Chapter 42

Excretory System

- The tissues and organs associated in the removal of waste products (called excretion) constitute the **excretory system**.
- **Excretion** is the "process of eliminating (from an organism) the waste products of metabolism of nitrogenous substances like amino acids and nucleic acids and other materials that are of no use.
- Some of these structures constitute the **urinary system** which is involved in the synthesis, separation and elimination of mainly nitrogenous waste products and other mineral salts.
- The urinary system **produces, stores and eliminates urine** after it produces and modifies a urinary filtrate **consisting of a large volume of hypotonic blood filtrate rich in serum proteins**.
- The **main aim of the excretion** is to maintain a constant body temperature by removing excess heat and maintain a constant internal environment in association with the other system of the body (called **homeostasis**).
- Excretion is an essential process in all forms of life. In **one celled organisms** wastes are discharged through the surface of the cell. The **higher plants eliminate** gases through the stomata, or pores, on the leaf surface. **Multicellular animals** have special excretory organs.
- The waste product could be nitrogenous, non – nitrogenous, chemicals, bile pigments, excess of water or CO_2.
- **Metabolism of carbohydrates and fats** produces CO_2 and H_2O which are easy to remove. Their excretion is effected through lungs (expired air), skin (sweat) or kidneys (urine).
- Carbon dioxide produced as the waste product during respiration, diffuses out of the cells into the lung tissue and leaves the body everytime we exhale.
- Other excretory products are pigments, mostly formed by the breakdown of haemoglobin; drugs etc.
- **Protein metabolism** produces nitrogenous waste material such as ammonia, which is the basic nitrogenous catabolite of protein, formed by breakdown of amino acids.
- Removal of the amino group (NH_2) is known as **deamination** and it converts the amino acid into a keto acid.
- Nitrogeneous waste **have the ability to change the pH of cells and interferes with membrane transport functions and may denature enzymes**.
- Some common nitrogenous excretory products are – **Ammonia** (very toxic and requires large amount of water, eg. aquatic invertebrate such as *Amoeba,* sponge, *Unio*, star fish etc.); **urea** (less toxic, eg. cartilaginous fishes, amphibians and mammals), **uric acid** (least toxic, eg. reptiles, birds and cockroaches), **trimethylamine oxide** (eg. marine bony fish, mollusca, crustaceae), **ornithuric acid** (birds), **guanine**, **creatinine** etc.
- The **main three nitrogenous wastes** are – **ammonia**, **urea** and **uric acid**.
- Animals excreting ammonia, urea and uric acid are respectively called as **ammonotelic, ureotelic** and **uricotelic animals.**
- Ammonia is **highly toxic** and **soluble in water** with which it forms ammonium hydroxide (NH_4OH) which injure cell directly by alkaline caustic action. Hence excretion of **ammonia requires large amounts of water to be lost from the body**.
- Ammonia is the **first metabolic waste product** of protein metabolism.
- **No energy is required** to produce ammonia.
- Ammonotelic organisms (without excretory system) **includes all aquatic invertebrates**, **bony fishes**, **aquatic amphibians**.
- The **terrestrial animals excrete urea** as nitrogenous waste product.
- Urea is **produced in liver** from some proteins

(ornithine, citrulline, arginine) and other nitrogen compound by deamination process **in presence of arginase enzyme.**

