Nephridium: Physiology and Function

In general, the excretory system in annelids consists of paired lobes, called nephridia, which are metamerically arranged and the inner aperture of the nephridium lies in the coelom, and the outer aperture is situated in the integument.

Definition of Nephridium:
An excretory tubule which opens to the exterior through **the nephridiopore** and the inner end of the tubule is blind (associated with terminal cells or **solenocytes**) in the **protonephridium** or opens in the coelom through the ciliated funnel or called **nephrostome in metanephridium**.

Research Work on Excretory System:
The excretory system in Annelida has had a long history. Many zoologists namely Gegenbaur (1833), Stephenson (1930), Goodrich (1946), K. N. Bahl (1934, '42, '45, '46, and '47) and Ramsay (1947) worked on nephridia of different species in Annelida. K. N. Bahl worked on nephridia of *Pheretima posthuma* and Ramsay worked on *Lumbricus.*

Structure of a Typical Nephridium:
(i) A typical nephridium (Fig. 17.58) consists of a **nephrostome or a ciliated funnel** which hangs into the coelom and leads to the **nephridial duct**.

(ii) The nephridial duct or body of the nephridium may be long, short, convoluted or modified otherwise.

(iii) The duct is ciliated internally, situated transversely and is accompanied by blood vessels.

(iv) The nephridial duct opens to the exterior by an opening, called **nephridiopore.**

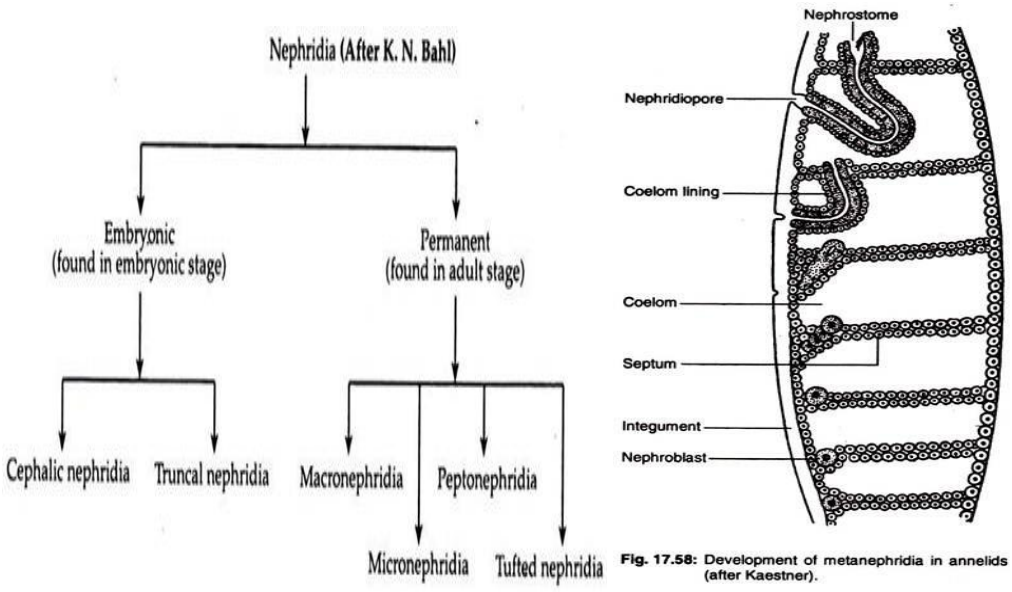

Fig. 17.58: Development of metanephridia in annelids (after Kaestner).

Origin:
Each nephridium develops from a single cell, called **nephroblast**. The nephridia are **ectodermal in origin**.

Classification of Nephridium:
Prof. K. N. Bahl classified nephridia which appears to be most plausible and accepted all over the world.

In following up the **developmental stages of nephridium of Annelida two** types of nephridial systems are encountered (Fig. 17.58). They are (A) **I**. **Provisional or embryonic nephridia** and **II.** the **Permanent nephridia.**

(I) Provisional or embryonic nephridia:

Embryonic nephridia are **temporary structures and disappear as soon as permanent nephridia start developing.**

It is divided into following:

1. Embryonic head nephridia: (i) **Paired in larva and embryos**. (ii) Their ends lie in the **embryonic head cavity.** (iii) **Solenocytes** at the end of the tube occur. (iv) They are found in many **polychaetes and oligochaetes**. (v) They are branched occasionally, e.g., *Echiurus, Polygordius*	**2. Embryonic trunk nephridia:** (i) **Strictly segmentally arranged**. (ii) Occur **one pair in each segment**. (iii) **Funnel opening into trunk region**. **Embryonic trunk nephridia:** Embryonic trunk nephridia may **persist** in those forms **where permanent nephridia do not develop**. **Five** such pairs of nephridia persist in *Nereis*. In most oligochaetes permanent nephridia are absent in some of the anterior segments. The same is true for many polychaetes and hirudinea.

