CHAPTER 5

Excretory Systems

PERFORMANCE OBJECTIVES
At the end of this chapter, students should be able to:

- identify and describe different types of excretory systems in plants and animals.
- explain the mechanisms of some of the excretory organs and relate structure to functions.

INTRODUCTION

Metabolic processes, which constantly occur in organisms, result in the formation of a number of products that are of little use to the body. These materials, which are sometimes formed in large quantities, are excretory products that are harmful. Cells also consist of water, carbohydrates, lipids, proteins and mineral salts. The protoplasm of cells breaks down when they die and so materials like carbon (IV) oxide, nitrogenous wastes, mineral salts and water are formed. Dead red blood cells decomposition is completed in the liver or spleen and discharged into the gall bladder, where they are stored as bile. These materials derived from the breakdown of protoplasm are eliminated from the body by means of excretory system.

Excretion is the process of getting harmful or useless molecules out of the cells and out of organisms. Sometimes useful substances such as excess water and excess oxygen are released from organisms as excretory products. This is because the body cannot store them for a long time.

In small organisms such as amoeba, excre- tion is accomplished by diffusion alone. In large organisms, the removal of wastes by diffusion alone becomes inadequate. This is because the body of each of these organisms is made up of several thousands of cells, which are distributed to form various tissues, organs and systems. Each cell has the ability to carry out its own respiration and other metabolic activities. While doing so, it produces waste substances such as carbon (IV) oxide, water and nitrogenous compounds. As a result, it becomes necessary that all the waste substances are collected and transported to spe- cial tissues or structures concerned with their removal. These result in the need for the devel- opment of a definite excretory system.

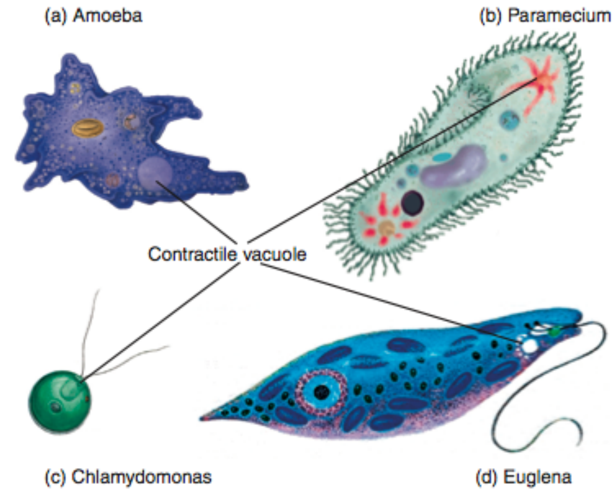
CONTRACTILE VACUOLES IN SOME UNICELLULAR ORGANISMS

Contractile vacuole, which is a simple device, is found in amoeba and other fresh water protozoans (i.e., unicellular organisms). It is a small sac lined with a membrane lying freely in the cytoplasm (Figure 5.1).

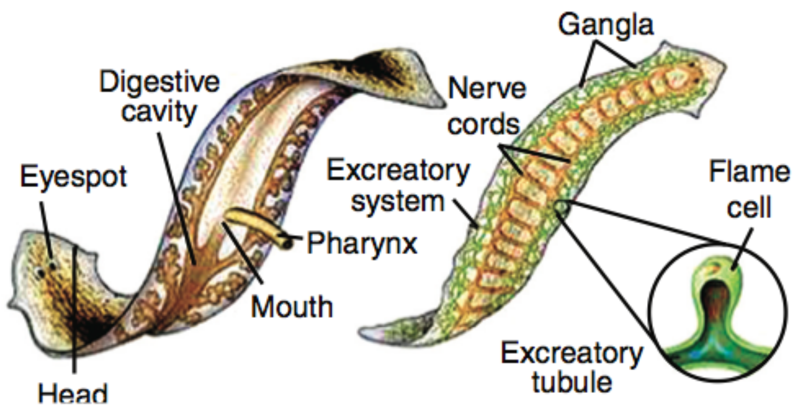
The cell membrane surrounding the amoeba is a semipermeable to water and because the osmotic pressure inside the animal is greater than outside the animal, water enters the cell by osmo- sis. To counter this, water is secreted into the contractile vacuole as fast as it enters the body. As this happens, the contractile vacuole expands and bursts, thus discharging its contents to the exterior through a small pore in the cell mem- brane after which the whole process is repeated. The energy required by the contractile vacuole is produced by the mitochondria found near the vac- uole. The contents of the contractile vacuole are water, carbon (IV) oxide and nitrogenous wastes.

