EXCRETORY PRODUCTS & THEIR ELIMINATION

Excretion is the elimination of metabolic wastes like **ammonia, urea, uric acid** etc. from the tissues.

Types of excretion

1. **Ammonotelism:** Process of excretion of **NH_3.**
   Ammonotelic animals: Aquatic invertebrates, aquatic insects, bony fishes, aquatic amphibians etc.
   NH_3 is highly toxic. So, excretion needs excess of water.
   NH_3 is readily soluble in water and is excreted by diffusion through body surface or gill surfaces (in fishes) as ammonium ions.
   Kidneys do not play any significant role in its removal.
2. **Ureotelism:** Process of excretion of **urea.**
   Ureotelic animals: Cartilaginous fishes, terrestrial & semi-aquatic amphibians (frogs, toads etc.), aquatic & semi-aquatic reptiles (alligators, turtles), mammals etc.
   In liver, NH_3 is converted into less toxic urea. So, it needs only moderate quantity of water for excretion.
   Some amount of urea may be retained in the kidney matrix of some animals to maintain a desired osmolarity.
3. **Uricotelism:** Process of excretion of **uric acid.** It is water insoluble & less toxic. So, water is not needed for excretion.
   Uricotelic animals: Insects, some land crustaceans, land snails, terrestrial reptiles & birds.

Ureotelism & uricotelism are needed for water conservation.

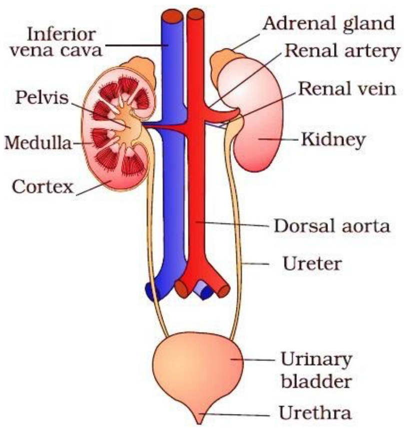
Some excretory organs in animals

- **Protonephridia (flame cells):** In Flatworms, rotifers, some annelids & cephalochordate (*Amphioxus*). Protonephridia are primarily for osmoregulation.
- **Nephridia:** In Annelids. Help in the removal of nitrogenous wastes and osmoregulation.
- **Malpighian tubules:** In Insects. Help in the removal of nitrogenous wastes and osmoregulation.
- **Antennal or green glands:** In Crustaceans (prawn etc.)
- **Kidneys:** In higher animals.

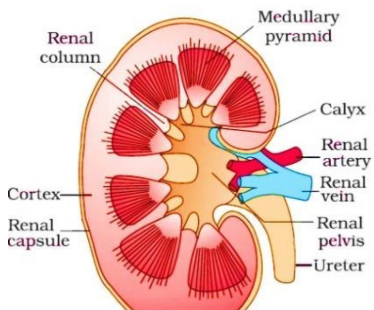
HUMAN EXCRETORY SYSTEM

It includes **kidneys, ureters, urinary bladder** & **urethra.**

Structure of Kidney



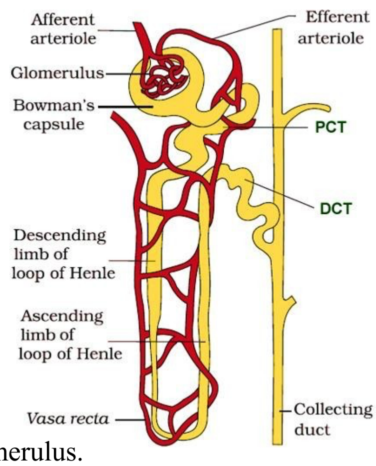
- Reddish brown, bean-shaped structures situated between the levels of last thoracic & 3rd lumbar vertebra.
- Length: **10-12 cm,** width: **5-7 cm,** thickness: **2-3 cm.** Average weight: **120-170 gm.**
- It is enclosed in a tough, 3-layered **fibrous renal capsule.**
- On the concave side of kidney, there is an opening (**hilum** or **hilus**) through which blood vessels, nerves, lymphatic ducts and ureter enter the kidney.



