CHAPTER - 00
EXCRETORY PRODUCTS AND THEIR ELIMINATION

Excretion - Process of elimination of metabolic waste

TYPES OF METABOLIC WASTE

I. Respiratory waste - CO_2 [200ml/ minute], Water [400ml/ day]

II. Nitrogenous waste - Ammonia, Urea, Uricacid, Creatine, Creatinine, Hippuric acid etc.

Classification of animals based on the Excretory Products

I. Ammonotelic animals

→ Animals excrete Ammonia and this Process called ammonotelism

→ Ammonia highly toxic and readily soluble in water

→ Ammonotelic animals need large amount of water for the elimination of ammonia

Examples : Aquatic invertebrates
Aquatic amphibia [Salamander]
Amphibian tadpole
Bony fishes
Crocodiles

II. Ureotelic animals

→ Animals excrete urea and this process called ureotelism

→ Urea is less toxic than ammonia and also soluble in water

→ Urea can be stored in the body for a considerable period of time

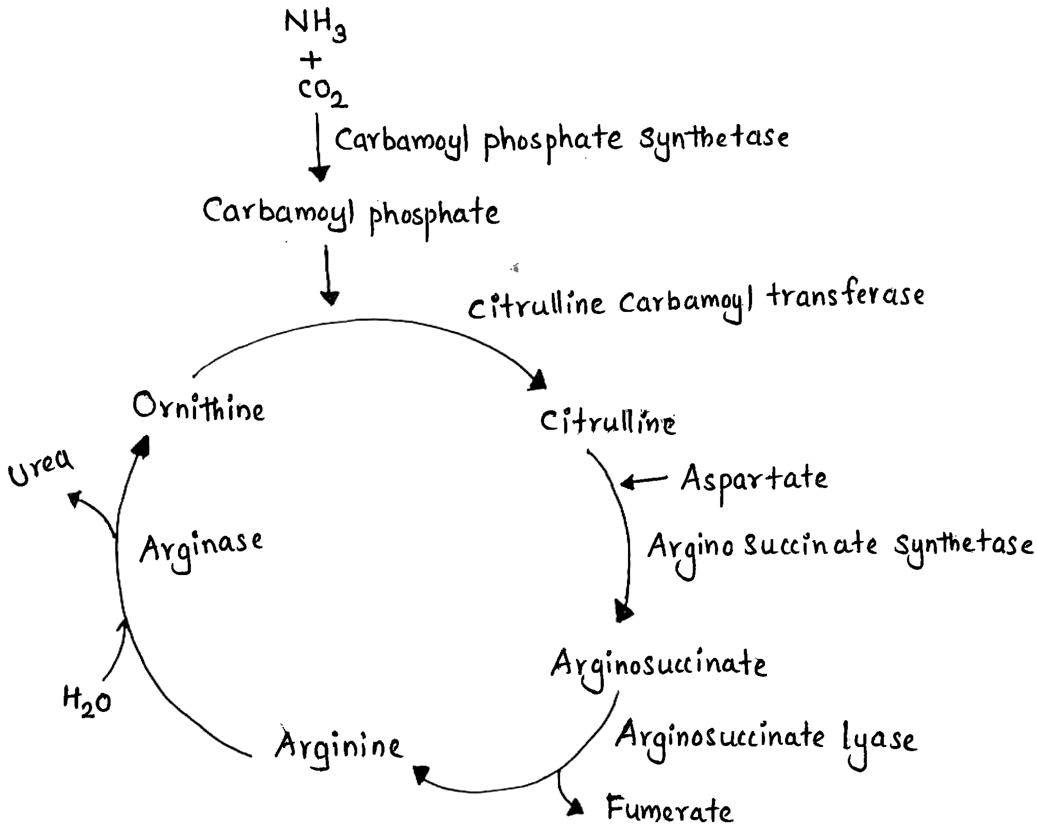
→ Production of urea required more energy

→ Ureotelic animals require moderate amount of water for the elimination of urea

Examples : Mammals including man
Cartilaginous fish
Ascaris
Semiaquatic and terrestrial amphibia [toad, frog]
Aquatic reptiles [Alligator, turtle]
Earthworm

Ornithine cycle or Urea cycle

* Discovered by Hans Krebs and Kurt Henseleit [1932]
* Urea cycle takesplace in Liver cell [Hepatocytes]



III. Uricotelic animals

→ Animals excrete uric acid and this process called uricotelism

→ Uric acid less toxic than ammonia and urea

→ Production of uric acid require large amount of energy

Examples : Land insects

Land snail

Land Reptiles

Birds

Note : Uricotelism is very important for land vertebrates laying shelled eggs.