FLAME CELLS IN FLATWORMS (FLAME CELL)

These are two longitudinal excretory canals, which open onto the dorsal surface of the flatworm by a number of minute pores. The main canals give off numerous branches, which ramify among the parenchyma cells. The final branches end in flame cells. These are cells, which have intracellular cavities and ducts, with numerous



▲ FIGURE 5.1 Contractile vacuole in some unicellular organisms



▲ FIGURE 5.2 A flame cell

cytoplasmic branches penetrating between the parenchyma cells. Projecting into the cavity of the cell is a bundle of long cilia, which arises from basal granules in the cytoplasm. These cilia are characterised by their flickering movement, which gives rise to the name flame cells. The lumen continues as a narrow intracellular duct, which enters one of the main intercellular ducts, e.g., turbellaria, planaria and fasciola.

Excretory substances are secreted into the cavity by the surrounding cells. The flickering cilia maintain an outward current and possibly produce a slightly negative hydrostatic pressure causing excess water to flow in from the spaces in the surrounding parenchyma.

NEPHRIDIA IN ANNELIDS

Each nephridium in the earthworm is a long coiled tube derived by the ingrowth of ectoderm and opens into the coelomic fluid of the segment anterior to the nephridiopore. The first part, nephrostome, is a minute flattened funnel with the upper lip larger than the lower lip. The upper lip is made up of a large central cell, which is thickly ciliated on the inner surface of the funnel. Around it is a border of small, columnar, marginal cells ciliated on the inner faces. The lower lips consist of a thickened cluster of small cells, which are not ciliated. All the cilia beat into the lumen of the tube. The nephro- stome leads into an intracellular duct, which bears two rows of lateral cilia. This duct passes through the septum into the narrow ciliated tube, which is again intracellular. After making several loops, the narrow tube leads into the wider brown ciliated tube, which bears three longitudinal rows of cilia. The brown tube makes only one loop and then passes into the wide non-ciliated tube. This leads

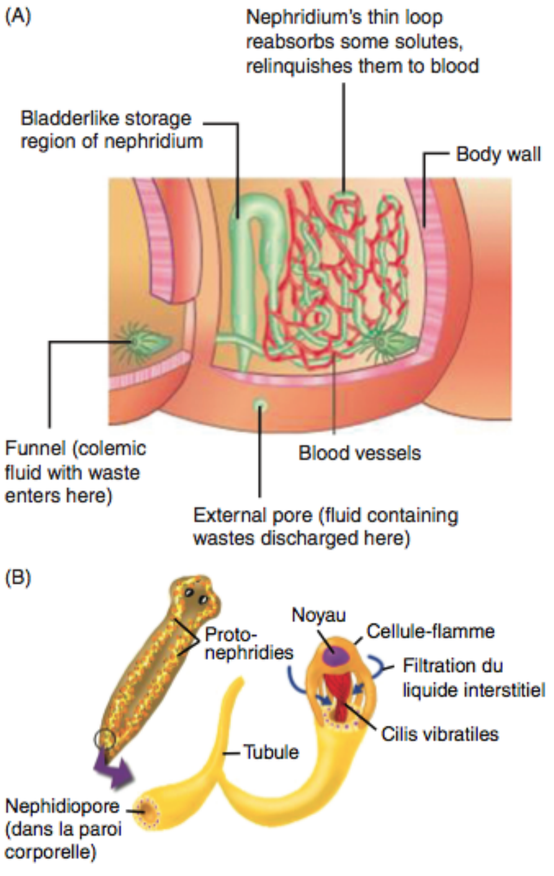


FIGURE 5.3 (A) Nephridium of earthworm and (B) Nephrostome

into the much wider muscular tube, at the exit of which is the nephridiopore, regulated by a sphinc- ter. All the coils of the nephridium are bound up in connective tissue, and numerous fine capillaries ramify among the coils.

A striking difference between nephridium and flame cell is that it opens at both ends, whereas flame cell opens at one end and the other being blind.

MALPIGHIAN TUBULES IN INSECTS

These tubules are ectodermal growth extending from the anterior region of the ileum of the insect into the haemocoel. They are long and extremely slender and penetrate among the viscera over the greater part of the thorax and abdomen. In the cockroach, they are in six groups, with about twelve tubules in each group.