- Hilum leads to funnel shaped cavity called **renal pelvis** with projections called **calyces.**
- A kidney has outer **cortex** & inner **medulla.**
- Medulla has few conical projections called **medullary pyramids (renal pyramids)** projecting into the calyces.
- Cortex extends in between the medullary pyramids as renal columns **(Columns of Bertini).**
- Each kidney has nearly one million tubular **nephrons**.

Nephron

- Nephrons are the structural & functional units of kidney.
- Each nephron has 2 parts: **Glomerulus** & **Renal tubule.**



- **Glomerulus:** A tuft of capillaries formed by **afferent arteriole** (a fine branch of renal artery). Blood from glomerulus is carried away by **efferent arteriole.**
- **Renal tubule:** It begins with a double walled cup-like **Bowman's capsule**, which encloses the glomerulus.

Glomerulus + Bowman's capsule = Malpighian body

- The tubule continues with **proximal convoluted tubule (PCT), Henle's loop** & **distal convoluted tubule (DCT).**
- Henle's loop is hairpin-shaped. It has **descending and ascending limbs.**
- The DCTs of many nephrons open into a **collecting duct**. Collecting duct extends from cortex to inner parts of medulla. They converge and open into the **renal pelvis** through **medullary pyramids** in the **calyces.**
- **Malpighian body (Renal corpuscle), PCT** and **DCT** are situated in **renal cortex. Loop of Henle** dips into **medulla.**
- The **efferent arteriole** forms a fine capillary network **(peritubular capillaries)** around the renal tubule. A minute vessel of this network runs parallel to Henle's loop forming a 'U' shaped **vasa recta**.

Types of nephrons

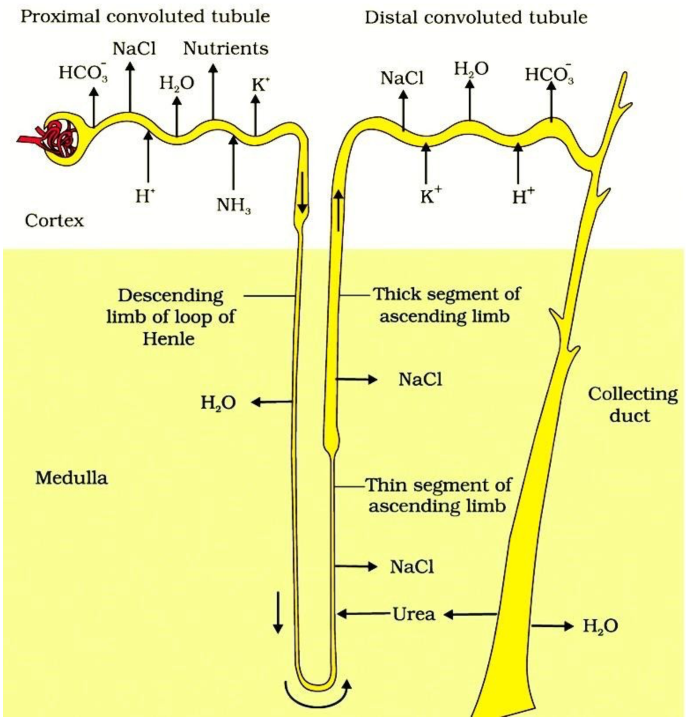
1. **Cortical nephrons** (85%): In this, the Henle's loop is short and extends only very little into the medulla. Vasa recta is absent or highly reduced.
2. **Juxtamedullary nephrons** (15%): In this, Henle's loop is long and runs deep into medulla. Vasa recta present.

URINE FORMATION (PHYSIOLOGY OF KIDNEY)

3 processes: Glomerular filtration, reabsorption & secretion.

