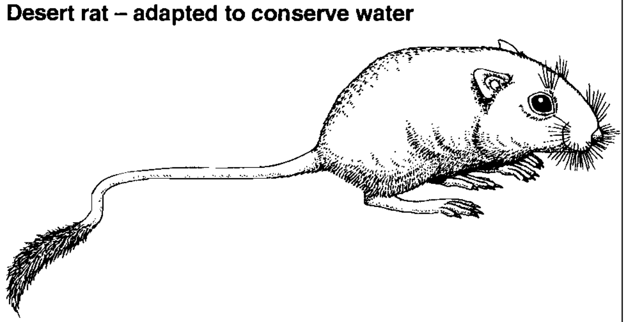
Excretory products and dialysis

EXCRETORY PRODUCTS OF LIVING ORGANISMS

Excretion is one of the basic life processes of all living organisms. The need for excretion is explained on page 48. Living organisms do not all excrete the same substances. Plants excrete oxygen, for example, whereas animals excrete carbon dioxide and nitrogenous waste products. Nitrogenous waste products are formed when surplus amino acids are broken down. The nitrogen compound that is excreted varies between groups of animals and can be related to the habitat and activities of the animal.

- Freshwater fish excrete ammonia, mostly through their gills, but also in urine. Ammonia is very toxic because it is alkaline and so has to be diluted in a large volume of water in urine. Freshwater fish have abundant supplies of water, so water losses can easily be replaced.
- Mammals excrete urea, which is much less toxic and so can be excreted in about a tenth as much water as ammonia. This is an advantage for mammals living in habitats with low water availability. The figure (below) shows a desert rat, with kidneys so efficient at water conservation that it never needs to drink water.
- Birds excrete uric acid, which has low toxicity and is only partially soluble in water. When water is reabsorbed during production of urine in the kidney, uric acid precipitates. The white semi-solid urine of birds contains very little water – only about a fiftieth as much as would be needed to excrete nitrogen as ammonia. Conservation of water and lower body mass are advantages to birds, especially in dry habitats and when flying.

Desert rat – adapted to conserve water



ARTIFICIAL EXCRETION

Humans cannot survive for long without a functioning kidney, unless an artificial method of excretion is used.
The commonest method is dialysis, using a kidney machine.

Patient during a session of dialysis

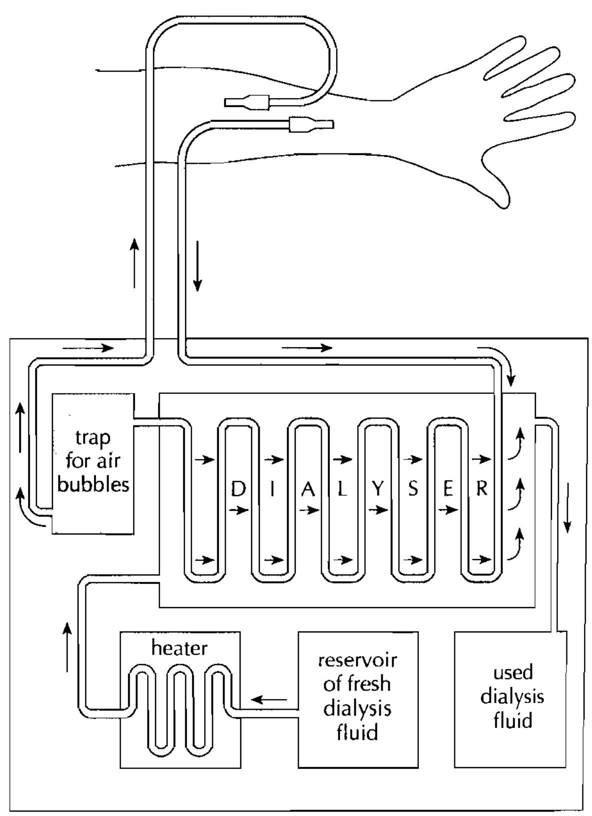
RENAL DIALYSIS

Dialysis involves the diffusion of solutes from a higher to a lower concentration through a semi-permeable membrane. The dialysis membrane used in kidney machines is usually made of cellulose acetate or nitrate. It has pores that let small solute particles pass through, but not large particles such as plasma proteins or blood cells. Blood flows on one side of the dialysis membrane and dialysis fluid on the other side (above). The formulation of the dialysis fluid ensures that only some substances diffuse into it from the blood.

