Excretory Products and their Elimination
• Ammonia, urea and uric acid are the major forms of nitrogenous wastes excreted by the animals. Ammonia is the most toxic form and requires large amount of water for its elimination, whereas uric acid, being the least toxic, can be removed with a minimum loss of water. The process of excreting ammonia is Ammonotelism.

• Mammals, many terrestrial amphibians and marine fishes mainly excrete urea and are called ureotelic animals.

• Reptiles, birds, land snails and insects excrete nitrogenous wastes as uric acid in the form of pellet or paste with a minimum loss of water and are called uricotelic animals.
Excretory Organs  In different Organisms

- **Protonephridia** or flame cells are the excretory structures in **Platyhelminthes** (Flatworms, e.g., *Planaria*), rotifers, some annelids and the cephalochordate – *Amphioxus*.
- Protonephridia are primarily concerned with ionic and fluid volume regulation, *i.e.*, osmoregulation.
- **Nephridia** are the tubular excretory structures of earthworms and other annelids. Nephridia help to remove nitrogenous wastes and maintain a fluid and ionic balance.
- **Malpighian tubules** are the excretory structures of most of the insects including cockroaches.
- Malpighian tubules help in the removal of nitrogenous wastes and osmoregulation.
- Antennal glands or **green glands** perform the excretory function in crustaceans like prawns.
HUMAN EXCRETORY SYSTEM

- Kidneys are reddish brown, bean shaped structures situated between the levels of last thoracic and third lumbar vertebra close to the dorsal inner wall of the abdominal cavity. Each kidney of an adult human measures 10-12 cm in length, 5-7 cm in width, 2-3 cm in thickness with an average weight of 120-170 g.

- The medulla is divided into a few conical masses (medullary pyramids) projecting into the calyces (sing.: calyx).

- The cortex extends in between the medullary pyramids as renal columns called Columns of Bertini
Kidneys – filter wastes and excess water from the blood.

Ureters – tubes that take urine from the kidney to the urinary bladder.

Urinary Bladder – a sack that stores urine.

Urethra – small tube that leads urine out of the body.
The renal tubule begins with a double walled cup-like structure called Bowman’s capsule, which encloses the glomerulus. Glomerulus alongwith Bowman’s capsule, is called the malpighian body or renal corpuscle.

The tubule continues further to form a highly coiled network – proximal convoluted tubule (PCT).

A hairpin shaped Henle’s loop is the next part of the tubule which has a descending and an ascending limb.

The ascending limb continues as another highly coiled tubular region called distal convoluted tubule (DCT). The DCTs of many nephrons open into a straight tube called collecting duct, many of which converge and open into the renal pelvis through medullary pyramids in the calyces.
Each kidney has nearly one million complex tubular structures called nephrons, which are the functional units. Each nephron has two parts – the glomerulus and the renal tubule. Glomerulus is a tuft of capillaries formed by the afferent arteriole – a fine branch of renal artery. Blood from the glomerulus is carried away by an efferent arteriole.
URINE FORMATION

- Urine formation involves three main processes
- Glomerular filtration,
- Reabsorption and
- Secretion,

Glomerular filtration

- The first step in urine formation is the filtration of blood, which is carried out by the glomerulus and is called glomerular filtration. On an average, 1100-1200 ml of blood is filtered by the kidneys per minute which constitute roughly 1/5th of the blood pumped out by each ventricle of the heart in a minute.
The glomerular capillary blood pressure causes filtration of blood through 3 layers, i.e., the endothelium of glomerular blood vessels, the epithelium of Bowman’s capsule and a basement membrane between these two layers.

The epithelial cells of Bowman’s capsule called podocytes are arranged in an intricate manner so as to leave some minute spaces called filtration slits or slit pores.

Blood is filtered so finely through these membranes, that almost all the constituents of the plasma except the proteins pass onto the lumen of the Bowman’s capsule.

Therefore, it is considered as a process of ultra filtration.
Glomerular filtration rate (GFR)

- The amount of the filtrate formed by the kidneys per minute is called **glomerular filtration rate (GFR)**. GFR in a healthy individual is approximately 125 ml/minute, i.e., 180 litres per day!