1. Glomerular filtration (ultrafiltration)

- The glomerular capillary blood pressure causes filtration of blood through 3 layers, i.e. **endothelium of glomerular blood vessels**, **epithelium of Bowman's capsule** & **a basement membrane** between these 2 layers.
- The epithelial cells **(podocytes)** of the Bowman's capsule are arranged in an intricate manner leaving some minute spaces called **filtration slits (slit pores).**
- Almost all constituents of the blood plasma except the proteins pass onto the lumen of the Bowman's capsule.
- About **1100-1200 ml of blood** is filtered by the kidneys per minute. It constitutes **$1/5^{th}$** of the blood pumped out by each ventricle of the heart in a minute.
- The amount of glomerular filtrate formed per minute is called **Glomerular filtration rate (GFR).**
- **Normal GFR = 125 ml/minute, i.e., 180 litres/day.**



2. Reabsorption

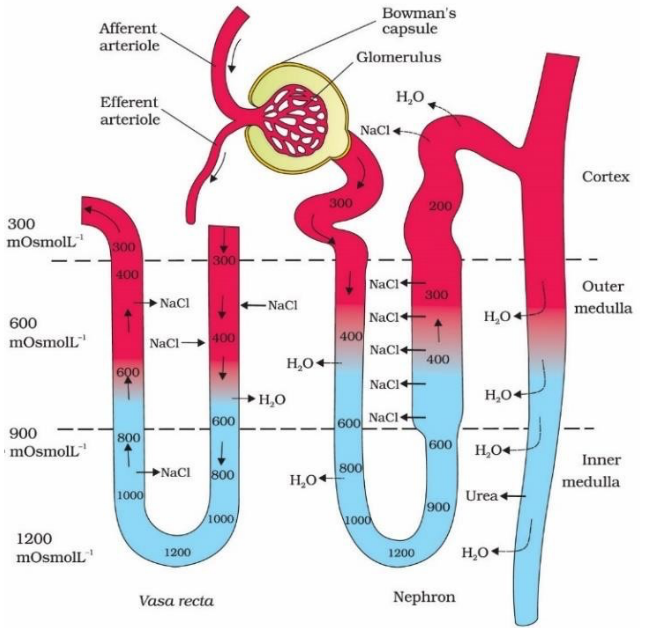
- **180 litres** of glomerular filtrate is produced daily. But about **99%** of this is reabsorbed by the renal tubules.
  So normal volume of urine released is **1.5 litres.**
- From the filtrate, **glucose, amino acids, Na^+,** etc. are reabsorbed **actively** and **nitrogenous wastes** are absorbed **passively**. Passive reabsorption of water occurs in the initial segments of the nephron.
- **PCT** reabsorbs most of the nutrients, and 70-80% of electrolytes & water. Simple cuboidal brush border epithelium of PCT increases surface area for reabsorption.
- **Loop of Henle** maintains high osmolarity of medullary interstitial fluid.
  Descending limb is permeable to water but almost impermeable to electrolytes. This concentrates the filtrate.
  In **ascending limb,** minimum reabsorption occurs. It is impermeable to water but allows transport of electrolytes.
  So, filtrate gets diluted.
- In **DCT,** conditional reabsorption of Na^+ & water takes place.
- **Collecting duct** extends from cortex to inner parts of medulla. It reabsorbs large amount of water to concentrate urine. It also allows passage of small amounts of urea into medullary interstitium to keep up the osmolarity.

3. Tubular Secretion

- Cells of **PCT** & **DCT** maintain **ionic** (Na-K balance) and **acid-base balance (pH)** of body fluids by selective secretion of H^+, K^+ & NH_3 into the filtrate and absorption of HCO_3^- from it.
- **Collecting duct** also maintains pH and ionic balance of blood by the secretion of H^+ and K^+ ions.