- It contains no urea or other excretory products, so these waste products diffuse into it rapidly.
- It has the same concentration of glucose, mineral ions and other desirable substances as normal blood plasma, so these substances do not diffuse unless the level in blood plasma is above or below normal.
- It contains dextran, a solute that cannot pass through the dialysis membrane and so causes excess water to move by osmosis from the blood to the dialysis fluid.

During dialysis the patient's blood flows through tubes or between sheets of dialysis membrane. The blood is taken from the patient and returned via needles inserted into a blood vessel in the arm. The dialysis fluid has to be gradually replaced throughout a session to maintain the concentration gradients. A large volume of fluid is used, in contrast to the human kidneys, which can excrete waste products with a very small loss of water.

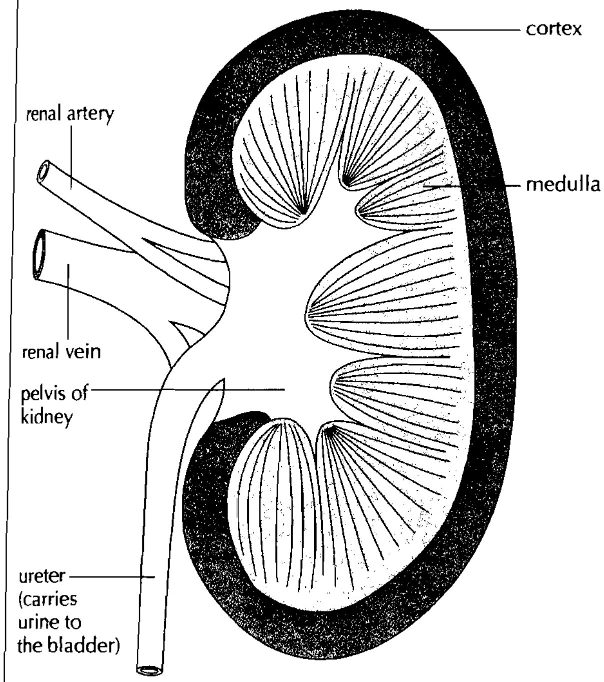
Structure of a kidney dialysis machine



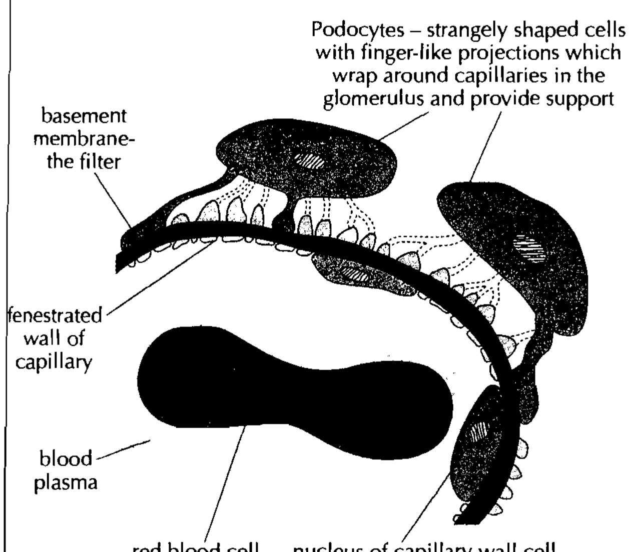
THE STRUCTURE OF THE KIDNEY

The kidneys produce urine. The figure (below) shows the structure of the kidney. The cortex and medulla of the kidney contain many narrow tubes called nephrons. The figure (below) shows the structure of a nephron, together with the associated glomerulus.