IV. Aminotelic animals

→ Animals excrete amino acids

Examples : Some mollusca [Unio]

Some echinoderms [Asterias]

V. Guanotelic animals

→ Animals excrete guanine

Example : Spiders

Excretory structures / Organs in different Animals

1. Protozoa - Plasma membrane

2. Porifera
3. Coelenterata
4. Ctenophore

} plasma membrane of each cell

5. Platyhelminthes
6. Rotifera

} protonephridia / flame cells

7. Aschelminthes - Excretory tube / Renette cells

8. Annelida - Nephridia [protonephridia / Flame cells found in some annelids]

9. Arthropoda

a) Insects, Centipedes, Millipedes, Scorpion - Malpighian tubule

b) Spiders, Limulus - Coxal gland

c) Prawn, Crab- Antennal gland or Green gland

d) Peripatus - Nephridia

10. Mollusca - Gills / Ctenidia, Keber's organ, Organ of Bojanus

11. Echinoderms - Specialised excretory organs absent
- Metabolic wastes eliminate through body surface

12. Hemichordata - Proboscis gland

13. Chordata

A) Urochordata - Neural gland

B) Cephalochordata - Protonephridia or Flame cells

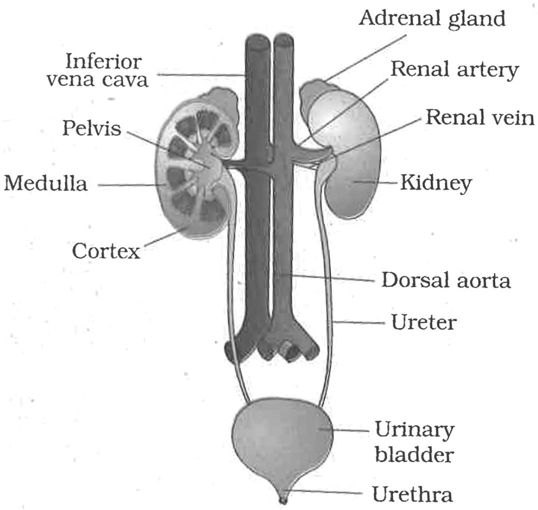
C) Vertebrates

i) Cyclostomes
ii) Pisces
iii) Amphibia
iv) Reptiles
v) Aves

} Kidney

Human Excretory System

* Paired kidneys
* Paired ureter
* Urinary bladder
* Urethra



I. Human kidneys - Metanephric kidney

Shape	- Bean
Colour	- Reddish brown
Thickness	- 2 - 3 cm
Width	- 5-7 cm
length	- 10-12 cm
weight	- 120-170 gm
Location	- Within abdominal cavity [close to dorsal inner wall of abdomen]

→ Position of right kidney slightly lower than the left kidney

→ As kidneys fused to abdominal wall on the dorsal side, the peritoneal covering present only on the ventral side of kidney [Retroperitoneal arrangement]

→ Kidneys located between last thoracic vertebrae and third lumbar vertebrae

→ The 11th and 12th pairs of ribs protect both kidneys

Kidneys covered by 3 protective layers - Outer renal fascia, middle adipose capsule and inner most renal capsule

→ Outer surface of kidney is convex in nature and the inner surface is concave in nature

→ Inner surface of the kidney has a notch called **hilum**

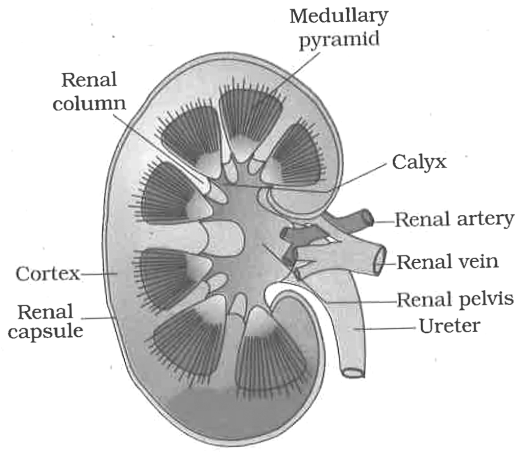
→ Though hilum, ureter, blood vessel and lymph vessel enter into the kidney

