CHAPTER 5. Excretion

Introduction

Excretion is a vital biological process that eliminates metabolic wastes from the body to maintain internal homeostasis. In **vertebrates**, excretion primarily occurs through the **kidneys**, whose functional units—the **nephrons**—filter blood, reabsorb essential substances, and excrete nitrogenous wastes such as urea or uric acid. In contrast, **invertebrates** employ a variety of excretory systems adapted to their body structure and habitat, including **nephridia** in earthworms, **Malpighian tubules** in insects, and **contractile vacuoles** in protozoa. While both groups aim to remove metabolic waste and regulate water balance, vertebrate kidneys represent a more **complex and efficient** evolutionary advancement compared to the **simpler and more diverse** mechanisms found in invertebrates.

I. Invertebrate Excretion

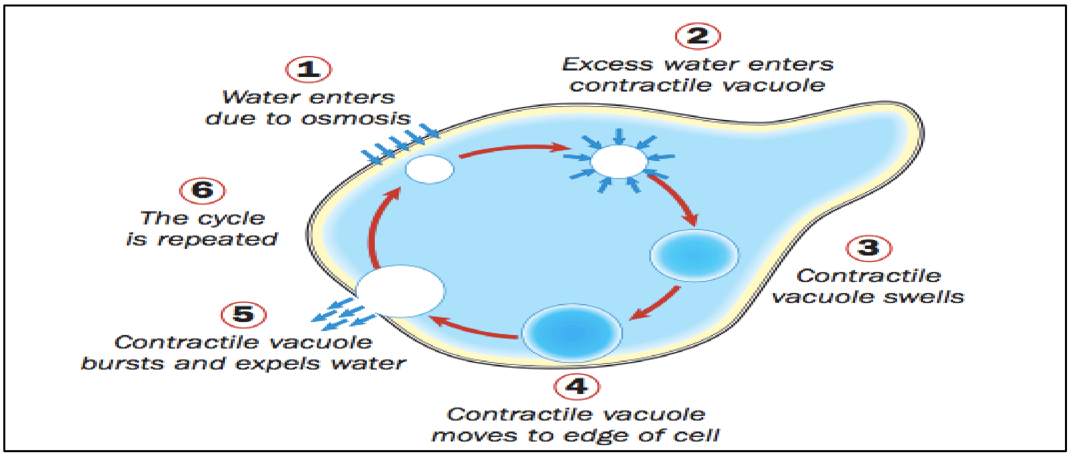
Invertebrates display a wide range of excretory systems adapted to their structure, habitat, and mode of life. The following are the main excretory mechanisms found among different invertebrate groups:

1. Protozoa

Protozoa are **unicellular organisms**, so all excretory and osmoregulatory processes occur within a **single cell**. They **do not have specialized excretory organs**. Instead, **metabolic wastes** such as ammonia and carbon dioxide are removed by **simple diffusion** across the cell membrane.

A key structure for **osmoregulation** is the **contractile vacuole**, especially in **freshwater protozoa**. Because water enters the cell continuously by osmosis, the contractile vacuole **collects excess water and expels it** through rhythmic contractions. This prevents the cell from **bursting** and maintains internal water balance.

In **marine protozoa**, where osmotic water movement is minimal, the **contractile vacuole is reduced or absent**.