- Urea is the **end product of protein or amino acid.**
- Urea is **eliminated in the form of urine.**
- **Formation of urea cycle, also known as the urea or ornithine cycle**, is a cycle of biochemical reactions occurring in many animal organisms that produces urea from ammonia (NH_4^+) due to lack of water.
- This cycle was the **first metabolic cycle discovered** by **Krebs and Hensenleit, 1932**.
- The urea cycle consists of **five reactions - two mitochondrial** and **three cytosolic** (*Refer table given below*).
- **Earthworm excrete ammonia** when sufficient water is available **but it eliminates urea** when water is not available in good quantity.
- In anurans (amphibians) the **larval tadpole excrete ammonia, while the adults produce urea.**
- **Uric acid** is the **nitrogenous waste product of** terrestrial animals such as **birds**, **many reptiles**, **insects** and **land snails** that do not have constant access to water or rather have limited access to water.
- Conversion of ammonia to uric acid and its subsequent elimination requires lesser amount of water as it is comparatively less soluble in water and less toxic as compared to ammonia.
- Uric acid is a **more complex molecule than urea so it requires more energy to produce.**
- **Xanthine oxidase** is needed in production of uric acid.
- **Bilirubins** are the **toxic bile pigment** formed in liver during disintegration of dead RBCs.
- In some reptiles and insects the uric acid is further changed into **allantoin.**
- Marine teleost fishes excrete a large proportion of nitrogen as **trimethylamine oxide**.
- **Guanine** is a **metabolic waste of nucleotide metabolism**, found in spider and penguin.
- The regulation of water content and salt concentration in the body of an organisms is called **osmoregulation.**
- **Osmoconformers** are organisms that show changes in the body fluid concentration according to the concentration of external environment, e.g., most of marine invertebrates.
- **Osmoregulators** are organisms that maintain a fixed osmotic concentration in the body fluid despite changes in the external environment.
- **Marine invertebrates and cartilaginous fish (chondrichthyes) are isotonic** in which the concentration of solutes in isotonic animals is approximately equal to that of their environment. As a result, they do not gain or lose water.
- Birds and reptiles living near the sea consume a large amount of salt in their diet. **Nasal salt glands** remove this excess salt from their body by secreting a concentrated salt solution.
- The kidneys of sea mammals (example seal, whales, porpoise) are able to maintain a constant salt concentration in their bodies by producing urine having high concentration of salt.
- Kangaroo rats (a desert mammal) **never have to drink water**. Their water comes from metabolic

Table : Reactions in urea cycle

Step	Reactant	Product	Catalyzed by	Location
1.	$2ATP + HCO_3^- + NH_4^+$	Carbamoyl phosphate + 2ADP + P_i	CPSI	Mitochondrial
2.	Carbamoyl phosphate + ornithine	Citrulline + P_i	OTC	Mitochondrial
3.	Citrulline + aspartate + ATP	Argininosuccinate + AMP + PP_i	ASS	Cytosolic
4.	Argininosuccinate	Arg + fumarate	ASL	Cytosolic
5.	Arg + H_2O	Ornithine + urea	ARGI	Cytosolic
CPSI – Carbamoyl phosphate synthetase; OTC - Ornithine transcarbamoylase; ASS – Arginosuccinate synthetase; ASL – Arginosuccinate lyase.				

water released during cellular respiration and water present in their food.

- In humans the **main organs of excretion** are the **kidneys** and **accessory urinary organs**, through which urine is eliminated, and the **large intestines**, from which solid wastes are expelled.
- The **skin and lungs** also **have excretory functions**.The **skin eliminates water and salt in sweat,** and the **lungs expel water vapour and carbon dioxide.**
- The waste products are **eliminated by urination and exhalation**.
- **Urination**, also called **micturition**, is the process of disposing urine from the urinary bladder through the urethra to the outside of the body.
- The **process of urination is usually under voluntary control**. When control over urination is lost or absent, this is called **urinary incontinence**.
- **Urinary retention** refers to the **inability to urinate**.
- **Perspiration** is another excretory process which removes salts and water, although the primary purpose is cooling.

EXCRETORY SYSTEM

- The **mammalian (human) urinary system** consists of – **two kidneys** (which form the urine), two **ureters** (which conduct the urine from kidneys to the urinary bladder), a **urinary bladder** (for storage of urine) and a **urethra** (through which the urine is voided by bladder contractions).
- Human beings are **ureotelic**.
- Kidney (**mesodermal** in origin) are **excretory and homoestatic organ**.
- An average sized kidney measures 10 to 12 cm in **length**, 5 to 6 cm in **width** and 3 to 4 cm in **thickness**, **each weighing about 150 g in adult male and about 135 g in female**.
- The human **kidneys** are **bean-shaped** excretory organs which filter wastes (especially urea) from the blood and excrete them, along with water, as urine.
- The medical field that studies the kidneys and diseases affecting the kidney is called **nephrology**.
- **Ureters** are narrow tubes started as a pelvis within kidney opening into a common urinary bladder which opens outside through urethra.
- **Urethra** is a muscular tube that connect urinary bladder and external opening of urinary tract.