→ Expanded funnel like part of ureter called **Renal Pelvis** with cup like projections called **calyces**

→ Inside the kidney, there are two zones, an **outer cortex** and an **inner medulla**

→ 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**



II. **Ureters** - Whitish muscular tube [25 - 30 cm in length]

III. **Urinary bladder**

* Pear shaped hollow muscular organ
* Situated in pelvic cavity
* Made of detrusor muscle
* Lined by transitional epithelium

IV. **Urethra**

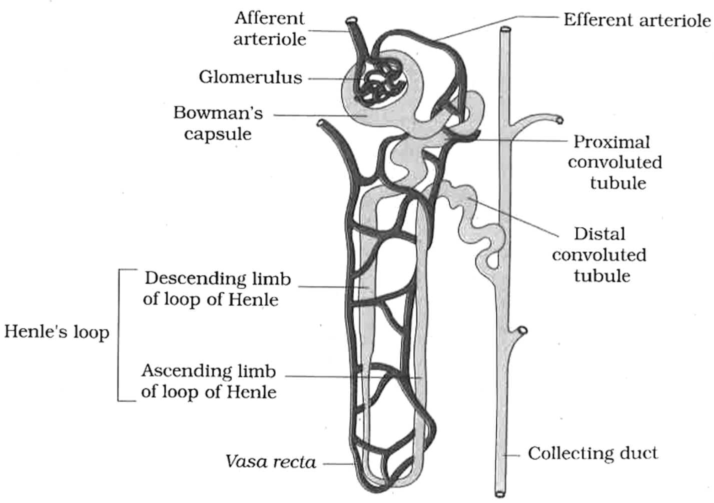
→ Fibrous and muscular tube which connects the urinary bladder to the external urethral meatus

Nephron [Uriniferous tubule]

→ Structural and functional unit of kidney

→ Each kidney has nearly one million nephron

→ Each nephron has two parts - **Renal corpuscle and Renal tubule**



A) Renal corpuscle / Malpighian corpuscle / Malpighian body

→ Composed of Bowman's capsule and glomeruli

a) Bowman's capsule

→ closed double walled cup like structure

→ the two walls of Bowman's capsule are outer parietal layer and inner visceral layer

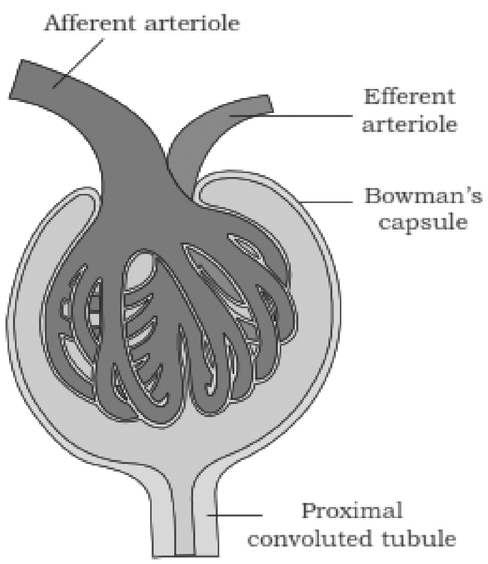
→ the outer wall consists of squamous epithelium

→ the podocytes forming the inner wall of the Bowman's capsule

→ the podocytes are arranged in an intrinsic manner so as to leave some minute spaces called **filtration slits or slit pores**

b) Glomeruli

→ tuft of blood capillaries formed by the afferent arteriole



B) Renal tubule - tubular part of nephron

a) Proximal Convoluted Tubule [PCT]

→ highly coiled tube

→ lined by cuboidal epithelium having brush border with more microvilli for increasing absorptive area.

