. If this fluid were left as it is, the animal's body would be drained dry in 30 minutes. In fact, as the fluid flows down the tubule, over 90% of the water in it is reabsorbed. The main part of this reabsorption takes place in the collecting tubes.

The amount of water removed from the collecting ducts is controlled by a hormone called **antidiuretic hormone (ADH)** produced by the **pituitary gland** , situated at the base of the brain. When the blood becomes more concentrated, as happens when an animal is deprived of water, ADH is secreted and causes more water to be absorbed from the collecting ducts so that concentrated urine is produced. When the animal has drunk plenty of water and the blood is dilute, no ADH is secreted and no or little water is absorbed from the collecting ducts, so dilute urine is produced. In this way the concentration of the blood is controlled precisely.

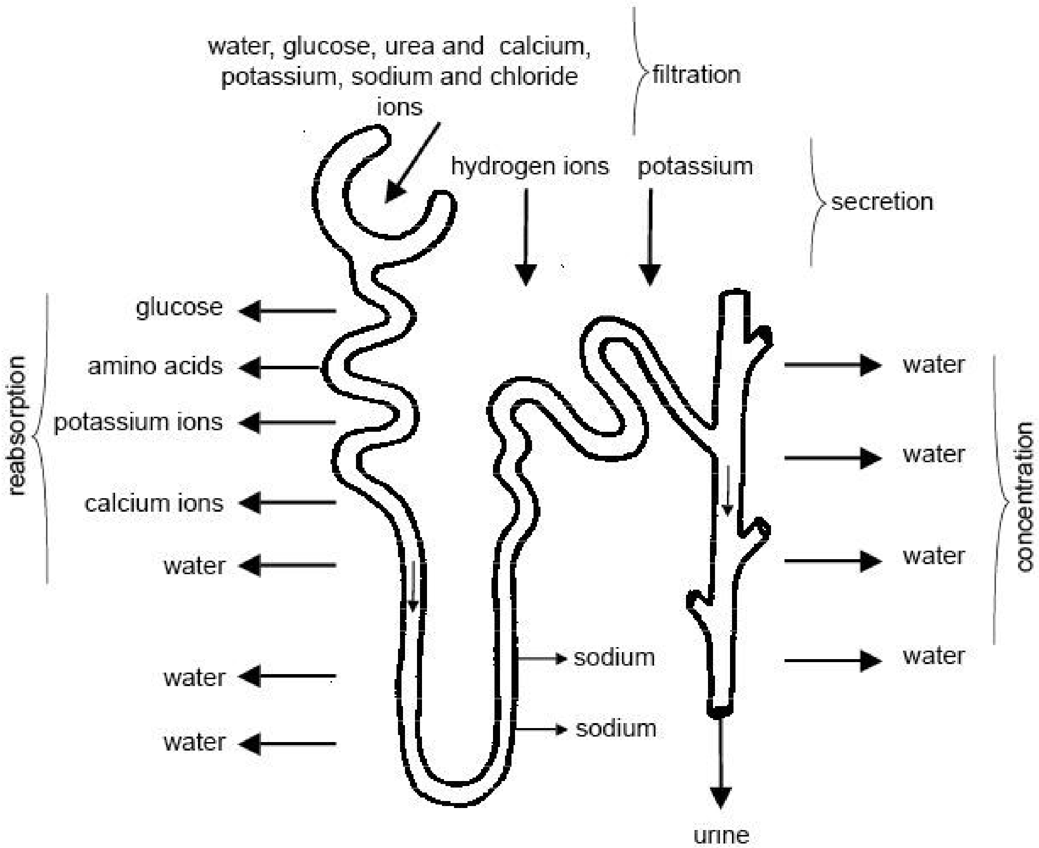

Figure 123

Diagram 12.8 - Summary of the processes involved in the formation of urine

12.8 Water Balance In Fish And Marine Animals

12.8.1 Fresh Water Fish

Although the skin of fish is more or less waterproof, the gills are very porous. The body fluids of fish that live in fresh water have a higher concentration of dissolved substances than the water in which they swim. In other words the body fluids of fresh water fish are **hypertonic** to the water (see chapter 3). Water therefore flows into the body by **osmosis** . To stop the body fluids being constantly diluted fresh water fish produce large quantities of dilute urine.

12.8.2 Marine Fish

Marine fish like the sharks and dogfish have body fluids that have the same concentration of dissolved substances as the water (**isotonic**) have little problem with water balance. However, marine bony fish like red cod, snapper and sole, have body fluids with a lower concentration of dissolved substances than seawater (they are **hypotonic** to seawater). This means that water tends to flow out of their bodies by osmosis. To make up this fluid loss they drink seawater and get rid of the excess salt by excreting it from the gills.

12.8.3 Marine Birds

Marine birds that eat marine fish take in large quantities of salt and some only have access to seawater for drinking. Bird's kidneys are unable to produce very concentrated urine, so they have developed a salt gland. This excretes a concentrated salt solution into the nose to get rid of the excess salt.

12.9 Diabetes And The Kidney

There are two types of diabetes. The most common is called sugar diabetes or **diabetes mellitus** and is common in cats and dogs especially if they are overweight. It is caused by the pancreas secreting insufficient **insulin** , the hormone that controls the amount of glucose in the blood. If insulin secretion is inadequate, the concentration of glucose in the blood increases. Any increase in the glucose in the blood automatically leads to an increase in glucose in the fluid filtered into the kidney tubule. Normally the kidney removes all the glucose filtered into it, but these high concentrations swamp this removal mechanism and urine containing glucose is produced. The main symptoms of this type of diabetes are the production of large amounts of dilute urine containing glucose, and excessive thirst.

The second type of diabetes is called **diabetes insipidus** . The name comes from the main symptom, which is the production of large amounts of very dilute and "tasteless" urine. It occurs when the pituitary gland produces insufficient ADH, the hormone that stimulates water re-absorption from the kidney tubule. When this hormone is lacking, water is not absorbed and large amounts of dilute urine are produced. Because so much water is lost in the urine, animals with this form of diabetes can die if deprived of water for only a day or so.

12.10 Other Functions Of The Kidney

The excretion of urea from the body and the maintenance of water balance, as described above, are the main functions of the kidney. However, the kidneys have other roles in keeping conditions in the body stable i.e. in maintaining homeostasis. These include:

- controlling the concentration of salt ions (Na^+, K^+, Cl^-) in the blood by adjusting how much is excreted or retained;
- maintaining the correct acidity of the blood. Excess acid is constantly being produced by the normal chemical reactions in the body and the kidney eliminates this.

12.11 Normal Urine

Normal urine consists of water (95%), urea, salts (mostly sodium chloride) and pigments (mostly from bile) that give it its characteristic colour.

12.12 Abnormal Ingredients Of Urine

If the body is not working properly, small amounts of substances not normally present may be found in the urine or substances normally present may appear in abnormal amounts.

- The presence of **glucose** may indicate diabetes (see above).
- Urine with red blood cells in it is called **haematuria** , and may indicate inflammation of the kidney,or urinary tract, cancer or a blow to the kidneys.
- Sometimes free **haemoglobin** is found in the urine. This indicates that the red blood cells in the blood have **haemolysed** (the membrane has broken down) and the haemoglobin has passed into the kidney tubules.
- The presence of **white blood cells** in the urine indicates there is an infection in the kidney or urinary tract.
- **Protein molecules** are usually too large to pass into the kidney tubule so no or only small amounts of proteins like **albumin** is normally found in urine. Large quantities of albumin indicate that the kidney tubules have been injured or the kidney has become diseased. High blood pressure also pushes proteins from the blood into the tubules.
- **Casts** are tiny cylinders of material that have been shed from the lining of the tubules and flushed out into the urine.
- **Mucus** is not usually found in the urine of healthy animals but is a normal constituent of horses' urine, giving it a characteristic cloudy appearance.

Tests can be carried out to identify any abnormal ingredients of urine. These tests are normally done by "**stix** ", which are small plastic strips with absorbent ends impregnated with various chemicals. A colour change occurs in the presence of an abnormal ingredient.

12.13 Excretion In Birds

Birds' high body temperature and level of activity means that they need to conserve water. Birds therefore do not have a bladder and instead of excreting urea, which needs to be dissolved in large amounts of water, birds produce uric acid that can be discharged as a thick paste along with the feces. This is the white chalky part of the bird droppings that land on you or your car.

12.14 Summary

- The excretory system consists of paired **kidneys** and associated blood supply. **Ureters** transport urine from the kidneys to the bladder and the **urethra** with associated sphincter muscles controls the release of urine.

- The kidneys have an important role in maintaining **homeostasis** in the body. They excrete the waste product urea, control the concentrations of water and salt in the body fluids, and regulate the acidity of the blood.
- A kidney consists of an outer region or **cortex,** inner **medulla** and a cavity called the **pelvis** that collects the urine and carries it to the ureter.
- The tissue of a kidney is composed of masses of tiny tubes called **kidney tubules** or **nephrons** . These are the structures that make the urine.
- High-pressure blood is supplied to the nephron via a tuft of capillaries called the **glomerulus** . Most of the contents of the blood except the cells and large protein molecules filter from the glomerulus into the (**Bowmans) capsule.** This fluid flows down a coiled part of the tubule (**proximal convoluted tubule**) where useful substances like glucose, amino acids and various ions are reabsorbed. The fluid flows to a looped portion of the tubule called the **Loop of Henle** where water is reabsorbed and then to another coiled part of the tubule (**distal convoluted tubule**) where more reabsorbtion and secretion takes place. Finally the fluid passes down the **collecting duct** where water is reabsorbed to form concentrated urine.

12.15 Worksheet

Use this Excretory System Worksheet[1] to help you learn the parts of the urinary system, the kidney and kidney tubule and their functions.

12.16 Test Yourself

The Urinary System Test Yourself can then be used to see if you understand this rather complex system.

1. Add the following labels to the diagram of the excretory system shown below. Bladder | ureter | urethra | kidney | dorsal aorta | vena cava | renal artery | vein

1 http://www.wikieducator.org/Excretory_System_Worksheet

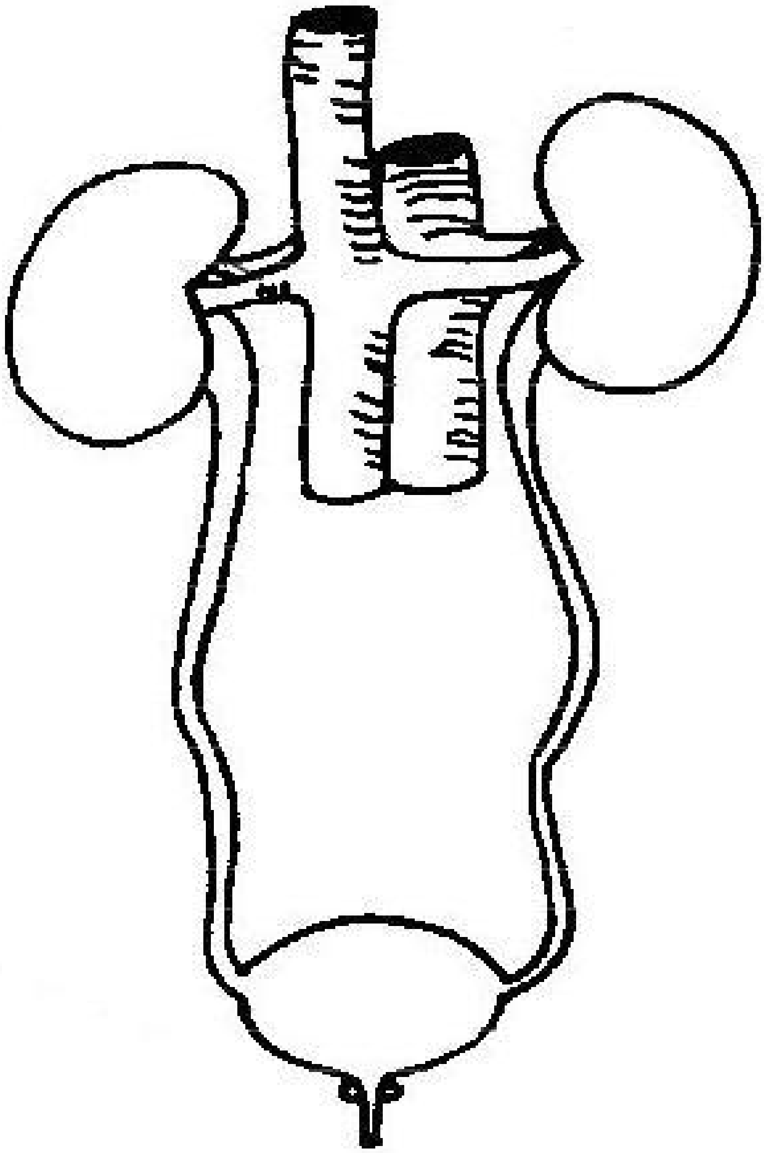

Figure 124

2. Using the words/phrases in the list below fill in the blanks in the following statements.

| cortex | amino acids | renal | glucose | water reabsorption | large proteins |

| bowman's capsule | diabetes mellitus | secreted | antidiuretic hormone (ADH) | blood cells |

| glomerulus | concentration of the urine | medulla | nephron |

a) Blood enters the kidney via the .... artery.

b) When cut across the kidney is seen to consist of two regions, the outer.............. and the inner..............

c) Another word for the kidney tubule is the..............................

d) Filtration of the blood occurs in the.............................

e) The filtered fluid (filtrate) enters the............................

f) The filtrate entering the e) above is similar to blood but does not contain................. or....................

g) As the fluid passes along the first coiled part of the kidney tubule................. and.................... are removed.

h) The main function of the loop of Henle is..

i) Hydrogen and potassium ions are.............................. into the second coiled part of the tubule.

j) The main function of the collecting tube is...

k) The hormone..................................... is responsible for controlling water reabsorption in the collecting tube.

l) When the pancreas secretes inadequate amounts of the hormone insulin the condition known as............................... results. This is most easily diagnosed by testing for................................ in the urine.

/Test Yourself Answers/[2]

12.17 Websites

- `http://www.biologycorner.com/bio3/nephron.html` Biology Corner. A fabulous drawing of the kidney and nephron to print off, label and colour in with clear explanation of function.
- `http://health.howstuffworks.com/adam-200032.htm` How Stuff Works. This animation traces the full process of urine formation and reabsorption in the kidneys, its path down the ureter to the bladder, and its excretion via the urethra. Needs Shockwave.
- `http://en.wikipedia.org/wiki/Nephron` Wikipedia. A bit more detail than you need but still good clear explanations and lots of information.

12.18 Glossary

- Link to Glossary[3]

2 https://en.wikibooks.org/wiki/%2FTest%20Yourself%20Answers%2F
3 http://en.wikibooks.org/wiki/Anatomy_and_Physiology_of_Animals/Glossary

Urinary System[4]

4 https://en.wikibooks.org/wiki/Category%3A

13 Reproductive System

Figure 125 original image by ynskjen[a] cc by

a http://flickr.com/photos/20299709@N00/151342191/

13.1 Objectives

After completing this section, you should know:

- the role of mitosis and meiosis in the production of gametes (sperm and ova)
- that gametes are haploid cells
- that fertilization forms a diploid zygote
- the major parts of the male reproductive system and their functions
- the route sperm travel along the male reproductive tract to reach the penis
- the structure of a sperm and the difference between sperm and semen
- the difference between infertility and impotence
- the main parts of the female reproductive system and their functions
- the ovarian cycle and the roles of FSH, LH, oestrogen and progesterone
- the oestrous cycle and the signs of heat in rodents, dogs, cats and cattle
- the process of fertilization and where it occurs in the female tract
- what a morula and a blastocyst are
- what the placenta is and its functions

13.2 Reproductive System

In biological terms sexual reproduction involves the union of **gametes** - the sperm and the ovum - produced by two parents. Each gamete is formed by **meiosis** (see Chapter 3). This means each contains only half the chromosomes of the body cells (**haploid**). Fertilization results in the joining of the male and female gametes to form a **zygote** which contains the full number of chromosomes (**diploid**). The zygote then starts to divide by **mitosis** (see Chapter 3) to form a new animal with all its body cells containing chromosomes that are identical to those of the original zygote (see diagram 13.1).

Diagram 13.1 - Sexual reproduction

The offspring formed by sexual reproduction contain genes from both parents and show considerable variation. For example, kittens in a litter are all different although they (usually) have the same mother and father. In the wild this variation is important because it means that when the environment changes some individuals may be better adapted to survive than others. These survivors pass their “superior” genes on to their offspring. In this way the characteristics of a group of animals can gradually change over time to keep pace with the changing environment. This “survival of the fittest” or “**natural selection** ” is the mechanism behind the theory of **evolution** .

13.3 Fertilization

In most fish and amphibia (frogs and toads) fertilisation of the egg cells takes place outside the body. The female lays the eggs and then the male deposits his sperm on or at least near them.

In reptiles and birds, eggs are fertilized inside the body when the male deposits the sperm inside the **egg duct** of the female. The egg is then surrounded by a resistant shell, "laid" by the female and the embryo completes its development inside the egg.

In mammals the sperm are placed in the body of the female and the eggs are fertilized internally. They then develop to quite an advanced stage inside the body of the female. When they are born they are fed on milk excreted from the mammary glands and protected by their parents until they become independent.

13.4 Sexual Reproduction In Mammals

The reproductive organs of mammals produce the **gametes** (sperm and egg cells), help them fertilize and then support the developing embryo.

13.5 The Male Reproductive System

The male reproductive system consists of a pair of testes that produce **sperm** (or**spermatozoa**), ducts that transport the sperm to the penis and glands that add secretions to the sperm to make **semen** (see diagram 13.2).

The various parts of the male reproductive system with a summary of their functions are shown in diagram 13.3.

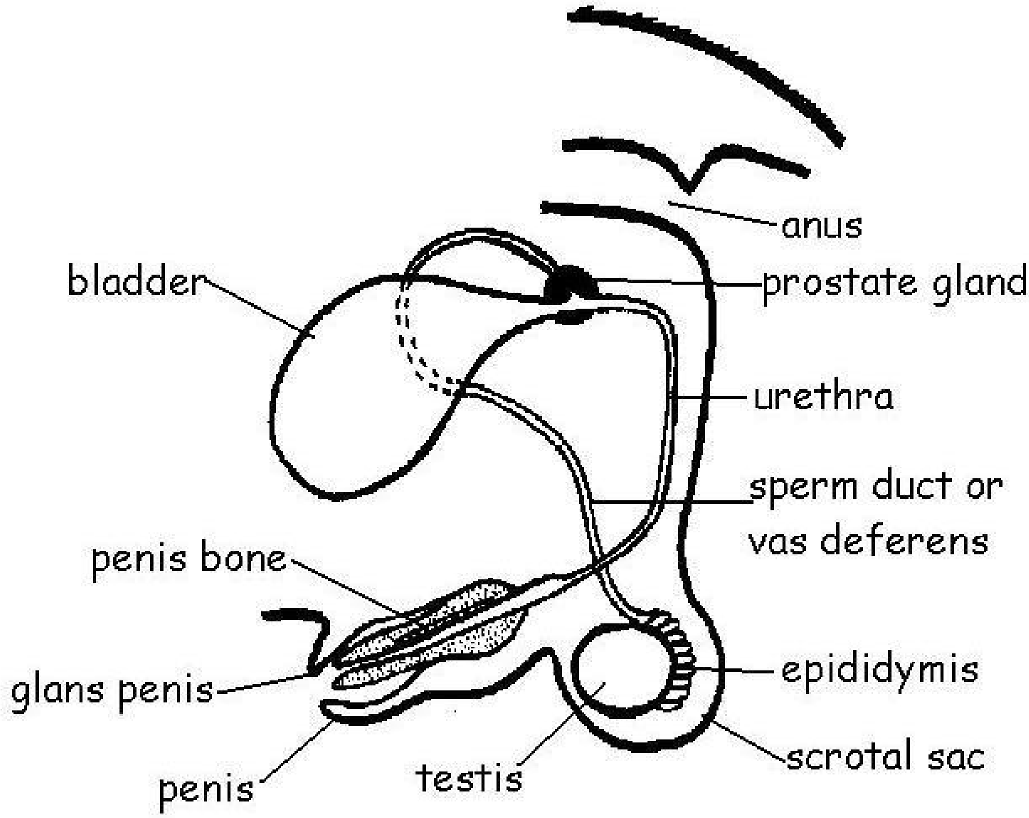

Figure 126

Diagram 13.2. The reproductive organs of a male dog

Figure 127

Diagram 13.3 - Diagram summarizing the functions of the male reproductive organs

13.5.1 The Testes

Sperm need temperatures between 2 to 10 degrees Centigrade lower and then the body temperature to develop. This is the reason why the testes are located in a bag of skin called the **scrotal sacs** (or **scrotum**) that hangs below the body and where the evaporation of secretions from special glands can further reduce the temperature. In many animals (including humans) the testes descend into the scrotal sacs at birth but in some animals they do not descend until sexual maturity and in others they only descend temporarily during the breeding season. A mature animal in which one or both testes have not descended is called a **cryptorchid** and is usually infertile.

The problem of keeping sperm at a low enough temperature is even greater in birds that have a higher body temperature than mammals. For this reason bird's sperm are usually produced at night when the body temperature is lower and the sperm themselves are more resistant to heat.

The testes consist of a mass of coiled tubes (the **seminiferous** or**sperm producing tubules**) in which the sperm are formed by meiosis (see diagram 13.4). Cells lying between the seminiferous tubules produce the male sex hormone **testosterone** .

When the sperm are mature they accumulate in the **collecting ducts** and then pass to the **epididymis** before moving to the **sperm duct** or **vas deferens** . The two sperm ducts join the **urethra** just below the bladder, which passes through the **penis** and transports both sperm and urine.

Ejaculation discharges the semen from the erect penis. It is brought about by the contraction of the epididymis, vas deferens, prostate gland and urethra.