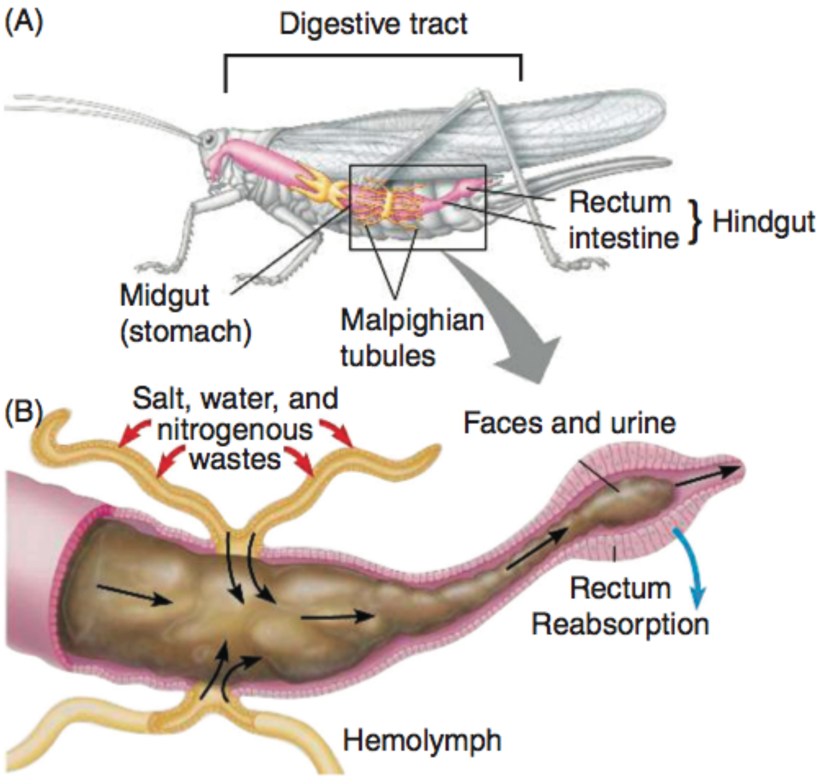


FIGURE 5.4 Malpighian tubules of the cockroach (A) showing the tubule on a cockroach and (B) showing the enlarged version of the tubule

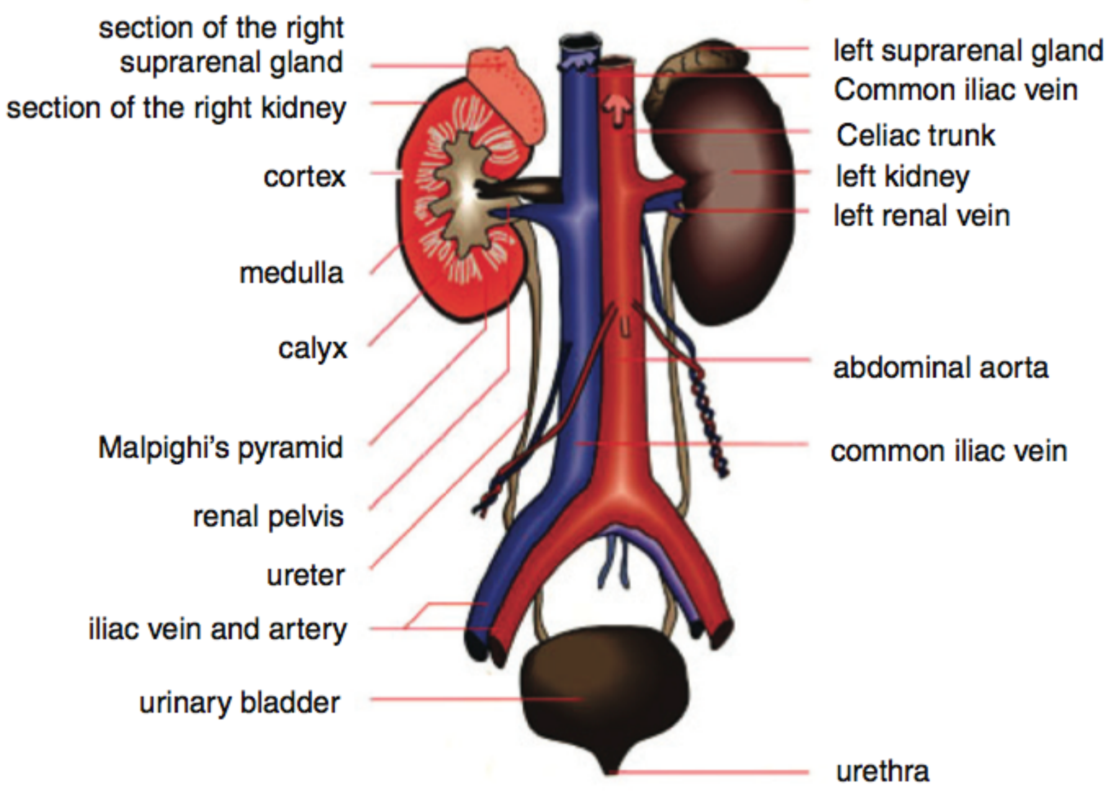
In insects such as the cockroach a lot of the carbon (IV) oxide is got rid of via the cuticle which is permeable to gases. Insects conserve water they obtain from the food they feed on by excreting uric acid through their malpighian tubules. Uric acid is a partly solid nitrogenous waste material.