Mechanism of concentration of the filtrate

- **Henle's loop** & **vasa recta** help to concentrate the urine.
- The flow of **filtrate** in the 2 **limbs of Henle's loop** and the flow of **blood** through the 2 **limbs of vasa recta** are in opposite directions (counter current pattern). This is called **Counter current mechanism.**
- Due to the counter current and proximity between Henle's loop & vasa recta, **osmolarity** increases from cortex **(300 $mOsmolL^{-1}$)** to the **inner medullary interstitium (1200 $mOsmolL^{-1}$).** This gradient is caused by **NaCl & urea.**
- NaCl is transported by ascending limb of Henle's loop that is exchanged with descending limb of vasa recta. NaCl is returned to interstitium by ascending limb of vasa recta. Similarly, small amount of urea enters the thin segment of the ascending limb of Henle's loop which is transported back to the interstitium by the collecting tubule. Thus electrolytes and urea are retained in the interstitium and maintain a **concentration gradient (interstitial gradient)** in medullary interstitium. It enables easy passage of water from collecting tubule to concentrate the filtrate (urine).
- Thus DCT & collecting duct produce urine **four times concentrated** than the initial filtrate formed (i.e. 300 $mOsmolL^{-1}$ to 1200 $mOsmolL^{-1}$).



MICTURITION

- Gradual filling of urinary bladder causes stretching. As a result, **stretch receptors** on its wall send impulses to CNS. The CNS passes on **motor messages.** It causes the contraction of **smooth muscles** of the bladder and simultaneous relaxation of the **urethral sphincter.** It results in **micturition** (release of urine).
- The neural mechanism causing micturition is called **micturition reflex.**
- An adult human excretes **1 to 1.5 litres** of urine (**25-30 gm urea)** per day.
- Urine is a **light yellow coloured watery fluid**, slightly **acidic (pH-6.0)** and has a characteristic odour.
- Various conditions affect the characteristics of urine.
- Analysis of urine helps in **clinical diagnosis** of many metabolic disorders and malfunctioning of the kidney.

E.g. **Glycosuria** (presence of glucose) and **Ketonuria** (ketone bodies) in urine indicates **diabetes mellitus.**

Role of Lungs, liver & skin in Excretion

- **Lungs:** Remove CO_2 **(200 mL/minute)** and **water.**
- **Liver:** Secretes bile containing **bilirubin, biliverdin, cholesterol, degraded steroid hormones, vitamins** and **drugs.** Most of them pass out along with digestive wastes.
- **Skin (Sweat glands & sebaceous glands): Sweat** contains water, NaCl, small amounts of urea, lactic acid, etc. Primary function of sweat is to give a **cooling effect** on body surface.

  Sebaceous glands eliminate **sterols, hydrocarbons, waxes etc.** through **sebum.** Sebum provides a protective oily covering for the skin.
- **Saliva** eliminates small amounts of nitrogenous wastes.

REGULATION OF THE KIDNEY FUNCTION

- It is done by hormonal feedback mechanisms involving the **hypothalamus, JGA** and the **heart.**
- Changes in **blood volume, body fluid volume** and **ionic concentration** activate **Osmoreceptors** in the body.

1. Regulation by ADH (vasopressin)

- When body fluid level decreases, the **osmoreceptors** stimulate **hypothalamus** to release **antidiuretic hormone (ADH)**. It stimulates water reabsorption from **DCT** & **collecting duct**. Thus, ADH prevents **diuresis** and increases body fluid volume.
- Increase in fluid volume switches off the osmoreceptors and suppresses ADH release to complete the feedback.
- ADH constricts blood vessels resulting in an increase of BP. This increases the glomerular blood flow and GFR.

2. Regulation by JGA (Renin-Angiotensin mechanism)

- **JGA (Juxta glomerular apparatus)** is a sensitive region formed by cellular modification of **DCT** and the **afferent arteriole** at the location of their contact.
- JGA regulates the **GFR.**
- A fall in glomerular blood flow/glomerular blood pressure/GFR activates the **JG cells** to release **renin.**
- Renin converts **angiotensinogen** in blood to **angiotensin I** and further to **angiotensin II** (a **vasoconstrictor**).
- Angiotensin II performs the following functions:
  - ❖ Increases glomerular blood pressure and thereby GFR.
  - ❖ Activates **adrenal cortex** to release **Aldosterone.**
- Aldosterone causes **reabsorption** of $\mathbf{Na^+}$ and **water** from the **distal parts** of the tubule. This also leads to an increase in blood pressure and GFR.