- The kidneys have built-in mechanisms for the regulation of glomerular filtration rate. One such efficient mechanism is carried out by juxta glomerular apparatus (JGA). JGA is a special sensitive region formed by cellular modifications in the distal convoluted tubule and the afferent arteriole at the location of their contact. A fall in GFR can activate the JG cells to release renin which can stimulate the glomerular blood flow and thereby the GFR back to normal.
Reabsorption

• A comparison of the volume of the filtrate formed per day (180 litres per day) with that of the urine released (1.5 litres), suggest that nearly 99 per cent of the filtrate has to be reabsorbed by the renal tubules. This process is called reabsorption.

• For example, substances like glucose, amino acids, Na+, etc., in the filtrate are reabsorbed actively whereas the nitrogenous wastes are absorbed by passive transport. Reabsorption of water also occurs passively in the initial segments of the nephron.
Figure 19.5 Reabsorption and secretion of major substances at different parts of the nephron (Arrows indicate direction of movement of materials.)
Tubular Reabsorption

- Occurs in the loop of Henle.
- Substances are reabsorbed in the following ways:
  - Active reabsorption
  - Passive reabsorption
Active Reabsorption

This is the process by which substances are reabsorbed.

• Carrier molecules on the microvilli join up with certain molecules from the filtrate and actively transport them through the epithelial cells to the blood.

• Energy from ATP is used to join the molecule to the carrier molecule. The following are actively reabsorbed:
  – All organic nutrients such as glucose, amino acids and water soluble vitamins are completely reabsorbed.
  – Sodium ions and fat soluble vitamins are selectively reabsorbed, according to the needs of the body.
Passive Reabsorption

• Passively = no energy needed.
• About 65% of the water is passively reabsorbed from the filtrate in the proximal convoluted tubule by osmosis.
• Chloride ions passively follow the path of sodium ions.
• Urea, uric acid and creatinine is not reabsorbed.
FUNCTION OF THE TUBULES

• **Proximal Convoluted Tubule (PCT):** PCT is lined by simple cuboidal brush border epithelium which increases the surface area for reabsorption. Nearly all of the essential nutrients, and 70-80 per cent of electrolytes and water are reabsorbed by this segment. PCT also helps to maintain the pH and ionic balance of the body fluids by selective secretion of hydrogen ions, ammonia and potassium ions into the filtrate and by absorption of HCO$_3^-$ from it.
• **Henle’s Loop**: Reabsorption in this segment is minimum. However, this region plays a significant role in the maintenance of high osmolarity of medullary interstitial fluid. The descending limb of loop of Henle is permeable to water but almost impermeable to electrolytes. This concentrates the filtrate as it moves down. The ascending limb is impermeable to water but allows transport of electrolytes actively or passively. Therefore, as the concentrated filtrate pass upward, it gets diluted due to the passage of electrolytes to the medullary fluid.
• **Distal Convoluted Tubule (DCT):** Conditional reabsorption of Na\(^+\) and water takes place in this segment. DCT is also capable of reabsorption of HCO\(_3\)\(–\) and selective secretion of hydrogen and potassium ions and NH\(_3\) to maintain the pH and sodium-potassium balance in blood.

• **Collecting Duct:** This long duct extends from the cortex of the kidney to the inner parts of the medulla. Large amounts of water could be reabsorbed from this region to produce a concentrated urine.

• It also plays a role in the maintenance of pH and ionic balance of blood by the selective secretion of H\(^+\) and K\(^+\) ions
MECHANISM OF CONCENTRATION OF THE FILTRATE

- Mammals have the ability to produce concentrated urine. The Henle’s loop and vasa recta play a significant role in this. The flow of filtrate in the two limbs of Henle’s loop is in opposite directions and thus forms a counter current. The flow of blood through the two limbs of vasa recta is also in a counter current pattern. The proximity between the Henle’s loop and vasa recta, as well as the counter current in them help in maintaining an increasing osmolarity towards the inner medullary interstitium, *i.e.*, from 300 mOsmolL–1 in the cortex to about 1200 mOsmolL–1 in the inner medulla.
This gradient is mainly caused by NaCl and urea. NaCl is transported by the ascending limb of Henle’s loop which is exchanged with the descending limb of vasa recta. NaCl is returned to the interstitium by the ascending portion of vasa recta. Similarly, small amounts of urea enter the thin segment of the ascending limb of Henle’s loop which is transported back to the interstitium by the collecting tubule. The above described transport of substances facilitated by the special arrangement of Henle’s loop and vasa recta is called the **counter current mechanism**.