KIDNEYS IN VERTEBRATES

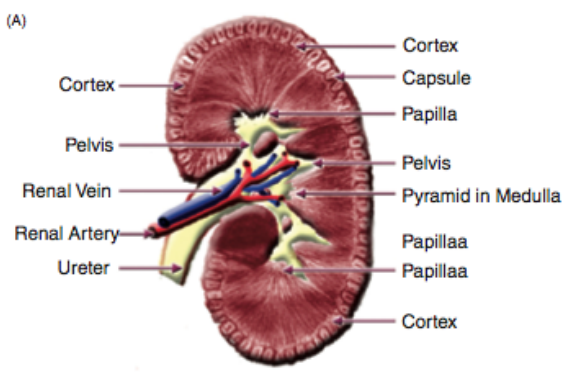
All vertebrates have a pair of kidneys, which form a part of the excretory system. In mammals, the kidneys are bean-shaped, dark red in colour and surrounded by fat. The right kidney is slightly lower in the body than the left.

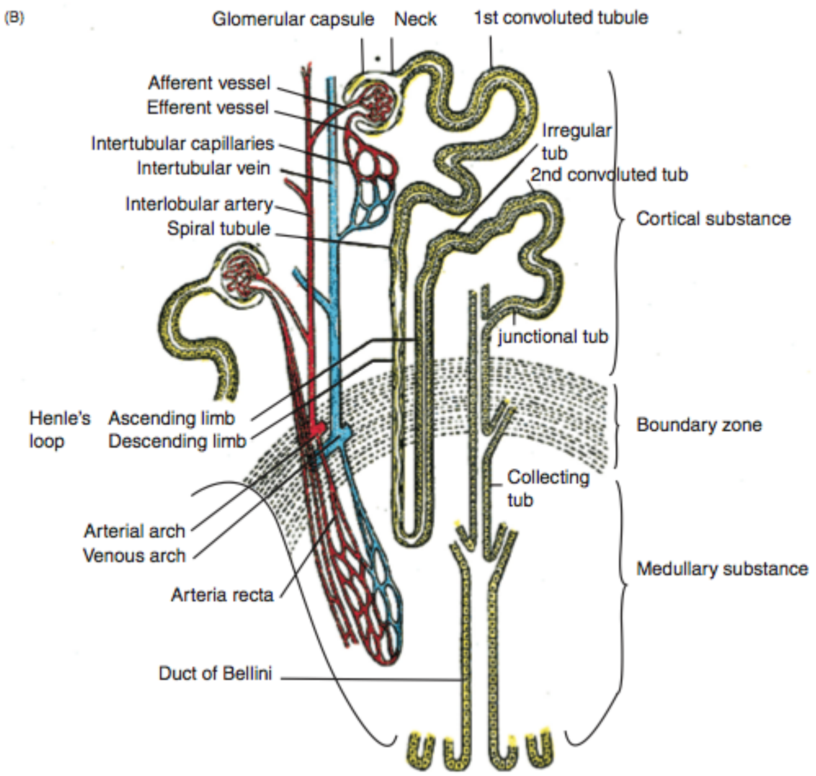
If a kidney is cut longitudinally into two, it will be seen to consist of two main regions: an outer dark-coloured cortex and an inner lighter coloured medulla (Figure 5.6A). When viewed under a micro- scope, a kidney consists of blood vessels, kidney tubules or nephrons and connective tissue. Each nephron (Figure 5.6B) begins in the cortex as a tiny cup-shaped structure known as the Bowmanâ€™s capsule, which surrounds capillaries called the glomerulus. The Bowmanâ€™s capsule leads into a coiled tube called the proximal tubule. This goes down to form a U-shaped structure, the Henleâ€™s loop. Finally, it coils again to form the distal tubule, which twists and empties into a collecting duct.

Renal artery, which branches from the dorsal aorta, brings digested food, nitrogenous waste



▲ **FIGURE 5.5** Human urinary system showing position of the kidneys





▲ FIGURE 5.6 (A) Mammalian kidney in section and (B) single kidney tubule and collecting duct

products and oxygenated blood to the kidney so that nitrogenous waste products (urea) can be removed.