Table : Organ of excretion in different animals

	Organ of excretion	**Name of animals**
1.	Contractile vacuoles & plasma membrane	Protozoans
2.	General body surface	*Hydra* and sponges
3.	Renette cells	Aschelminthes
4.	Flame cells (solenocytes) & protonephridia	*Planarians*
5.	Nephridia & chloragogen cells	Earthworm (annelida)
6.	Malpighian tubules	Insects (arthropoda)
7.	Coxal gland	Spider (arachnida, phylum-arthropoda)
8.	Green gland	Prawn (crustacea, phylum arthropoda)
9.	Keber's organ or organs of Bojanus	Mollusca
10.	Skin	Amphibia
11.	Kidneys	Vertebrates

- Urethra **is smaller in females and longer in males.**
- Urethra **conduct urine to the exterior**. The urethral sphincters keep the urethra closed except during voiding of urine.
- **Urinary bladder** is sac like structure which **stores urine temporarily**. Ureters and urinary bladder are **lined by flexible transitional epithelium.**
- The kidneys are **retroperitoneal**, which means they lie behind the peritoneum, the lining of the abdominal cavity (means **posterior part of the abdomen**).They are approximately at the vertebral level T_{12} to L_3.
- The **right kidney sits just below the liver**, the **left below the diaphragm and adjacent to the spleen.**
- The asymmetry within the abdominal cavity caused by the liver results in the **right kidney to be slightly lower than the left one.**
- A deep notch or concavity is present at the medial border - the **hilus (hilum),** and it is through this region the blood vessels-renal artery and vein, ureter and nerves pass.

Types of kidney

- Types of kidneys are of following types – **archinephros**, **pronephric**, **mesonephric** and **metanephric**.
- **Archinephros**, found in the larvae of some cyclostomes, is the **basic and ancestral form of kidney**.
- **Pronephric kidney** or **anterior kidney** is found only in cyclostomes and tadpole of frogs. It is **developed from anterior most part of the nephrostome and are the primitive kidney**.
- **Mesonephric kidney** or **middle kidney** is found only in fish and frog. It is **developed just after pronephros** in the nephrostome.
- Mesonephric kidney is the **second stage in the development of the kidney**.
- **Metanephric kidney** or **posterior kidney** (**most advanced type**) is found in reptiles, birds and mammals. It is formed from the **posteriormost part** of nephrostome, behind embryonic mesonephros.

