Excretory product, Structure of nephron and Mechanism of urine formation

Modes of Excretion

- **Excretion** is the process by which living organisms get rid of the waste substances either totally or partially accumulated during metabolic activities.
- **Nitrogenous waste products** are substances which contain nitrogen and are produced during the metabolism of proteins and amino acids.
- Depending on the nature of the nitrogenous compound being excreted, animals exhibit three modes of excretion.

Ammonotelism	Ureotelism	Uricotelism
• Ammonia is excreted. • Animals excreting ammonia as a major excretory product are called **ammonotelic animals**. • Example: Bony Fish	• Urea is excreted • Animals excreting urea as the major nitrogenous waste are called **ureotelic animals**. • Example: Mammals	• Uric acid is excreted. • Animals excreting uric acid as the major nitrogenous waste are called **uricotelic animals**. • Example: Reptiles

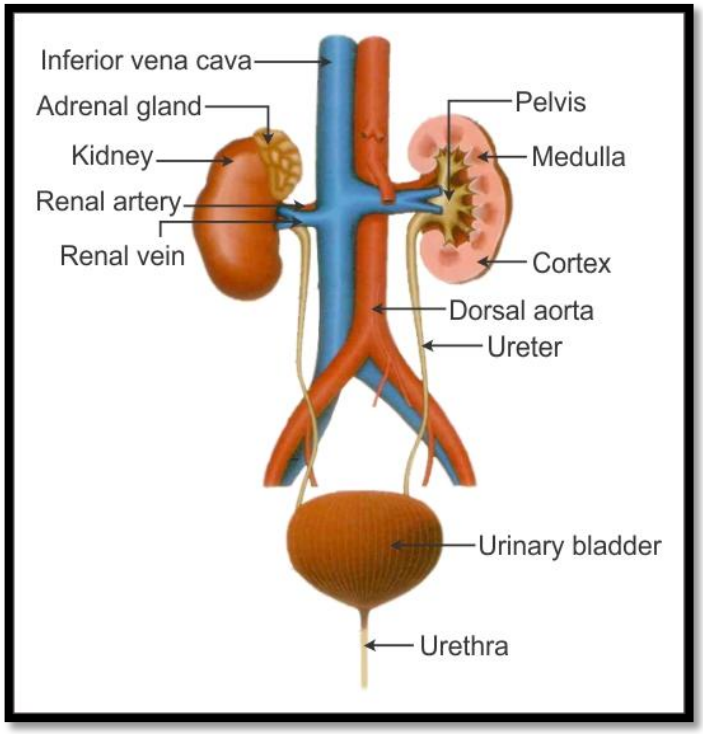
Organs of Excretion

- Organs which are associated with excretion are called **excretory organs**.

Animal group	Excretory structures
1. **Protozoans**	• In protozoans, nitrogenous wastes are excreted with the help of the **contractile vacuole**.
2. **Sponges**	• Ammonia is excreted through the body surface by the water current.
3. **Coelenterates**	• Waste is excreted by the simple diffusion through the body surface.
4. **Platyhelminthes**	• Protonephridia or flame cells.
5. **Annelids**	• Nephridia remove nitrogenous waste and water from the coelomic fluid.
6. **Echinoderms**	• Ammonia is excreted by diffusion through the thin walls of tube feet and dermal branchiae.

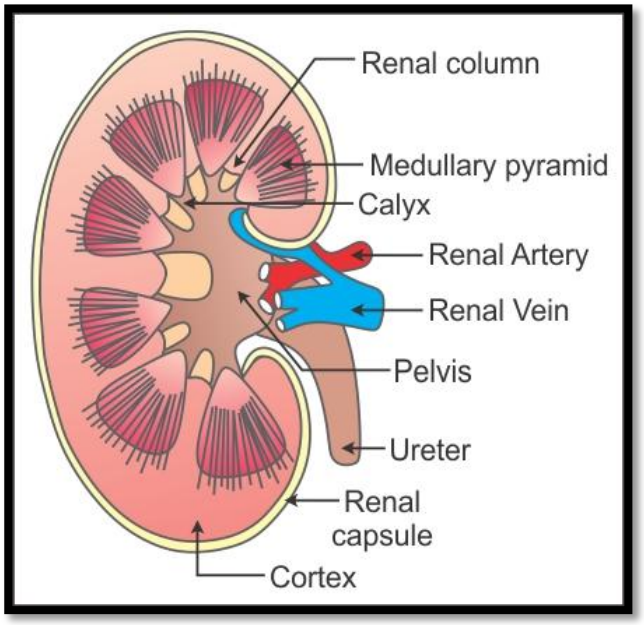
Human Excretory System

- There is a pair of dark red, bean shaped **kidneys**.
- Kidneys are located on either side of the vertebral column
- Each kidney measures 10–12 cm in length, 5–7 cm in width and 2–3 cm in thickness.
- **Ureters** are tube-like structures which arise from the notch, i.e. **hilum** of each kidney.
- The ureters connect behind with the urinary bladder.
- The **urinary bladder** is muscular sac-like structure. It stores urine temporarily.
- **Urethra** is the short muscular tube which expels urine out of the body.