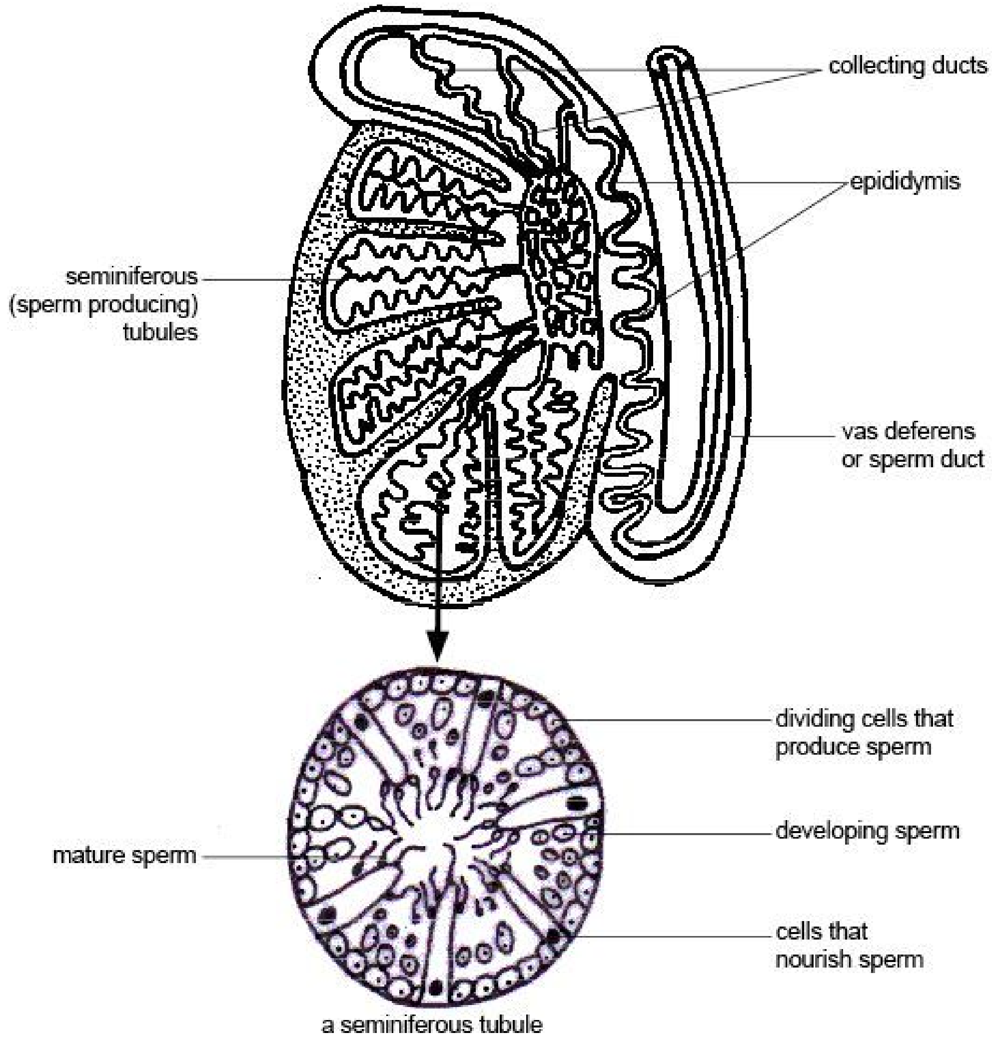

Figure 128

Diagram 13.4 - The testis and a magnified seminiferous tubule

13.5.2 Semen

Semen consists of 10% sperm and 90% fluid and as sperm pass down the ducts from testis to penis, (accessory) glands add various secretion...

13.5.3 Accessory Glands

Three different glands may be involved in producing the secretions in which sperm are suspended, although the number and type of glands varies from species to species.

Seminal vesicles are important in rats, bulls, boars and stallions but are absent in cats and dogs. When present they produce secretions that make up much of the volume of the semen, and transport and provide nutrients for the sperm.

The **prostate gland** is important in dogs and humans. It produces an alkaline secretion that neutralizes the acidity of the male urethra and female vagina.

Cowper's glands (bulbourethral glands) have various functions in different species. The secretions may lubricate, flush out urine or form a gelatinous plug that traps the semen in the female reproductive system after copulation and prevents other males of the same species fertilizing an already mated female. Cowper's glands are absent in bears and aquatic mammals.

13.5.4 The Penis

The penis consists of connective tissue with numerous small blood spaces in it. These fill with blood during sexual excitement causing erection.

Penis Form And Shape

Dogs, bears, seals, bats and rodents have a special bone in the penis which helps maintain the erection (see diagram 13.2). In some animals (e.g. the bull, ram and boar) the penis has an "S" shaped bend that allows it to fold up when not in use. In many animals the shape of the penis is adapted to match that of the vagina. For example, the boar has a corkscrew shaped penis, there is a pronounced twist in bulls' and it is forked in marsupials like the opossum. Some have spines, warts or hooks on them to help keep them in the vagina and copulation may be extended to help retain the semen in the female system. Mating can last up to three hours in minks, and dogs may "knot" or "tie" during mating and can not separate until the erection has subsided.

13.5.5 Sperm

Sperm are made up of three parts: a **head** consisting mainly of the nucleus, a **midpiece** containing many mitochondria to provide the energy and a **tail** that provides propulsion (see diagram 13.5).

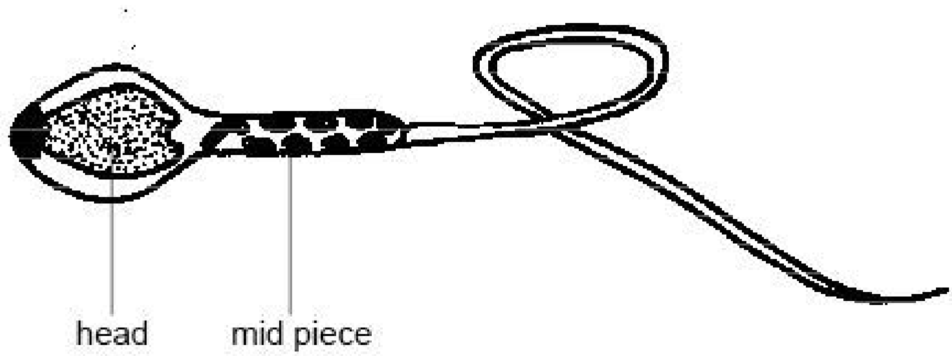

Figure 129

Diagram 13.5 - A sperm

A single ejaculation may contain 2-3 hundred million sperm but even in normal semen as many as 10% of these sperm may be abnormal and infertile. Some may be dead while others are inactive or deformed with double, giant or small heads or tails that are coiled or absent altogether.

When there are too many abnormal sperm or when the sperm concentration is low, the semen may not be able to fertilize an egg and the animal is infertile. Make sure you don't confuse infertility with impotence, which is the inability to copulate successfully.

Sperm do not live forever. They have a definite life span that varies from species to species. They survive for between 20 days (guinea pig) to 60 days (bull) in the epididymis but once ejaculated into the female tract they only live from 12 to 48 hours. When semen is used for artificial insemination, storage under the right conditions can extend the life span of some species.

13.5.6 Artificial Insemination

In many species the male can be artificially stimulated to ejaculate and the semen collected. It can then be diluted, stored and used to **inseminate** females. For example bull semen can be diluted and stored for up to 3 weeks at room temperature. If mixed with an antifreeze solution and stored in "straws" in liquid nitrogen at minus 79°C it will keep for much longer. Unfortunately the semen of chickens, stallions and boars can only be stored for up to 2 days.

Dilution of the semen means that one male can be used to fertilise many more females than would occur under natural conditions. There are also advantages in the male and female not having to make physical contact. It means that owners of females do not have to buy expensive males and the possibility of transmitting sexually transmitted diseases is reduced. Routine examination of the semen for sperm concentration, quality and activity allows only the highest quality semen to be used so a high success rate is ensured.

Since the lifespan of sperm in the female tract is so short and ova only survive from 8 to 10 hours the timing of the artificial insemination is critical. Successful conception depends upon detecting the time that the animal is "on heat" and when ovulation occurs.

13.6 The Female Reproductive Organs

The female reproductive system consists of a pair of **ovaries** that produce egg cells or **ova** and **fallopian tubes** where fertilisation occurs and which carry the fertilised ovum to the **uterus** . Growth of the foetus takes place here. The **cervix** separates the uterus from the **vagina** or birth canal, where the sperm are deposited (see diagram 13.6).

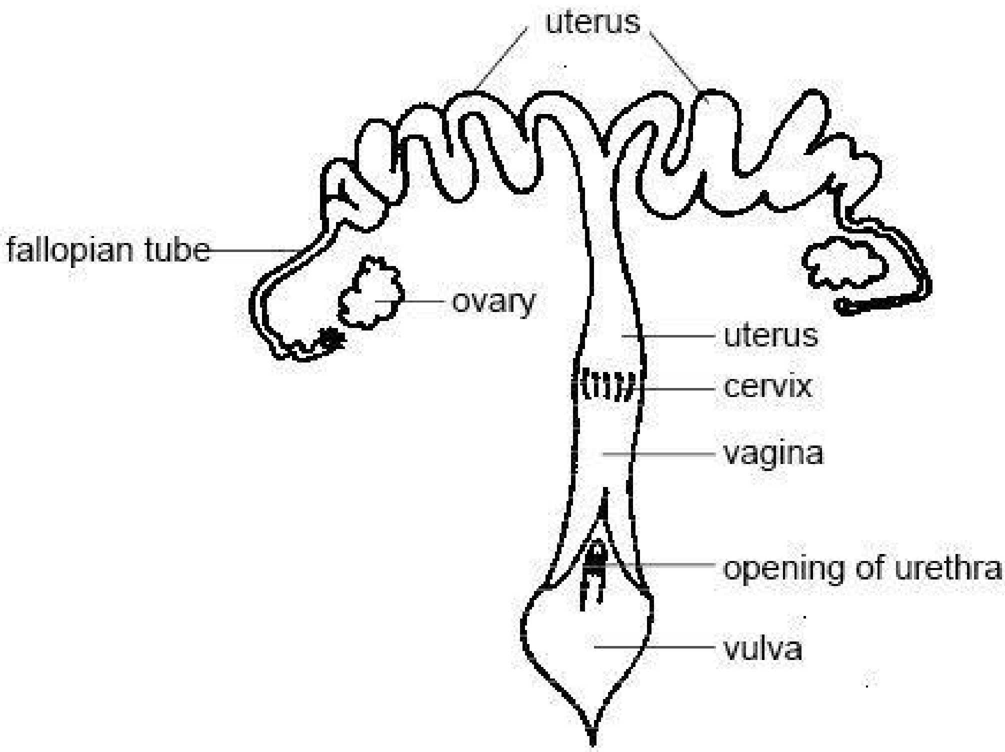

Figure 130

Diagram 13.6. - The reproductive system of a female rabbit

Note that primates like humans have a uterus with a single compartment but in most mammals the uterus is divided into two separate parts or **horns** as shown in diagram 13.6.

13.6.1 The Ovaries

Ovaries are small oval organs situated in the abdominal cavity just ventral to the kidneys. Most animals have a pair of ovaries but in birds only the left one is functional to reduce weight (see below).

The ovary consists of an inner region (**medulla**) and an outer region (**cortex**) containing egg cells or ova. These are formed in large numbers around the time of birth and start to develop after the animal becomes sexually mature. A cluster of cells called the **follicle** surrounds and nourishes each ovum.

13.6.2 The Ovarian Cycle

The **ovarian cycle** refers to the series of changes in the ovary during which the follicle matures, the ovum is shed and the **corpus luteum** develops (see diagram 13.7).

Numerous undeveloped ovarian follicles are present at birth but they start to mature after sexual maturity. In animals that normally have only one baby at a time only one ovum will mature at once but in litter animals several will. The mature follicle consists of outer cells that provide nourishment. Inside this is a fluid-filled space that contains the ovum.

A mature follicle can be quite large, ranging from a few millimetres in small mammals to the size of a golf ball in large animals. It bulges out from the surface of the ovary before eventually rupturing to release the ovum into the abdominal cavity. Once the ovum has been shed, a blood clot forms in the empty follicle. This develops into a tissue called the **corpus luteum** that produces the hormone **progesterone** (see diagram 13.9). If the animal becomes pregnant the corpus luteum persists, but if there is no pregnancy it degenerates and a new ovarian cycle usually.

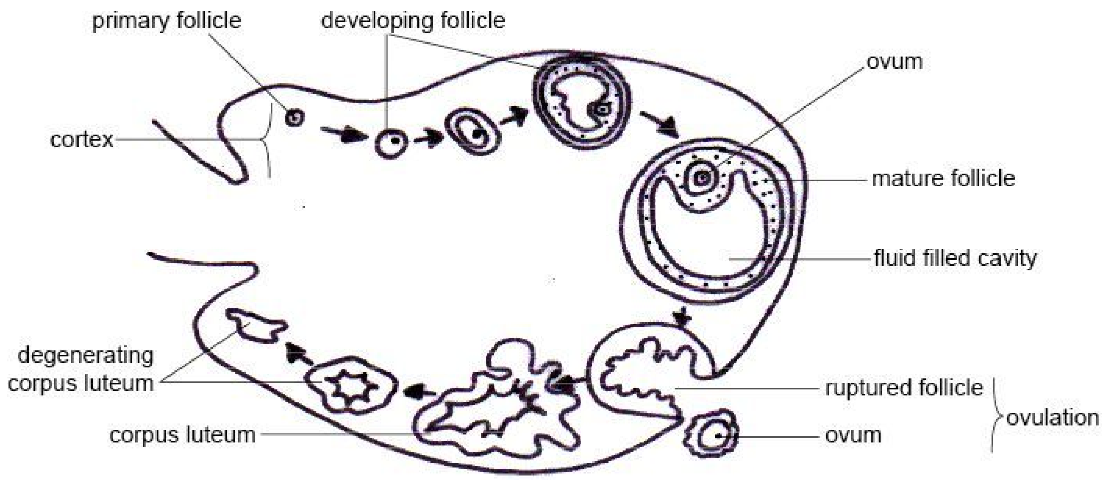

Figure 131

Diagram 13.7 - The ovarian cycle showing from the top left clockwise: the maturation of the ovum over time, followed by ovulation and the development of the corpus luteum in the empty follicle

13.6.3 The Ovum

When the ovum is shed the nucleus is in the final stages of meiosis (cell division). It is surrounded by few layers of follicle cells and a tough membrane called the **zona pelluc** ida (see diagram 13.8).

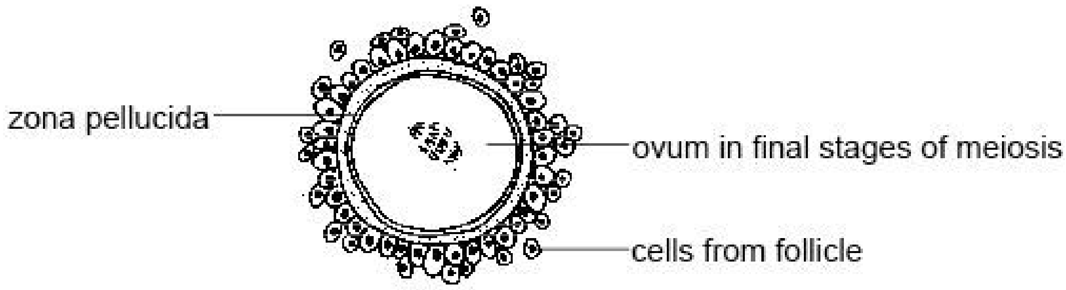

Figure 132

Diagram 13.8 - An ovum

13.6.4 The Oestrous Cycle

The **oestrous cycle** is the sequence of hormonal changes that occurs through the **ovarian cycle** . These changes influence the behaviour and body changes of the female (see diagram 13.9).

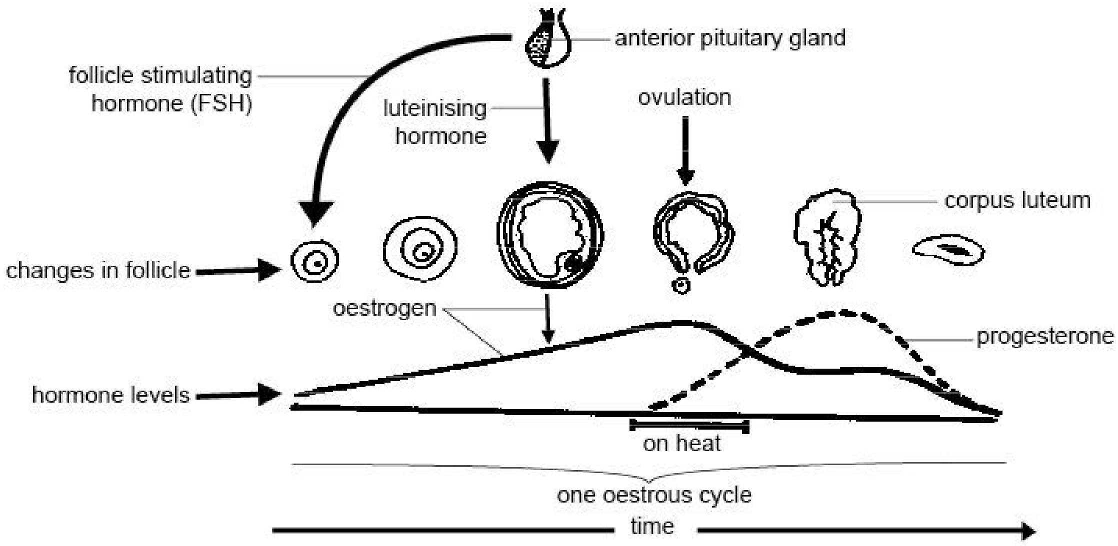

Figure 133

Diagram 13.9 - The oestrous cycle

The first hormone involved in the oestrous cycle is **follicle stimulating hormone (F.S.H.),** secreted by the **anterior pituitary gland** (see chapter 16). It stimulates the follicle to develop. As the follicle matures the outer cells begin to secrete the hormone **oestrogen** and this stimulates the mammary glands to develop. It also prepares the lining of the uterus to receive a fertilised egg. Ovulation is initiated by a surge of another hormone from the anterior pituitary, **luteinising hormone (L.H.).** This hormone also influences the development of the corpus luteum, which produces **progesterone** , a hormone that prepares the lining of the uterus for the fertilised ovum and readies the mammary glands for milk production. If no pregnancy takes place the corpus luteum shrinks and the production of progesterone decreases. This causes FSH to be produced again and a new oestrous cycle begins.

For fertilisation of the ovum by the sperm to occur, the female must be receptive to the male at around the time of ovulation. This is when the hormones turn on the signs of "**heat** ", and she is "**in season** " or "**in oestrous** ". These signs are turned off again at the end of the oestrous cycle.

During the oestrous cycle the lining of the uterus (**endometrium**) thickens ready for the fertilised ovum to be implanted. If no pregnancy occurs this thickened tissue is absorbed and the next cycle starts. In humans and other higher primates, however, the endometrium is shed as a flow of blood and instead of an oestrous cycle there is a **menstrual cycle** .

The length of the oestrous cycle varies from species to species. In rats the cycle only lasts 4-5 days and they are sexually receptive for about 14 hours. Dogs have a cycle that lasts 60-70 days and heat lasts 7-9 days and horses have a 21-day cycle and heat lasts an average of 6 days.

Ovulation is spontaneous in most animals but in some, e.g. the cat, and the rabbit, ovulation is stimulated by mating. This is called **induced ovulation** .

13.6.5 Signs Of Oestrous Or Heat

- When on heat a bitch has a blood stained discharge from the **vulva** that changes a little later to a straw coloured one that attracts all the dogs in the neighbourhood.
- Female cats "call" at night, roll and tread the carpet and are generally restless but will "stand" firm when pressure is placed on the pelvic region (this is the lordosis response).
- A female rat shows the lordosis response when on heat. It will "mount" other females and be more active than normal.
- A cow mounts other cows (bulling), bellows, is restless and has a discharge from the vulva.

13.6.6 Breeding Seasons And Breeding Cycles

Only a few animals breed throughout the year. This includes the higher primates (humans, gorillas and chimpanzees etc.), pigs, mice and rabbits. These are known as **continuous breeders** .

Most other animals restrict reproduction to one or two seasons in the year-**seasonal breeders** (see diagram 13.10). There are several reasons for this. It means the young can be born at the time (usually spring) when feed is most abundant and temperatures are favourable. It is also sensible to restrict the breeding season because courtship, mating, gestation and the rearing of young can exhaust the energy resources of an animal as well as make them more vulnerable to predators.

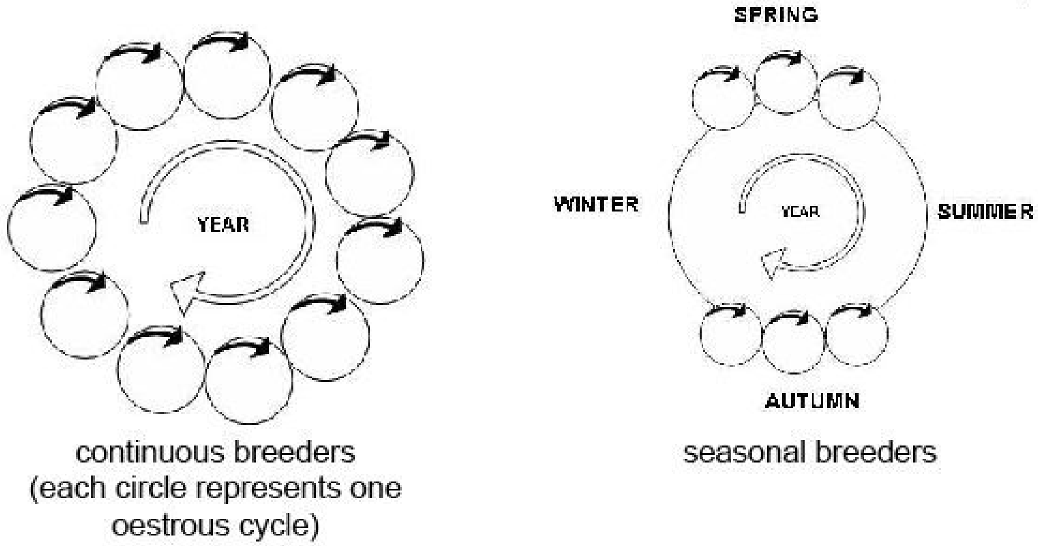

Figure 134

Diagram 13.10 - Breeding cycles

The timing of the breeding cycle is often determined by day length. For example the shortening day length in autumn will bring sheep and cows into season so the foetus can gestate through the winter and be born in spring. In cats the increasing day length after the winter solstice (shortest day) stimulates breeding. The number of times an animal comes into season during the year varies, as does the number of oestrous cycles during each season. For example a dog usually has 2-3 seasons per year, each usually consisting of just one oestrous cycle. In contrast ewes usually restrict breeding to one season and can continue to cycle as many as 20 times if they fail to become pregnant.

13.7 Fertilisation and Implantation

13.7.1 Fertilisation

The opening of the fallopian tube lies close to the ovary and after ovulation the ovum is swept into its funnel-like opening and is moved along it by the action of cilia and wave-like contractions of the wall.

Copulation deposits several hundred million sperm in the vagina. They swim through the cervix and uterus to the fallopian tubes moved along by whip-like movements of their tails and contractions of the uterus. During this journey the sperm undergo their final phase of maturation so they are ready to fertilise the ovum by the time they reach it in the upper fallopian tube.

High mortality means only a small proportion of those deposited actually reach the ovum. The sperm attach to the outer zona pellucida and enzymes secreted from a gland in the head of the sperm dissolve this membrane so it can enter. Once one sperm has entered, changes in the **zona pellucida** prevent further sperm from penetrating. The sperm loses its tail and the two nuclei fuse to form a **zygote** with the full set of paired chromosomes restored.