Structure of a kidney in vertical section



Structure of part of a glomerulus



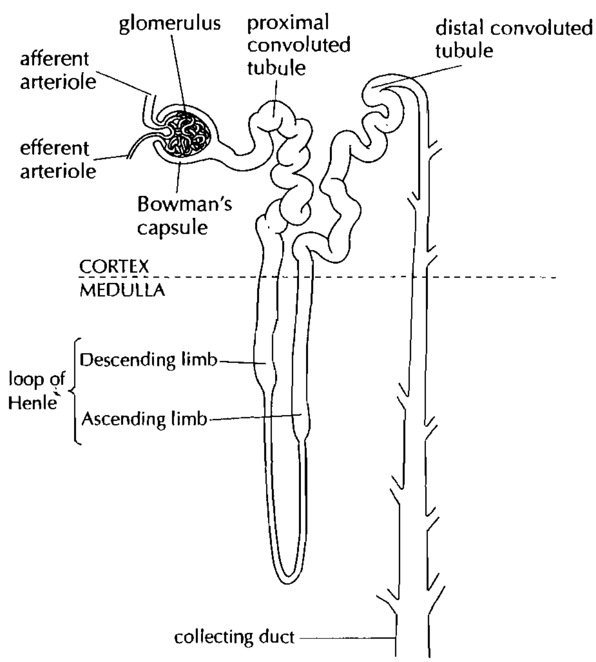
ULTRAFILTRATION IN THE GLOMERULUS

The function of the glomerulus is production of a filtrate from blood by a process called **ultrafiltration**. Part of the blood plasma escapes through the walls of all capillaries, but in the glomerulus 20% escapes, which is much greater than usual. There are two main reasons for this.

- The blood pressure is very high, because the vessel taking blood away from the glomerulus is narrower than the vessel bringing blood.
- The capillaries in the glomerulus are fenestrated – they have many pores through them.

These pores are large enough to allow any molecules through, but on the outside of the capillary wall is a basement membrane, composed of a gel of glycoproteins (below). The basement membrane acts as a filter as it only allows molecules with a molecular mass below 68 000 to pass through. It lets all substances in blood plasma through except plasma proteins. The fluid produced by ultrafiltration is collected by the Bowman's capsule and flows on into the proximal convoluted tubule.

Structure of the nephron



COMPARISON OF THE CONTENTS OF FLUIDS IN THE KIDNEY

The physiology of the kidney can be studied by comparing the content of blood flowing to and from the kidney with the content of glomerular filtrate and urine.

Content (mg per 100 ml of blood)

	Blood plasma in renal artery	Glomerular filtrate	Urine	Blood plasma in renal vein
Glucose	90	90	0	90
Urea	30	30	2000	24
Proteins	740	0	0	740
Sodium ions	900	900	1200	720

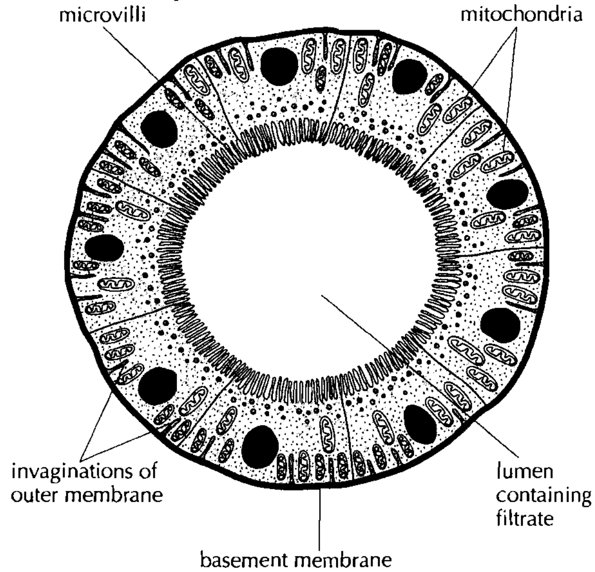
Blood in the renal artery has higher oxygen levels and lower CO_2 levels than blood in the renal vein.