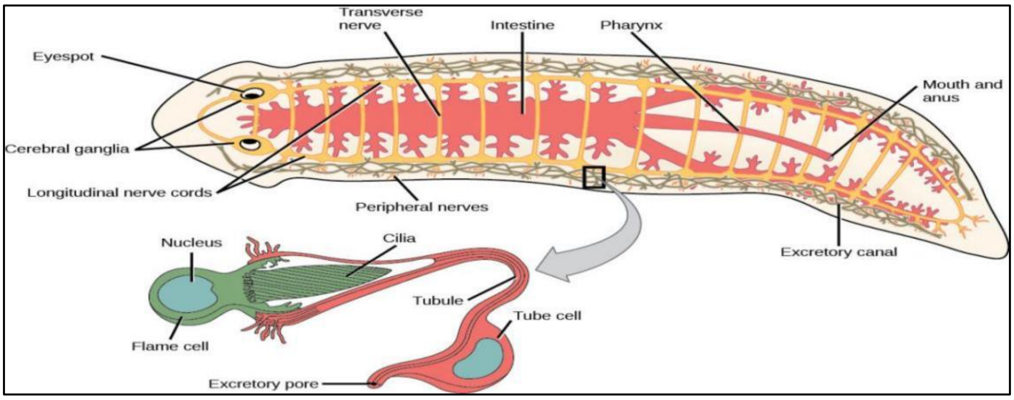
Excretory Mechanisms In Protozoans

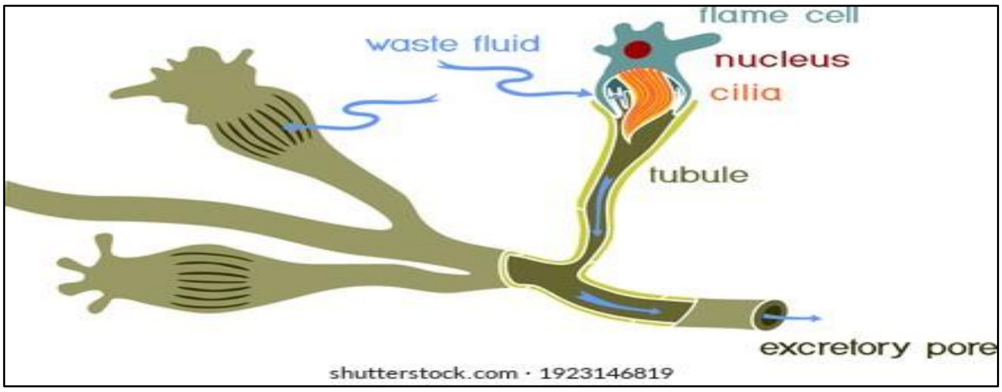
2. Platyhelminthes (Flatworms)

Platyhelminthes (flatworms) have a simple excretory system made of **protonephridia**, which are networks of fine tubules used for **excretion** and **osmoregulation**. Each protonephridium begins with a **flame cell**, a terminal cell with beating cilia that create a current to draw wastes and excess water into the tubules. The fluid moves through the **tubules**, where some useful substances may be reabsorbed, and the remaining waste is expelled outside through **excretory pores (nephridiopores)**.

In **free-living flatworms** like *Planaria*, this system is well developed to remove excess water entering by osmosis. In **parasitic flatworms** such as *Taenia* and *Fasciola*, the system is simpler but still functions to remove metabolic waste.

Overall, the protonephridial system with flame cells allows flatworms to **maintain water and ionic balance** effectively.





Flatworm Flame Cell Structure

3. Annelids

Annelids have a **well-developed excretory system** made up of **nephridia**, which remove nitrogenous wastes and regulate water and salt balance. Each body segment usually has a **pair of nephridia**, giving the system a **metameric (segmental)** arrangement.

The most common type in earthworms is the **metanephridium**, consisting of:

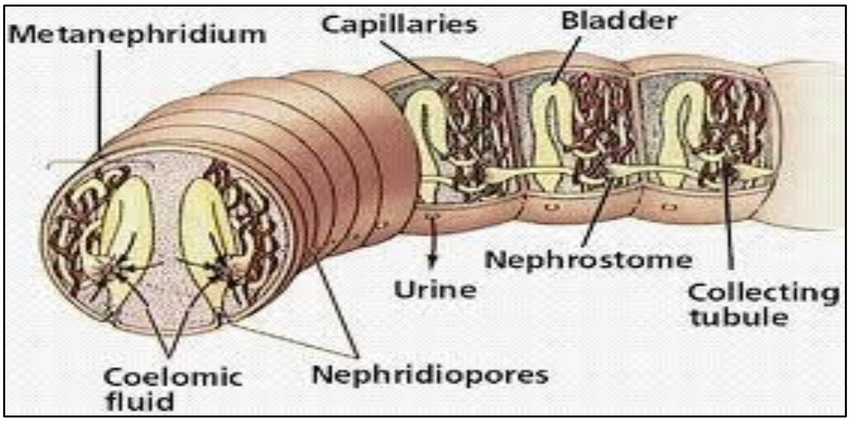
- A **ciliated funnel (nephrostome)** that collects waste from the coelomic fluid
- A **coiled tubule** where useful substances (water, salts, nutrients) are **reabsorbed**
- A **nephridiopore** that expels remaining waste to the outside