The blood that leaves the kidney is deoxy- genated and is carried away by renal vein to the inferior (posterior) vena cava.

The urine formed passes from each kidney into a ureter. The left and right ureters lead to a muscular sac called the bladder in which urine is stored temporarily. The bladder opens to a short tube, urethra, which leads to the exterior.

OTHER EXCRETORY ORGANS IN MAMMALS

(i) The skin excretes water, salts and urea. Skin excretes wastes by means of sweat glands, which consist of coiled tubes, open- ing exteriorly as sweat pores. Sweat is composed of 95% water and 3% dissolved salts (e.g., sodium chloride).

(ii) Lungs excrete carbon (IV) oxide and water. Carbon (IV) oxide can be harmful if it accumulates too much as it forms carbonic acid. Excess of carbonic acid is capable of upsetting the delicate acid base balance of the body fluids.

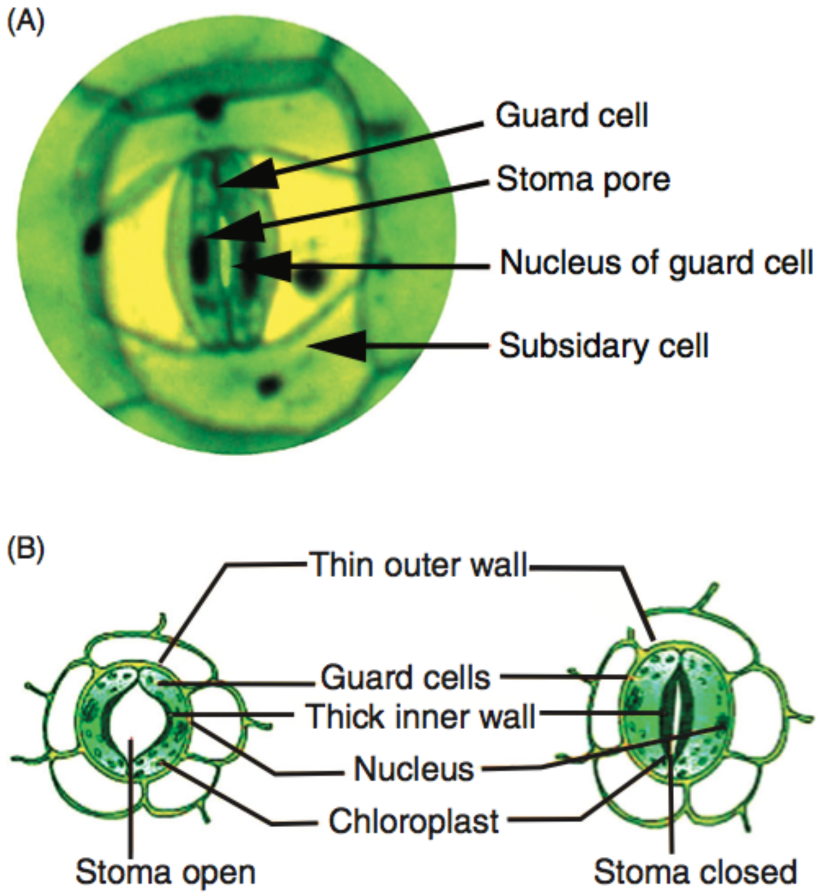


FIGURE 5.7 (A) Guard cells in section and (B) appearance of open and closed stomata in surface view and cross section

STOMATA AND LENTICELS IN PLANTS

In general, plants are much less active than ani- mals and produce waste products at a much slower rate. Hence, they have no need for specialised excretory organs. The main excretory products, which are water, oxygen and carbon (IV) oxide, are got rid of by diffusion through the stomata and lenticels.

EXCRETION IN STOMATA: Stomata are pores in the epidermis bounded by specialised epidermal cells known as guard cells. In conjunction with the guard cells, other adjacent and distinctive epidermal cells may assist in the opening and closing of the pore. These are known as acces- sory cells. Stomata are usually found on the aerial parts of stems and leaves and on flower parts. Underground rhizomes and some aquatic plants may possess them. They may be irregularly scat- tered or arranged in parallel rows. The guard cells are bean shaped and fit together with the pore between them. The size of the pore alters according to how turgid the guard cells are. This in turn depends on the osmotic pressure within the guard cells. When the pressure is low, the guard cells are flabby and the stoma is closed. When it is high, the guard cells are turgid and the stoma opens.