- provisional nephridia were present in the larval stage
- subsequently permanent nephridial development never occurred there.
- Thus the absence of permanent nephridia in the anterior segments may be explained.
- Structurally embryonic nephridium is similar to those of permanent nephridium.
- But in *Glycera* and *Phyllodoce* the inner aperture and in *Hirudinea* both inner and outer apertures are absent.

(II) Permanent nephridia:
Characters same as typical nephridium:

- **Ciliated nephrostome opening into coelom.**
- Long internally coiled duct opens externally by **nephridiopore**.
- **Nephrostome and nephridiopore** may occur in the **same segment** or the **former a segment forward.**

B) Depending upon the size and number present in a segment the nephridia are divided into 4 types:
(a) Meganephridia or Holonephridia. (b) Micronephridia or Meronephridia

(c) Peptonephridia. (d) Tufted nephridia.

(a) Meganephridia or Holonephridia:

- These are large in size and one pair in each segment.

(b) Micronephridia or Meronephridia:

- These are small and numerous in each segment.
- It is believed that the micro-nephridia are nothing but broken or disintegrated meganephridia.

(c) Peptonephridia:

- These are formed by the **modification of salivary glands in buccal and pharyngeal** region in the form of clusters

- found in **oligochaeta,**
- aid in **digestion.**

(d) Tufted nephridia:

- derived from **micro or macro-nephridia**
- **incompletely branched and are grouped together**
- These are usually found in **one or several of pre-clitellar segments of many earthworms.**
- Bahl (1942) states that they represent an **intermediate stage between a holonephridium and a group of completely separated meronephridia.**

C) Again, the nephridia may be closed or open according to the presence of nephrostome:
(i) Open type:
When the nephridium possesses a funnel.

(ii) Closed type:
Lacking a funnel in the nephridium.

D) The nephridia may be exonephric type or enteronephric type according to their opening to the exterior, found in pheretima:
(a) Exo-nephric type:

- Having exterior opening, e.g., Integumentary nephridia.

(b) Enteronephric type:

- Open into the enteric canal, e.g., Septal nephridia and pharyngeal nephridia.

All the nephridia in ***Pheretima*** **are of micronephric** type. The nephridia of *Lumbricus, Chaetogaster* and *Nereis* are meganephric. It is believed that the micronephridia are nothing but broken or disintegrated meganephridia.

In *Megascolecidae* both micronephridia and meganephridia are present even in the same segment. In *Serpula,* meganephridia are present in the anterior segments while micronephridia occur in the posterior segments.

Some polychaetes possess Protonephridia in which inner end of each nephridium terminates in flame cells and there is no nephrostome, as seen in flatworms and usually other type of nephridia, called metanephridia in which inner end of the nephridium has an open funnel or nephrostome.

Permanent Nephridia in different Classes:
Polychaeta:
In most polychaetes metanephridia are present.

A typical metanephridium consists of the following:

- An inner ciliated aperture opening into the body cavity or coelom and is called **nephrostome.**
- A **canal or coiled tube** connected to the nephrostome. The canal **is dilated internally and sometimes its internal wall is glandular.**
- A **terminal end** which usually terminates in a **laterally placed aperture**, called **nephridiopore**.

In *Errantia* each segment has a pair of nephridia. *Arenicola* is provided only with six pairs. In **Capitellidae** there may be one to six pairs of permanent nephridia in each of the trunk segments. In **Terebellidae** there are one to three pairs of nephridia in the thorax.

Sabellidae and Serpulidae have one pair in the thorax. But in all these families numerous nephridia occur in the posterior segments. Numerous nephridia are housed in Earthworm. The wide funnels and short ducts of these nephridia suggest that they serve as gonoducts in some forms.

In many polychaetes like Phyllgdoce segmentally arranged ciliated funnels, called **coelomoducts**, are present (Fig. 17.59). **These ducts rarely open to the outside and often coalesce partially or completely with the nephridia and thus the function of excretory and reproductive ducts combine in one set of segmental organ**.