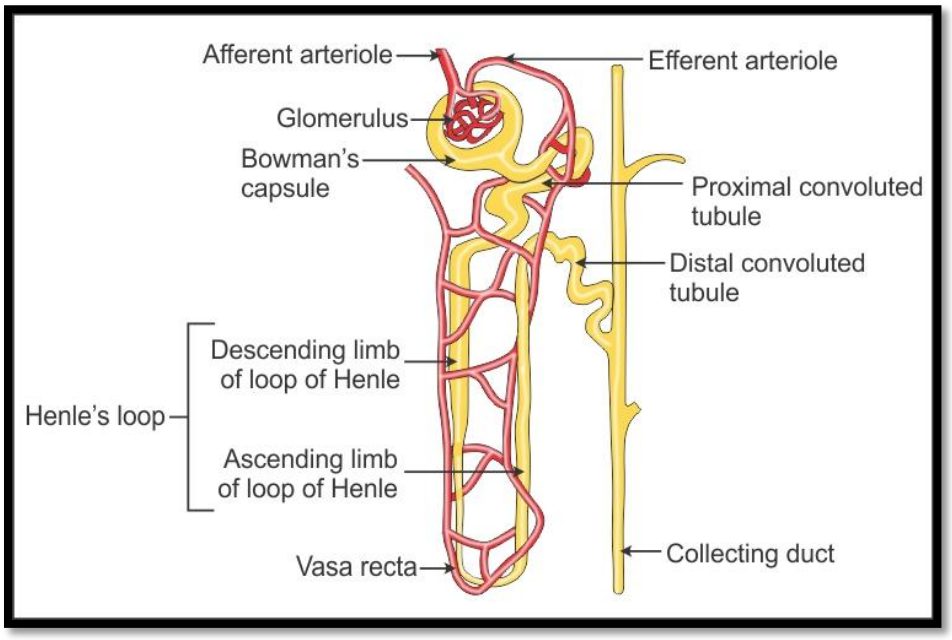


L. S. of Kidney

- The outer layer of the kidney is tough and called **capsule**.
- The inner concave surface of the kidney has a notch called **hilum**. Ureters, blood vessels and nerves enter the kidney through the hilum.
- The hilum extends into a flat, funnel-shaped region called the **pelvis**.
- The longitudinal section of the kidney shows two regions—an outer dark **cortex** and an inner lighter **medulla**.
- The medulla is composed of conical **renal pyramids** or **medullary pyramids**.
- Medullary pyramids project into calyces.
- The cortex extends in between the renal pyramids. These extensions are called **columns of Bertini**.
- The apex of each pyramid, i.e. **papilla**, projects into the pelvis.



Structure of Nephrons



- Uriniferous tubules or nephrons are the structural and functional units of the kidney.
- Each kidney is formed of about 1 million nephrons.
- Each nephron is made of a glomerulus and a renal tubule.

Glomerulus

- It is a **tuft of anatomising blood capillaries** formed by the fine branches of the **afferent arteriole**. These capillaries of the glomerulus again unite to form the **efferent arteriole**.

Renal Tubule

Bowman's Capsule	**Proximal Convoluted Tubule (PCT)**	**Loop of Henle**	**Distal Convoluted Tubule (DCT)**
• The Bowman's capsule lies in the **cortex**. • It is a thin double-walled, cup-like depression. It is the blind end of the nephron. • The glomerulus is located in the concave depression of the Bowman's capsule. • The Bowman's capsule and the glomerulus together are called **Malpighian**	• PCT lies in the **cortex**. • It is also known as the **first convoluted tubule**. • The Bowman's capsule continues into the PCT.	• It lies in the **medulla**. • It has a descending limb and an ascending limb. • Each limb has a thick region towards the cortex and a thin region towards the medulla.	• It lies in the **cortex**. • Its short terminal part is called a **collecting tubule**. • The collecting tubule opens into the **collecting duct**. • The **collecting duct** receives the contents of many renal tubules.

Capsule or **Renal Capsule**.			

Types of Nephrons

- **Cortical Nephron:** The loop of Henle is short and extends very little in the medulla.
- **Juxta Medullary Nephron:** The loop of Henle is very long and runs deep into the medulla.

Urine Formation

- The process formation of urine involves three steps.

Ultrafiltration

- It occurs in the Malpighian body.
- The hydrostatic pressure developed inside the glomerulus, filters the liquid part of blood into the lumen of the Bowman's capsule.
- The filtrate is called the **glomerular filtrate**. It contains water, urea, salts, glucose and other plasma solutes.
- Since the pressure occurs under great pressure it is called **ultrafiltration**.
- About 1100 − 1200 ml of blood is filtered by the kidneys per minute. It constitutes roughly about $1/5^{th}$ of the total blood pumped by each ventricle of the heart in a minute.
- The amount of filtrate formed by the kidneys per minute is called the **glomerular filtration rate (GFR)**.
- GFR of a healthy individual is approximately **125 ml/minute** which is **180 litres per day**.