3. Regulation by ANF

- ANF check on the renin- angiotensin mechanism.
- An increase in blood flow to the atria of the heart causes the release of **Atrial Natriuretic Factor (ANF).**
- ANF causes **vasodilation** (dilation of blood vessels) and thereby decreases the blood pressure.

DISORDERS OF EXCRETORY SYSTEM

- **Uremia**: Accumulation of urea in blood due to malfunction of kidney. It may lead to **kidney failure (renal failure).**
- **Renal calculi:** Stone or insoluble mass of crystallized salts (oxalates, etc.) formed within the kidney.
- **Glomerulonephritis:** Inflammation of glomeruli.

Hemodialysis

- It is a process of removal of **urea** in patients with uremia.
- The **dialyzing unit** (artificial kidney) contains a coiled **cellophane tube** surrounded by **dialyzing fluid.** It has same composition of plasma except nitrogenous wastes.
- Blood drained from a convenient artery is pumped into **dialyzing unit** after adding anticoagulant like **heparin.**
- The porous **cellophane membrane** of the tube allows the passage of molecules based on concentration gradient.
- As nitrogenous wastes are absent in dialyzing fluid, these substances freely move out, thereby clearing the blood.
- The purified blood is pumped back to the body through a vein after adding **anti-heparin** to it.

Kidney transplantation

- It is the ultimate method in the correction of **acute renal failures.** A functioning kidney is taken from a donor.
- It is better to receive kidney from a close relative to minimize chances of rejection by immune system of host.

MODEL QUESTIONS

1. Terrestrial animals are generally either ureotelic or uricotelic, not ammonotelic. Why?
2. Note the relationship between first two words and fill up the fourth place
   a) Bony fishes: Ammonotelism   Birds:…………………
   b) JG cells: Renin   Atria:………………….
3. Complete the following sentences
   a) Reabsorption of water from DCT is facilitated by the hormone................
   b) Angiotensin ll activates the adrenal cortex to release.................
   c) In cases of Kidney failure, urea can be removed by the process called................
4. Match the following

A	B	B
Malpighian body	Urethral sphincter	Oxalates
Uraemia	Glomerulus	Release of urine
Renal calculi	Accumulation of urea	Afferent and efferent arterioles
Micturition	Crystallized salts	Kidney failure

5. Prepare a flowchart of filtrate flow in the nephron using the flow terms.
   Collecting duct, PCT, DCT, Ascending limb of Henle’s loop, descending limb of Henle’s loop, Bowman’s capsule
6. “Counter current system plays an important role in concentrating urine.” Name any two regions inside the kidney, where the counter current system is seen.
7. Complete the flowchart given below:
   (Hint: Angiotensin II, JG cells, Constricts blood vessels, Angiotensinogen, Aldosterone)

.... **A** .....

Fall in glomerular blood flow → .... **B**.... → Renin

Angiotensin I

Converting enzyme

.... **C** .....

Secretion of .... **D** .... **E** .....

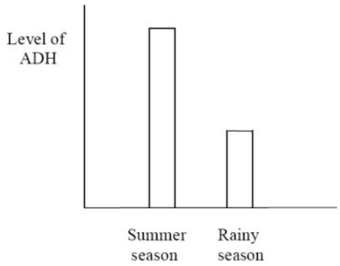
↓   ↓

Reabsorption of Na⁺ and water from distal parts of the tubule   Increase in BP and GFR

↓

Increase in BP and GFR

8. Observe the diagram



   a) In which season ADH production is higher?
   b) Why the production of ADH varies in different seasons?