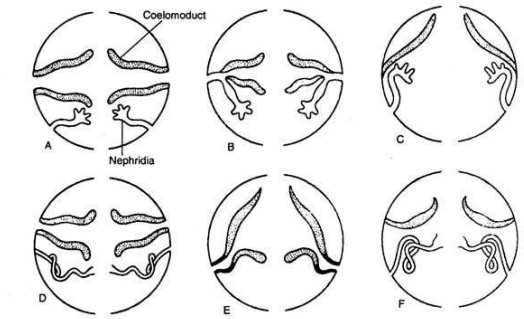

Fig. 17.59: Relationship of nephridia and coelomoducts in polychaeta (after Parker and Haswell). A. Hypothetical stage (Nephridia closed and coelomoducts separate). B. In Phyllodocidae (Nephridia closed but united with coelomoduct). C. In Nephthyidae (Coelomoduct reduced as ciliated organ). D. In *Dasybranchus* (Coelomoduct separate from nephridia with nephrostomes). E. In most annelids (Nephridia with nephrostomes united with coelomoducts to form segmental organ). F. In *Nereis* (Nephridia with nephrostomes and separate coelomoducts reduced as ciliated organ).

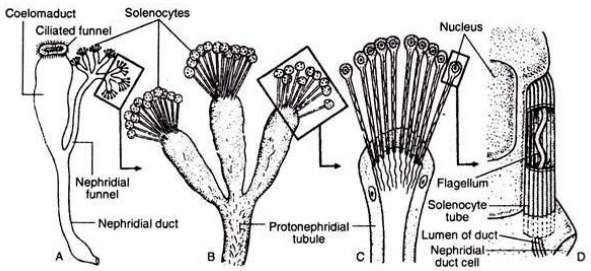

Fig. 17.60: Structure of protonephridium and coelomoduct in *phyllodice*. A. Protonephridium and coelomoduct in *phyllodoce;* B. Branched end protonephridium in *phyllodoce;* C. Solenocytes of a single protonephridial branch; D. E.M. structure of a solonocyte (after various sources).

Protonephridia:

- Some families like Phyllodocidae and Glyceridae have protonephridia in place of metanephridia.
- In protonephridia (Fig. 17.60), the **ciliated coelomic aperture (nephrostome) is absent.**
- The tubes thus open blindly in the coelom and are branched. Separate or groups of specially modified cells, called **solenocytes,** remain attached to the blind end of the tubes.
- Each solenocyte is a round cell with a slender tubular projection which anchors on the blind tube.

Electron micrographs show that the long tube of protonephridium consists of a membrane with more than 15 longitudinal ridges or rods and internally carries an unusually long flagellum to drive the internally accumulated fluid (Fig. 17. 60).

Oligochaetes:

- In oligochaetes **metanephridia** are usually present in all segments excepting a few anterior segments.
  - A metanephridium differs from a protonephridium in **having a ciliated funnel or nephrostome.**
  - In aquatic forms reproductive segments lack nephridia.
  - As a rule there is one pair of nephridia in each segment but in Brachidrilus, there are two pairs, in Trinephros, there are three pairs, and there are four pairs in Acanthoarilus in each segment.
  - **Plectonephric nephridia:** In tropical Megascolecidae, the nephridial primordia in each segment splits and as a result numerous nephridia occur in each segment. These nephridia are called diffused or plectonephric nephridia.
  - In the tropical *Phretima posthuma* many nephridia open into the pharynx **(Peptonephric)** and in the **alimentary canal (Enteronephric).** This is a device for **the reabsorption of water.**

Hirudinaria:

- In *Hirudinaria* the permanent nephridium is lacking in many anterior and posterior segments.

- The **metanephridium** consists of a **ciliated nephrostome or funnel** that leads into an **ampulla filled with amoebocytes** and closed off against a nephridial duct.

- Besides the nephrostome all parts of the nephridium are formed by a close set of **gland cell traversed by intracellular spaces or ducts**. The nephrostome may start from the **coelomic spaces, from ventral median channel (Glossiphonia), from contractile spherical enlargement or ampullae (Haemopis) or from blood sinuses in which the testes lie (Hirudo).**

- In Pontobdella distinct nephridium is absent and its place is taken up by a complex network situated on the ventral side of the body.

- The anal tubes in Echiuroidea are considered as excretory structures. The nephridia act as osmoregulatory organs specially in freshwater forms.