→ the cells contain abundant mitochondria

b) Henle's loop

→ Hair pin shaped tube, made of two parallel limbs

i) Descending limb

ii) Ascending limb

→ Thick segment of descending and ascending limb lined by cuboid epithelium with less microvilli and mitochondria

→ Thin segment of descending and ascending limb lined by flat squamous epithelial cells with less mitochondria

c) Distal Convoluted Tubule [DCT]

→ highly coiled tube

→ lined by cuboid epithelium with less microvilli and mitochondria

d) Collecting duct

→ It is a part of many nephron

→ lined by cuboidal epithelium with less microvilli and mitochondria

→ the collecting duct enter medulla and form **duct of Bellini** the duct run through renal pyramids

Note : The efferent arteriole emerging from the glomerulus forms a fine capillary network around the renal tubule called the **peritubular capillaries**

→ A minute vessel of peritubular capillary runs parallel to the Henle's loop forming a 'U' shaped **vasa recta**

Types of Nephron			
Juxta medullary Nephron			**Cortical Nephron**
1	They are about 15% of total nephron	1	They are about 85% of total nephron
2	They are large in size	2	They are small in size
3	Henle's loop is very long and extend deep into the medulla	3	Henle's loop is very short and extend little into the medulla
4	Juxta glomerular apparatus [JGA] present	5	Juxta glomerular apparatus [JGA] absent
5	Vasa recta present	6	Vasa recta reduced or absent

Urine formation

* Urine - pale yellow coloured fluid

* pH of urine is 6 [4.5 - 8.2]

* Yellow colour of urine is due to presence of urochrome

* Urine formation involves three processes - Glomerular filtration, Tubular reabsorption and tubular secretion

I. Glomerular filtration / Ultra filtration / Pressure filtration

→ filtration carried out by the glomeruli

→ It is a passive process and non - selective process

→ On an average 1100 - 1200 ml of blood is filtered by the kidneys per minute which constitute roughly $\frac{1}{5}^{th}$ of the blood pumbed out by each ventricle of heart in a minute

→ The glomerular capillary blood pressure causes filtration of blood through 3 layers - the endothelium of glomerular blood vessel, the epithelium of Bowman's capsule and a basement membrane between these layers

→ Blood is filtered so finely through these layers, that almost all the constituents of plasma except he proteins, lipid and blood cells pass on to the lumen of Bowman's capsule. Therefore, it is - considered as a process of ultra filtration.

Glomerular Filtration Rate [GFR]

The amount of the filtrates formed by the kidneys per minute.

→ GFR in a healthy individual is approximately 125ml/ minute, ie 180L/ day

Pressure in Renal circulation

1. **Glomerular Blood Hydrostatic Pressure [GBHP]**- 60mmHg

→ Blood pressure in glomeruli, promote filtration

2. **Blood Colloidal Osmotic Pressure [BCOP]** - 30 mmHg

→ Pressure exerted by plasma proteins in blood of glomerular capillary

→ This pressure oppose filtration

3. **Capsular Hydrostatic Pressure [CHP]** - 20 mm Hg

→ Pressure exerted by filtrate within Bowman's capsule against filtration

Effective Filtration Pressure [EFP] = GBHP - [BCOP + CHP]

= 60 - [30 + 20]

= 60 - 50 = 10 mm Hg

II. Tubular Reabsorption

→ Absorption of useful substances from glomerular filtrate into interstitial fluid and peritubular capillaries [99%]

a) **Proximal Convoluted Tubule [PCT]**

→ 70-80% of electrolytes and water are reabsorbed by this segment

→ Glucose, aminoacids, Na^+, K^+ are reabsorbed by active transport

→ Cl^-, Urea and other anions are reabsorbed by Passive transport

→ Water reabsorbed by osmosis

→ The filtrate is isotonic to blood plasma

Note

i) High threshold Substance

→ Substance Completely reabsorbed from the filtrate

eg : - Glucose, Amino acid

ii) Low threshold substance

→ Substance reabsorbed in small quantity

eg : - Urea, Phosphate

iii) Non - threshold / Athreshold substance

→ Substances not at all reabsorbed

eg :- Hippuric acid, Creatinine

b) Henle's loop - Consist of descending and ascending limb

i) Descending limb

→ Permeable to water but almost impermeable to electrolytes

→ Water reabsorbed due to increasing osmolarity of interstitial fluid

→ The filtrate become hypertonic to blood plasma

ii) **Ascending limb**

→ Permeable to electrolytes but impermeable to water

→ The filtrate become hypotonic to blood plasma

c) Distal Convoluted Tubule [DCT]

→ Reabsorption of Na^+ under the influence of aldosterone

→ Reabsorption of water under the influences of antidiuretic hormone [ADH]

d) Collecting duct

→ Entire length of collecting duct is permeable to water

→ Reabsorption of Na^+ under the influence of aldosterone

→ Reabsorption of water under the influence of ADH

→ Small amount of urea enter into the medullary interstitium to keep up osmolarity and large amount of water could be reabsorbed to produce concentrate urine, thus the filtrate become hypertonic to blood plasma.