13.7.2 Development Of The Morula And Blastocyst

As the fertilised egg travels down the fallopian tube it starts to divide by mitosis. First two cells are formed and then four, eight, sixteen, etc. until there is a solid ball of cells. This is called a **morula** . As division continues a hollow ball of cells develops. This is a **blastocyst** (see diagram 13.11).

13.7.3 Implantation

Implantation involves the blastocyst attaching to, and in some species, completely sinking into the wall of the uterus.

13.8 Pregnancy

13.8.1 The Placenta And Foetal Membranes

As the **embryo** increases in size, the **placenta** , **umbilical cord** and **foetal membranes** (often known collectively as the **placenta**) develop to provide it with nutrients and remove waste products (see diagram 13.12). In later stages of development the embryo becomes known as a **foetus** .

The placenta is the organ that attaches the foetus to the wall of the uterus. In it the blood of the foetus and mother flow close to each other but never mix (see diagram 13.13). The closeness of the maternal and foetal blood systems allows diffusion between them. Oxygen and nutrients diffuse from the mother's blood into that of the foetus and carbon dioxide and excretory products diffuse in the other direction. Most maternal hormones (except adrenaline), antibodies, almost all drugs (including alcohol), lead and DDT also pass across the placenta. However, it protects the foetus from infection with bacteria and most viruses.

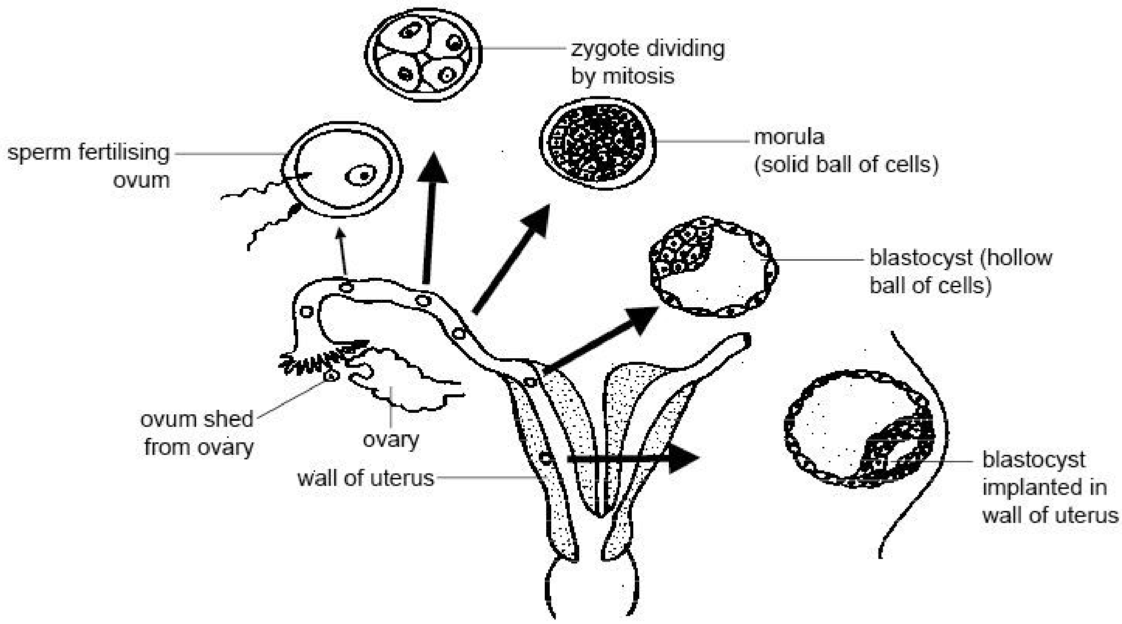

Figure 135

Diagram 13.11 - Development and implantation of the embryo

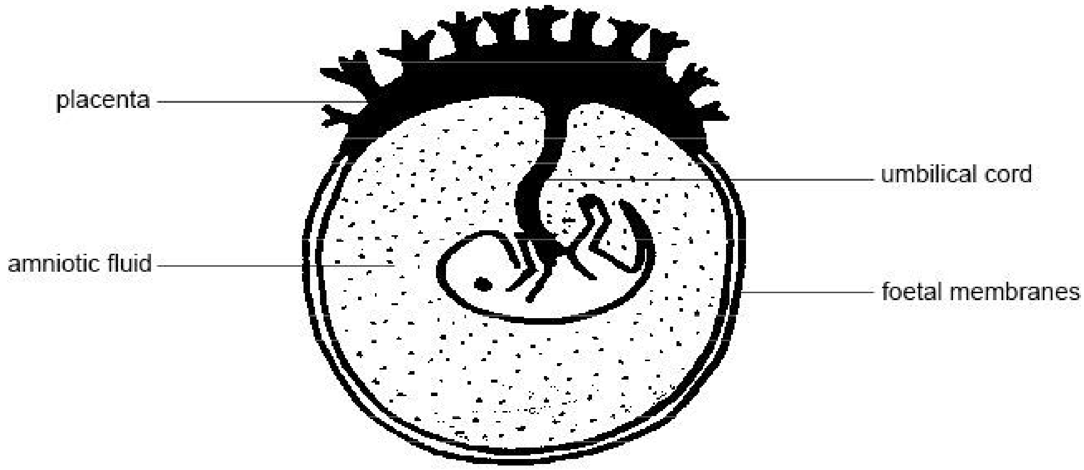

Figure 136

Diagram 13.12. The foetus and placenta

The foetus is attached to the placenta by the **umbilical cord** . It contains arteries that carry blood to the placenta and a vein that returns blood to the foetus. The developing foetus becomes surrounded by membranes. These enclose the amniotic fluid that protects the foetus from knocks and other trauma (see diagram 13.12).

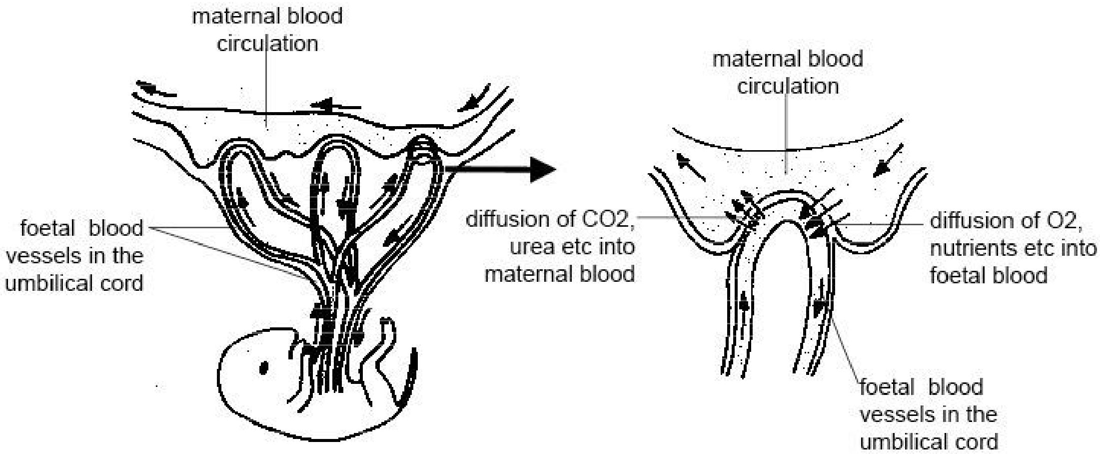

Figure 137

Diagram 13.13 - Maternal and foetal blood flow in the placenta

13.8.2 Hormones During Pregnancy

The corpus luteum continues to secrete progesterone and oestrogen during pregnancy. These maintain the lining of the uterus and prepare the mammary glands for milk secretion. Later in the pregnancy the placenta itself takes over the secretion of these hormones.

Chorionic gonadotrophin is another hormone secreted by the placenta and placental membranes. It prevents uterine contractions before labour and prepares the mammary glands for lactation. Towards the end of pregnancy the placenta and ovaries secrete **relaxin** , a hormone that eases the joint between the two parts of the pelvis and helps dilate the cervix ready for birth.

13.8.3 Pregnancy Testing

The easiest method of pregnancy detection is ultrasound which is noninvasive and very reliable Later in gestation pregnancy can be detected by taking x-rays.

In dogs and cats a blood test can be used to detect the hormone **relaxin** .

In mares and cows palpation of the uterus via the rectum is the classic way to determine pregnancy. It can also be done by detecting the hormones **progesterone** or **equine chorionic gonagotrophin** (**eCG**) in the urine. A new sensitive test measures the amount of the hormone, **oestrone sulphate** , present in a sample of faeces. The hormone is produced by the foal and placenta, and is only present when there is a living foal.

In most animals, once pregnancy is advanced, there is a window of time during which an experienced veterinarian can determine pregnancy by feeling the abdomen.

13.8.4 Gestation Period

The young of many animals (e.g. pigs, horses and elephants) are born at an advanced state of development, able to stand and even run to escape predators soon after they are born. These animals have a relatively long gestation period that varies with their size e.g. from 114 days in the pig to 640 days in the elephant.

In contrast, cats, dogs, mice, rabbits and higher primates are relatively immature when born and totally dependent on their parents for survival. Their gestation period is shorter and varies from 25 days in the mouse to 31 days in rabbits and 258 days in the gorilla.

The babies of marsupials are born at an extremely immature stage and migrate to the pouch where they attach to a teat to complete their development. Kangaroo joeys, for example, are born 33 days after conception and opossums after only 8 days.

13.9 Birth

13.9.1 Signs Of Imminent Birth

As the pregnancy continues, the mammary glands enlarge and may secrete a milky substance a few days before birth occurs. The vulva may swell and produce thick mucus and there is sometimes a visible change in the position of the foetus. Just before birth the mother often becomes restless, lying down and getting up frequently. Many animals seek a secluded place where they may build a nest in which to give birth.

13.9.2 Labour

Labour involves waves of uterine contractions that press the foetus against the cervix causing it to dilate. The foetus is then pushed through the cervix and along the vagina before being delivered. In the final stage of labour the placenta or “afterbirth” is expelled.

13.9.3 Adaptations Of The Foetus To Life Outside The Uterus

The foetus grows in the watery, protected environment of the uterus where the mother supplies oxygen and nutrients, and waste products pass to her blood circulation for excretion. Once the baby animal is born it must start to breathe for itself, digest food and excrete its own waste. To allow these functions to occur blood is re-routed to the lungs and the glands associated with the gut start to secrete. Note that newborn animals can not control their own body temperature. They need to be kept warm by the mother, littermates and insulating nest materials.

13.10 Milk Production

Cows, manatees and primates have two mammary glands but animals like pigs that give birth to large litters may have as many as 12 pairs. Ducts from the gland lead to a nipple or teat and there may be a sinus where the milk collects before being suckled (see diagram 13.14).

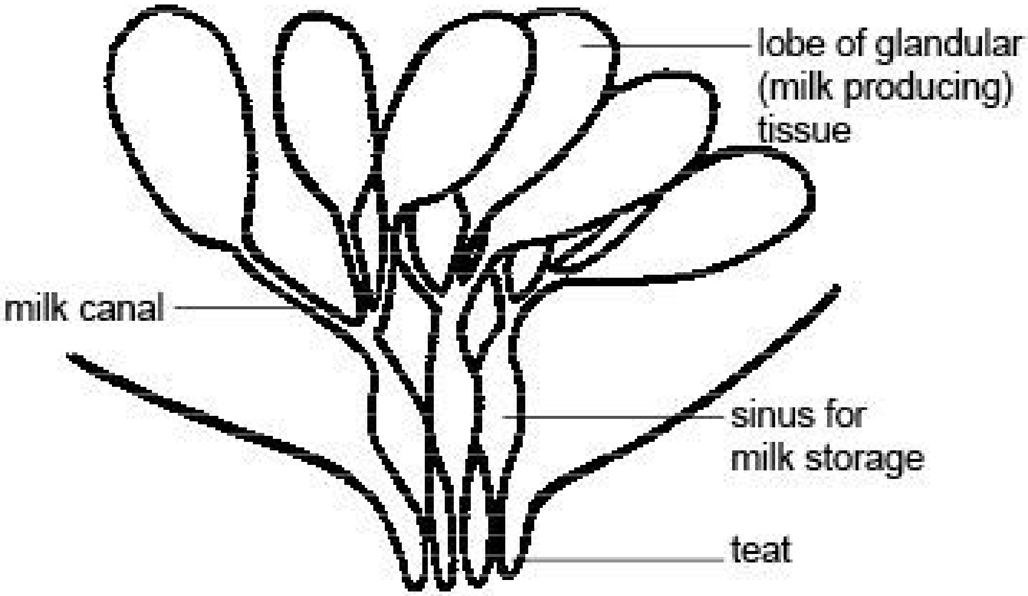

Figure 138

Diagram 13.14 - A mammary gland

The hormones **oestrogen** and **progesterone** stimulate the mammary glands to develop and **prolactin** promotes the secretion of the milk. **Oxytocin** from the pituitary gland releases the milk when the baby suckles. The first milk is called **colostrum** . It is a rich in nutrients and contains protective antibodies from the mother. Milk contains fat, protein and milk sugar as well as vitamins and most minerals although it contains little iron. Its actual composition varies widely from species to species. For example whale's and seal's milk has twelve times more fat and four times more protein than cow's milk. Cow's milk has far less protein in it than cat's or dog's milk. This is why orphan kittens and puppies cannot be fed cow's milk.

13.11 Reproduction In Birds

Male birds have testes and sperm ducts and male swans, ducks, geese and ostriches have a penis. However, most birds make do with a small amount of erectile tissue known as a **papilla** . To reduce weight for flight most female birds only have one ovary - usually the left, which produces extremely yolky eggs. The eggs are fertilised in the upper part of the oviduct (equivalent to the fallopian tube and uterus of mammals) and as they pass down it **albumin** (the white of the egg), the membrane beneath the shell and the shell are laid down over the yolk. Finally the egg is covered in a layer of mucus to help the bird lay it (see diagram 13.15).

Most birds lay their eggs in a nest and the hen sits on them until they hatch. Ducklings and chicks are relatively well developed when they hatch and able to forage for their own food. Most other nestlings need their parents to keep them warm, clean and fed. Young birds grow rapidly and have voracious appetites that may involve the parents making up to 1000 trips a day to supply their need for food.

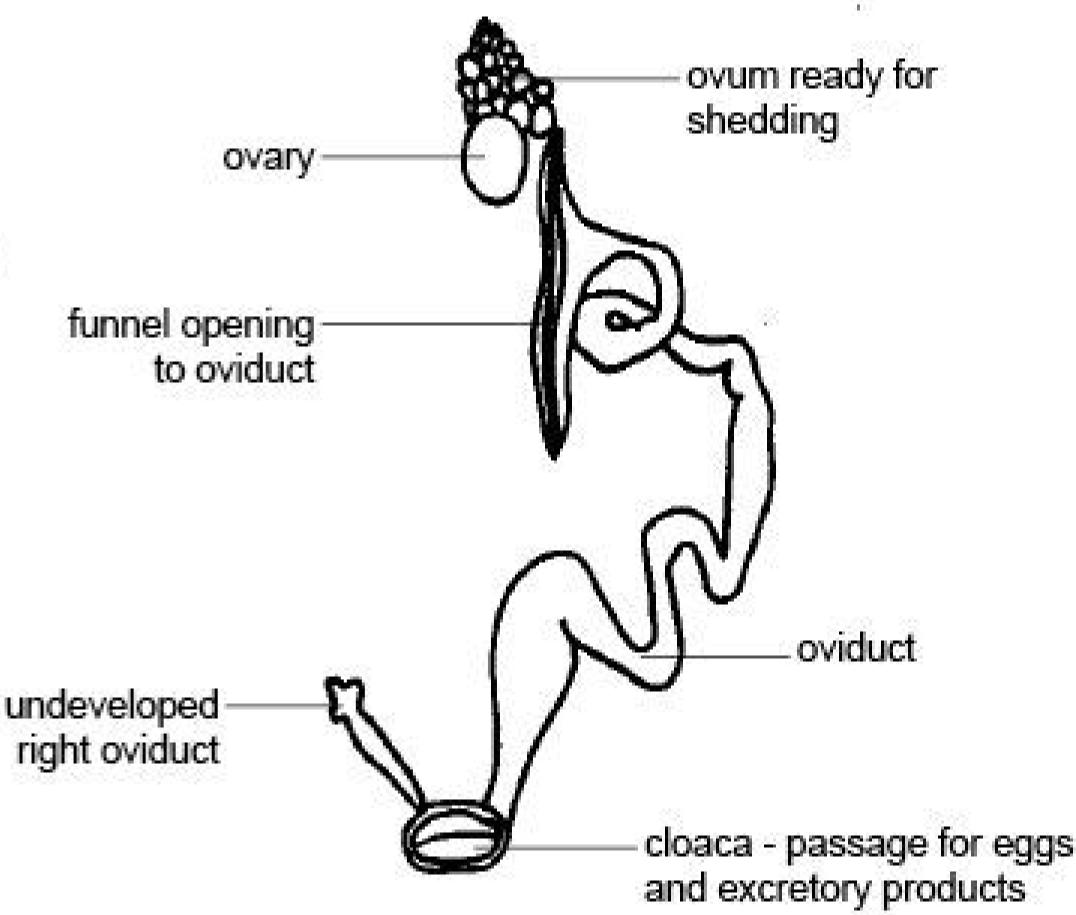

Figure 139

Diagram 13.15 - Female reproductive organs of a bird

13.12 Summary

- **Haploid** gametes (sperm and ova) are produced by meiosis in the **gonads** (testes and ovaries).
- Fertilisation involves the fusing of the gametes to form a diploid **zygote** .
- The male reproductive system consists of a pair of **testes** that produce sperm (or **spermatozoa**), ducts that transport the sperm to the penis and glands that add secretions to the sperm to make semen.

- Sperm are produced in the **seminiferous tubules** , are stored in the **epididymis** and travel via the **vas deferens** or **sperm duct** to the junction of the bladder and the **urethra** where various accessory glands add secretions. The fluid is now called **semen** and is ejaculated into the female system down the **urethra** that runs down the centre of the penis.
- Sperm consist of a head, a midpiece and a tail.
- **Infertility** is the inability of sperm to fertilize an egg while **impotence** is the inability to copulate successfully.
- The female reproductive system consists of a pair of **ovaries** that produce **ova** and **fallopian tubes** where fertilisation occurs and which carry the fertilised ovum to the **uterus** . Growth of the foetus takes place here. The **cervix** separates the uterus from the **vagina** , the birth canal and where the sperm are deposited.
- The **ovarian cycle** refers to the series of changes in the ovary during which the follicle matures, the ovum is shed and the **corpus luteum** develops.
- The **oestrous cycle** is the sequence of hormonal changes that occurs through the ovarian cycle. It is initiated by the secretion of **follicle stimulating hormone (F.S.H.),** by the **anterior pituitary gland** which stimulates the **follicle** to develop. The follicle secretes **oestrogen** which stimulates **mammary gland** development. **luteinising hormone (L.H.)** from the anterior pituitary initiates **ovulation** and stimulates the **corpus luteum** to develop. The corpus luteum produces **progesterone** that prepares the lining of the uterus for the fertilised ovum.
- **Signs of oestrous** or heat differ. A bitch has a blood stained discharge, female cats and rats are restless and show the lordosis response, while cows mount other cows, bellow and have a discharge from the vulva.
- After fertilisation in the fallopian tube the **zygote** divides over and over by mitosis to become a ball of cells called a **morula** . Division continues to form a hollow ball of cells called the **blastocyst** . This is the stage that **implants** in the uterus.
- The **placenta, umbilical cord** and **foetal membranes** (known as the **placenta**) protect and provide the developing foetus with nutrients and remove waste products.

13.13 Worksheet

Reproductive System Worksheet[1]

13.14 Test Yourself

1. Add the following labels to the diagram of the male reproductive organs below.

   testis | epididymis | vas deferens | urethra | penis | scrotal sac | prostate gland

Diagram of the Male Reproductive System

2. Match the following descriptions with the choices given in the list below.

1 `http://www.wikieducator.org/Reproductive_System_Worksheet`

accessory glands | vas deferens or sperm duct | penis | scrotum | fallopian tube | testes | urethra | vagina | uterus | ovary | vulva

a) Organ that delivers semen to the female vagina

b) Where the sperm are produced

c) Passage for sperm from the epididymis to the urethra

d) Carries both sperm and urine down the penis

e) Glands that produce secretions that make up most of the semen

f) Bag of skin surrounding the testes

g) Where the foetus develops

h) This receives the penis during copulation

i) Where fertilisation usually occurs

j) Ova travel along this tube to reach the uterus

k) Where the ova are produced

l) The external opening of the vagina

3. Which hormone is described in each statement below?

a) This hormone stimulates the growth of the follicles in the ovary

b) This hormone converts the empty follicle into the corpus luteum and stimulates it to produce progesterone

c) This hormone is produced by the cells of the follicle

d) This hormone is produced by the corpus luteum

e) This hormone causes the mammary glands to develop

f) This hormone prepares the lining of the uterus to receive a fertilised ovum

4. State whether the following statements are true or false. If false write in the correct answer.

a) Fertilisation of the egg occurs in the uterus

b) The fertilised egg cell contains half the normal number of chromosomes

c) The morula is a hollow ball of cells

d) The mixing of the blood of the mother and foetus allows nutrients and oxygen to transfer easily to the foetus

e) The morula implants in the wall of the uterus

f) The placenta is the organ that supplies the foetus with oxygen and nutrients

g) Colostrum is the first milk

h) Young animals often have to be given calcium supplements because milk contains very little calcium

/Test Yourself Answers/[2]

13.15 Websites

- http://www.anatomicaltravel.com/CB_site/Conception_to_birth3.htm Anatomical travel. Images of fertilisation and the development of the (human) embryo through to birth.
- http://www.uchsc.edu/ltc/fert.swf Fertilisation. A great animation of fertilisation, formation of the zygote and first mitotic division. A bit advanced but still worth watching.
- http://www.uclan.ac.uk/facs/health/nursing/sonic/scenarios/salfordanim/heart.swf Sonic. An animation showing the foetal blood circulation through the placenta to the changes allowing circulation through the lungs after birth.
- http://en.wikipedia.org/wiki/Estrus Wikipedia. As always, good interesting information although some terms and concepts are beyond the requirements of this level.