Coelomoduct:

- Each mesodermal pouch in ancestral coelomates was provided with a pair of ducts, called **coelomoducts (gonoducts**)

- it serves as a **passage for the exit of gametes and a single nephridial tubule, for the removal of nitrogenous wastes.**

- These primitive nephridia resembled the **platy- helminthic type of excretory organs**. That is, they consisted of **ectodermal tubules projecting into the coelom and ending in specialised cells, called solenocytes.**

Nephromyxia:

- In many polychaetes the **association between the coelomoduct (gonoduct) and nephridium** makes an interesting study.

- Instead of remaining separate they show **total or partial fusion** and form a **dual segmental organ, called nephromyxia**.

- As the **nephridium is ectodermal in origin and the coelomoduct is mesodermal in origin a nephromixium is formed by the participation of both ectoderm and mesoderm.**

- The nephromixium performs **two functions**. In one hand, it serves the function of **excretion** and on the other hand, it also serves as **a passage for the exit of gametes**.

- In some cases they share the **same external opening but when the association between them becomes very close they often share the same duct.**

The combinations of the coelomoduct and the nephridium are of the following types:

(a) Protonephromyxium:

In this case the **coelomoduct becomes united to a protonephridium**. Both reproductive and excretory products are conveyed to the exterior by it. Protonephromyxia condition occurs in ***Phyllodoce.***

(b) Metanephromyxium:

In this case the **coelomoduct becomes united to a metanephridium** as in ***Hesione.***

(c) Mixonephridium:

In this case **complete fusion between the coelomoduct and the nephridium** results in the formation of a simple funnel-like organ only. Mixonephridia condition is most prominent in ***Arenicola.***

Ciliated Organs:

The coelomoducts alone become very much reduced in some case and give rise to **ciliated organs which do not open to outside.** In ***Nereis*** such ciliated organs are found and they remain attached to the dorsolateral longitudinal muscles.

Physiology of Nephridium*:*

- In most annelids, the blood vascular system and coelom (if present) are involved in the **excretion of waste products**.
- The polychaetes in which the blood-vascular system is absent or reduced contain protonephridia. The remaining groups of polychaetes and others possess blood-vascular system and metanephridia.
- In proto-nephridia, the ultrafiltration of the coelomic fluid takes place with the help of terminal cells (e.g. solenocytes) and the filtrate fluid passes down through the protonephridial tubule.
- Along the protonephridial tubule some sub-substances such as salts and amino acids are reabsorbed and the chief excretory product ammonia is excreted through the nephridiopore.
- The mouth of metanephridium contains open ciliated funnel or **nephrostome** through which coelomic fluid is drawn by the action of cilia of funnel and the fluid when passing through the metanephridium tubule, some substances like salts, amino acids are resorbed and the nitrogenous waste products like ammonia (20%), amino acids and urea (40%) are excreted and the urea level varies in different groups of annelids in which environment they live.

Functions of Nephridium:
(i) It **eliminates the liquid nitrogenous waste products** from the body to the exterior.

(ii) It **eliminates the basic and non-volatile acid radicals** from the body.

(iii) It **maintains the water balance of the body**.

(iv) It **regulates the osmotic relation between the blood and tissue**.

(v) In some cases, they act as **gonoducts (coelomoducts) by conveying reproductive units**.

Excretory System of Nephridia (Earthworm)
These are of three types according to their location in the body:
Septal nephridia Integumentary nephridia Pharyngeal nephridia.

1. **Septal Nephridia:**

- These are found situated on the inter-segmental septum between 15th and 16th segments to the posterior side of the body.
- Each septum bears nephridia on both the surfaces arranged in semicircles around the intestine, two rows in front of the septum and two behind it.
- Each septum has about 40 to 50 nephridia in front and the same number behind, so that each segment possesses 80 to 100 septal nephridia except the 15th segment which has only 40 to 50 nephridia.
- These are not found in the segments up to 14th.

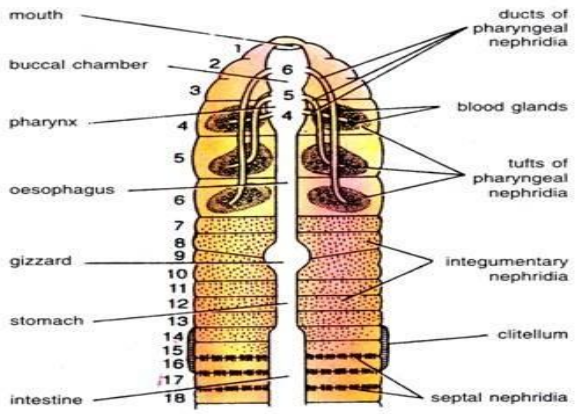

Fig. 66.21. *Pheretima*. Different types of nephridia and general plan of their distribution.