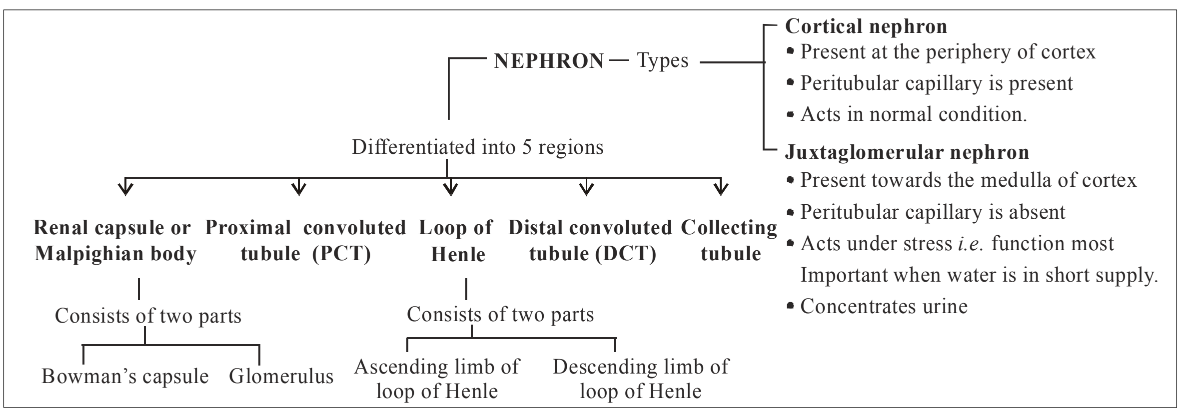
- The **upper parts** of the kidneys are partially **protected by the eleventh and twelfth ribs**, and each **whole kidney is surrounded by two layers of fat (the perirenal fat and the pararenal fat) which help to cushion it**.
- The **outermost portion** of the kidney is called the **renal cortex**, which sits directly beneath the kidney's loose connective tissue capsule.
- The **renal cortex** is **granular in appearance** because the tubules here are much convoluted (proximal and distal convoluted tubules) and contain malphigian corpuscles.
- **Cortex is subdivided into** alternating radial tracts known as **rays** and **labyrinths**.
- The **rays** are radially straight since they contain the straight parts of proximal tubules and the collecting ducts. They are continuous with striated medulla, hence called **medullary rays**.
- The **labyrinths** have a granular appearance because the convoluted tubules, which compose them, are cut irregularly.
- Deep to the cortex lies the **renal medulla**, which is **divided into** 10-20 **renal pyramids** in humans. Each pyramid together with the associated overlying cortex forms a renal lobe.
- The lateral boundaries of the pyramid are formed by the projection of the darker cortex which are named as **renal columns of Bertini**.
- **Renal medulla** mainly **contains loop of Henle, collecting tubules and ducts of Bellini.**
- The tip of each pyramid (called a **papilla) empties into a calyx**, and the calyces empty into the renal pelvis.
- The pelvis **transmits urine to the urinary bladder** *via* **the ureter.**
- Each "kidney" **receives its blood supply from the renal artery,** two of which branch from the abdominal aorta.
- Due to the position of the aorta, the inferior vena cava and the kidneys in the body, the **right renal artery is normally longer than the left renal artery**. The right renal artery normally crosses posterior to the inferior vena cava.
- Upon entering the hilum of the kidney, the **renal artery divides into smaller interlobar arteries situated between the renal papillae**.
- At the outer medulla, the interlobar arteries branch into **arcuate arteries**, which course along the border between the renal medulla and cortex, giving off still smaller branches, the **cortical radial arteries** (sometimes called **interlobular arteries**).
- Branching off these cortical arteries are the **afferent arterioles supplying the glomerular capillaries**, which drain into **efferent arterioles**.
- The walls of the afferent arteriole **contain specialized smooth muscle cells** (juxtaglomerular apparatus or cells**) that synthesize renin**.
- These juxtaglomerular cells or apparatus **play a major role in the renin-angiotensin system**, which helps regulate blood volume and pressure.
- Juxtaglomerular apparatus or juxtaglomerular cells includes – granular **juxtaglomerular cells** in the afferent arteriole; **macula densa** of the proximal part of the distal collecting tubule; and agranular **Polkissen or Lacis cells.**
- **Polkissen or lacis cells** are situated in the angle created by the entrance and exit of the afferent and efferent arterioles of each glomerulus.
- Blood leaves the capillaries of the glomerulus *via* an **efferent arteriole** and enters capillaries in the medulla called **peritubular capillaries,** which collect much of the water that was lost through the glomerulus.
- Blood from these capillaries collects in renal

venules and leaves the kidney *via* the **renal vein.**

- The **renal veins connect the kidney to the inferior vena cava**. Because the inferior vena cava is on the right half of the body, the left renal vein is generally the longer of the two.
- Efferent arterioles of glomeruli closest to the medulla (those that belong to juxtamedullary nephrons) send branches into the medulla, forming the **vasa recta**.
- Along with the loop of Henle, these vasa recta **play a crucial role in the establishment of the nephron's countercurrent exchange system.**
- **Counter current mechanism** (the process due to which the urine is made hypertonic) is regular exchange of Na^+ ions between the ascending and descending limbs of kidney.
- Blood supply is **intimately linked to blood pressure**.