EXCRETION IN LENTICELS: They are structurally differentiated parts of the periderm, which stand

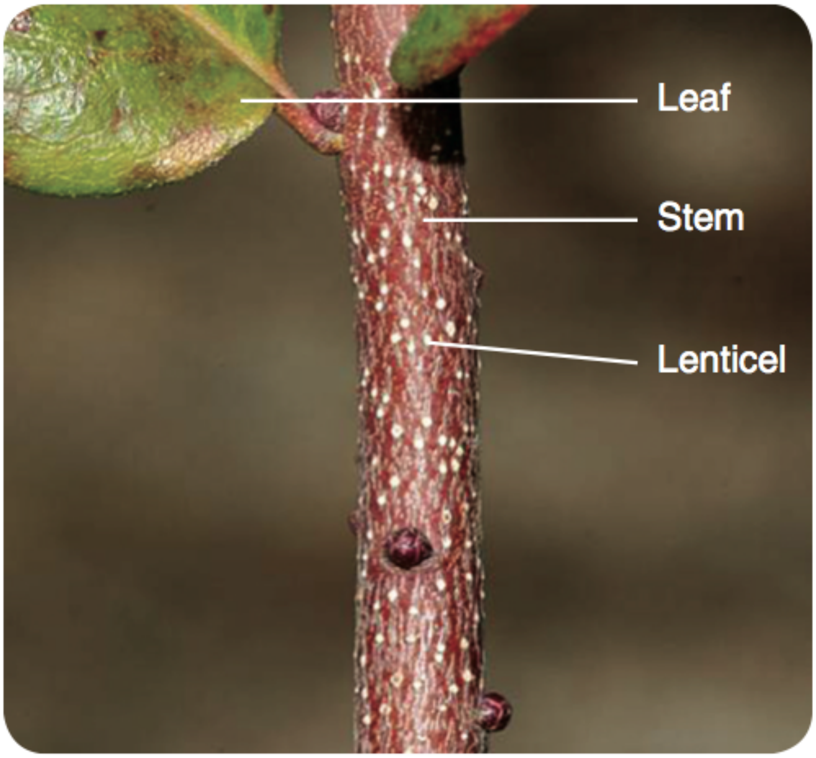


FIGURE 5.8 Lenticel on a young twig

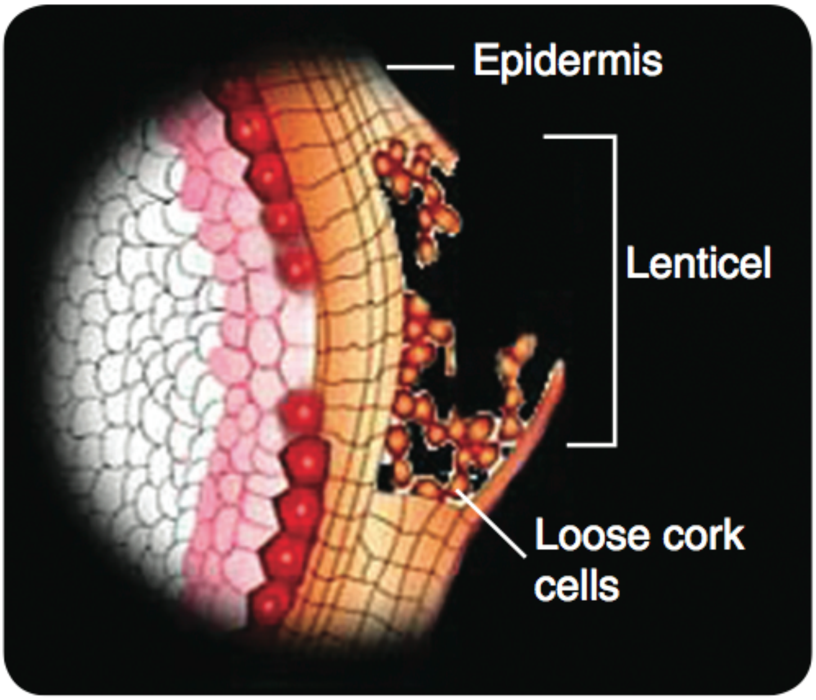


FIGURE 5.9 Formation of lenticel

out because of the very loose cell arrangement and lack of suberisation. They vary greatly in size according to species but can be seen as protru- sions of loose substance through cracks in the periderm (Figure 5.8). In a stem undergoing secondary thickening, the first lenticels usually arise beneath the stoma in the epidermis. The cells below the stomata lose their chlorophyll and divide repeatedly to form a loose mass. Gradually, the region of division penetrates deeper into the cortex, and the place of division of the cells becomes regularly parallel to the surface so that a lenticel phellogen is formed. This proceeds to cut off more and more loose cells towards the exterior and eventually the epidermis is ruptured (Figure 5.9).