III. **Tubular Secretion [Augmentation]**

→ Tubular cells secrete substance into the filtrate

→ Tubular secretion is also an important for maintain ionic and acid base balance of the body fluids

a) **Proximal Convoluted Tubule**

→ Secrete Creatinine, Hippuric acid, Pigments, Drugs into the filtrate

→ Secretion of H^+, NH_3 maintain ionic and acid base balance in the blood

b) **Henle’s loop**

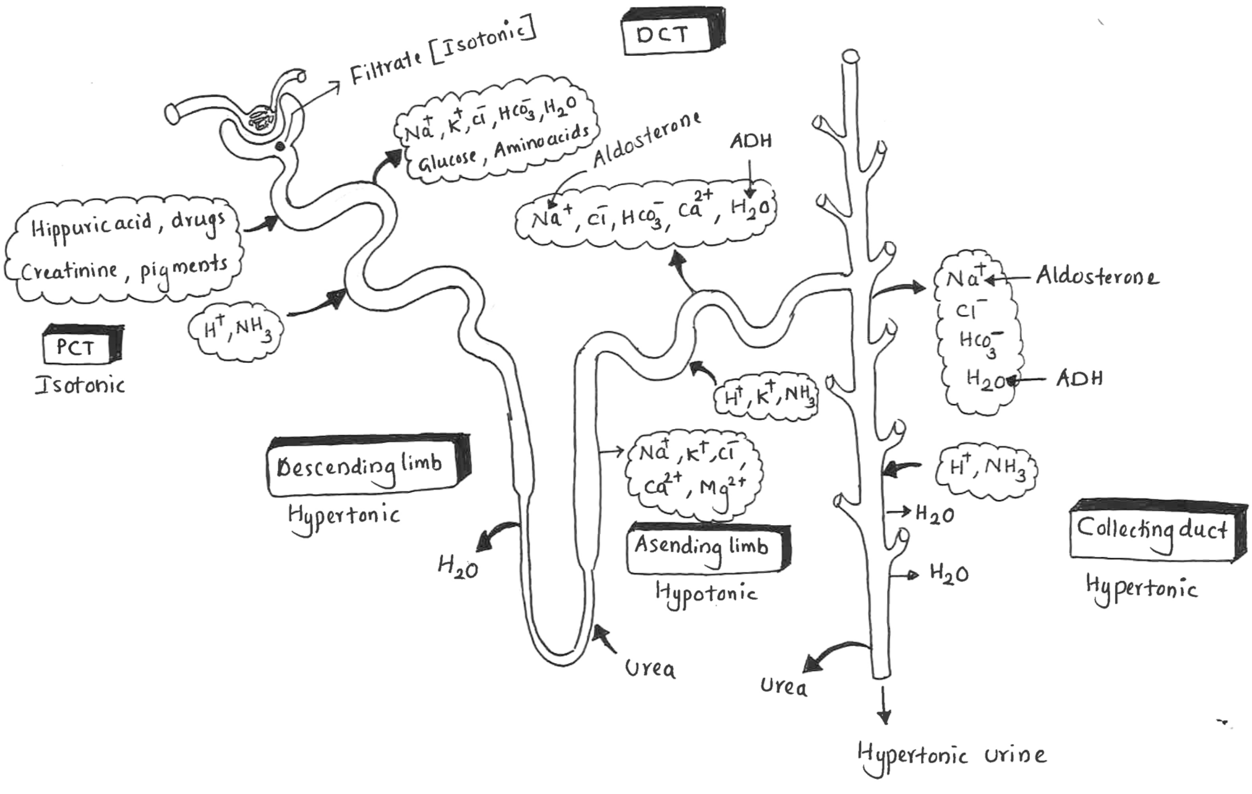
Urea enters the filtrate by diffusion in the thin segment of the ascending limb of Henle’s loop