13.16 Glossary

- Link to Glossary[3]

[4]

2 https://en.wikibooks.org/wiki/%2FTest%20Yourself%20Answers%2F
3 http://en.wikibooks.org/wiki/Anatomy_and_Physiology_of_Animals/Glossary
4 https://en.wikibooks.org/wiki/Category%3A

14 Nervous System

Figure 140 original image by Royalty-free image collection[a] cc by

a http://flickr.com/photos/royalty-free-images/139764662/

14.1 Objectives

After completing this section, you should know:

- the role of the nervous system in coordinating an animal's response to the environment
- that the nervous system gathers, sorts and stores information and initiates movement
- the basic structure and function of a neuron
- the structure and function of a synapse and neurotransmitter chemicals
- the nervous pathway known as a reflex with examples
- that training can develop conditioned reflexes in animals
- that the nervous system can be divided into the central and peripheral nervous systems
- that the brain is surrounded by membranes called meninges
- the basic parts of the brain and the function of the cerebral hemispheres, hypothalamus, pituitary, cerebellum and medulla oblongata
- the structure and function of the spinal cord
- that the peripheral nervous system consists of cranial and spinal nerves and the autonomic nervous system
- that the autonomic nervous system consists of sympathetic and parasympathetic parts with different functions

14.2 Coordination

Animals must be able to sense and respond to the environment in which they live if they are to survive. They need to be able to sense the temperature of their surroundings, for example, so they can avoid the hot sun. They must also be able to identify food and escape predators.

The various systems and organs in the body must also be linked so they work together. For example, once a predator has identified suitable prey it has to catch it. This involves coordinating the contraction of the muscle so the predator can run, there must then be an increased blood supply to the muscles to provide them with oxygen and nutrients. At the same time the respiration rate must increase to supply the oxygen and remove the carbon dioxide produced as a result of this increased activity. Once the prey has been caught and eaten, the digestive system must be activated to digest it.

The adjustment of an animal's response to changes in the environment and the complex linking of the various processes in the body that this response involves are called **co-ordination** . Two systems are involved in co-ordination in animals. These are the **nervous** and **endocrine systems** . The first operates via electrical impulses along nerve fibres and the second by releasing special chemicals or hormones into the bloodstream from glands.

14.3 Functions of the Nervous System

The nervous system has three basic functions:

1. **Sensory function** - to sense changes (known as stimuli) both outside and within the body. For example the eyes sense changes in light and the ear responds to sound waves.

Inside the body, stretch receptors in the stomach indicate when it is full and chemical receptors in the blood vessels monitor the acidity of the blood.

2. **Integrative function** - processing the information received from the sense organs. The impulses from these organs are analysed and stored as memory. The many different impulses from different sources are sorted, synchronised and co-ordinated and the appropriate response initiated. The power to integrate, remember and apply experience gives higher animals much of their superiority.

3. **Motor function** - The third function is the response to the stimuli that causes muscles to contract or glands to secrete.

All nervous tissue is made up of nerve cells or **neurons.** These transmit high-speed signals called **nerve impulses** . Nerve impulses can be thought of as being similar to an electric current.

14.4 The Neuron

Neurons are cells that have been adapted to carry nerve impulses. A typical neuron has a **cell body** containing a nucleus, one or more branching filaments called **dendrites** which conduct nerve impulses towards the cell body and one long fibre, an **axon** , that carries the impulses away from it. Many axons have a sheath of fatty material called **myelin** surrounding them. This speeds up the rate at which the nerve impulses travel along the nerve (see diagram 14.1).

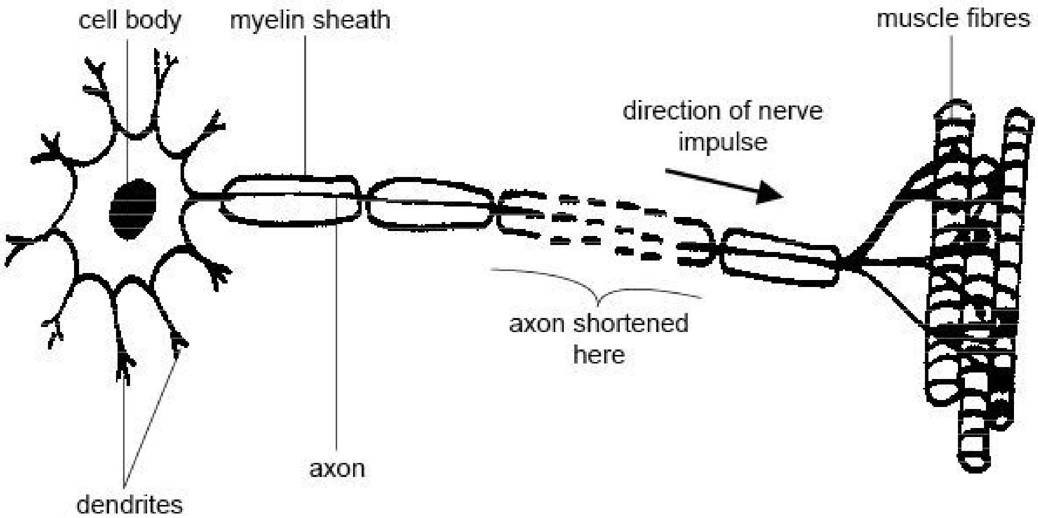

Figure 141

Diagram 14.1 - A motor neuron

The cell body of neurons is usually located in the brain or spinal cord while the axon extends the whole distance to the organ that it supplies. The neuron carrying impulses from the spinal cord to the hind leg or tail of a horse, for example, can be several feet long. A **nerve** is a bundle of axons.

A **sensory neuron** is a nerve cell that transmits impulses from a sense receptor such as those in the eye or ear to the brain or spinal cord. A **motor neuron** is a nerve cell that transmits impulses from the brain or spinal cord to a muscle or gland. A **relay neuron** connects sensory and motor neurons and is found in the brain or spinal cord (see diagrams 14.1 and 14.2).

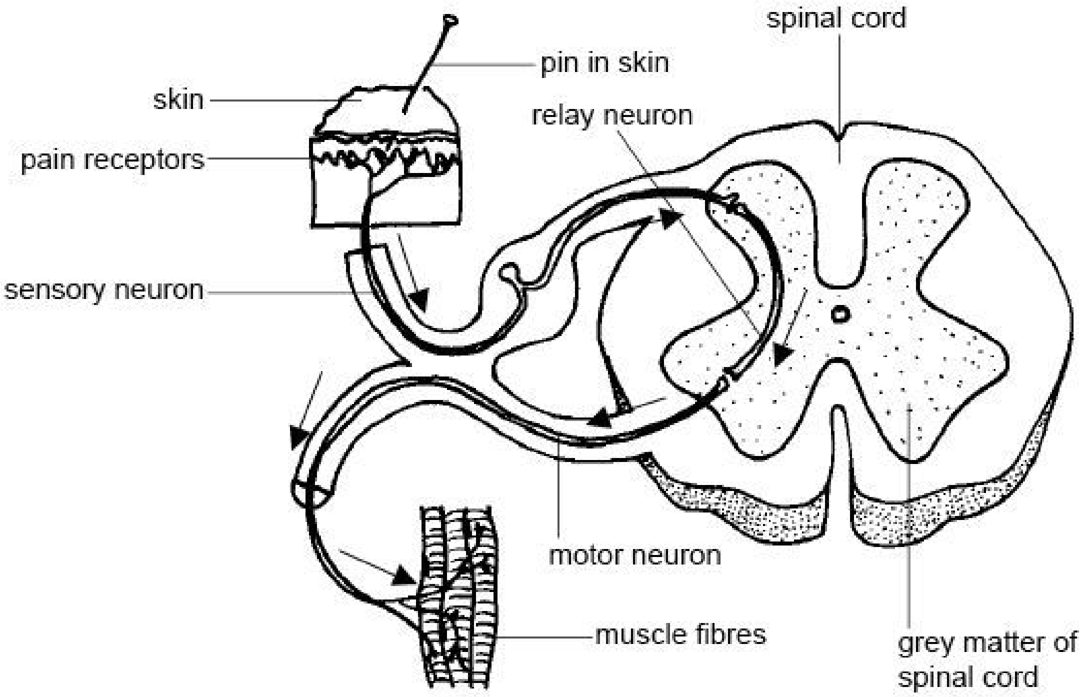

Figure 142

Diagram 14.2 - The relationship between sensory, relay and motor neurons

14.4.1 Connections Between Neurons

The connection between adjacent neurons is called a **synapse** . The two nerve cells do not actually touch here for there is a microscopic space between them. The electrical impulse in the neurone before the synapse stimulates the production of chemicals called **neurotransmitters** (such as **acetylcholine**), which are secreted into the gap.

The neurotransmitter chemicals diffuse across the gap and when they contact the membrane of the next nerve cell they stimulate a new nervous impulse (see diagram 14.3). After the impulse has passed the chemical is destroyed and the synapse is ready to receive the next nerve impulse.

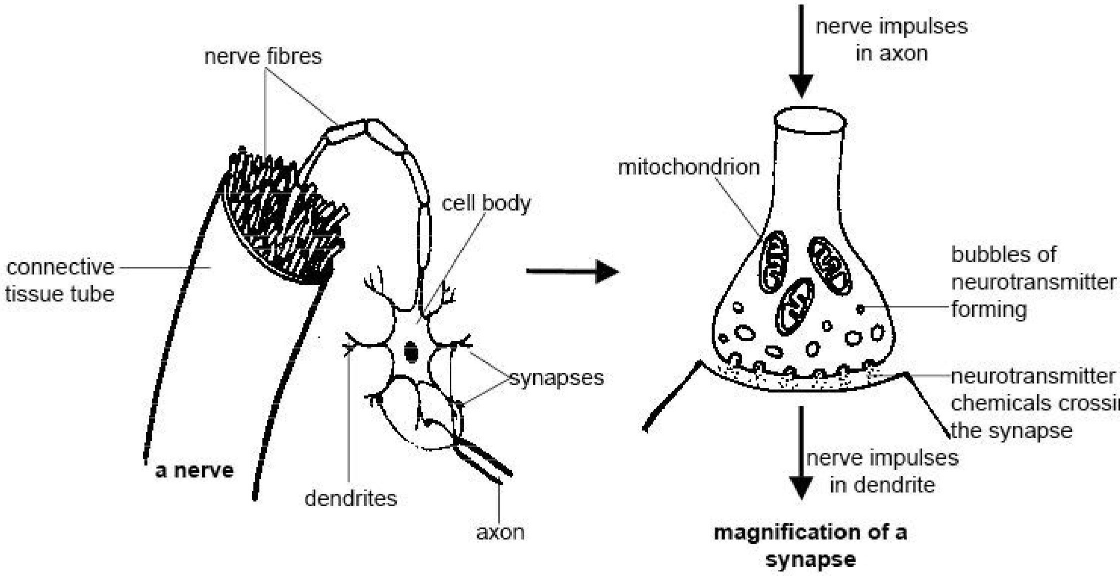

Figure 143

Diagram 14.3 - A nerve and magnification of a synapse

14.5 Reflexes

A **reflex** is a rapid automatic response to a stimulus. When you accidentally touch a hot object and automatically jerk your hand away, this is a reflex action. It happens without you having to think about it. Animals automatically blink when an object approaches the eye and cats twist their bodies in the air when falling so they land on their paws. (Please don't test this one at home with your pet cat!).

Swallowing, sneezing, and the constriction of the pupil of the eye in bright light are also all reflex actions.

The path taken by the nerve impulses in a reflex is called a **reflex arc** . Most reflex arcs involve only three neurons (see diagram 14.4). The **stimulus** (a pin in the paw) stimulates the pain receptors of the skin, which initiate an impulse in a sensory neuron. This travels to the spinal cord where it passes, by means of a synapse, to a connecting neuron called the relay neuron situated in the spinal cord. The relay neuron in turn makes a synapse with one or more motor neurons that transmit the impulse to the muscles of the limb causing them to contract and remove the paw from the sharp object. Reflexes do not require involvement of the brain although you are aware of what is happening and can, in some instances, prevent them happening. Animals are born with their reflexes. You can think of them as being wired in.

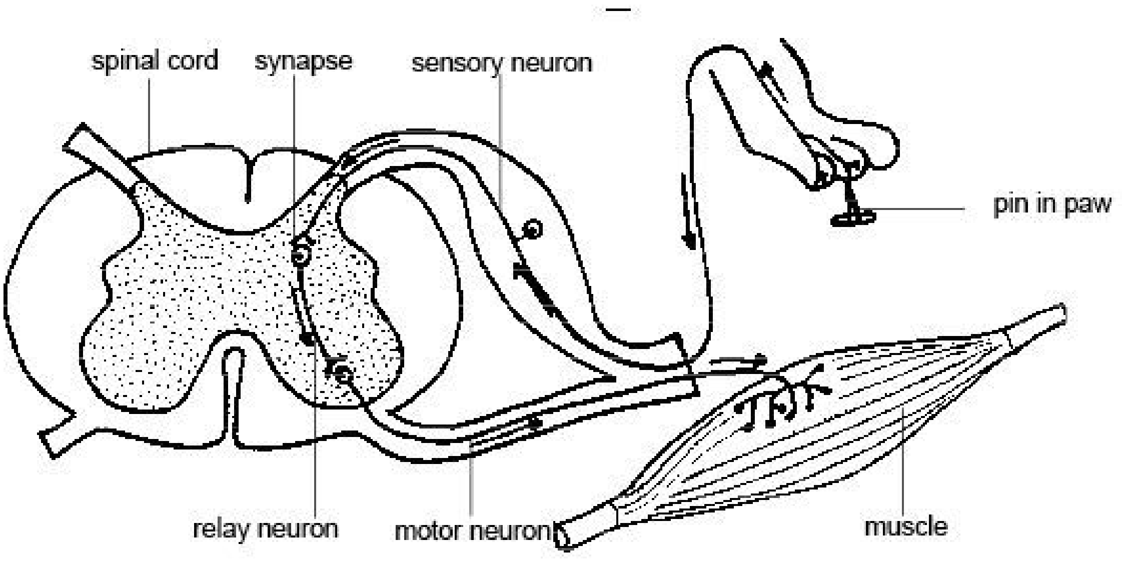

Figure 144

Diagram 14.4 - A reflex arc

14.5.1 Conditioned Reflexes

In most reflexes the stimulus and response are related. For example the presence of food in the mouth causes the salivary glands to release saliva. However, it is possible to train animals (and humans) to respond to different and often quite irrelevant stimuli. This is called a **conditioned reflex** .

A Russian biologist called Pavlov carried out the classic experiment to demonstrate such a reflex when he conditioned dogs to salivate at the sound of a bell ringing. Almost every pet owner can identify reflexes they have conditioned in their animals. Perhaps you have trained your cat to associate food with the opening of the fridge door or accustomed your dog to the routines you go through before taking them for a walk.

14.6 Parts of the Nervous System

When we describe the nervous system of vertebrates we usually divide it into two parts (see diagram 14.5).

1. The **central nervous system** (**CNS**) which consists of the brain and spinal cord.

2. The **peripheral nervous system** (**PNS**) which consists of the nerves that connect to the brain and spinal cord (cranial and spinal nerves) as well as the **autonomic** (or involuntary) nervous system.

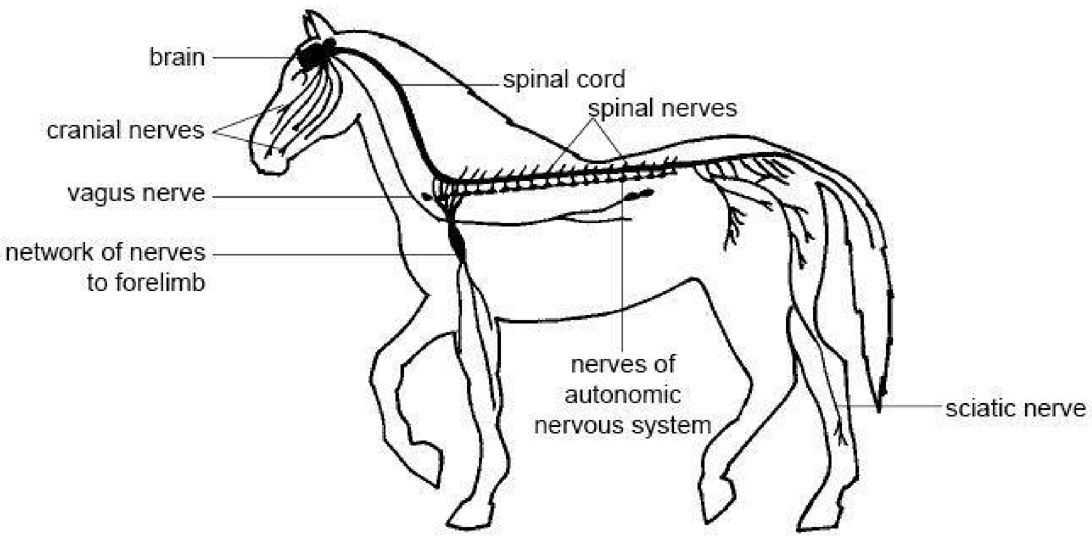

Figure 145

Diagram 14.5 - The nervous system of a horse

14.6.1 The Central Nervous System

The **central nervous system** consists of the brain and spinal cord. It acts as a kind of 'telephone exchange' where a vast number of cross connections are made.

When you look at the brain or spinal cord some regions appear creamy white (**white matter**) and others appear grey (**grey matter**). White matter consists of masses of nerve axons and the grey matter consists of the nerve cells. In the brain the grey matter is on the outside and in the spinal cord it is on the inside (see diagram 14.2).

The Brain

The major part of the brain lies protected within the sturdy "box" of skull called the **cranium** . Surrounding the fragile brain tissue (and spinal cord) are protective membranes called the **meninges** (see diagram 14.6), and a crystal-clear fluid called **cerebrospinal fluid** , which protects and nourishes the brain tissue. This fluid also fills four cavities or **ventricles** that lie within the brain.

Brain tissue is extremely active and, even when an animal is resting, it uses up to 20% of the oxygen taken into the body by the lungs. The **carotid artery** , a branch off the dorsal aorta, supplies it with the oxygen and nutrients it requires. Brain damage occurs if brain tissue is deprived of oxygen for only 4-8 minutes.

The brain consists of three major regions:

1. the **fore brain** which includes the **cerebral hemispheres** , **hypothalamus** and **pituitary gland** ;
2. the **hind brain** or **brain stem** , contains the **medulla oblongata** and **pons** and
3. the **cerebellum** or “little brain” (see diagram 14.6).

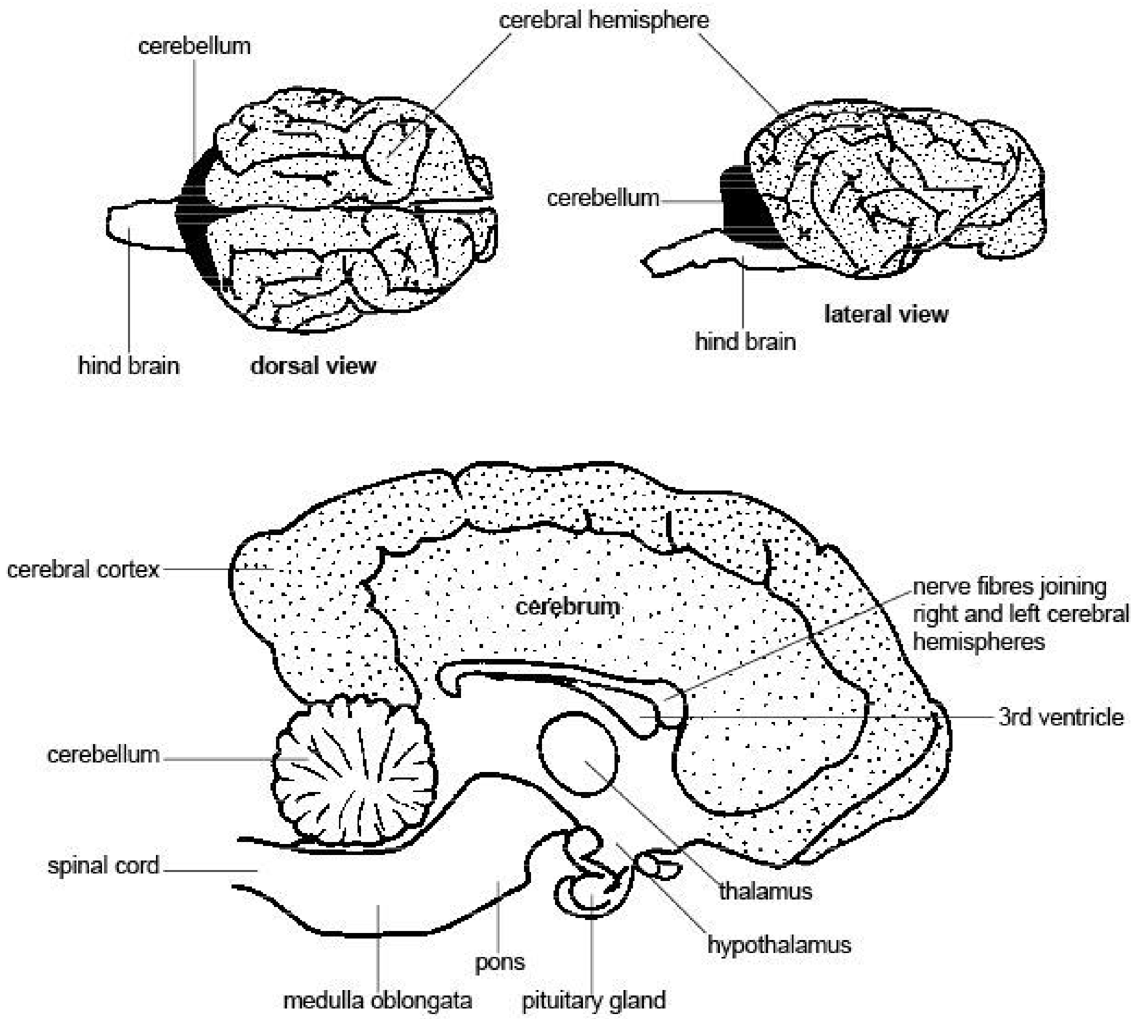

Figure 146

Diagram 14.6 - Longitudinal section through the brain of a dog

Mapping the brain

In humans and some animals the functions of the different regions of the cerebral cortex have been mapped (see diagram 14.7).

Diagram 14.7 - The functions of the regions of the human cerebral cortex

The Forebrain

The **cerebral hemispheres** are the masses of brain tissue that sit on the top of the brain. The surface is folded into ridges and furrows called **sulci** (singular sulcus). They make this part of the brain look rather like a very large walnut kernel. The two hemispheres are separated by a deep groove although they are connected internally by a thick bundle of nerve fibres. The outer layer of each hemisphere is called the **cerebral cortex** and this is where the main functions of the cerebral hemispheres are carried out.

The cerebral cortex is large and convoluted in mammals compared to other vertebrates and largest of all in humans because this is where the so-called “higher centres” concerned with memory, learning, reasoning and intelligence are situated.

Nerves from the eyes, ears, nose and skin bring sensory impulses to the cortex where they are interpreted. Appropriate voluntary movements are initiated here in the light of the memories of past events.