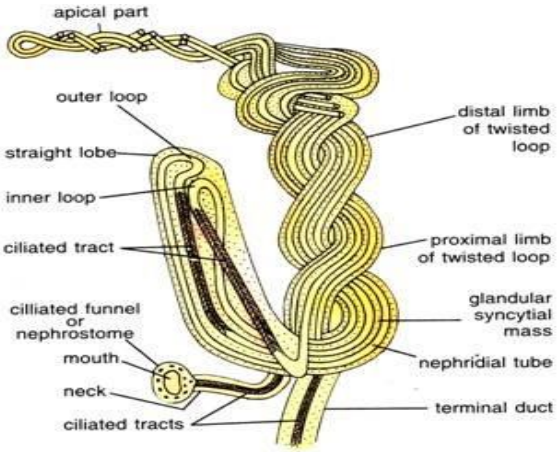

Fig. 66.22. *Pheretima*. A septal nephridium.

Structure:

The septal nephridia may be considered typical of all the nephridia of *Pheretima*. Each septal nephridium (Fig. 66.22) consists of nephrostome, neck, body of nephridium and the terminal duct.

Nephrostome:

- It is also known as ciliated funnel or nephridiostome.
- It is the proximal flattened funnel-shaped structure of the nephridium lying in the coelom.
- It has an elliptical mouth-like opening leading into an intracellular canal of the large central cell, the margins of the opening are surrounded by a large upper lip and a smaller lower lip.
- The lips are provided with several rows of small ciliated marginal cells and the central canal is also ciliated.

Neck:

- The nephrostome leads into a short and narrow ciliated canal forming the neck. It joins the nephrostome to the body of nephridium.

Body of Nephridium:

- The body of nephridium has two parts a short straight lobe and a long-twisted loop.
- The loop is formed by two limbs— the proximal limb and the distal limb.
- Both these limbs are twisted spirally around each other, the number of twists varies from nine to thirteen.
- The neck of nephridium and the terminal duct join together and remain connected with the proximal limb of the twisted loop, while the distal limb becomes the straight lobe.

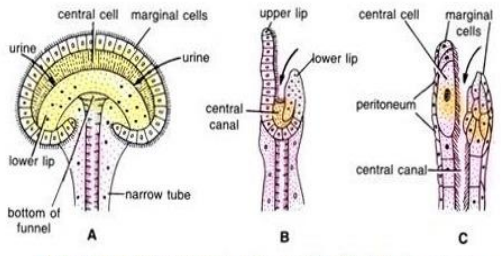

Fig. 66.23. A—Nephrostome of earthworm; B and C—L.S of nephrostome.

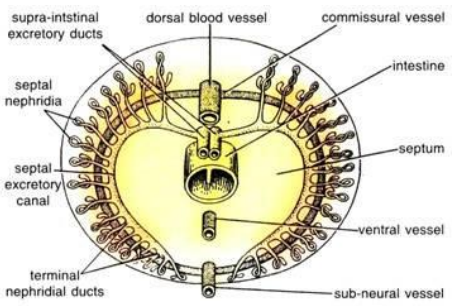

Fig. 66.24. *Pheretima*. The arrangement of septal nephridial system in relation to the intestine.

- Internally the nephridium is made of a connective tissue matrix having long coiled nephridial duct forming loops.

- There are four such canals in the straight lobe, three in the lower part and two in the upper part of the limbs of twisted loop.

- Two canals of the straight lobe out of the four are ciliated like the ciliated canal of the neck.

Terminal Duct:

- It is short and narrow with a terminal excretory duct.

- It joins the nephridium with septal excretory canal.

Relation of septal nephridia with intestine:

- The nephridia hang freely in the coelom and are attached only by their terminal ducts.

- They open by their terminal ducts into two septal excretory canals lying on the posterior surface of the septum, one on each side of the intestine, each begins ventrally but dorsally it opens in the supra-intestinal excretory duct of its own side.

- The supra-intestinal excretory ducts are two parallel longitudinal canals lying above the gut and below the dorsal vessel (Fig. 66.24).