NEPHRON

- The **basic structural** and **functional unit of the kidney** is the **nephron**, of which there are more than a million (approximately 1.3 million) in each normal adult human kidney.
- Nephrons **regulate water and soluble matter** (especially electrolytes) in the body by first filtering the blood, then reabsorbing some necessary fluid and molecules while secreting other, unneeded molecules.
- Reabsorption and secretion are accomplished with both cotransport and countertransport mechanisms established in the nephrons and associated collecting ducts.
- Nephrons **eliminate wastes from the body, regulate blood volume and pressure, control levels of electrolytes and metabolites, and regulate blood pH**.
- **Functions of nephron are vital to life and are regulated by the endocrine system by hormones** such as antidiuretic hormone, aldosterone, and parathyroid hormone.
- **Two types of nephrons** present in kidney are: **cortical and juxtamedullary nephrons**.
- **Cortical nephrons** (70–80%) close to kidney surface, **have a shorter loop of Henle and peritubular capillary network.**
- **Juxtamedullary nephrons** (20–30%) at the junction of renal cortex and medulla, **have a longer loop of Henle and vasa recta.**
- Juxtamedullary nephrons are **important in the counter current mechanisms** in which the kidney concentrate the urine.
- Each **nephron is composed of** an initial **filtering component** (the **renal corpuscle**) and **a tubule** specialized for reabsorption and secretion (the **renal tubule**).
- The renal corpuscle **filters out large solutes from the blood, delivering water and small solutes to the renal tubule for modification.**
- The renal corpuscle (or Malpighian corpuscle) is **composed of a glomerulus and Bowman's capsule**.
- The malpighian corpuscle is named after **Marcello Malpighi** (1628 - 1694), an Italian physician and biologist.
- **Glomerulus** is a capillary (fenestrated) tuft that **receives its blood supply from an afferent arteriole of the renal circulation.**
- The remainder of the blood not filtered into the glomerulus passes into the narrower **efferent arteriole.**



The **glomerulus (plural glomeruli) in olfaction** is a structure in the olfactory bulb. It is made up of a globular tangle of axons from the olfactory receptor neurons in the olfactory epithelium and dendrites from the mitral cells, tufted cells and other cells types.

Glomeruli are important waystations in the pathway from the nose to the olfactory cortex. Each glomerulus receives input from olfactory receptor neurons. The glomerulus is the **basic unit in the odour map of the olfactory bulb**.

- The **diameter of the afferent arteriole is much more** than that of efferent arteriole.
- **Bowman's capsule** (also called the **glomerular capsule**) is a blind sac which surrounds the glomerulus.
- Bowman's capsule is composed of **inner visceral (simple squamous epithelial cells)** and **outer parietal (simple squamous epithelial cells) layers.**
- Bowman's capsule is named after **Sir William Bowman** (1816 - 1892), a British surgeon and anatomist.
- The **visceral layer** lies just beneath the thickened glomerular basement membrane and is **made of podocytes** which send foot processes over the length of the glomerulus.
- Foot processes interdigitate with one another forming **filtration slits** that, in contrast to those in the glomerular endothelium, are spanned by diaphragms.
- The **size of the filtration slits restricts the passage of large molecules** (eg, albumin) and **cells** (eg, red blood cells and platelets). In addition**, foot processes have a negatively-charged coat (glycocalyx)** that limits the filtration of negatively-charged molecules, such as albumin.
- Between the visceral and parietal layers is **Bowman's space**, into which the filtrate enters after passing through the podocytes' filtration slits.
- Unlike the visceral layer, the **parietal layer does not function in filtration**. Rather, the **filtration barrier is formed by three components**: the diaphragms of the filtration slits, the thick glomerular basement membrane, and the glycocalyx secreted by podocytes.
- The **process of filtration of the blood in the Bowman's capsule** is **ultrafiltration (or glomerular filtration)**, and the **normal rate of filtration is 125 ml/min**.

Any protein under roughly 30 kilodaltons can pass freely through the membrane, although there is some extra hindrance for negatively charges of the basement membrane and the podocytes. Any small molecules such as water, glucose, salt (NaCl), amino acids, and urea pass freely into Bowman's space, but cells, platelets and large proteins do not. As a result, the filtrate leaving the Bowman's capsule is very **similar to blood plasma in composition** as it passes into the proximal convoluted tubule.

- The filtrate leaving the Bowmans capsule is very **similar to blood plasma in compostion** as it passes into the proximal convoluted tubule.
- **Measuring the glomerular filtration rate** (GFR) is a **diagnostic test of kidney function**. A decreased GFR may be a sign of renal failure.
- The **renal tubule functions as a dialysis unit**, in which the fluid inside the tubule is the internal solution and the blood (in capillaries surrounding the tubule) acts as the external solution.
- The **renal tube consists of three parts:** the **proximal convoluted tubule, the loop of Henle,** and **the distal convoluted tubule.**
- **Proximal convoluted tubules (PCT) or pars convoluta** is about 14 mm long and lined by a single layer of cubical cells.