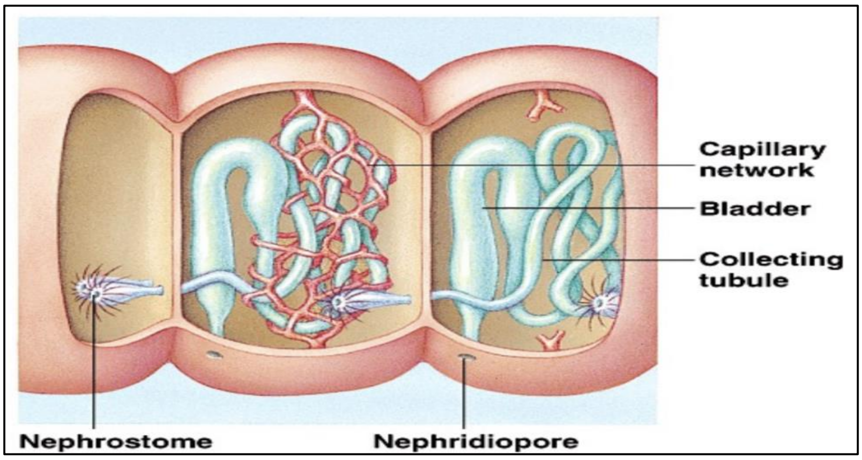
In **earthworms (Lumbricus terrestris)**, there are **three types of nephridia**:

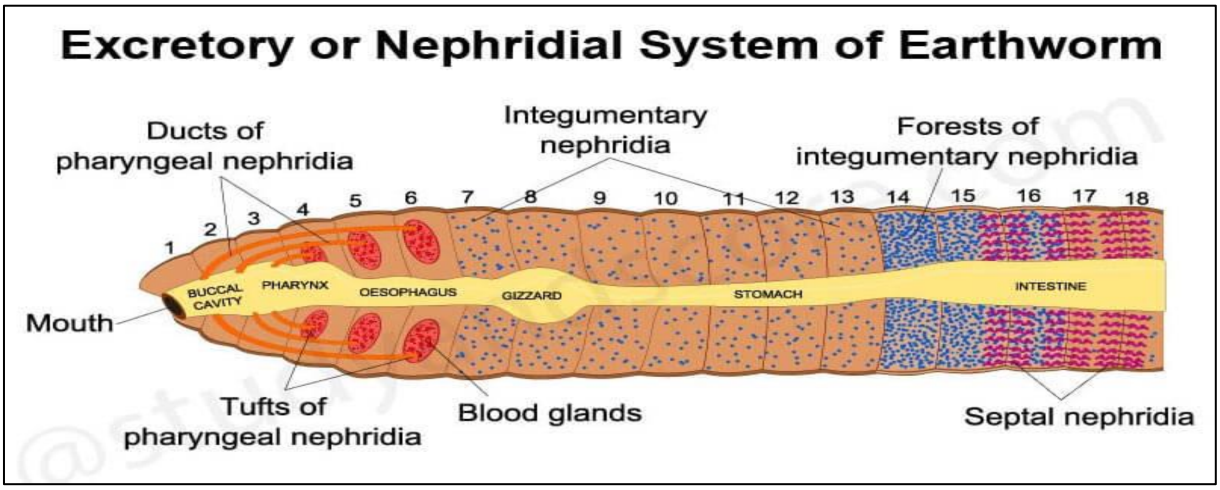
1. **Septal nephridia** → on septa between segments, opening into the intestine
2. **Integumentary nephridia** → in the body wall, opening directly to the exterior
3. **Pharyngeal nephridia** → near the anterior end, functioning around the pharynx

Marine annelids (e.g., *Nereis*) are **ammonotelic** and excrete **ammonia**, while **terrestrial annelids** (e.g., earthworms) are **ureotelic**, excreting **urea**, which helps **conserve water**.

Overall, the annelid excretory system is more **efficient and advanced** than that of flatworms, representing an important evolutionary improvement in **osmoregulation and waste removal**.