c) **Distal Convoluted Tubule [DCT]**

→ Selective secretion of H^+, K^+ and NH_3 helps to maintain ionic and acid-base balance in the blood

d) **Collecting duct**

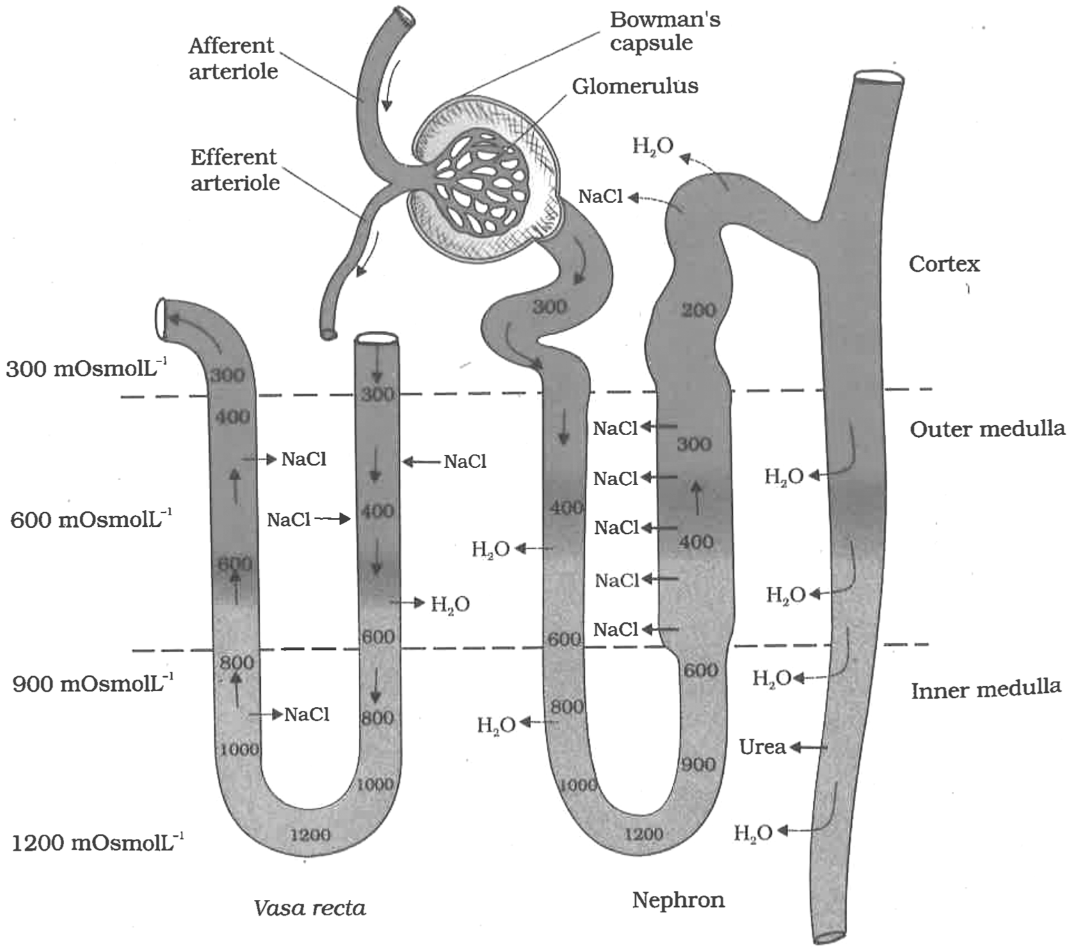
→ Selective secretion of H^+, K^+ and NH_3 helps to maintain ionic and acid-base balance in the blood



Mechanism of Concentration of the filtrate

[Counter Current Mechanism]

Mammals have the ability to produce a 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 m 0smolL^{-1} in the cortex to about 1200 m0s molL^{-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 amount 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 to 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.



Regulation of kidney function

The functioning of the kidney's is efficiently monitored and regulated by hormonal feedback mechanisms involving the hypothalamus. JGA and to a certain extent, the heart.

Osmoreceptors in the body are activated by changes in blood volume, body fluid volume and ionic concentration. 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 1 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 decreases 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. In response, the stretch receptors on the walls of the bladder send signals to the CNS. The CNS passes on motor messages to initiate the contraction of smooth muscles of the bladder and simultaneous relaxation of the urethral sphincter causing the release of 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. Various conditions can affect the characteristics of urine. Analysis of urine helps in clinical diagnosis of many metabolic disorders as well as malfunctioning of the kidney. For example presence of glucose (Glycosuria) and ketone bodies (Ketonuria) in urine are indicative of diabetes mellitus.