Different regions of the cortex are responsible for particular sensory and motor functions, e.g. vision, hearing, taste, smell, or moving the fore-limbs, hind-limbs or tail. For example, when a dog sniffs a scent, sensory impulses from the organ of smell in the nose pass via the olfactory (smelling) nerve to the olfactory centres of the cerebral hemispheres where the impulses are interpreted and co-ordinated.

In humans and some animals the functions of the different regions of the cerebral cortex have been mapped (see diagram 14.8).

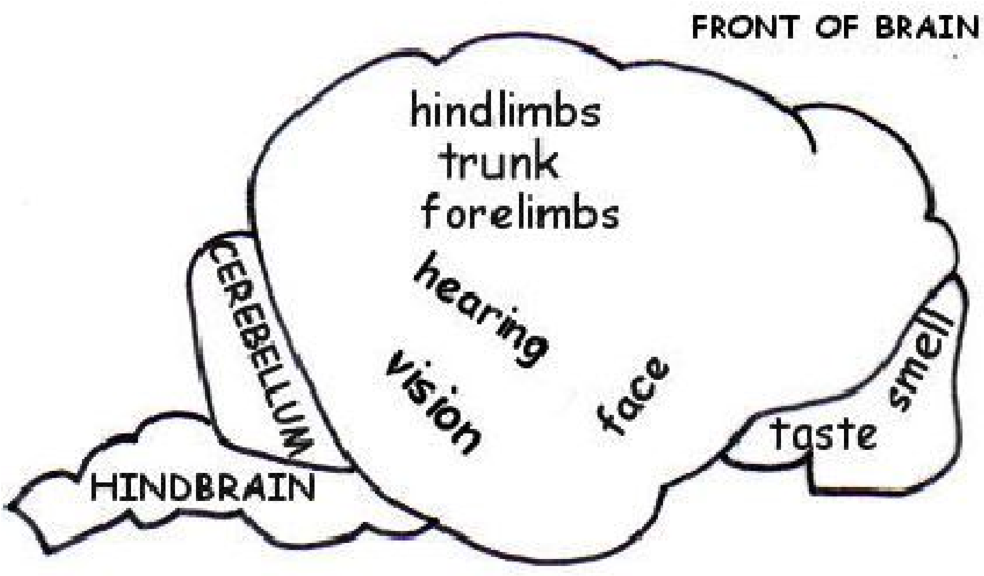

Figure 147

Diagram 14.8 - The functions of the regions of the cerebral cortex

The **hypothalamus** is situated at the base of the brain and is connected by a “stalk” to the **pituitary gland** , the “master” hormone-producing gland (see chapter 16). The hypothalamus can be thought of as the bridge between the nervous and endocrine (hormone producing) systems. It produces some of the hormones that are released from the pituitary gland and controls the release of others from it.

It is also an important centre for controlling the internal environment of the animal and therefore maintaining homeostasis. For example, it helps regulate the movement of food through the gut and the temperature, blood pressure and concentration of the blood. It is also responsible for the feeling of being hungry or thirsty and it controls sleep patterns and sex drive.

The Hindbrain

The **medulla oblongata** is at the base of the brain and is a continuation of the spinal cord. It carries all signals between the spinal cord and the brain and contains centres that control vital body functions like the basic rhythm of breathing, the rate of the heartbeat and the activities of the gut. The medulla oblongata also co-ordinates swallowing, vomiting, coughing and sneezing.

The Cerebellum

The **cerebellum** (little brain) looks rather like a smaller version of the cerebral hemispheres attached to the back of the brain. It receives impulses from the organ of balance (vestibular organ) in the inner ear and from stretch receptors in the muscles and tendons. By co-ordinating these it regulates muscle contraction during walking and running and helps maintain the posture and balance of the animal. When the cerebellum malfunctions it causes a tremor and uncoordinated movement.

The Spinal Cord

The spinal cord is a cable of nerve tissue that passes down the channel in the vertebrae from the hindbrain to the end of the tail. It becomes progressively smaller as paired **spinal nerves** pass out of the cord to parts of the body. Protective membranes or meninges cover the cord and these enclose cerebral spinal fluid (see diagram 14.9).

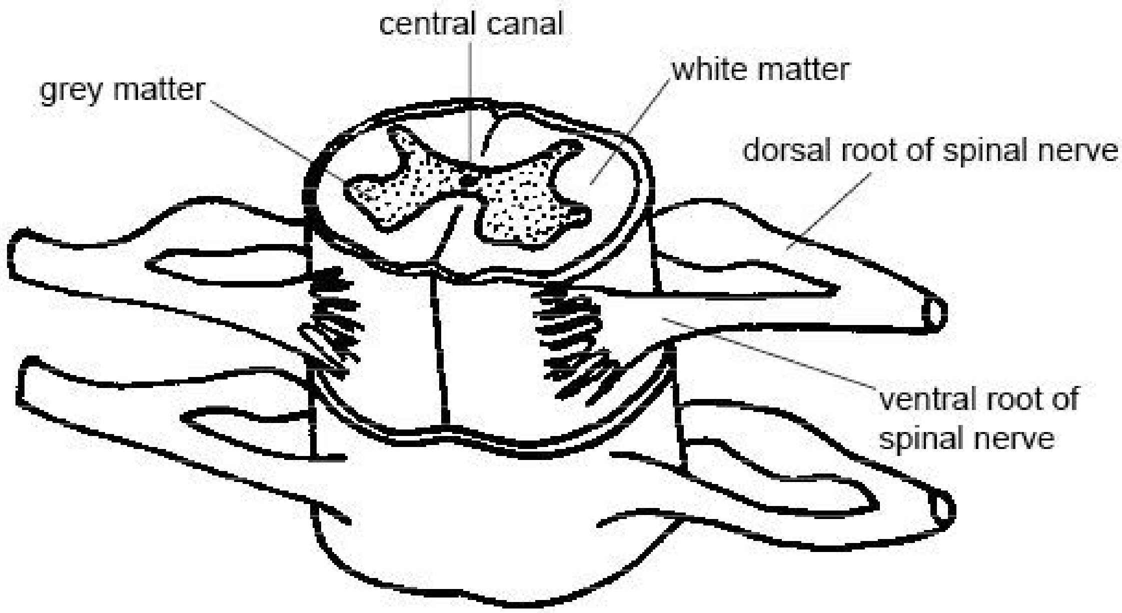

Figure 148

Diagram 14.9 - The spinal cord

If you cut across the spinal cord you can see that it consists of white matter on the outside and grey matter in the shape of an H or butterfly on the inside.

14.6.2 The Peripheral Nervous System

The **peripheral nervous system** consists of nerves that are connected to the brain (**cranial nerves**), and nerves that are connected to the spinal cord (**spinal nerves**). The **autonomic nervous** system**is also part of the peripheral nervous system.**

Cranial Nerves

There are twelve pairs of cranial nerves that come from the brain. Each passes through a hole in the cranium (brain case). The most important of these are the olfactory, optic, acoustic and vagus nerves.

The **olfactory nerves** - (smell) carry impulses from the olfactory organ of the nose to the brain.

The **optic nerves** - (sight) carry impulses from the retina of the eye to the brain.

The **auditory (acoustic) nerves** - (hearing) carry impulses from the cochlear of the inner ear to the brain.

The **vagus nerve** - controls the muscles that bring about swallowing. It also controls the muscles of the heart, airways, lungs, stomach and intestines (see diagram 14.5).

Spinal Nerves

Spinal nerves connect the spinal cord to sense organs, muscles and glands in the body. Pairs of spinal nerves leave the spinal cord and emerge between each pair of adjacent vertebrae (see diagram 14.9).

The **sciatic nerve** is the largest spinal nerve in the body (see diagram 14.5). It leaves the spinal cord as several nerves that join to form a flat band of nervous tissue. It passes down the thigh towards the hind leg where it gives off branches to the various muscles of this limb.

The Autonomic Nervous System

The **autonomic nervous system** controls internal body functions that are not under conscious control. For example when a prey animal is chased by a predator the autonomic nervous system automatically increases the rate of breathing and the heartbeat. It dilates the blood vessels that carry blood to the muscles, releases glucose from the liver, and makes other adjustments to provide for the sudden increase in activity. When the animal has escaped and is safe once again the nervous system slows down all these processes and resumes all the normal body activities like the digestion of food.

The nerves of the autonomic nervous system originate in the spinal cord and pass out between the vertebrae to serve the various organs (see diagram 14.10).There are two main parts to the autonomic nervous system -- the **sympathetic system** and the **parasympathetic system** .

The **sympathetic system** stimulates the "flight, fright, fight" response that allows an animal to face up to an attacker or make a rapid departure. It increases the heart and respiratory rates, as well as the amount of blood flowing to the skeletal muscles while blood flow to less critical regions like the gut and skin is reduced. It also causes the pupils of the eyes to dilate. Note that the effects of the sympathetic system are similar to the effects of the hormone adrenaline (see Chapter 16).

The **parasympathetic system** does the opposite to the sympathetic system. It maintains the normal functions of the relaxed body. These are sometimes known as the "housekeeping" functions. It promotes effective digestion, stimulates defaecation and urination and maintains a regular heartbeat and rate of breathing.

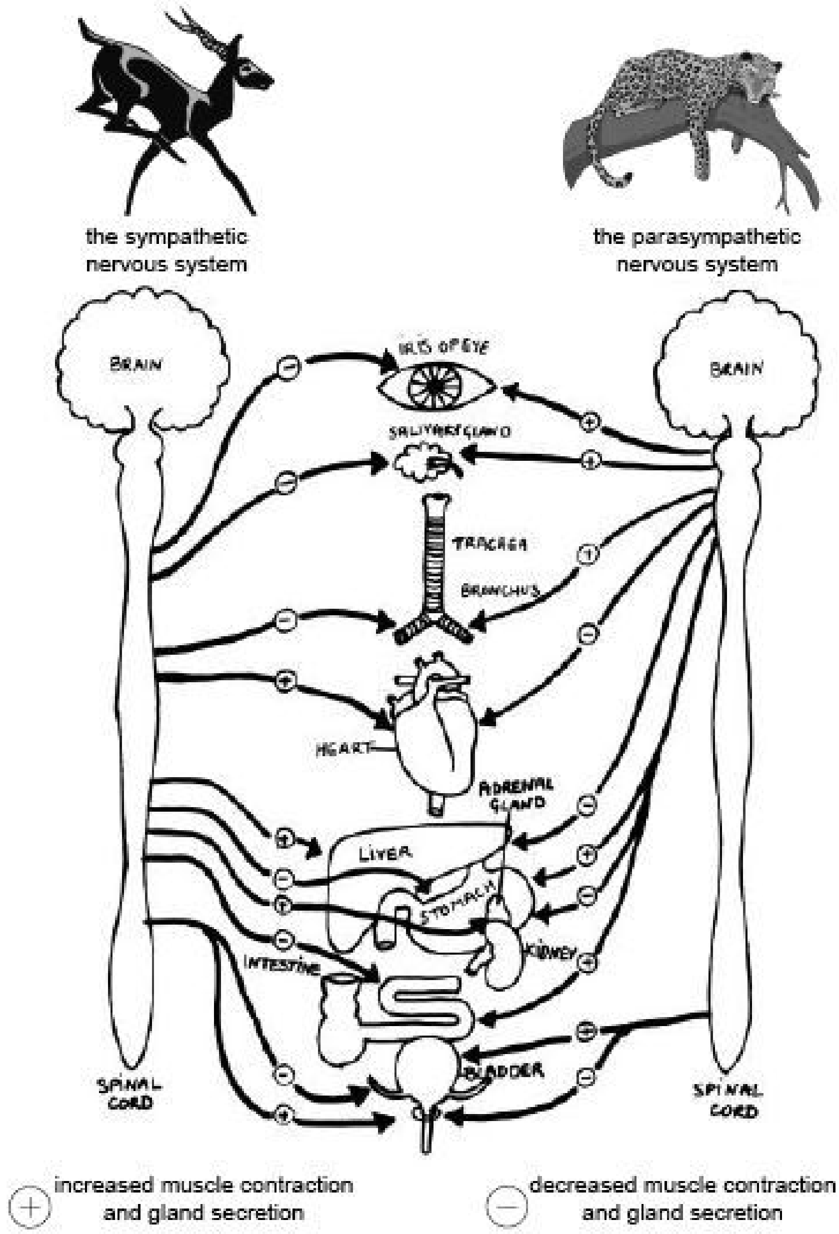

Figure 149

Diagram 14.10 - The function of the sympathetic and parasympathetic nervous systems

14.7 Summary

- The **neuron** is the basic unit of the nervous system. It consists of a **cell body** with a nucleus, filaments known as **dendrites** and a long fibre known as the **axon** often surrounded by a **myelin sheath** .
- A **nerve** is a bundle of axons.

- **Grey matter** in the brain and spinal cord consists mainly of brain cells while **white matte** r consists of masses of axons.
- **Nerve Impulses** travel along axons.
- Adjacent neurons connect with each other at **synapses** .
- **Reflexes** are automatic responses to stimuli. The path taken by nerve impulses involved in reflexes is a **reflex arc** . Most reflex arcs involve 3 neurons - a **sensory neuron** , a **relay neuron** and a **motor neuron** . A stimulus, a pin in the paw for example, initiates an impulse in the sensory neuron that passes via a synapse to the relay neuron situated in the spinal cord and then via another synapse to the motor neurone. This transmits the impulse to the muscle causing it to contract and remove the paw from the pin.
- The nervous system is divided into 2 parts: the **central nervous system** , consisting of the brain and spinal cord and the **peripheral nervous system** consisting of nerves connected to the brain and spinal cord. The **autonomic nervous system** is considered to be part of the peripheral nervous system.
- The brain consists of three major regions: 1. the **fore brain** which includes the **cerebral hemispheres** (or **cerebrum**), **hypothalamus** and **pituitary gland** ; 2. the **hindbrain** or **brain stem** containing the **medulla oblongata** and 3. the **cerebellum** .
- Protective membranes known as the **meninges** surround the brain and spinal cord.
- There are 12 pairs of cranial nerves that include the optic, olfactory, acoustic and **vagus** nerves.
- The **spinal cord** is a cable of nerve tissue surrounded by meninges passing from the brain to the end of the tail. **Spinal nerves** emerge by a **ventral** and **dorsal root** between each vertebra and connect the spinal cord with organs and muscles.
- The **autonomic nervous system** controls internal body functions not under conscious control. It is divided into 2 parts with 2 different functions: the **sympathetic nervous system** that is involved in the flight and fight response including increased heart rate, bronchial dilation, dilation of the pupil and decreased gut activity. The **parasympathetic nervous system** is associated with decreased heart rate, pupil constriction and increased gut activity.

14.8 Worksheet

Nervous System Worksheet[1]

14.9 Test Yourself

1. Add the following labels to this diagram of a motor neuron.

cell body | nucleus | axon | dendrites | myelin sheath | muscle fibres

1 http://www.wikieducator.org/Nervous_System_Worksheet

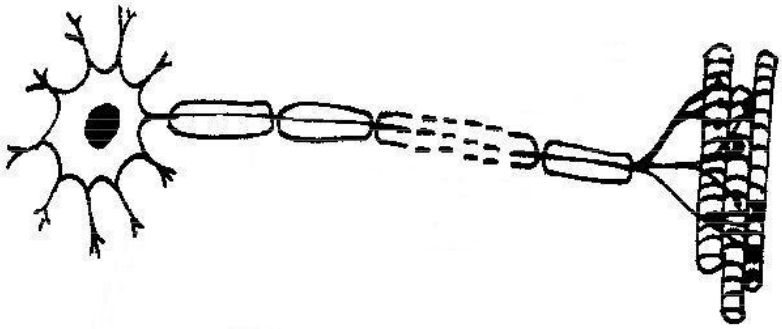

Figure 150

2. What is a synapse?

3. What is a reflex?

4. Rearrange the parts of a reflex arc given below in the order in which the nerve impulse travels from the sense organ to the muscle.

sense organ | relay neuron | motor neuron | sensory neuron | muscle fibres

5. Add the following labels to the diagram of the dog's brain shown below.

cerebellum | cerebral hemisphere | cerebral cortex | pituitary gland | medulla oblongata

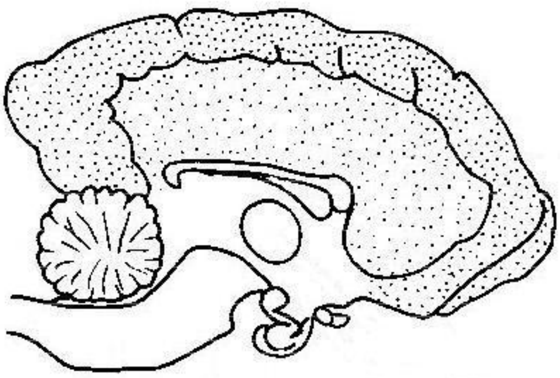

Figure 151

6. What is the function of the meninges that cover the brain and spinal cord

7. Give 3 effects of the action of the sympathetic nervous system.

/Test Yourself Answers/[2]

14.10 Websites

- http://en.wikipedia.org/wiki/Neuron Wikipedia. Lots of good information here but as usual a warning that there are terms and concepts that are beyond the scope of this course. Also try 'reflex action' ; 'autonomic nervous system' ;
- http://images.google.co.nz/imgres?imgurl=http://static.howstuffworks.com/gif/brain-neuron.gif&imgrefurl=http://science.howstuffworks.com/brain1.htm&h=296&w=394&sz=17&hl=en&start=5&tbnid=LWLRI9lW_5PZhM:&tbnh=93&tbnw=124&prev=/images%3Fq%3Dneuron%26svnum%3D10%26hl%3Den%26lr%3D%26sa%3DN How Stuff Works. This site is for the neuron but try 'neuron types', 'brain parts' and 'balancing act' too.
- http://web.archive.org/web/20060821134839/http://www.bbc.co.uk/schools/gcsebitesize/flash/bireflexarc.swf Reflex Arc. Nice clear and simple animation of a reflex arc.

14.11 Glossary

- Link to Glossary[3]

[4]

2 https://en.wikibooks.org/wiki/%2FTest%20Yourself%20Answers%2F
3 http://en.wikibooks.org/wiki/Anatomy_and_Physiology_of_Animals/Glossary
4 https://en.wikibooks.org/wiki/Category%3A

15 The Senses

Figure 152 original image by miss pupik[a] cc by

a http://flickr.com/photos/miss_pupik/5350317/

15.1 Objectives

After completing this section, you should know:

- that the general senses of touch, pressure, pain etc. are situated in the dermis of the skin and in the body
- that the special senses include those of smell, taste, sight, hearing, and balance
- the main structures of the eye and their functions
- the route taken by light through the eye to the retina
- the role of the rods and cones in the retina
- the advantages of binocular vision
- the main structures of the ear and their functions
- the route taken by sound waves through the ear to the cochlea
- the role of the vestibular organ (semicircular canals and otolith organ) in maintaining balance and posture

15.2 The Sense Organs

Sense organs allow animals to sense changes in the environment around them and in their bodies so that they can respond appropriately. They enable animals to avoid hostile environments, sense the presence of predators and find food.

Animals can sense a wide range of stimuli that includes, touch, pressure, pain, temperature, chemicals, light, sound, movement and position of the body. Some animals can sense electric and magnetic fields. All sense organs respond to stimuli by producing nerve impulses that travel to the brain via a sensory nerve. The impulses are then processed and interpreted in the brain as pain, sight, sound, taste etc.

The senses are often divided into two groups:

1. The **general senses** of touch, pressure, pain and temperature that are distributed fairly evenly through the skin. Some are found in muscles and within joints.

2. The **special senses** which include the senses of smell, taste, sight, hearing and balance. The special sense organs may be quite complex in structure.

15.3 Touch And Pressure

Within the dermis of the skin are numerous modified nerve endings that are sensitive to touch and pressure. The roots of hairs may also be well supplied with sensory receptors that inform the animal that it is in contact with an object (see diagram 15.1). Whiskers are specially modified hairs.

15.4 Pain

Receptors that sense pain are found in almost every tissue of the body. They tell the animal that tissues are dangerously hot, cold, compressed or stretched or that there is not enough blood flowing in them. The animal may then be able to respond and protect itself from further damage

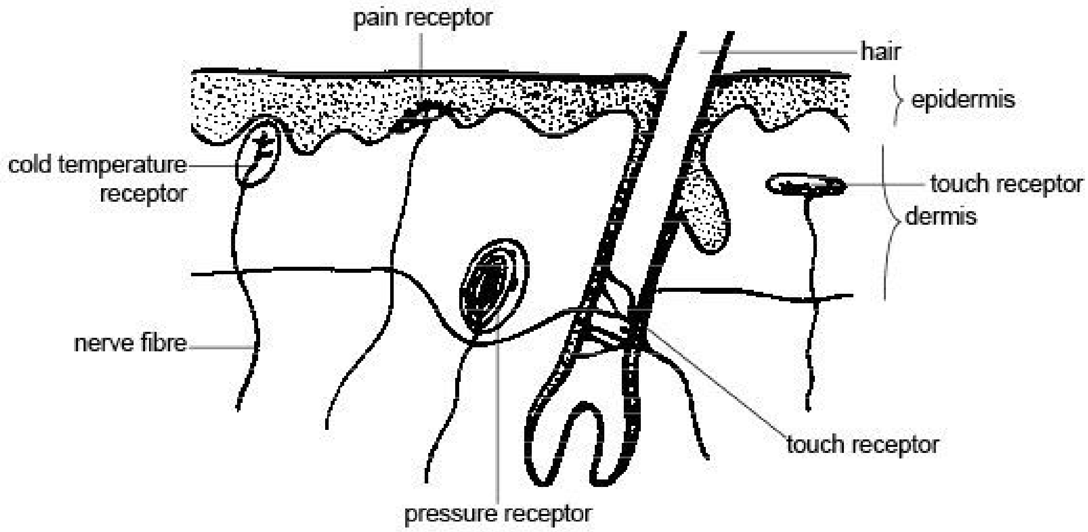

Figure 153

Diagram 15.1 - The general senses in the skin

15.5 Temperature

Nerve endings in the skin respond to hot and cold stimuli (See diagram 15.1).

15.6 Awareness Of Limb Position

There are sense organs in the muscles, tendons and joints that send continuous impulses to the brain that tell it where each limb is. This information allows the animal to place its limbs accurately and know their exact position without having to watch them.

15.7 Smell

Animals use the sense of smell to locate food, mark territory, identify their own offspring and the presence and sexual condition of a potential mate. The organ of smell (**olfactory organ**) is located in the nose and responds to chemicals in the air. It consists of modified nerve cells that have several tiny hairs on the surface. These emerge from the epithelium on the roof of the nose cavity into the mucus that lines it. As the animal breathes, chemicals in the air dissolve in the mucus. When the sense cell responds to a particular molecule, it fires an impulse that travels along the **olfactory nerve** to the brain where it is interpreted as an odour (see diagram 15.2).