Urine production and osmoregulation

SELECTIVE RE-ABSORPTION IN THE PROXIMAL CONVOLUTED TUBULE

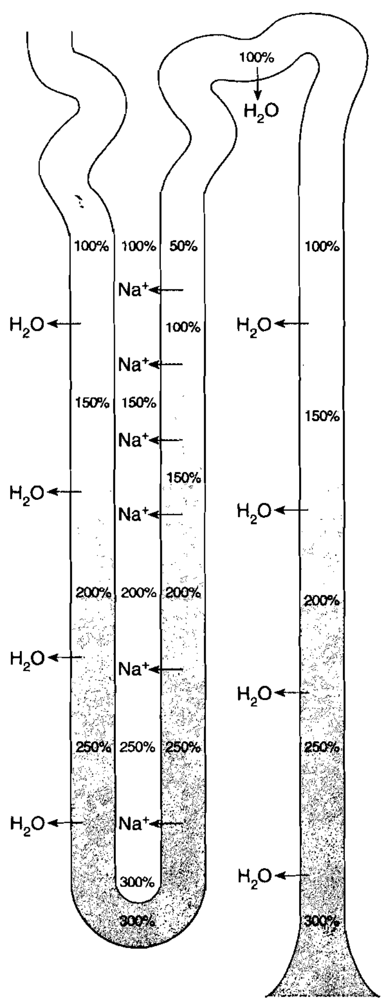
Large volumes of glomerular filtrate are produced – about 1 litre every 10 minutes by the two kidneys. As well as waste products, the filtrate contains substances that the body needs, which must be re-absorbed into the blood. Most of this **selective re-absorption** happens in the proximal convoluted tubule. The wall of the nephron consists of a single layer of cells. In the proximal convoluted tubule the cells have microvilli projecting into the lumen (right), giving a large surface area for absorption. Pumps in the membrane re-absorb useful substances by active transport, using ATP produced by mitochondria in the cells. All of the glucose in the filtrate is re-absorbed. About 80% of the mineral ions, including sodium is re-absorbed. Active transport of solutes makes the total solute concentration higher in the cells of the wall than in the filtrate in the tubule. Water therefore moves from the filtrate to the cells and on into the adjacent blood capillary by osmosis. About 80% of the water in the filtrate is re-absorbed, leaving 20% of the original volume to flow on into the loop of Henle.

Structure of the proximal convoluted tubule



THE ROLE OF THE LOOP OF HENLE

Glomerular filtrate flows deep into the medulla in descending limbs of the loops of Henle and then back out to the cortex in ascending limbs. Descending limbs and ascending limbs are opposite in terms of permeability. Descending limbs are permeable to water but not to sodium ions. Ascending limbs are permeable to sodium ions but not to water (right). Ascending limbs pump sodium ions from the filtrate into the medulla by active transport, creating a high solute concentration in the medulla.
As the filtrate flows down the descending limb into this region of high solute concentration, some water is drawn out by osmosis. This dilutes the fluids in the medulla slightly. However the filtrate that leaves the loop of Henle is more dilute than the fluid entering it, showing that the overall effect of the loop of Henle is to increase the solute concentration of the medulla. This is the role of the loop of Henle – to create an area of high solute concentration in the cells and tissue fluid of the medulla.
After the loop of Henle, the filtrate passes through the distal convoluted tubule, where the ions can be exchanged between the filtrate and the blood to adjust blood levels. It then passes into the collecting duct.



Movements of water and sodium ions in the loop of Henle and the collecting duct. Solute concentrations inside and outside the nephron are shown as a percentage of normal blood solute concentration

OSMOREGULATION IN THE COLLECTING DUCT

Osmoregulation is the control of water and solute levels. The collecting duct has an important role in osmoregulation. If the water content of the blood is too low, the pituitary gland secretes ADH. This hormone makes the cells of the collecting duct produce membrane channels called aquaporins, which makes the collecting duct permeable to water. As the filtrate passes down the collecting duct through the medulla, the high solute concentration of the medulla causes most of the water in the filtrate to be re-absorbed by osmosis. A small volume of concentrated urine is produced.
If the water content of the blood is too high, ADH is not secreted, aquaporins are broken down and the collecting duct becomes much less permeable to water. Little water is reabsorbed as the filtrate passes down the collecting duct and a large volume of dilute urine is produced. In this way the water content of the blood is kept within narrow limits.The urine produced by the collecting ducts drains into the renal pelvis and down the ureter to the bladder.