Role of other organs in Excretion

1) Lungs- remove large amount of CO_2 [200 ml / minute] and also significant quantities of water every day [400 ml/ day]

2) Liver

$\rightarrow$ Secrete bile containing substances like bilirubin, biliverdin, cholesterol, degraded steroid hormone, vitamins and drugs

$\rightarrow$ Most of these substances ultimately pass out along with digestive wastes

3) Skin - has two types of glands

a) Sweat gland (Sudoriferous gland)

$\rightarrow$ Excrete sweat

i) eliminate water, NaCl, Urea, Lactic acid etc through sweat

ii) Primary function of sweat is to facilitate a cooling effect on the body surface

b) Sebaceous gland (Oil gland)

$\rightarrow$ Excrete Sweat

i) eliminate sterols, hydrocarbon and was through sebum

ii) Provide protective oily covering for the skin

Note : Small amount of urea eliminated through saliva

Abnormal Urine Condition

1. Glycosuria	- Presence of glucose in urine
2. Ketonuria	- Presence ketones in urine
3. Albuminuria	- Presence of albumin in urine
4. Hematuria	- Presence of blood or blood cell in urine
5. Haemoglobinuria	- Presence of haemoglobin in urine
6. Polyuria/ Diuresis	- Excess loss of water through urine
7. Pyuria	- Presence of pus in urine
8. Dysuria	- Painful urination

Disorder of excretory System

1. Diabetes insipidus

Cause - Deficiency of Antidiuretic hormone [ADH]

Symptoms - Excess loss of water through urine

Indicator - Diuresis / Polyuria

2. Diabetes Mellitus

Cause - Deficiency of insulin

Symptoms - Presence of excess amount of sugar in urine

Indicator - Glycosuria, Ketonuria, diuresis

3. Renal calculi / Kidney stone

Soluble or insoluble mass of crystallised salts [oxalate] formed within the kidney

4. **Nephritis [Bright's disease]**

Inflammation of kidney

a) Pyelonephritis - inflammation of Renal Pelvis

b) Glomerulo nephritis - Inflammation of glomeruli

Cause : Autoimmune disorder

Streptococcal infections

5. **Renal failure [RF] or kidney failure**

decrease or cessation of glomerular filtration

Acute Renal failure [ARF]

Both kidneys abruptly stop working

Main features of ARF

a) Oligouria - Scanty urine production, daily urine out put less than 250ml

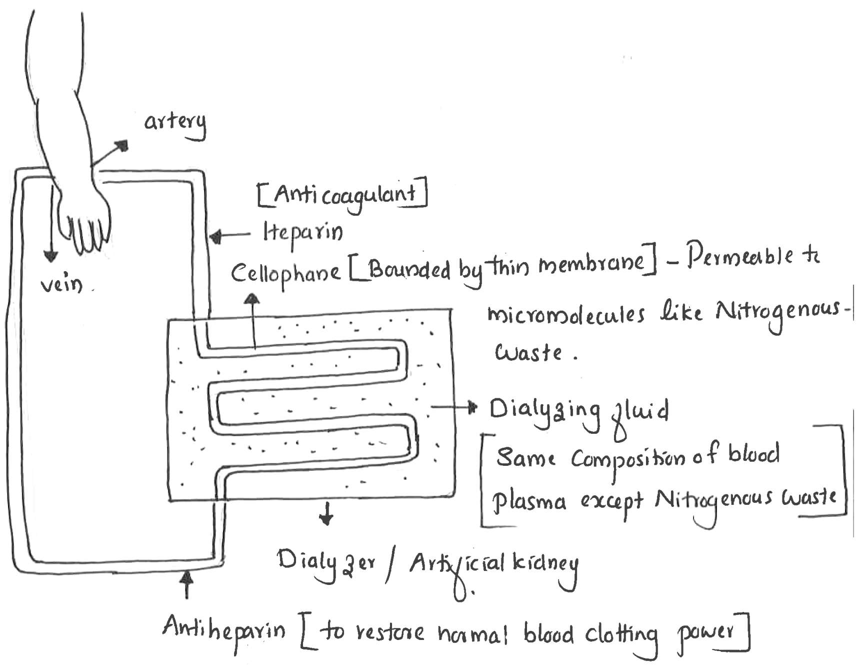
b) Anuria - daily urine output less than 50ml