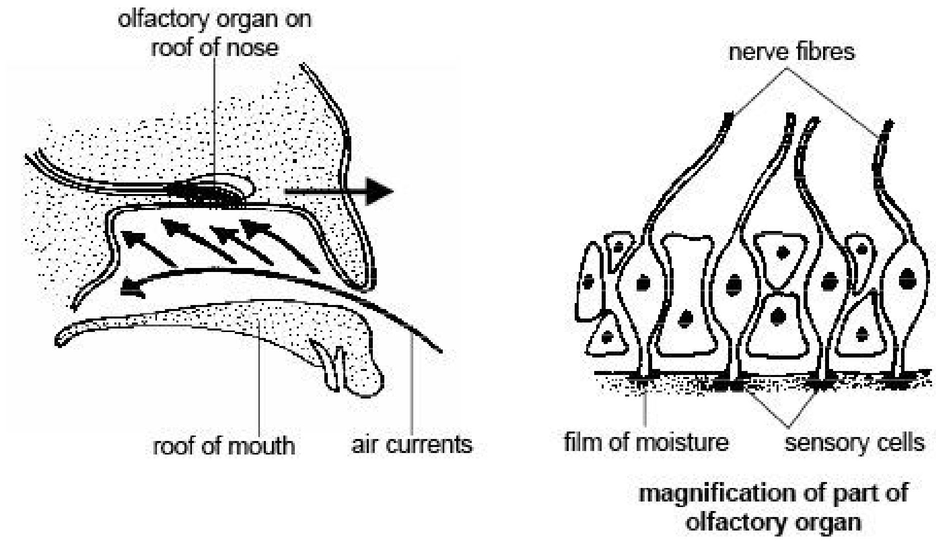

Figure 154

Diagram 15.2 - The olfactory organ - the sense of smell

The olfactory sense in humans is rudimentary compared to that of many animals. Carnivores that hunt have a very highly developed sensitivity to scents. For example a polar bear can smell out a dead seal 20 km away and a bloodhound can distinguish between the trails of different people although it may sometimes be confused by the criss-crossing trail of identical twins.

Snakes and lizards detect odours by means of **Jacobson's organ** . This is situated on the roof of the mouth and consists of pits containing sensory cells. When snakes flick out their forked tongues they are smelling the air by carrying the molecules in it to the Jacobson's organ.

15.8 Taste

The sense of taste allows animals to detect and identify dissolved chemicals. In reptiles, birds, and mammals the taste receptors (**taste buds**) are found mainly to the upper surface of the tongue. They consist of pits containing sensory cells arranged rather like the segments of an orange (see diagram 15.3). Each receptor cell has a tiny "hair" that projects into the saliva to sense the chemicals dissolved in it.

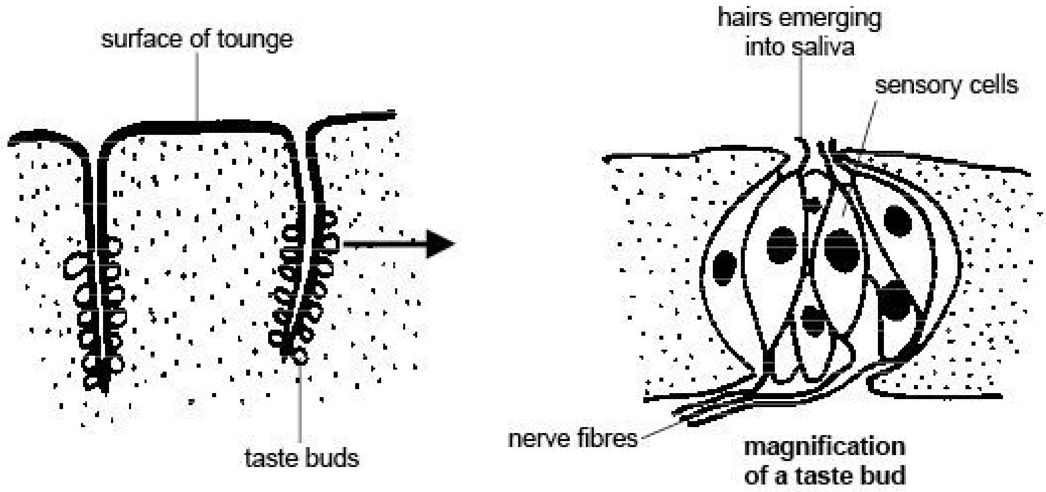

Figure 155

Diagram 15.3. Taste buds on the tongue

The sense of taste is quite restricted. Humans can only distinguish four different tastes (sweet, sour, bitter and salt) and what we normally think of as taste is mainly the sense of smell. Food is quite tasteless when the nose is blocked and cats often refuse to eat when this happens.

15.9 Sight

The eyes are the organs of sight. They consist of spherical **eyeballs** situated in deep depressions in the skull called the **orbits** . They are attached to the wall of the orbit by six muscles, which move the eyeball. Upper and lower **eyelids** cover the eyes during sleep and protect them from foreign objects or too much light, and spread the tears over their surface.

The **nictitating membrane** or **haw** is a transparent sheet that moves sideways across the eye from the inner corner, cleansing and moistening the cornea without shutting out the light. It is found in birds, crocodiles, frogs and fish as well as marsupials like the kangaroo. It is rare in mammals but can be seen in cats and dogs by gently opening the eye when it is asleep. **Eyelashes** also protect the eyes from the sun and foreign objects.

15.9.1 Structure of the Eye

Lining the eyelids and covering the front of the eyeball is a thin epithelium called the **conjunctiva** . Conjunctivitis is inflammation of this membrane. **Tear glands** that open just under the top eyelid secrete a salty solution that keeps the exposed part of the eye moist, washes away dust and contains an enzyme that destroys bacteria.

The wall of the eyeball is composed of three layers (see diagram 15.4). From the outside these are the **sclera** , the **choroid** and the **retina** .

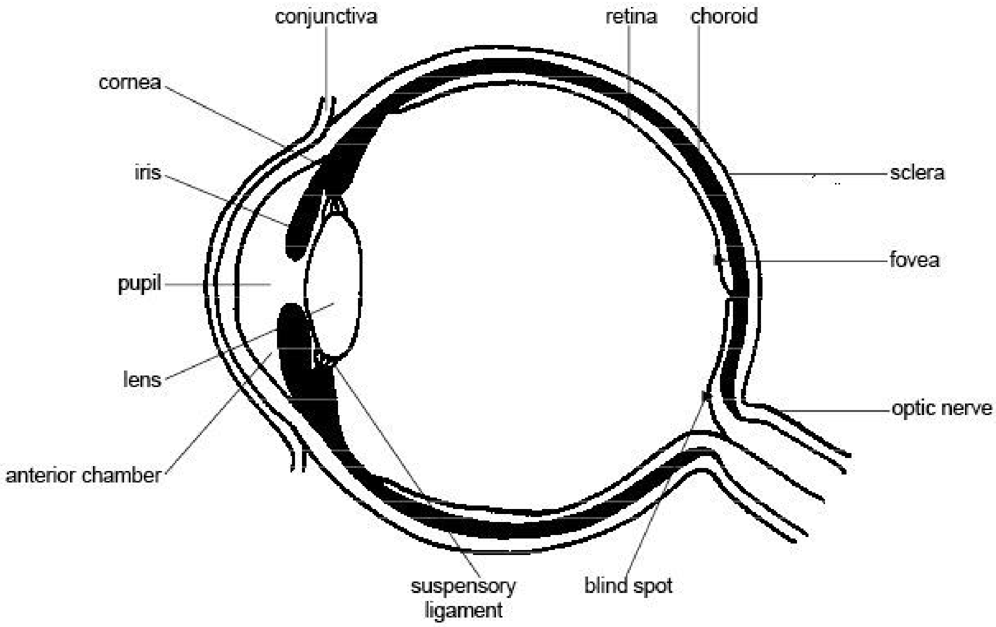

Figure 156

Diagram 15.4 - The structure of the eye

The **sclera** is a tough fibrous layer that protects the eyeball and gives it rigidity. At the front of the eye the sclera is visible as the "**white** " of the eye, which is modified as the transparent **cornea** through which the light rays have to pass to enter the eye. The cornea helps focus light that enters the eye.

The **choroid** lies beneath the sclera. It contains a network of blood vessels that supply the eye with oxygen and nutrients. Its inner surface is highly pigmented and absorbs stray light rays. In nocturnal animals like the cat and possum this highly pigmented layer reflects light as a means of conserving light. This is what makes them shine when caught in car headlights.

At the front of the eye the choroid becomes the **iris** . This is the coloured part of the eye that controls the amount of light entering the **pupil** of the eye. In dim light the pupil is wide open so as much light as possible enters while in bright light the pupils contract to protect the retina from damage by excess light.

The **pupil** in most animals is circular but in many nocturnal animals it is a slit that can close completely. This helps protect the extra-sensitive light sensing tissues of animals like the cat and possum from bright sunlight.

The inner layer lining the inside of the eye is the **retina** . This contains the light sensing cells called **rods** and **cones** (see diagram 15.5).

The **rod cells** are long and fat and are sensitive to dim light but cannot detect colour. They contain large amounts of a pigment that changes when exposed to light. This pigment comes from vitamin A found in carrots etc. A deficiency of this vitamin causes night blindness. So your mother was right when she told you to eat your carrots as they would help you see in the dark!

The **cone cells** provide colour vision and allow animals to see details. Most are found in the centre of the retina and they are most densely concentrated in a small area called the **fovea** . This is the area of sharpest vision, where the words you are reading at this moment are focussed on your retina.

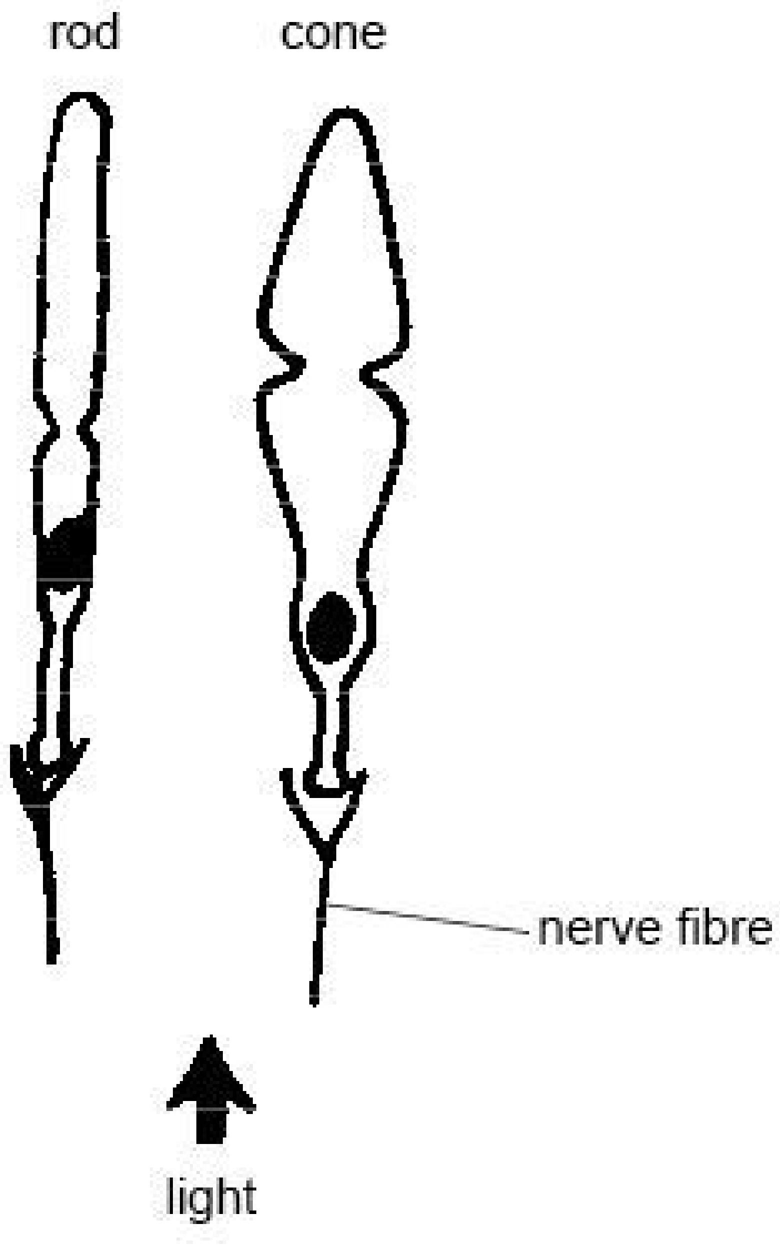

Figure 157

Diagram 15.5 - A rod and cone from the retina

The nerve fibres from the cells of the retina join and leave the eye via the **optic nerve** . There are no rods or cones here and it is a **blind spot** . The optic nerve passes through the back of the orbit and enters the brain.

The **lens** is situated just behind the pupil and the iris. It is a crystalline structure with no blood vessels and is held in position by a ligament. This is attached to a muscle, which changes the shape of the lens so both near and distant objects can be focussed by the eye. This ability to change the focus of the lens is called **accommodation** . In many mammals the muscles that bring about accommodation are poorly developed, Rats, cows and dogs, for example, are thought to be unable to focus clearly on near objects.

In old age and certain diseases the lens may become cloudy resulting in blurred vision. This is called a **cataract** . Within the eyeball are two cavities, the **anterior and posterior chambers** , separated by the lens. They contain fluids the **aqueous and vitreous humours** respectively, that maintain the shape of the eyeball and help press the retina firmly against the choroid so clear images are seen.

15.9.2 How The Eye Sees

Eyes work quite like a camera. Light rays from an object enter the eye and are focused on the retina (the "film") at the back of the eye. The cornea, the lens and the fluid within the eye all help to focus the light. They do this by bending the light rays so that light from the object falls on the retina. This bending of light is called **refraction** . The light stimulates the light sensitive cells of the retina and nerve impulses are produced that pass down the optic nerve to the brain (see diagram 15.6).

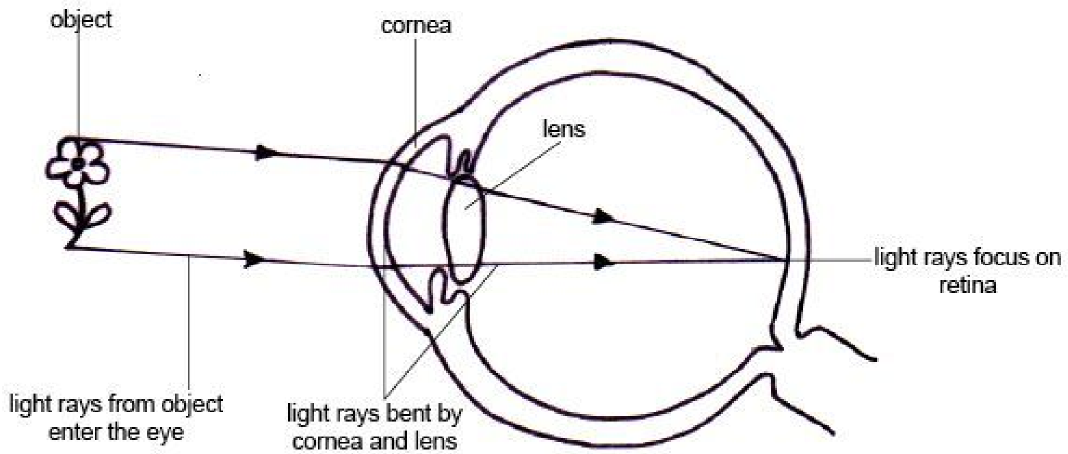

Figure 158

Diagram 15.6 - How the light travels from the object to the retina of the eye

15.9.3 Colour Vision In Animals

As mentioned before, the retina has two different kinds of cells that are stimulated by light - rods and cones . In humans and higher primates like baboons and gorillas the rods function in dim light and do not perceive colour, while the cones are stimulated by bright light and perceive details and colour.

Other mammals have very few cones in their retinas and it is believed that they see no or only a limited range of colour. It is, of course, difficult to find out exactly what animals do see. It is thought that deer, rats, and rabbits and nocturnal animals like the cat are colour-blind, and dogs probably see green and blue. Some fish and most birds seem to have better colour vision than humans and they use colour, often very vivid ones, for recognizing each other as well as for courtship and protection.

15.9.4 Binocular Vision

Animals like cats that hunt have eyes placed on the front of the head in such a way that both eyes see the same wide area but from slightly different angles (see diagram 15.7). This is called binocular vision**. Its main advantage is that it enables the animals to estimate the distance to the prey so they can chase it and pounce accurately.**

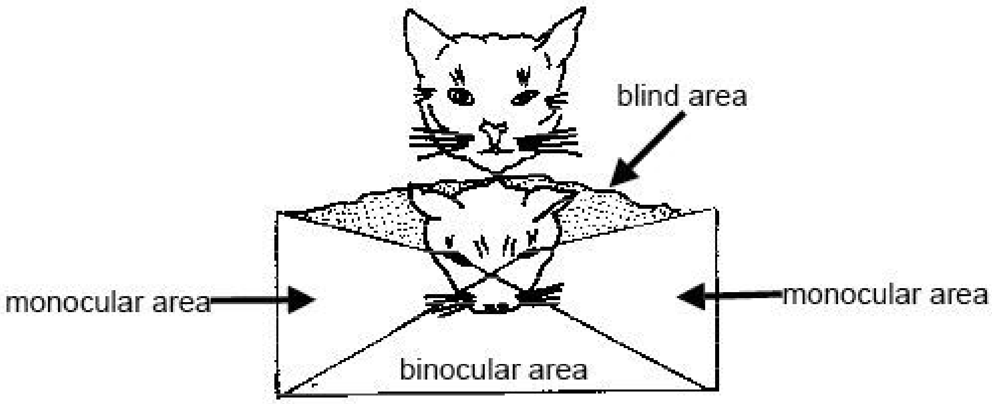

Figure 159

Diagram 15.7 - Well developed binocular vision in predator animals like the cat

In contrast plant-eating prey animals like the rabbit and deer need to have a wide panoramic view so they can see predators approaching. They therefore have eyes placed on the side of the head, each with its own field of vision (see diagram 15.8). They have only a very small area of binocular vision in front of the head but are extremely sensitive to movement.

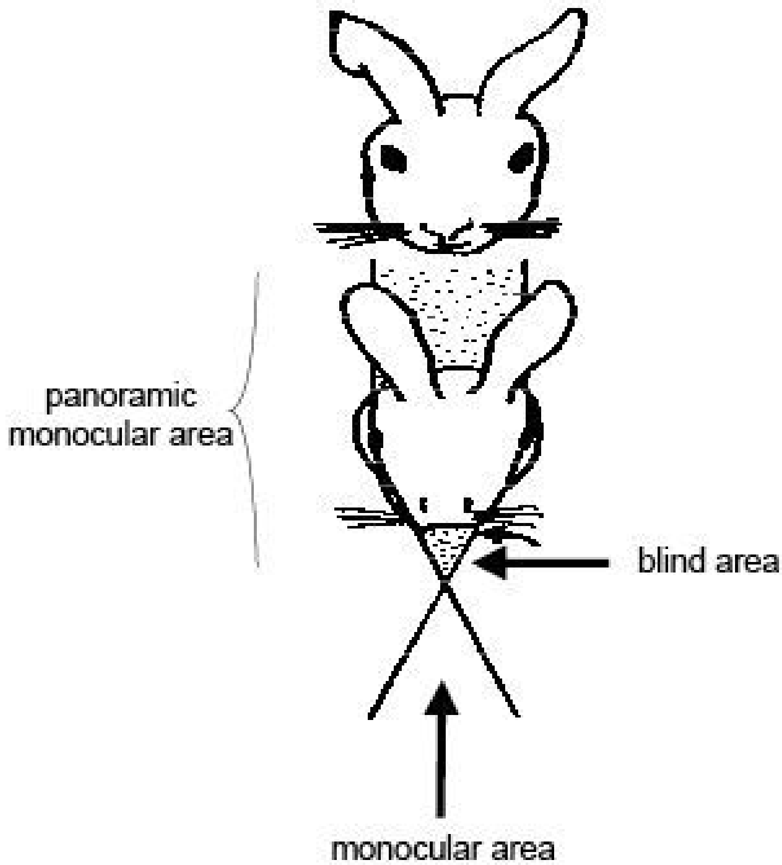

Figure 160

Diagram 15.8 - Panoramic monocular vision in prey animals like the rabbit

15.10 Hearing

Animals use the sense of hearing for many different purposes. It is used to sense danger and enemies, to detect prey, to identify prospective mates and to communicate within social groups. Some animals (e.g. most bats and dolphins) use sound to “see” by echolocation. By sending out a cry and interpreting the echo, they sense obstacles or potential prey.

15.10.1 Structure of the Ear

Most of the ear, the organ of hearing, is hidden from view within the boney skull. It consists of three main regions: the **outer ear, the middle ear** and the **inner ear** (see diagram 15.9).

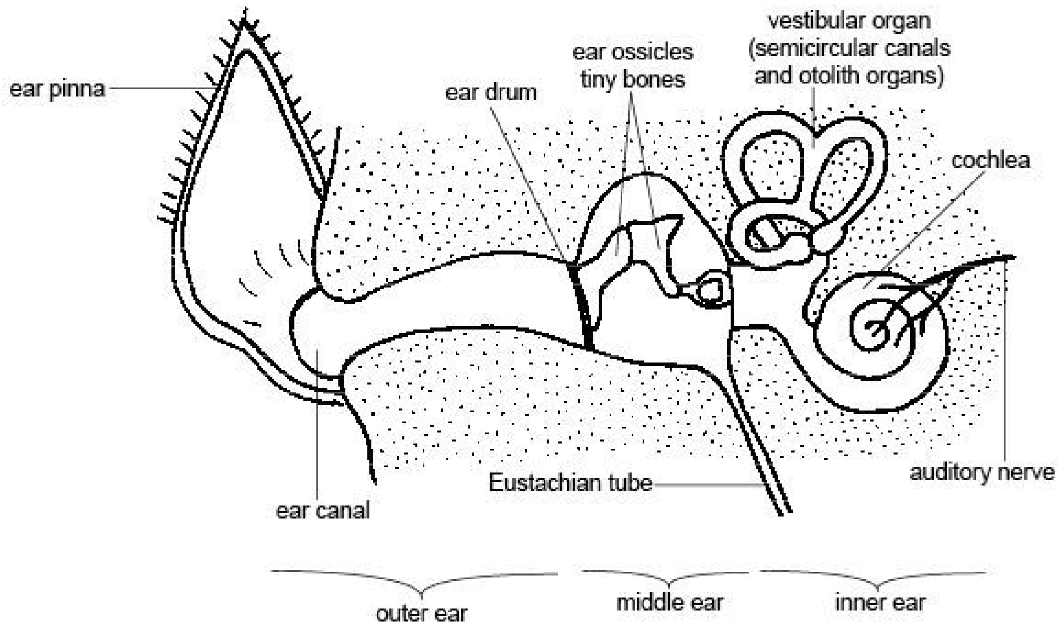

Figure 161

Diagram 15.9 - The ear

The **outer ear** consists of an **ear canal** leading inwards to a thin membrane known as the **eardrum** or **tympanic membrane** that stretches across the canal. Many animals have an external ear flap or **pinna** to collect and funnel the sound into the ear canal. The pinnae (plural of pinna) usually face forwards on the head but many animals can swivel them towards the source of the sound.