Prominent plants excretory products are water, carbon (IV) oxide and oxygen. They are excreted through the stomata and lenti- cels. Green plants like tomato and potato have glands that secrete water, a process called guttation. This is seen at the apex and margin. Other waste products produced by plants are tannins, poisonous nitrogenous alkaloid and anthocyanins, which give colour to the petals of many flowers. In order not to interfere with the plants activities, these waste products are con- verted to harmless insoluble compounds and stored within the plant body, e.g., some plant cells contain calcium oxide, glucose and alka- loid compounds.

EXCRETORY MECHANISM IN SOME ANIMALS

EXCRETORY MECHANISM IN EARTHWORM

The job of the nephridium in the earthworm is to get rid of surplus water and conserve salts; the reverse is the case in most terrestrial animals. Carbon (IV) oxide is effectively removed from the body at the skin surfaces by diffusion. It is also removed inform of calcium carbonate excreted into the gut by the oesophageal pouches.

Waste substances mainly urea, resulting from metabolic activities, tend to accumulate in the coelomic fluid contained in the body cavity of each segment. The nephrostome or nephridial funnel, which is richly supplied with rhythmically beating cilia, drains the fluid from the chamber in which it lies and passes the fluid along the narrow coiled tube through the brown tube and then into the muscular tube. The more valuable substances like sugar and salt contained within the fluid are reabsorbed as they pass through the tubes. Urine accumulates in the muscular tube, which is emptied when the sphincter is opened. The urine is hypotonic to both the blood and coelomic fluid. It contains on the average, 3 mg of urea, 3 mg chlorine and 30 mg protein per 100 cm3 of fluid.

EXCRETORY MECHANISM IN INSECTS

The insect tissues produce nitrogenous waste in the form of soluble potassium urate, which is liberated into the blood and taken up by the cells lining the malpighian tubules. The tubules are muscular and their writhing movements facilitate the absorption of urate by stirring up the blood. In the cells of the tubule, the potassium urate reacts with water and carbon (IV) oxide (from respira- tion) to form potassium trioxocarbonate (IV) and uric acid. The former is reabsorbed into the blood to such an extent that the proximal end of the malpighian tubule becomes filled with solid crys- tals of uric acid. Water is further reabsorbed by the folded walls of the rectal glands so that by the time urine leaves the body, it is very much more concentrated than the blood.

The remarkable ability of insects to conserve water has contributed towards their success as a group. This is largely due to the action of their malpighian tubules and rectal glands. Insects conserve water more effectively than any other group of animals because they do not drink water. They pass out semisolid waste (uric acid), which contains very little quantity of water.

EXCRETORY MECHANISM IN MAMMALS

The kidneys of mammals accomplish their task of excretion by purifying the blood through filtration and selective absorption.

FILTRATION: This takes place in the Bowmanâ€™s capsule and is made possible by two processes, namely:

(i) The pressure created by the narrowness of capillaries.

(ii) The barrier formed by the endothelial lining of glomerular capillaries and the basement membrane of the Bowmanâ€™s capsule, which retains molecules above a certain size, while allowing smaller ones to pass through.

Blood in the renal artery and its arterioles is always under pressure. When it reaches a glomerulus, it is slowed down by the narrowness of the capillaries and by the fact that the arteriole leading from the glomerulus is narrower than the one leading into it. A high pressure is developed, and the blood containing dissolved substances like urea, water, glucose and mineral salts are forced through the walls of the capillaries in the Bowmanâ€™s capsule. From the capsule, the liquid (glomerular filtrate) enters the tubules. This is ultrafiltration.

SELECTIVE REABSORPTION: As this liquid passes along the tubules, selective reabsorption takes place. Certain substances are passed back into the blood, whereas others are retained. Glucose is reabsorbed in the proximal tubules, whereas sodium and chloride ions are reabsorbed in the distal tubules and the collecting ducts. Water is reabsorbed in both the proximal and distal tubules and the collecting ducts.

The reabsorption of glucose and mineral salts involves active transport. This is because the transfer of these materials occurs against a concentration gradient and diffusion alone cannot account for it. The reabsorption of water can be linked partly to osmosis and to a hormone known as the anti-diuretic hormone (ADH). After reab- sorption, the resulting fluid known as urine then trickles down the ureter and collects in the blad- der, which stretches to accommodate it. When the bladder is full, the muscle called urethral sphincter that guards the aperture between the bladder and urethra relaxes, and urine is passed out of the body through the urethra.