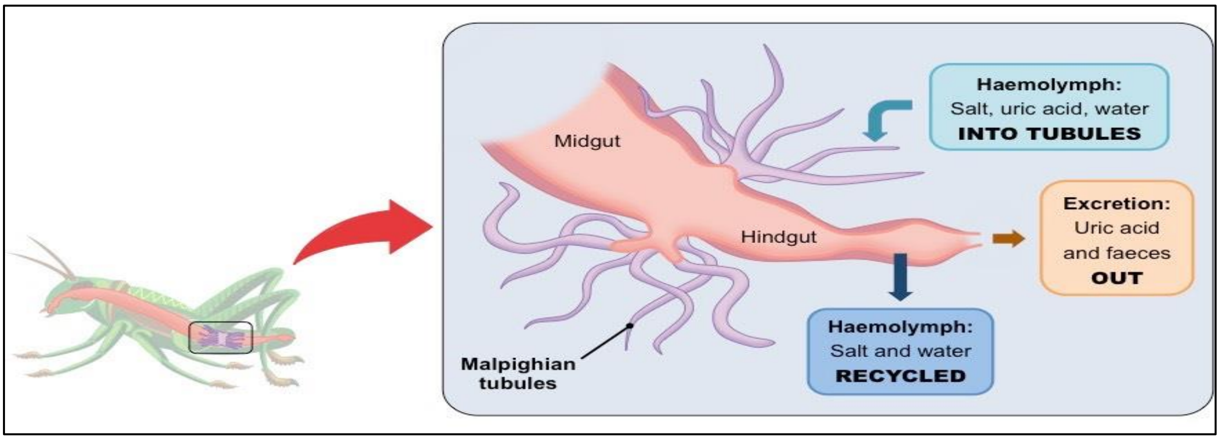






4. Insects and Arachnids

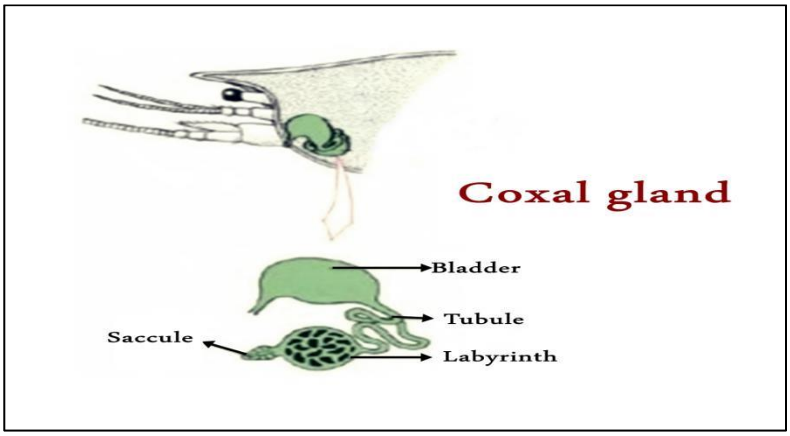
Insects and arachnids possess efficient **excretory systems** that enable them to conserve **water** in terrestrial environments. In insects, the primary excretory organs are the **Malpighian tubules**, which extend from the midgut–hindgut junction into the **hemocoel**. These tubules collect **nitrogenous wastes** (mainly **uric acid**) and excess ions from the hemolymph and pass them into the **hindgut**, where **water** and **salts** are reabsorbed. The remaining uric acid is excreted as a **semisolid paste**, minimizing water loss. Additional structures such as **rectal glands** and the **fat body** help in **water reabsorption**, **ion regulation**, and **detoxification**. In arachnids, waste is also removed by **Malpighian tubules**, but they possess additional **coxal glands** near the base of the legs, which aid in excretion and **osmoregulation**. Both insects and arachnids are **uricotelic**, excreting uric acid to conserve water, which is a key adaptation for **terrestrial** survival.



Malpighian Tubules

5. Crustaceans

Crustaceans possess specialized excretory organs called **antennal** or **green glands,** located at the base of the antennae. These glands play a crucial role in filtering the hemolymph, selectively reabsorbing useful substances, and excreting nitrogenous wastes such as ammonia into the surrounding water. Each gland consists of three main parts: the **end sac (or saccule)**, which collects the filtrate from the hemolymph; the **labyrinth**, where selective reabsorption of ions and water occurs; and the **bladder**, which temporarily stores the final urine before it is discharged through an excretory pore near the antenna. This system is functionally analogous to nephridia but highly adapted to the aquatic lifestyle of crustaceans, maintaining osmotic and ionic balance within their bodies.



Excretory System in Crustaceans

II. Vertebrate Excretion

In vertebrates, excretion is primarily performed by the **kidneys**, which are responsible for removing nitrogenous wastes, regulating water and electrolyte balance, and maintaining internal homeostasis. The functional unit of the kidney is the **nephron**, a microscopic structure that filters blood, reabsorbs essential substances, and excretes waste products in the form of urine. The nature of nitrogenous waste varies among vertebrate groups, reflecting adaptations to their environment and mode of life.