In dogs the ear canal is long and bent and often traps wax or provides an ideal habitat for mites, yeast and bacteria.

The **middle ear** consists of a cavity in the skull that is connected to the **pharynx** (throat) by a long narrow tube called the **Eustachian tube** . This links the middle ear to the outside air so that the air pressure on both sides of the eardrum can be kept the same. Everyone knows the uncomfortable feeling (and affected hearing) that occurs when you drive down a steep hill and the unequal air pressures on the two sides of the eardrum cause it to distort. The discomfort is relieved when you swallow because the Eustachian tubes open and the pressure on either side equalises.

Within the cavity of the middle ear are three of the smallest bones in the body, the **auditory ossicles** . They are known as the hammer, the anvil and the stirrup because of their resemblance to the shape of these objects. These tiny bones articulate (move against) each other and transfer the vibrations of the eardrum to the membrane covering the opening to the inner ear.

The **inner ear** is a complicated series of fluid-filled tubes imbedded in the bone of the skull. It consists of two main parts. These are the **cochlea** where sound waves are converted to nerve impulses and the **vestibular organ** that is associated with the sense of balance and has no role in hearing (see later).

The **cochlea** looks rather like a coiled up snail shell. Within it there are specialised cells with fine hairs on their surface that respond to the movement of the fluid within the cochlea by producing nervous impulses that travel to the brain along the **auditory nerve** .

15.10.2 How The Ear Hears

Sound waves can be thought of as vibrations in the air. They are collected by the ear pinna and pass down the ear canal where they cause the eardrum to vibrate. (An interesting fact is that when you are listening to someone speaking your eardrum vibrates at exactly the same rate as the vocal cords of the person speaking to you).

The vibration of the eardrum sets the three tiny bones in the middle ear moving against each other so that the vibration is transferred to the membrane covering the opening to the inner ear. As well as transferring the vibration, the tiny ear bones also amplify it. The three tiny bones are called the stirrup, anvil, and hammer. They were called such of their form. In the human ear this amplification is about 20 times while in desert-dwelling animals like the kangaroo rat it is 100 times. This acute hearing warns them of the approach of predators like owls and snakes, even in the dark.

The vibration causes waves in the fluid in the inner ear that pass down the cochlea. These waves stimulate the tiny hair cells to produce nerve impulses that travel via the auditory nerve to the cerebral cortex of the brain where they are interpreted as sound.

To summarise: The route sound waves take as they pass through the ear is: **External ear | tympanic membrane | ear ossicles | inner ear |cochlear | hair cells**

The hair cells generate a nerve impulse that travels down the auditory nerve to the brain.

Remember that sound waves do not pass along the Eustachian tube. Its function is to equalise the air pressure on either side of the tympanic membrane.

15.11 Balance

The **vestibular organ** of the inner ear helps an animal maintain its posture and keep balanced by monitoring the movement and position of the head. It consists of two structures - the **semicircular canals** and the **otolith organs** .

The **semicircular canals** (see diagram 15.10) respond to movement of the body. They tell an animal whether it is moving up or down, left or right. They consist of three canals set in three different planes at right angles to each other so that movement in any direction can be registered. The canals contain fluid and sense cells with fine hairs that project into the fluid. When the head moves the fluid swirls in the canals and stimulates the hair cells. These send nerve impulses along the **vestibular nerve** to the **cerebellum** .

Note that the semicircular canals register acceleration and deceleration as well as changes in direction but do not respond to movement that is at a constant speed.

The **otolith organs** are sometimes known as gravity receptors. They tell you if your head is tilted or if you are standing on your head. They consist of bulges at the base of the semi circular canals that contain hair cells that are covered by a mass of jelly containing tiny pieces of chalk called **otoliths** (see diagram 15.10). When the head is tilted, or moved suddenly, the otoliths pull on the hair cells, which produce a nerve impulse. This travels down the **vestibular nerve** to the **cerebellum** . By coordinating the nerve impulses from the semicircular canals and otolith organs the cerebellum helps the animal keep its balance.

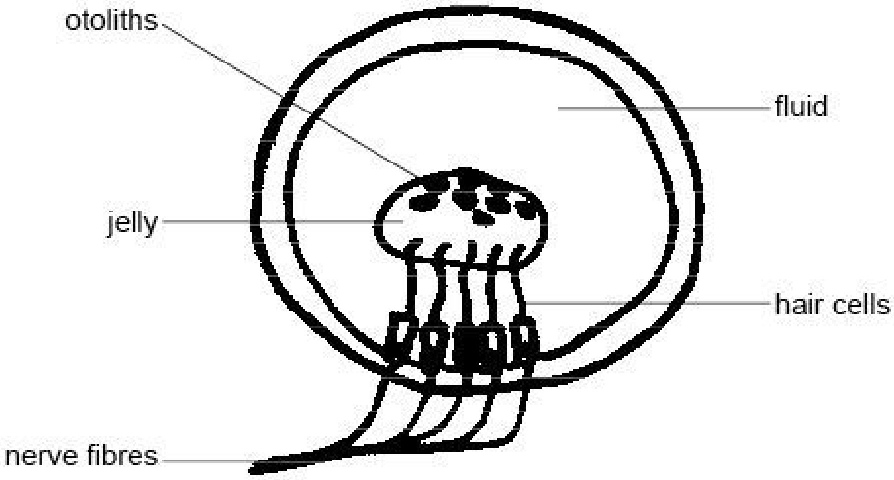

Figure 162

Diagram 15.10 - Otolith Organs

15.12 Summary

- Receptors for touch, pressure, pain and temperature are found in the skin. Receptors in the muscles, tendons and joints inform the brain of limb position.
- The **olfactory organ** in the nose responds to chemicals in the air i.e. smell.
- **Taste buds** on the tongue respond to a limited range of chemicals dissolved in saliva.
- The eyes are the organs of sight. Spherical **eyeballs** situated in orbits in the skull have walls composed of 3 layers.
- The tough outer **sclera** protects and holds the shape of the eyeball. At the front it becomes visible as the white of the eye and the transparent **cornea** that allows light to enter the eye.
- The middle layer is the **choroid** . It most animals it absorbs stray light rays but in nocturnal animal it is reflective to conserve light. At the front of the eye it becomes the **iris** with muscles to control the size of the **pupil** and hence the amount of light entering the eye.
- The inner layer is the **retina** containing the light receptor cells: the **rods** for black and white vision in dim light and the **cones** for colour and detailed vision. Nerve impulses generated by these cells leave the eye for the brain via the **optic nerve** .
- The **lens** (with the cornea) helps focus the light rays on the retina. Muscles alter the shape of the lens to allow near and far objects to be focussed.

- **Aqueous humour** fills the space immediately behind the cornea and keeps it in shape and **vitreous humour** , a transparent jelly-like substance, fills the space behind the lens allowing light rays to pass through to the retina.
- The ear is the organ of hearing and balance.
- The external **pinna** helps funnel sound waves into the ear and locate the direction of the sound. The sound waves travel down the external **ear canal** to the **eardrum** or **tympanic membrane** causing it to vibrate. This vibration is transferred to the **auditory ossicles** of the middle ear which themselves transfer it to the inner ear. Here receptors in the **cochlea** respond by generating nerve impulses that travel to the brain via the **auditory** (acoustic) nerve.
- The **Eustachian tube** connects the middle ear with the pharynx to equalise air pressure on either side of the tympanic membrane.
- The **vestibular organ** of the inner ear is concerned with maintaining balance and posture. It consists of the **semicircular canals** and the **otolith organs** .

15.13 Worksheet

Senses Worksheet[1]

15.14 Test Yourself

1. Where are the organs that sense pain, pressure and temperature found?
2. Which sense organ responds to chemicals in the air?
3. Match the words in the list below with the following descriptions.

optic nerve | choroid | cornea | aqueous humor | retina | cones | iris | vitreous humour | sclera | lens

a) Focuses light rays on the retina.

b) Respond to colour and detail.

c) Outer coat of the eyeball.

d) Carries nerve impulses from the retina to the brain.

e) The chamber behind the lens is filled with this.

f) This layer of the eyeball reflects light in nocturnal animals like the cat.

g) This is the transparent window at the front of the eye.

h) This constricts in bright light to reduce the amount of light entering the eye.

i) The light rays are focused on here by the lens and cornea.

j) The chamber in front of the lens is filled with this.

1 http://www.wikieducator.org/Special_Senses_Worksheet

4. Add the following labels to the diagram of the ear below.

pinna | Eustachian tube | cochlea | tympanic membrane | external ear canal | ear ossicles | semicircular canals

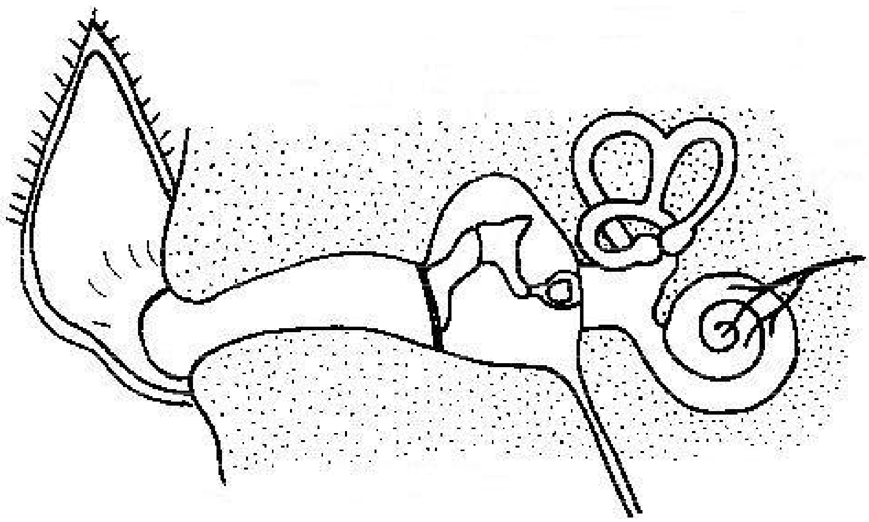

Figure 163

5. What is the role of the Eustachian tube?
6. What do the ear ossicles do?
7. What is the role of the semicircular canals?

/Senses Test Yourself Answers/[2]

15.15 Websites

- `http://en.wikipedia.org/wiki/Sense` Wikipedia. The old faithful. You can explore here to your hearts desire. Try 'eye', 'ear', 'taste' etc. but also 'equilibrioception', and 'echolocation'.
- `http://www.bbc.co.uk/science/humanbody/body/factfiles/smell/smell_ani_f5.swf` BBC Science and Nature. BBC animation of (human) olfactory organ and smelling.
- `http://www.bbc.co.uk/science/humanbody/body/factfiles/taste/taste_ani_f5.swf` BBC Science. BBC animation of (human) taste buds and tasting.
- `http://web.archive.org/web/20071121213719/http://www.bishopstopford.com/faculties/science/arthur/Eye%20Drag%20%26%20Drop.swf` Eye Diagram. A diagram of the eye to label and test your knowledge.

2 https://en.wikibooks.org/wiki/%2FSenses%20Test%20Yourself%20Answers%2F

- http://www.bbc.co.uk/science/humanbody/body/factfiles/hearing/hearing_animation.shtml BBC on Hearing. BBC animation of hearing. Well worth looking at.
- http://www.wisc-online.com/objects/index_tj.asp?objid=AP1502 Ear Animation. Another great animation of the ear and hearing.
- http://www.bbc.co.uk/science/humanbody/body/factfiles/balance/balance_ani_f5.swf BBC Balance Animation. An animation of the action of the otolith organ (called macula in this animation)

15.16 Glossary

- Link to Glossary[3]

Senses[4]

3 http://en.wikibooks.org/wiki/Anatomy_and_Physiology_of_Animals/Glossary
4 https://en.wikibooks.org/wiki/Category%3A

16 Endocrine System

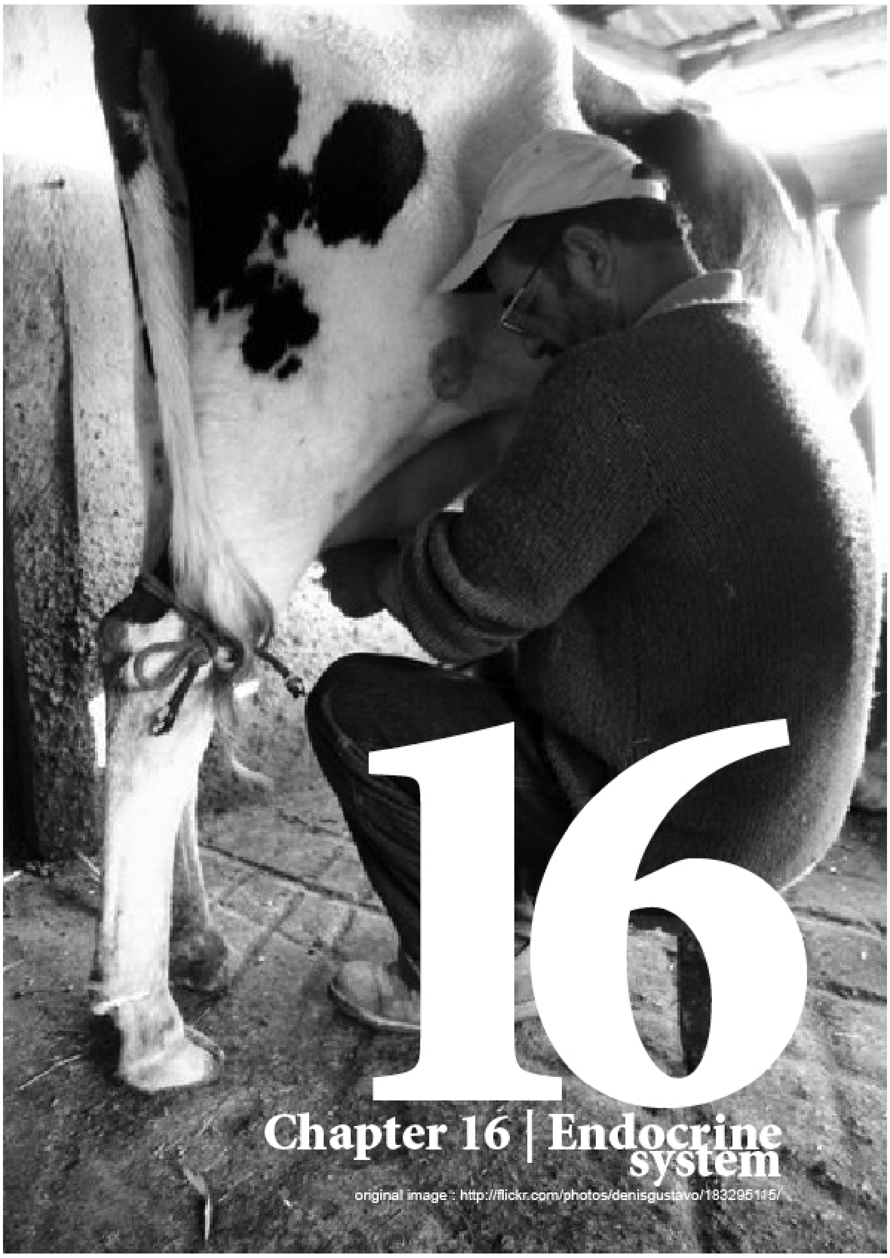

Figure 164 original image by Denis Gustavo[a] cc by

a http://flickr.com/photos/denisgustavo/183295115/

16.1 Objectives

After completing this section, you should know:

- The characteristics of endocrine glands and hormones
- The position of the main endocrine glands in the body
- The relationship between the pituitary gland and the hypothalamus
- The main hormones produced by the two parts of the pituitary gland and their effects on the body
- The main hormones produced by the pineal, thyroid, parathyroid and adrenal glands, the pancreas, ovary and testis and their effects on the body
- What is meant by homeostasis and feedback control
- The homeostatic mechanisms that allow an animal to control its body temperature, water balance, blood volume and acid/base balance

16.2 The Endocrine System

In order to survive, animals must constantly adapt to changes in the environment. The **nervous** and **endocrine systems** both work together to bring about this adaptation. In general the nervous system responds rapidly to short-term changes by sending electrical impulses along nerves and the endocrine system brings about longer-term adaptations by sending out chemical messengers called hormones into the blood stream.

For example, think about what happens when a male and female cat meet under your bedroom window at night. The initial response of both cats may include spitting, fighting and spine tingling yowling - all brought about by the nervous system. Fear and stress then activates the adrenal glands to secrete the hormone **adrenaline** which increases the heart and respiratory rates. If mating occurs, other hormones stimulate the release of ova from the ovary of the female and a range of different hormones maintains pregnancy, delivery of the kittens and lactation.

16.3 Endocrine Glands And Hormones

Hormones are chemicals that are secreted by **endocrine glands** . Unlike exocrine glands (see chapter 5), endocrine glands have no ducts, but release their secretions directly into the blood system, which carries them throughout the body. However, hormones only affect the specific **target organs** that recognize them. For example, although it is carried to virtually every cell in the body, **follicle stimulating hormone** (FSH), released from the **anterior pituitary gland** , only acts on the follicle cells of the ovaries causing them to develop.

A nerve impulse travels rapidly and produces an almost instantaneous response but one that lasts only briefly. In contrast, hormones act more slowly and their effects may be long lasting. Target cells respond to minute quantities of hormones and the concentration in the blood is always extremely low. However, target cells are sensitive to subtle changes in hormone concentration and the endocrine system regulates processes by changing the rate of hormone secretion.

The main endocrine glands in the body are the **pituitary, pineal, thyroid, parathyroid** , and **adrenal glands** , the **pancreas, ovaries** and **testes** . Their positions in the body are shown in diagram 16.1.

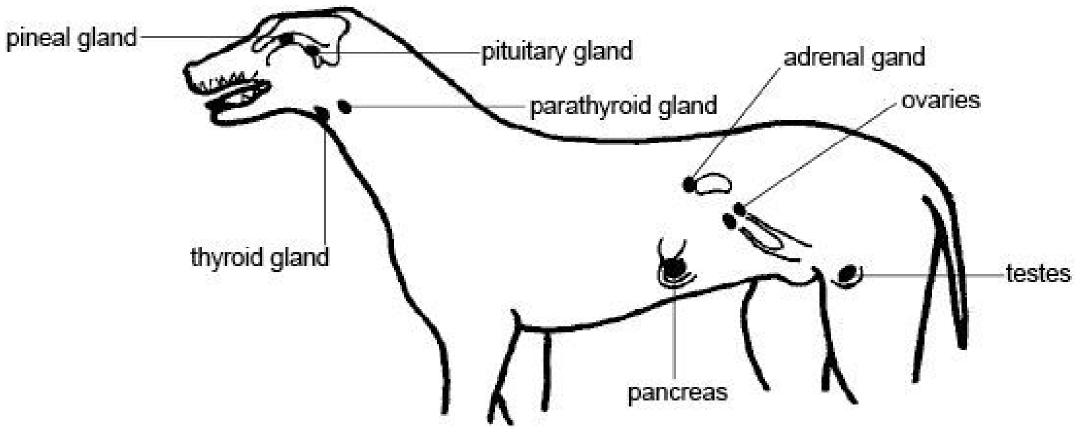

Figure 165

Diagram 16.1 - The main endocrine organs of the body

16.4 The Pituitary Gland And Hypothalamus

The **pituitary gland** is a pea-sized structure that is attached by a stalk to the underside of the cerebrum of the brain (see diagram 16.2). It is often called the "master" endocrine gland because it controls many of the other endocrine glands in the body. However, we now know that the pituitary gland is itself controlled by the **hypothalamus** . This small but vital region of the brain lies just above the pituitary and provides the link between the nervous and endocrine systems. It controls the **autonomic nervous system** , produces a range of hormones and regulates the secretion of many others from the pituitary gland (see Chapter 7 for more information on the hypothalamus).

The pituitary gland is divided into two parts with different functions - the **anterior** and **posterior pituitary** (see diagram 16.3).