'Proximal' means that it is near Bowman's capsule, and 'convoluted' describes its coiled and looped shape.

- Cells of the proximal convoluted tubule **have numerous microvilli and mitochondria which provide surface area and energy and closeness of blood capillaries**.
- **Selective reabsorption occurs** in the proximal convoluted tubule.
- The **loop of Henle** (sometimes known as the nephron loop) is a U-shaped tube that **consists of a descending limb** and **ascending limb.**
- Loop of Henle **begins in the cortex**, receiving filtrate from the proximal convoluted tubule, extends into the medulla, and then returns to the cortex to empty into the distal convoluted tubule only in juxtamedullary nephrons. In other nephrons, the loop merely extends through the kidneys cortex.
- Its **primary role is to concentrate the salt in the interstitium**, the tissue surrounding the loop.
- The **longer the nephron**, the better **it performs its**

countercurrent exchange mechanism.

- **Loop of Henle** is **short or absent** in other vertebrates like reptiles which cannot secrete hyperosmotic urine.
- **Descending limb** are **thin walled, lined by squamous epithelium.**
- Descending limb is **permeable to water but completely impermeable to salt**, and thus only indirectly contributes to the concentration of the interstitium.
- Longer descending limbs allow more time for water to flow out of the filtrate, so **longer limbs make the filtrate more hypertonic than shorter limbs.**
- **Ascending limb** are **thick walled formed by cuboidal epithelium** and **impermeable to water**. It **actively reabsorbs** the remaining 25% of the filtered K^+ and some amounts of Cl^-, some Na^+ is also reabsorbed by diffusion due to electrostatic attraction of reabsorbed Cl^-.
- The ascending limb actively **pumps sodium out of the filtrate, generating the hypertonic interstitium** that drives countercurrent exchange. In passing through the ascending limb, the filtrate grows hypotonic since it has lost much of its sodium content. This hypotonic filtrate is passed to the distal convoluted tubule in the renal cortex.
- The **distal convoluted tubule (DCT)**, a portion between the loop of Henle and the collecting duct system, is **partly responsible for the regulation of potassium, sodium, calcium,** and **pH.**
- The DCT **regulates pH** by absorbing bicarbonate and secreting protons (H^+) into the filtrate. **Sodium and potassium levels are controlled by secreting K^+ and absorbing Na^+**.
- Sodium absorption by the distal tubule is **mediated by the hormone aldosterone**.
- The DCT **also participates in calcium regulation by absorbing Ca^{2+} in response to parathyroid hormone.**

Histologically, cells of the DCT can be differentiated from cells of the proximal convoluted tubule :

- DCT cells do not have an apical brush border
- DCT cells are less eosinophilic than proximal cells
- DCT cells have less cytoplasm
- DCT cells are more likely to have visible nuclei

- **Thiazide diuretics inhibit** Na+/Cl- reabsorption from the DCT.
- DCT is **lined by cuboidal epithelium without brush border**.
- The **reabsorptive activity of the distal convoluted tubule** is **under the influence of ADH (vasopressin)**, which is one **determinant of the volume of urinary output**.
- The **collecting duct** system **begins in the renal cortex** and **extends deep into the medulla.**
- As the urine travels down the collecting duct system, it passes by the medullary interstitium which has a high sodium concentration as a result of the loop of Henle's countercurrent multiplier system.
- Though the collecting duct is normally impermeable to water, it **becomes permeable in the presence of antidiuretic hormone (ADH)**.
- The collecting ducts unite with each other in the medulla to form still **larger ducts of Bellini** which open into renal pelvis.
- The **epithelium of the collecting ducts is made up** of **principle cells (P cells)** and **intercalated cells (I cells)**.
- The **P cells**, which predominate are relatively tall and have few organelles. They are **involved in Na^+ reabsorption**.
- The **I cells**, which are present in smaller numbers and also found in the distal tubules, have more microvilli, cytoplasmic vesicles, and mitochondria. They are **concerned with acid secretion and HCO_3^- transport**.
- Lower portions of the collecting duct are also permeable to urea, allowing some of it to enter the medulla of the kidney, thus maintaining its high ion concentration (which is very important for the nephron).