6. **Uremia** - accumulation of urea in blood

Urea can be removed through haemodialysis

Artificial kidney / Dialyser/ Dialysing machine

Machine used in remove toxic substances from blood of patient whose both kidney are completely damaged and this process is known as haemodialysis



Homeostasis

Maintanance of constant internal environment

Osmoregulation

Maintainance of salt water concentration [osmotic concentration] in the body

Osmotic concentration is based on osmolarity

Osmolarity

Milliosmole solute concentration in a litre of water

Unit of osmolarity expressed as Milli0smol L^{-1} / m0smol L^{-1}

Osmolarity of fresh water - 50 m0smol L^{-1}

Osmolarity of sea water - 1000 m0smol L^{-1}

Osmosis

Movement of solvent from solution of low solute concentration to solution of high solute concentration through semipermeable membrane

Types of Osmoregulation

1. **Osmoconformers / Poikilosmotic / Osmolabile**

   They are organism that try to match the osmolarity of their body with their surrounding. In other words, their internal osmotic concentration changes according to changes in surrounding medium.

   eg : Aquatic invertebrates, Elasmobranches, Myxine

2. **Osmoregulator / Homeosmotic / Osmostable**

   They can keep constant internal osmotic concentration irrespective of changes in the surrounding medium

   eg : Aquatic vertebrates

   Types of animals based on the salinity tolerance

1. **Stenohaline**

   They can live only a narrow range of salinity variation

   eg : Aquatic invertebrates

2. **Euryhaline**

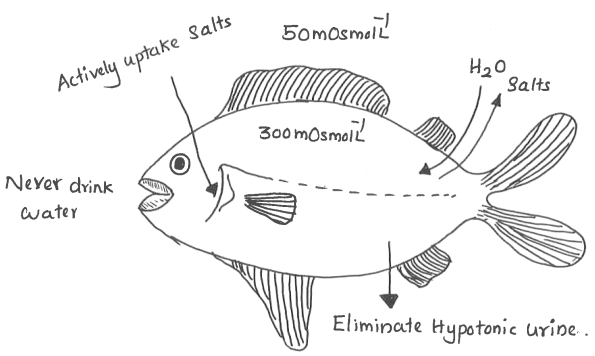
   They can tolerate wide range of salinity variation

   eg : Petromyzon - exhibit anandromous migration

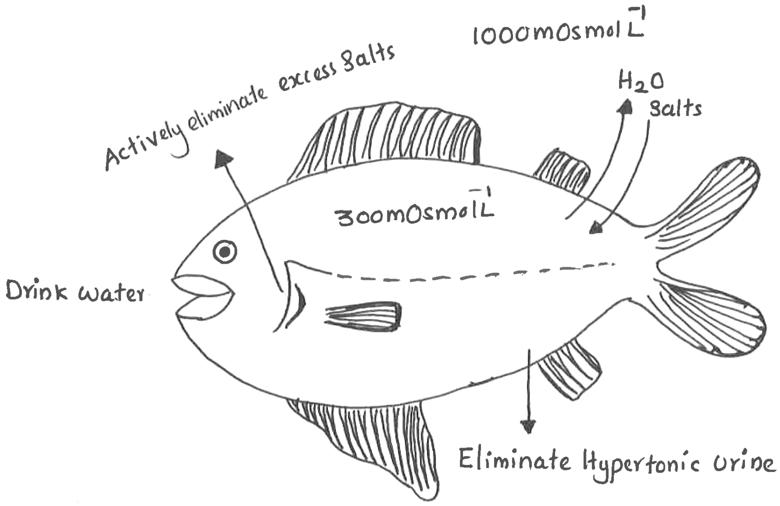
   American eel : exhibit catadromous migration

Osmoregulation in Fishes

Osmoregulation in Fresh water Bony fishes



Osmoregulation in Sea water Bony fishes



Osmoregulation in Elasmobranches [eg : Shark]

Urea and trimethyl amine oxide [TMAO] retension in blood makes isotonic with surrounding water