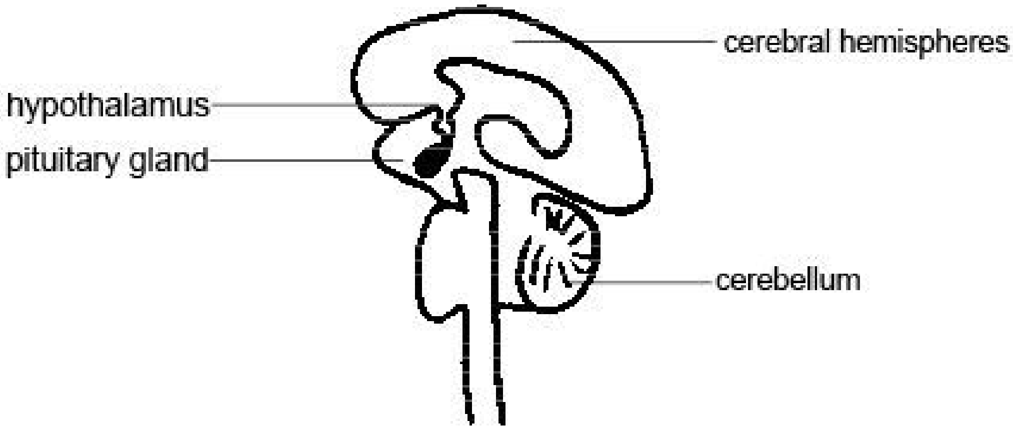

Figure 166

Diagram 16.2 - The position of the pituitary gland and hypothalamus

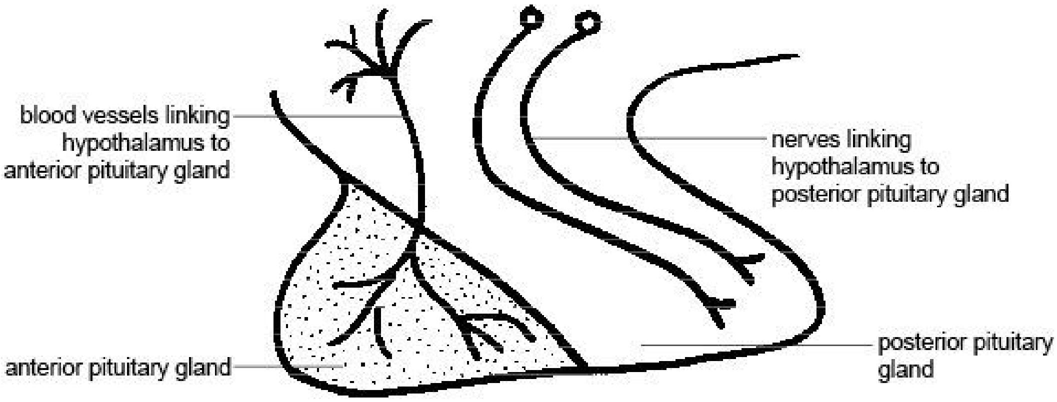

Figure 167

Diagram 16.3 - The anterior and posterior pituitary

The **anterior pituitary gland** secretes hormones that regulate a wide range of activities in the body. These include:

1. **Growth hormone** that stimulates body growth.
2. **Prolactin** that initiates milk production.
3. **Follicle stimulating hormone (FSH**) that stimulates the development of the **follicles** of the ovaries. These then secrete **oestrogen** (see chapter 6).
4. **melanocyte stimulating hormone (MSH**) that causes darkening of skin by producing melanin
5. **lutenizing hormone (LH**) that stimulates ovulation and production of progesterone and testosterone

16.5 The Pineal Gland

The **pineal gland** is found deep within the brain (see diagram 16.4). It is sometimes known as the 'third eye" as it responds to light and day length. It produces the hormone **melatonin** , which influences the development of sexual maturity and the seasonality of breeding and hibernation. **bright light inhibits melatonin secretion** low level of melatonin in bright light makes one feel good and these increases fertility High level of melatonin in deam light makes an animal tired and depressed therefore low fertility in animals

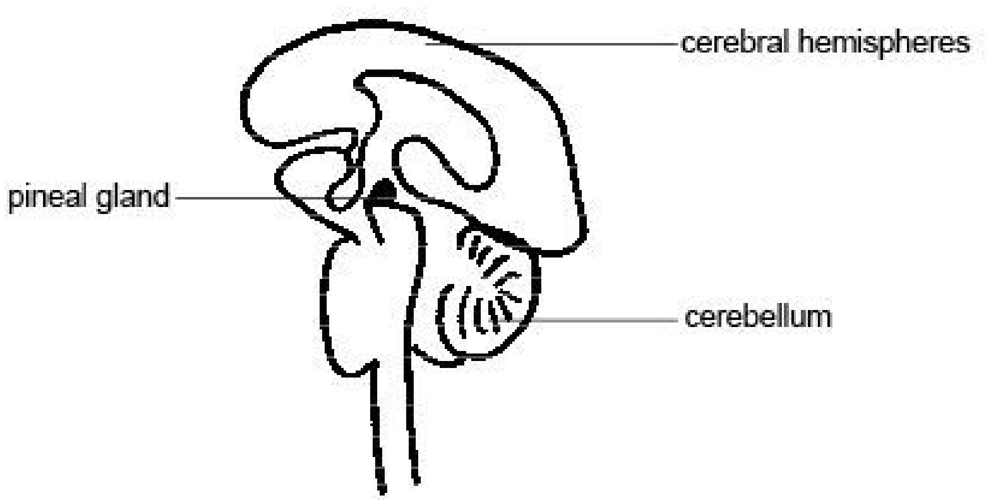

Figure 168

Diagram 16.4 - The pineal gland

16.6 The Thyroid Gland

The **thyroid gland** is situated in the neck, just in front of the windpipe or trachea (see diagram 16.5). It produces the hormone **thyroxine** , which influences the rate of growth and development of young animals. In mature animals it increases the rate of chemical reactions in the body.

Thyroxine consists of 60% **iodine** and too little in the diet can cause **goitre** , an enlargement of the thyroid gland. Many inland soils in New Zealand contain almost no iodine so goitre can be common in stock when iodine supplements are not given. To add to the problem, chemicals called **goitrogens** that occur naturally in plants like kale that belong to the **cabbage family** , can also cause goitre even when there is adequate iodine available.

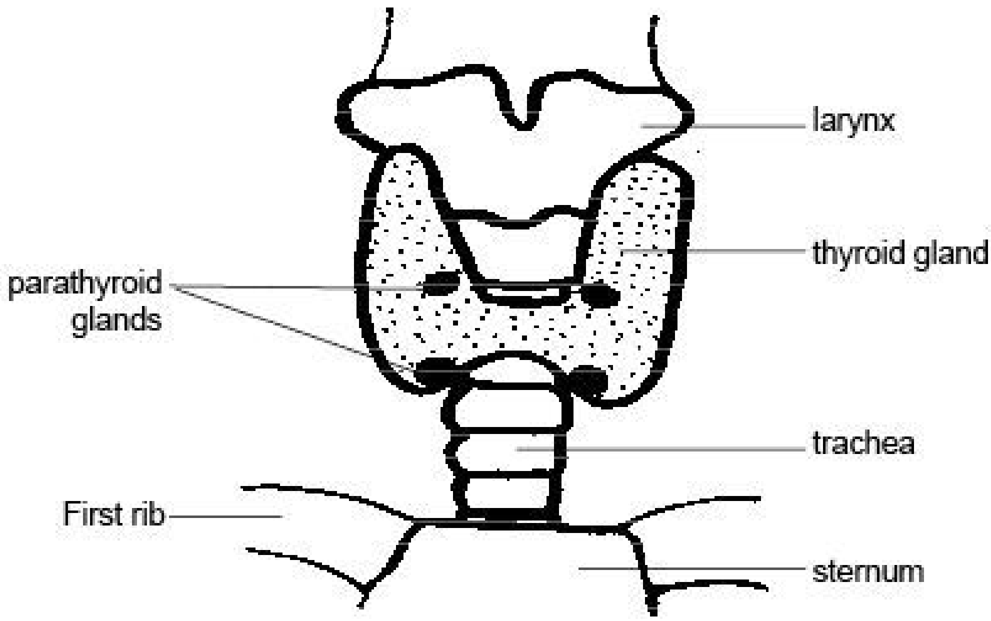

Figure 169

Diagram 16.5 - The thyroid and parathyroid glands

16.7 The Parathyroid Glands

The **parathyroid glands** are also found in the neck just behind the thyroid glands (see diagram 16.5). They produce the hormone **parathormone** that regulates the amount of **calcium** in the blood and influences the excretion of **phosphates** in the urine.

16.8 The Adrenal Gland

The **adrenal glands** are situated on the cranial surface of the kidneys (see diagram 16.6). There are two parts to this endocrine gland, an outer **cortex** and an inner **medulla** .

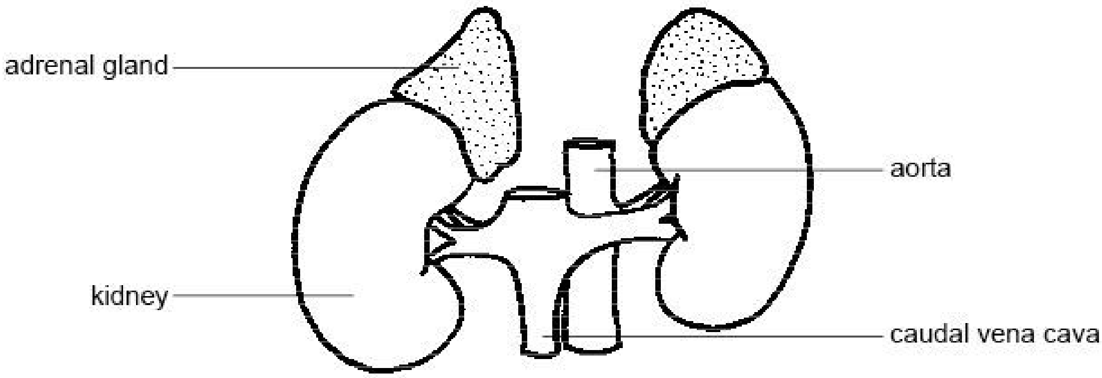

Figure 170

Diagram 16.6 - The adrenal glands

The **adrenal cortex** produces several hormones. These include:

1. **Aldosterone** that regulates the concentration of **sodium and potassium** in the blood by controlling the amounts that are secreted or reabsorbed in the kidney tubules.

2. **Cortisone** and **hydrocortisone** (cortisol) that have complex effects on glucose, protein and fat metabolism. In general they increase metabolism. They are also often administered to animals to counteract allergies and for treating arthritic and rheumatic conditions. However, prolonged use should be avoided if possible as they can increase weight and reduce the ability to heal.

3. **Male and female sex hormones** similar to those secreted by the ovaries and testes.

The hormones secreted by the adrenal cortex also play a part in "**general adaptation syndrome** " which occurs in situations of prolonged stress.

The **adrenal medulla** secretes **adrenalin** (also called **epinephrine**). Adrenalin is responsible for the so-called flight fight, fright response that prepares the animal for emergencies. Faced with a perilous situation the animal needs to either fight or make a rapid escape. To do either requires instant energy, particularly in the skeletal muscles. Adrenaline increases the amount of blood reaching them by causing their blood vessels to dilate and the heart to beat faster. An increased rate of breathing increases the amount of oxygen in the blood and glucose is released from the liver to provide the fuel for energy production. Sweating increases to keep the muscles cool and the pupils of the eye dilate so the animal has a wide field of view. Functions like digestion and urine production that are not critical to immediate survival slow down as blood vessels to these parts constrict.

Note that the effects of adrenalin are similar to those of the sympathetic nervous system.

16.9 The Pancreas

In most animals the **pancreas** is an oblong, pinkish organ that lies in the first bend of the small intestine (see diagram 16.7). In rodents and rabbits, however, it is spread thinly through the mesentery and is sometimes difficult to see.

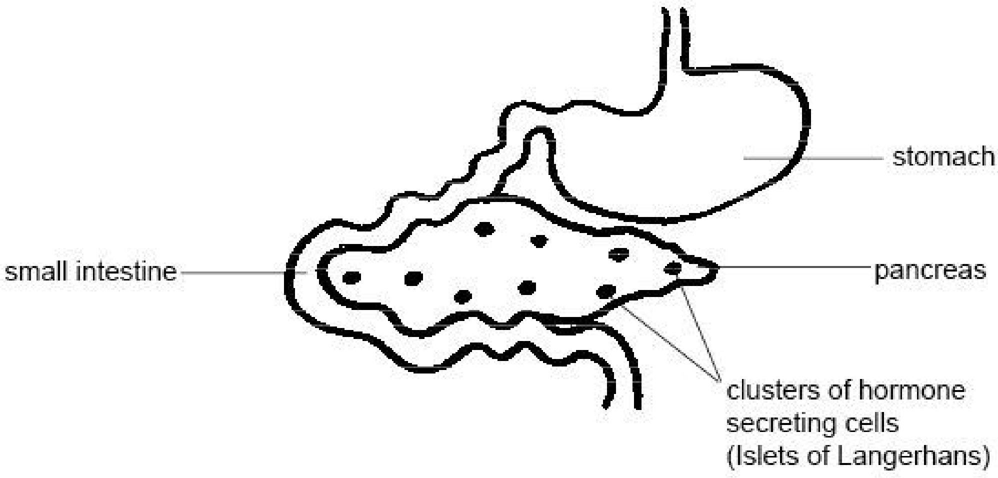

Figure 171

Diagram 16.7 - The pancreas

Most of the pancreas acts as an **exocrine gland** producing digestive enzymes that are secreted into the small intestine. The endocrine part of the organ consists of small clusters of cells (called **Islets of Langerhans**) that secrete the hormone **insulin** . This hormone regulates the amount of **glucose** in the blood by increasing the rate at which glucose is converted to glycogen in the liver and the movement of glucose from the blood into cells.

In **diabetes mellitus** the pancreas produces insufficient insulin and glucose levels in the blood can increase to a dangerous level. A major symptom of this condition is glucose in the urine.

16.10 The Ovaries

The ovaries, located in the lower abdomen, produce two important sex hormones.

1. The **follicle cells** , under the influence of **FSH** (see the pituitary gland above), produce **oestrogen** , which stimulates the development of female sexual characteristics - the mammary glands, generally smaller build of female animals etc. It also stimulates the thickening of the lining of the uterus in preparation for pregnancy (see chapter 13).

2. **Progesterone** is produced by the **corpus luteum** , the endocrine gland that develops in the empty follicle following ovulation (see chapter 13). It promotes the further preparation of the uterine lining for pregnancy and prevents the uterus contracting until the baby is born.

16.11 The Testes

Cells around the sperm producing ducts of the testis produce the hormone **testosterone** . This stimulates the development of the male reproductive system and the male sexual characteristics - generally larger body of male animals, mane in lions, tusks in boars, etc

16.12 Summary

- **Hormones** are chemicals that are released into the blood by **endocrine glands** i.e. Glands with no ducts. Hormones act on specific **target organs** that recognize them.
- The main endocrine glands in the body are the **hypothalamus, pituitary, pineal, thyroid, parathyroid** and **adrenal glands,** the **pancreas, ovaries** and **testes** .
- The **hypothalamus** is situated under the **cerebrum** of the brain. It produces or controls many of the hormones released by the pituitary gland lying adjacent to it.
- The **pituitary gland** is divided into two parts: the **anterior pituitary** and the **posterior pituitary** .
- The **anterior pituitary** produces:
  - **Growth hormone** that stimulates body growth
  - **Prolactin** that initiates milk production
  - **Follicle stimulating hormone** (**FSH**) that stimulates the development of **ova**
  - **Luteinising hormone (LH**) that stimulates the development of the **corpus luteum**
  - Plus several other hormones
- The **posterior pituitary** releases:
  - **Antidiuretic hormone** (ADH) that regulates **water loss** and raises **blood pressure**
  - **Oxytocin** that stimulates milk "let down".
- The **pineal gland** in the brain produces **melatonin** that influences **sexual development** and **breeding cycles** .
- The **thyroid gland** located in the neck, produces thyroxine, which influences the **rate of growth** and **development** of young animals. Thyroxine consists of 60% **iodine** . Lack of iodine leads to **goitre** .
- The **parathyroid glands** situated adjacent to the thyroid glands in the neck produce **parathormone** that regulates blood **calcium** levels and the excretion of **phosphates** .
- The **adrenal gland** located adjacent to the kidneys is divided into the outer **cortex** and the inner **medulla** .
- The **adrenal cortex** produces:
  - **Aldosterone** that regulates the blood concentration of **sodium and potassium**
  - **Cortisone** and **hydrocortisone** that affect **glucose, protein** and **fat** metabolism
  - Male and female **sex hormones**
- The **adrenal medulla** produces **adrenalin** responsible for the **flight, fright, fight** response that prepares animals for emergencies.
- The **pancreas** that lies in the first bend of the small intestine produces**insulin** that regulates blood **glucose** levels.
- The **ovaries** are located in the lower abdomen produce 2 important sex hormones:

  - The **follicle cells** of the developing ova produce **oestrogen** , which controls the development of the **mammary glands** and prepares the uterus for pregnancy.
  - The **corpus luteum** that develops in the empty **follicle** after ovulation produces **progesterone** . This hormone further prepares the **uterus** for pregnancy and maintains the pregnancy.
- The **testes** produce **testosterone** that stimulates the development of the **male reproductive system** and **sexual characteristics** .

16.13 Homeostasis and Feedback Control

Animals can only survive if the environment within their bodies and their cells is kept constant and independent of the changing conditions in the external environment. As mentioned in module 1.6, the process by which this stability is maintained is called homeostasis. The body achieves this stability by constantly monitoring the internal conditions and if they deviate from the norm initiating processes that bring them back to it. This mechanism is called feedback control. For example, to maintain a constant body temperature the hypothalamus monitors the blood temperature and initiates processes that increase or decrease heat production by the body and loss from the skin so the optimum temperature is always maintained. The processes involved in the control of body temperature, water balance, blood loss and acid/base balance are summarized below.

16.14 Summary of Homeostatic Mechanisms

16.14.1 1. Temperature control

The biochemical and physiological processes in the cell are sensitive to temperature. The optimum body temperature is about 37°C [99°F] for mammals, and about 40°C [104°F] for birds. Biochemical processes in the cells, particularly in muscles and the liver, produce heat. The heat is distributed through the body by the blood and is lost mainly through the skin surface. The production of this heat and its loss through the skin is controlled by the hypothalamus in the brain which acts rather like a thermostat on an electric heater. .

(a) When the body temperature rises above the optimum, a decrease in temperature is achieved by:

- Sweating and panting to increase heat loss by evaporation.
- Expansion of the blood vessels near the skin surface so heat is lost to the air.
- Reducing muscle exertion to the minimum.

(b) When the body temperature falls below the optimum, an increase in temperature can be achieved by:

- Moving to a heat source e.g. in the sun, out of the wind.
- Increasing muscular activity

- Shivering
- Making the hair stand on end by contraction of the hair erector muscles or fluffing of the feathers so there is an insulating layer of air around the body
- Constricting the blood vessels near the skin surface so heat loss to the air is decreased

16.14.2 2. Water balance

The concentration of the body fluids remains relatively constant irrespective of the diet or the quantity of water taken into the body by the animal. Water is lost from the body by many routes (see module 1.6) but the kidney is the main organ that influences the quantity that is lost. Again it is the hypothalamus that monitors the concentration of the blood and initiates the release of hormones from the posterior pituitary gland. These act on the kidney tubules to influence the amount of water (and sodium ions) absorbed from the fluid flowing along them.

(a) When the body fluids become too concentrated and the osmotic pressure too high, water retention in the kidney tubules can be achieved by:

- An increased production of antidiuretic hormone (ADH) from the posterior pituitary gland, which causes more water to be reabsorbed from the kidney tubules.
- A decreased blood pressure in the glomerulus of the kidney results in less fluid filtering through into the kidney tubules so less urine is produced.

(b) When the body fluids become too dilute and the osmotic pressure too low, water loss in the urine can be achieved by:

- A decrease in the secretion of ADH, so less water is reabsorbed from the kidney tubules and more diluted urine is produced.
- An increase in the blood pressure in the glomerulus so more fluid filters into the kidney tubule and more urine is produced.
- An increase in sweating or panting that also increases the amount of water lost.

Another hormone, aldosterone, secreted by the cortex of the adrenal gland, also affects water balance indirectly. It does this by increasing the absorption of sodium ions (Na-) from the kidney tubules. This increases water retention since it increases the osmotic pressure of the fluids around the tubules and water therefore flows out of them by osmosis.

16.14.3 3. Maintenance of blood volume after moderate blood loss

Loss of blood or body fluids leads to decreased blood volume and hence decreased blood pressure. The result is that the blood system fails to deliver enough oxygen and nutrients to the cells, which stop functioning properly and may die. Cells of the brain are particularly vulnerable. This condition is known as shock.

If blood loss is not extreme, various mechanisms come into play to compensate and ensure permanent tissue damage does not occur. These mechanisms include:

- Increased thirst and drinking increases blood volume.
- Blood vessels in the skin and kidneys constrict to reduce the total volume of the blood system and hence retain blood pressure.
- Heart rate increases. This also increases blood pressure.
- Antidiuretic hormone (ADH) is released by the posterior pituitary gland. This increases water re-absorption in the collecting ducts of the kidney tubules so concentrated urine is produced and water loss is reduced. This helps maintain blood volume.
- Loss of fluid causes an increase in osmotic pressure of the blood. Proteins, mainly albumin, released into the blood by the liver further increase the osmotic pressure causing fluid from the tissues to be drawn into the blood by osmosis. This increases blood volume.
- Aldosterone, secreted by the adrenal cortex, increases the absorption of sodium ions (Na-) and water from the kidney tubules. This increases urine concentration and helps retain blood volume.

If blood or fluid loss is extreme and the blood volume falls by more than 15-25%, the above mechanisms are unable to compensate and the condition of the animal progressively deteriorates. The animal will die unless a vet administers fluid or blood.

16.14.4 4. Acid/ base balance

Biochemical reactions within the body are very sensitive to even small changes in acidity or alkalinity (i.e. pH) and any departure from the narrow limits disrupts the functioning of the cells. It is therefore important that the blood contains balanced quantities of acids and bases.

The normal pH of blood is in the range 7.35 to 7.45 and there are a number of mechanisms that operate to maintain the pH in this range. Breathing is one of these mechanisms.

Much of the carbon dioxide produced by respiration in cells is carried in the blood as carbonic acid. As the amount of carbon dioxide in the blood increases the blood becomes more acidic and the pH decreases. This is called acidosis and when severe can cause coma and death. On the other hand, alkalosis (blood that is too alkaline) causes over stimulation of the nervous system and when severe can lead to convulsions and death.

(a) When vigorous activity generating large quantities of carbon dioxide causes the blood to becomes too acidic it can be counteracted in two ways:

- By the rapid removal of carbon dioxide from the blood by deep, panting breaths

By the secretion of hydrogen ions (H+) into the urine by the kidney tubules.

(b) When over breathing or hyperventilation results in low levels of carbon dioxide in the blood and the blood is too alkaline, various mechanisms come into play to bring the pH back to within the normal range. These include:

- A slower rate of breathing
- A reduction in the amount of hydrogen ions (H+) secreted into the urine.

16.14.5 SUMMARY

Homeostasis is the maintenance of constant conditions within a cell or animal's body despite changes in the external environment.

Thebody temperature of mammals and birds is maintained at an optimum level by a variety of heat regulation mechanisms. These include:

- Seeking out warm areas,
- Adjusting activity levels,

blood vessesl on the body surface,

- Contraction of the erector muscles so hairs and feathers stand up to form an insulating layer,
- Shivering,
- Sweating and panting in dogs.

Animals maintain water balance by:

- adjusting level of antidiuretic hormone(ADH)
- adjusting level of aldosterone,
- adjusting blood flow to the kidneys
- adjusting the amount of water lost through sweating or panting.

Animals maintain blood volume after moderate blood loss by:

- Drinking,
- Constriction of blood vessels in the skin and kidneys,
- increasing heart rate,
- secretion of antidiuretic hormone
- secretion of aldosterone
- drawing fluid from the tissues into the blood by increasing the osmotic pressure of the blood.

Animals maintain the acid/base balance or pH of the blood by:

- Adjusting the rate of breathing and hence the amount of CO2 removed from the blood.
- Adjusting the secretion of hydrogen ionsinto the urine.

16.15 Worksheet

Endocrine System Worksheet[1]

16.16 Test Yourself

1. What is Homeostasis?

1 http://www.wikieducator.org/Endocrine_System_Worksheet

2. Give 2 examples of homeostasis

3. List 3 ways in which animals keep their body temperature constant when the weather is hot

4. How does the kidney compensate when an animal is deprived of water to drink

5. After moderate blood loss, several mechanisms come into play to increase blood pressure and make up blood volume. 3 of these mechanisms are:

6. Describe how panting helps to reduce the acidity of the blood

/Test Yourself Answers/[2]

16.17 Websites

- http://www.zerobio.com/drag_oa/endo.htm A drag and drop hormone and endocrine organ matching exercise.
- http://en.wikipedia.org/wiki/Endocrine_system Wikipedia. Much, much more than you ever need to know about hormones and the endocrine system but with a bit of discipline you can glean lots of useful information from this site.

16.18 Glossary

- Link to Glossary[3]

[4]

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Version 3, 29 June 2007

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