This mechanism helps to maintain a concentration gradient in the medullary interstitium. Presence of such interstitial gradient helps in an easy passage of water from the collecting tubule thereby concentrating the filtrate (urine). Human kidneys can produce urine nearly four times concentrated than the initial filtrate formed.
Figure 19.6 Diagrammatic representation of a nephron and *vasa recta* showing counter current mechanisms.
An excessive loss of fluid from the body can activate these receptors which stimulate the hypothalamus to release antidiuretic hormone (ADH) or vasopressin from the neurohypophysis. ADH facilitates water reabsorption from latter parts of the tubule, thereby preventing diuresis. An increase in body fluid volume can switch off the osmoreceptors and suppress the ADH release to complete the feedback. ADH can also affect the kidney function by its constrictory effects on blood vessels. This causes an increase in blood pressure. An increase in blood pressure can increase the glomerular blood flow and thereby the GFR.
The JGA plays a complex regulatory role. A fall in glomerular blood flow/glomerular blood pressure/GFR can activate the JG cells to release renin which converts angiotensinogen in blood to angiotensin I and further to angiotensin II. Angiotensin II, being a powerful vasoconstrictor, increases the glomerular blood pressure and thereby GFR. Angiotensin II also activates the adrenal cortex to release Aldosterone. Aldosterone causes reabsorption of Na+ and water from the distal parts of the tubule. This also leads to an increase in blood pressure and GFR. This complex mechanism is generally known as the Renin-Angiotensin mechanism.

An increase in blood flow to the atria of the heart can cause the release of Atrial Natriuretic Factor (ANF). ANF can cause vasodilation (dilation of blood vessels) and thereby decrease the blood pressure. ANF mechanism, therefore, acts as a check on the renin-angiotensin mechanism.
Micturition

- Urine formed by the nephrons is ultimately carried to the urinary bladder where it is stored till a voluntary signal is given by the central nervous system (CNS). This signal is initiated by the stretching of the urinary bladder as it gets filled with urine.

- The process of release of urine is called micturition and the neural mechanisms causing it is called the micturition reflex.

- An adult human excretes, on an average, 1 to 1.5 litres of urine per day. The urine formed is a light yellow coloured watery fluid which is slightly acidic (pH-6.0) and has a characteristic odour. On an average, 25-30 gm of urea is excreted out per day.
ROLE OF OTHER ORGANS IN EXCRETION

- Kidneys – filter out excess water and urea

- Lungs – filter out carbon dioxide, $\text{CO}_2$, from the blood.

- Skin – excretes water, as sweat, which contains some trace chemical wastes, including urea.
DISORDERS OF THE EXCRETORY SYSTEM

- **Hemodialysis** - Malfunctioning of kidneys can lead to accumulation of urea in blood, a condition called uremia, which is highly harmful and may lead to kidney failure. In such patients, urea can be removed by a process called hemodialysis. Blood drained from a convenient artery is pumped into a dialysing unit after adding an anticoagulant like heparin. The unit contains a coiled cellophane tube surrounded by a fluid (dialysing fluid) having the same composition as that of plasma except the nitrogenous wastes. The porous cellophane membrane of the tube allows the passage of molecules based on concentration gradient. As nitrogenous wastes are absent in the dialysing fluid, these substances freely move out, thereby clearing the blood. The cleared blood is pumped back to the body through a vein after adding anti-heparin to it. This method is a boon for thousands of uremic patients all over the world.
- **Renal calculi**: Stone or insoluble mass of crystallised salts (oxalates, etc.) formed within the kidney.
- **Glomerulonephritis**: Inflammation of glomeruli of kidney.