URINE FORMATION

- The **formation of urine** is the result of the following process – **ultra filtration or glomerular filtration** of the blood plasma by the glomeruli; **selective reabsorption** by the tubules, and **secretion** by the tubules.
- **Glomerular filtration** is the **first of the three processes that form urine.**
- The molecules that leave the blood and enter the glomerular capsule are called the **glomerular filtrate.**
- If the glomerular filtrate were excreted from the body unchanged, persons would be in **constant**

danger of both dehydration and starvation.

- Glomerular filtration occurs because **the pressure of the blood flowing in the glomerular capillaries is higher than the pressure of the filtrate in Bowman's capsule**.
- **Effective filtration pressure** may be expressed as –
  EFP = GCP – (GOP + CHP)
  where, EFP = effective or net filtration pressure; GCP = glomerular capillary pressure; GOP = glomerular osmotic pressure; CHP = capsular hydrostatic pressure.
- **Tubular reabsorption** is the **second process in the formation of urine from filtrate**. As a result of tubular reabsorption, much of the filtrate passes out of the nephron tubule and returns to the blood through the peritubular capillaries.
- **Reabsorption occurs** within cell, three regions of the nephron and in the collecting duct, **but most of it takes place within the proximal convoluted tubule.**
- Depending on the type of molecule being reabsorbed, movement into and out of epithelial cells occurs by **passive transport or active transport.**
- **Water and urea**, for example, are **reabsorbed by passive transport**, by which they move from regions of higher concentration to regions of lower concentration.
- Water is reabsorbed by **osmosis** and urea by **simple diffusion. Water is reabsorbed** in all parts of the tubule **except the ascending loop of Henle.**
- Glucose and amino acids are reabsorbed by **active transport.**
- The **reabsorption of Na^+** occurs by **both passive and active transport**. Na^+ moves passively by diffusion from the filtrate into tubule cells but is actively transported out of the tubule cells on its way to the peritubular capillaries.
- **Renal threshold** of a substance is its highest concentration in the blood upto which it is totally reabsorbed from the glomerular filtrate.
- **High threshold substances** are almost completely absorbed from nephric filtrate, e.g., glucose, amino acids, vitamin C, Na^+, water. **Glucose** has a **threshold value of 180 mg/100 ml**.
- **Low threshold substances** (in which only very small reabsorption occurs) are urea, uric acid, xanthin, phosphate and **non-threshold substances** are not at all reabsorbed, e.g., creatinine, hippuric acid.
- Certain chemicals in the blood that are not removed by filtration from the glomerular capillaries are removed by a third process of urine formation called **tubular secretion.**
- Ions removed from the blood by tubular secretion include potassium (K^+), hydrogen (H^+) and ammonium (NH_4^+) and foreign substances like drugs, penicillin, uric acid, creatine etc.
- The **secretion of H^+** is an **important way in which kidneys help control blood pH**.
- **Water reabsorption** is **controlled by antidiuretic hormone (ADH)**, secreted by posterior pituitary gland, in negative feedback and **aldosterone hormone** (secreted by adrenal cortex) regulates the transfer of sodium from the nephron to the blood.
- ADH increases the reabsorption of water by the distal tubule and collecting duct.
- **Dehydration results in an increase in ADH**, while **water sufficiency results in low ADH** allowing for diluted urine.
- The **more ADH**, the more permeable the ducts, the more water reabsorbed; the **less ADH**, the less permeable the ducts, the less water reabsorbed. This is **related to the high osmolarity of the interstitium due to the countercurrent multiplier system of the loops of Henle**.
- Drugs called **diuretics** increase the production of dilute urine and prevent the excessive water retention and tissue swelling (oedema) that may accompany congestive heart failure, high blood pressure and other conditions.
- **Alcohol inhibits the secretion of ADH**, thus increases water loss.
- Under the **deficiency of ADH**, a disease called **diabetes insipidus** is caused in which the output of urine may reach 3-40 litre/day in place of normal 1.2–1.8 litre/day. Frequent urination and thirst is the symptoms of the disease.
- **Renin** (secreted by the cells of afferent arteriole) initiates a series of chemical reactions that ultimately result in **aldosterone** secretion from the adrenal cortex, which **acts primarily on the distal convoluted tubule to promote absorption of sodium and excretion of potassium.**
- Renin acts in the following way : renin ⇒ adrenal cortex ⇒ aldosterone ⇒ distal convoluted tubule ⇒ reabsorption of sodium and excretion of potassium.
- The presence of too much blood in the circulatory system stimulates the heart to produce **atrial natriuretic hormone (ANH)**.
- This hormone **inhibits the release of aldosterone**