- These excretory ducts begin from the 15th segment and run to the last segment, they communicate- with each other for a short space behind each septum, then either the right or the left duct opens by a ductule into the lumen of the intestine near the septum.
- Thus, each segment has one such opening into the intestine of either the left or the right supra-intestinal excretory duct.

- The waste collected by the nephridia is discharged through the excretory canals and ducts into the lumen of the intestine.

- Such nephridia opening into the intestine are called enteronephric nephridia.

2. Integumentary Nephridia:

- In each segment of the body from 7th to the last segment, numerous nephridia are found attached inside the lining of the body wall.

- These are called integumentary nephridia which are about 200-250 in each segment except the segment of the clitellar region where they number 2,000-2,500 in each segment.

- These nephridia are small-sized, without nephrostome and without any opening into the coelom.

- Hence, they are called closed type of nephridia. Each integumentary nephridium is V-shaped with a short straight lobe and a twisted loop, its lumen has two ciliated canals.

- Each nephridium opens by a nephridiopore on the outer surface of the body wall directly.

- Since the integumentary nephridia discharge the excretory wastes directly outside, hence, they are called exonephric nephridia.

3. Pharyngeal Nephridia:

- These nephridia lie in three paired tufts, one on either side of the anterior region of the alimentary canal in the segments 4th, 5th and 6th.

- The tufts of pharyngeal nephridia also contain blood glands.
- Each pharyngeal nephridium is about the size of a septal nephridium but it is of the closed type having no funnel or nephrostome.
- It has a short straight lobe and a spirally twisted loop; its lumen has ciliated canals.
- Ductules arise from each nephridium and unite to form a single thick- walled duct on each side in each segment.
- The two ducts of nephridia of segment 6th open into the buccal cavity in segment 2nd and the paired ducts of nephridia of segments 4th and 5th open into the pharynx in segment 4th.
- These nephridia also discharge their wastes into the alimentary canal and are, therefore, enteronephric but such enteronephric nephridia which open into the anterior region of the alimentary canal (buccal cavity and pharynx) are called peptonephridia because they may have taken the function of digestive glands.
- Recently it has been reported that the pharyngeal nephridia of P. posthuma produce a variety of enzymes like **amylase, chimosin, prolinase, prolidase, dipeptidases, aminopeptidase, lipase, etc., which hydrolyse various foodstuffs. Thus, such nephridia work like the salivary glands.**

Physiology of Excretion:

- Like other animals, in earthworms also, the protein catabolism results in the formation of **nitrogenous waste substances like certain amino acids, ammonia and urea.**
- **Uric acid is not found in the earthworms**.
- However, **the amino acids are degraded to form free ammonia and the urea is synthesised in the chloragogen cells which are released into the coelomic fluid and also in the blood for its removal. Free amino acids are not excreted but traces of creatinine occur in the urine.**
- Moreover, **the nitrogen excreted in different forms in a well fed worm is about 72% NH_3, 5% urea and remaining other compounds, while in a starved worm NH_3 8.6%, urea 84.5% and remaining being other compounds. But generally, the excretion is 42% NH_3, 50% urea, 0.6% amino acids and remaining being other compounds.**
- So, we can say that in a well fed earthworm, **NH_3 predominates the nitrogenous excretory wastes, hence, it is ammonotelic, while a starved one is ureotelic**.
- An earthworm **excretes the nitrogenous wastes in the form of urine** which generally contains **urea, water, traces of ammonia and creatinine**.
- Nephridia excrete these substances from the body of earthworm.
- The various excretory wastes from the coelomic fluid are drawn into the **nephrostomes of septal nephridia or into the excretory canals of other nephridia along with some other useful substances.**
- These products are **either discharged into the intestine (by enteronephric nephridia) or outside by the nephridiopores (by exonephric nephridia).**
- The body of nephridia also absorbs some wastes.
- However, the **useful substances are reabsorbed and the passing out waste remains concentrated for various nitrogenous compounds.**

- The **excreted waste substances are removed out from the body with faeces.**
- The nephridia, in addition to excretory, are also **osmoregulatory** in function.
- The nephridia **help in conserving water by reabsorption from the excreted products during summers and winters, so they pass hypertonic urine in relation to blood.**
- During rainy season, the **urine is dilute due to lesser reabsorption of water.**
- The **enteronephric nature of nephridia provides another device for conserving water**.