Selective Reabsorption

- The useful substance present in the glomerular filtrate is reabsorbed in PCT, Henle's loop and DCT. This is called **selective reabsorption**.

Tubular Secretion

- The substances which are in excess amount in the body or which are unwanted by the body such as drug consumed through medicines, water are secreted into DCT. This is called **tubular secretion**.

Functions of Tubules

Proximal Convoluted Tubule (PCT)	Loop of Henle	Distal Convoluted Tubule (DCT)	Collecting Duct
• It is specialised for reabsorption.	• Reabsorption is minimum in the loop of Henle.	• DCT is responsible for the conditional absorption of water and Na^+.	• The collecting duct extends from the cortex of the kidney to the inner parts of the medulla.
• Entire glucose, most of Ca^{2+}, amino acids, K^+, Na^+, Cl^-, 70–80% of water and electrolytes are reabsorbed.	• The **descending limb** is permeable to water but impermeable to electrolytes, hence the water moves out from the filtrate making the filtrate concentrated. • The **ascending limb** is permeable to electrolytes and impermeable to water, hence, electrolytes move out from the filtrate, making it dilute. • This helps in maintaining the high osmolarity in the medullary interstitial fluid.	• It also reabsorbs HCO_3^- ions and amino acids. • It secretes K^+ ions, ammonia, hydrogen into the filtrate to maintain the pH and ionic concentration of blood.	• A large amount of water can be reabsorbed to produce concentrated urine. • Some urea is also reabsorbed. •

Mechanism of Concentration of Filtrate

- The urine is concentrated in the **loop of Henle** and **vasa recta**.
- In the two limbs of the loop of Henle, urine flows in the opposite direction which forms the counter current.
- Similarly, the flow of blood in the two limbs of the vasa recta are also in the counter current pattern.
- This system of a liquid flowing in the two limbs in two opposite directions is termed **counter current mechanism**.
- It helps to maintain the concentration gradient in the renal medulla and hence helps in concentrating urine by the loop of Henle.
- In the ascending limbs of the loop of Henle, Na+ ions leave the filtrate and enter into the surrounding interstitial fluid.
- Increased concentration of electrolytes in the interstitial fluid increases its osmolarity.
- This results in drawing out of water from the descending limb by osmosis.
- The descending limb is permeable to water as well as for the passive diffusion of NaCl.
- Water drawn into the interstitial fluid quickly enters the vasa recta.
- Entry of NaCl in the glomerular filtrate decreases the difference in salt concentration between the glomerular filtrate and the interstitial fluid. Hence, very less water is reabsorbed in the descending limb and the urine becomes hypertonic.
- Vasa recta are the blood capillaries which are around the loop of Henle.
- The vasa recta run parallel to each other and with the limbs of the loop of Henle.
- Water and solutes which leave the loop of Henle enter the vasa recta.
- The vasa recta carry this water and solutes away from the interstitial fluid to maintain osmolarity.
- This also increases the blood volume in the vasa recta.

Regulation of Kidney Function

- The glomerular filtration rate (GFR) is regulated by three methods:
- **Myogenic Autoregulation:** When the systemic blood pressure increases, the afferent arteriole narrows down which decreases GFR.
- **Neural Control:** Nerve fibres of the sympathetic nervous system innervate the blood vessels of the kidneys which decreases the GFR.
- **Hormonal Control:**

Anti-diuretic Hormone (ADH)	Renin	Atrial Natriuretic Factor
• The increased secretion of ADH promotes the reabsorption of water in DCT and collecting ducts.	• When there is a decrease in the GFR, juxta glomerular apparatus activates and secretes renin. Renin converts angiotensinogen (protein) into angiotensin (peptide).	• Atrial natriuretic factor (ANF) inhibits the release of renin and hence control the GFR
• Increased volume of body fluids results in the reduced secretion of ADH which decreases the permeability of DCT and collecting ducts for water.	• Angiotensin increases the GFR	•

Micturition

- The process of release of urine is called **micturition**.
- When the bladder is filled with urine, the receptors present in the walls of the bladder send signals to the central nervous system.
- The central nervous system passes on motor messages which initiate the contraction of smooth muscles of the urinary bladder and the relaxation of the urethral sphincters, causing the release of urine.

Role of Other Excretory Organs

- **Sweat Glands:** Sweat glands excrete sweat which contains NaCl, urea and lactic acid. Sweating help in maintain the temperature of the body.
- **The Lungs:** The lungs remove carbon dioxide and water vapour through expiration.
- **Liver:** The liver eliminates cholesterol, inactivated products of steroid hormones, vitamins and drugs.
- **Large Intestine:** Epithelial cells of the large intestine remove salts such as calcium phosphate and they are eliminated through faeces.