by the adrenal cortex and **ADH** by the posterior pituitary causing the kidneys to excrete excess water.

- The hormone, **erythropoietin,** a circulating glycoprotein is produced by interstitial cells in the peritubular capillary bed of the kidney.
- Erythropoietin is **concerned with the regulation of normal erythropoiesis.**
- In the kidneys primary prostaglandins causes an increase in renal blood flow and vasodilation.
- **Kininogen** produced by the kidneys **has an anti-hypertensive effect and regulates blood pressure**.
- Kidneys play an important role in **vitamin D metabolism**.
- **Micturition** is the act of emptying the bladder or passing urine. The total volume of urine (approx. 1.5 lt) in 24 hours is much less than the amount of glomerular filtration (approx. 170 lt).
- Urine is **transparent, amber coloured, hypertonic fluid** with a **slightly acidic pH (average - 6.0).**
- The **yellow colour** of the urine is **caused by the pigment urochrome**.
- **Least concentration of urea** is found **in renal vein.**
- **Highest concentration of urea** is found **in hepatic vein.**
- **Kidney transplantation** or renal transplantation is the organ transplant of a kidney in a patient with chronic renal failure or some renal tumors.
- **Renal failure or kidney failure** is the loss of the kidneys' ability to excrete wastes, concentrate urine, and conserve electrolytes, *means* a condition where the kidneys fail to function properly.
- The **first successful kidney transplantations** were done in 1954 in Boston and Paris. The transplantation was done between identical twins, to eliminate any problems of an immune reaction. It was actually the **first successful human organ transplant in history.**
- The **artificial kidney** uses the principle of dialysis to purify the blood of patients whose own kidneys have failed.
- **Dialysis** is a method of removing toxic substances (impurities or wastes) from the blood when the kidneys are unable to do so.
- In haemodialysis (also known as artificial kidney) the patient's blood is passed through a tube to a semipermeable membrane **(dialyzer)** that filters out waste products. The cleaned blood is then returned back to the body. The procedure is monitored by a machine, which also provides the dialysis fluid, mixing it from a concentrate and water.

DISORDERS

- **Albuminuria** is presence of albumin in urine and it occurs when the filtering pores enlarge in size (it is the indication of increase in glomerular permeability).
- **Nephritis or Brights disease** infection is caused by bacteria (Streptococci) which results in inflammation of kidney that involves glomerulus.
- **Pyelonephritis** is inflammation of the tissue of kidneys and the ureters in the pelvic region.
- **Renal stone** is formation of calculi (large stones) in the kidney due to dehydration, excess uric acid formation, excess calcium intake etc.
- **Polyuria** occurs when excess amount of dilute urine is passed out as in diabetes insipidus.
- **Uraemia** is the increased concentration of urea in blood.
- **Alkaptonuria** is a genetic disease in which homogentisic acid is excreted out with urine.
- **Pyuria** is presence of pus in the urine.
- **Glycosuria** is presence of glucose in urine due to diabetes.
- **Haematuri**a is presence of blood in the urine. **Anuria** is the failure of kidney to form urine.
- **Ketosis** is the presence of ketones or acetone bodies in urine due to metabolism of fatty acids instead of glucose during diabetes, starvation and pregnancy.
- Acetone bodies are acetoacetic acid, beta-hydroxybutyric acid and acetone.
- **Cystitis** is the inflammation of urinary bladder, caused by bacteria. It is **more common in female due to short urethra**.
- **Gout** is high level of uric acid in blood.
- **Dysuria** is painful urination. **Diuresis** is a condition in which the excretion volume of urine is increased.

End of the Chapter