SUGGESTED PRACTICALS

1. Observation of the malpighian tubules of a cockroach

(i) A set of several dissected cockroaches will be provided.

(ii) Observe the malpighian tubules with the aid of a hand lens.

(iii) Try to count the number of tubules using your forceps to tease them out.

2. Examination of a mammalian kidney

(i) Collect some rats, your teacher will help to kill them and guide you in the dissection.

(ii) Identify the 2 kidneys and where they are found (position).

(iii) Note the blood vessels that serve them.

(iv) Cut the kidney longitudinally into two.

(v) Identify the various parts of the kidney.

(vi) Draw and label a cut half of the kidney to show the various parts.

CHAPTER SUMMARY

â– Excretion is the removal of harmful or unwanted waste products [e.g., nitrogenous substances, excess water and carbon (IV) oxide] out of the body.

â– In small organisms, excretion is accomplished by diffusion alone. In large animals, diffusion becomes inadequate because the body is much more complex and made up of thousands of cells. Each cell has the ability to carry out its own metabolic activi- ties and in the process produces waste products. This brings about the need for the development of definite excretory systems.

â– There are different excretory systems in different organisms, which serve the same purpose of removal of wastes from the body. The structure of these systems is deter- mined by the type of waste products being removed and the level of efficiency.

â– In unicellular organisms, the excretory system is mainly the contractile vacuole, which removes water, carbon (IV) oxide and nitrogenous wastes in solution.

â– In flatworms, flame cells serve as an excretory system.

â– Nephridium is the excretory system in earthworms. It is made up of nephrostome, tubes and nephridiopore.

â– Ectodermal growths called malpighian tubules form the excretory system of insects. They are attached to the anterior region of ileum.

â– All vertebrates have a pair of kidneys, which form the part of the excretory system.

â– Excretory mechanisms differ in different organisms.

â– In earthworms, carbon (IV) oxide is effectively removed by diffusion, urea passes through the different tubes of the nephridium, sugar and mineral salts are absorbed and urine formed is emptied through the nephridiopore.

â– In insects, the main waste products are potassium trioxocarbonate (IV) and uric acid. The former is reabsorbed into the blood and uric acid moves through the gut and is passed out through the malpighian tubules as a semisolid waste.

â– In mammals, excretion is achieved by filtration and reabsorption. As the blood passes through the Bowmanâ€™s capsule, it is filtered, and the waste products and some useful substances (e.g., glucose, amino acids and vitamins) enter into the tubules; there is selective reabsorption – sugar, salts and water form urine, and this goes out through the collecting ducts. From these ducts, urine passes out at intervals through the urethra.

REVISION QUESTIONS

Choose the correct options to the following questions.

1. Which of the following structures is used for the elimination of liquid waste in paramecium?

a. Food vacuole b. Oral groove c. Anal pore d. Contractile vacuole

2. The excretory organs in ï¬‚atworms are called

a. nephridia. b. malpighian tubules. c. ï¬‚ame cells. d. kidneys.

3. Which of the following substances is contained in the renal artery?

a. Less water b. Less Urea c. More glucose d. More carbon (IV) oxide

4. Which of the following groups of animals has the greatest ability to conserve water?

a. Insects b. Flatworms c. Earthworms d. Unicellular organisms

5. The main excretory products of flowering plants are

a. water, carbon (IV) oxide and tannin.
b. water, alkaloids and carbon (IV) oxide.

c. tannin, oxygen and carbon (IV) oxide.

d. water, oxygen and carbon (IV) oxide.

<u>Essay Questions</u>

1. The diagram on the right represents parts of a kidney tubule with its set of capillaries. Examine the diagram and answer the following questions.

(a) The vessel taking blood to the capillaries is larger in diameter than the vessel taking the blood away. What effect will this have on the capillaries?

(b) Name two components of blood that do not pass out of the capillaries into the tubule.

(c) Name a substance leaving the capillaries and entering the tubule, which will be completely reabsorbed, but forms the bulk of the dissolved waste in the urine.

2. (a) Deï¬ne excretion.

(b) (i) Why is excretion important in organisms?

(ii) Draw and label the vertical section of a mammalian kidney and the malpighian tubule of an insect.

3. (a) Draw and label the nephridium of an earthworm.

(b) Compare the method of excretion in the earthworm and insect.

4. (a) Draw a fully labelled drawing of a nephron.

(b) Describe the excretory mechanism in a mammal.

5. (a) List ï¬ve excretory products in plants.

(b) Brieï¬,y explain the role of stomata in plant excretion.