2.1. Pisces (Fishes)

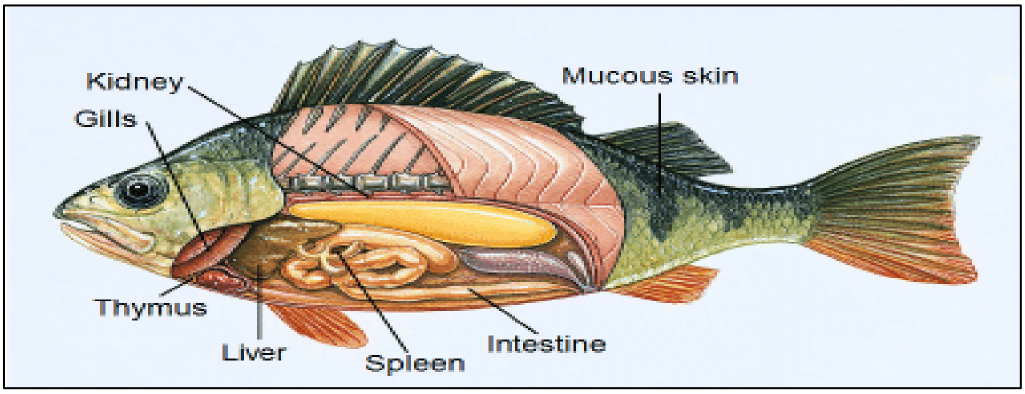
Fishes possess an efficient **excretory system** adapted to their **aquatic environment**, where maintaining **osmotic** and **ionic balance** is crucial. The main excretory organs are the **mesonephric kidneys** (or **opisthonephric kidneys** in adults), which lie along the dorsal side of the body cavity. From each kidney arises a **ureter** that opens into a **urinary bladder** (in some species) or directly into the **cloaca** or **urinary pore**.

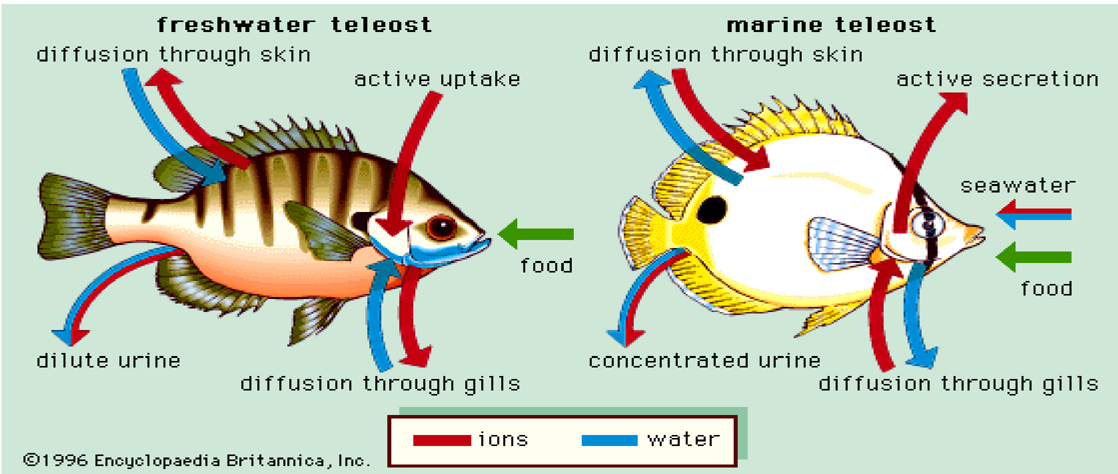
Each kidney contains many **nephrons**, the functional units of excretion. A nephron includes a **glomerulus** for filtration, **Bowman's capsule** for collecting filtrate, and **tubules** for **reabsorption** and **secretion**. The kidneys remove **nitrogenous wastes** and play a key role in **osmoregulation**.

Most fishes are **ammonotelic**, excreting **ammonia**, which easily diffuses out through the **gills**. Some species may excrete **urea** (**ureotelic**) or **uric acid** (**uricotelic**) depending on water availability.

The mechanism differs between freshwater and marine fishes:

- **Freshwater fishes** live in a **hypotonic environment** where water enters the body by **osmosis**. They excrete **large amounts of dilute urine** and actively **absorb salts** through the gills.
- **Marine fishes** live in a **hypertonic environment**, losing water by osmosis. They **drink seawater**, excrete **concentrated salts** via **chloride cells** in the gills, and produce **small amounts of concentrated urine** to conserve water.





2.2. Amphibians

Amphibians, such as **frogs**, **toads**, and **salamanders**, possess intermediate **excretory adaptations** that allow them to live both in **water** and on **land**. The main excretory organs are the **mesonephric kidneys** (or **opisthonephric kidneys** in adults). Each kidney is elongated and located dorsally beside the **vertebral column**. From each kidney, a **ureter** opens into the **cloaca**, a common chamber for the **digestive**, **urinary**, and **reproductive** systems.

The kidneys are composed of many **nephrons**, each containing a **glomerulus**, **Bowman's capsule**, and **tubules** (**proximal**, **distal**, and **collecting ducts**) that perform **filtration**, **reabsorption**, and **secretion** to form **urine**.

Amphibians show flexibility in **nitrogenous waste** excretion:

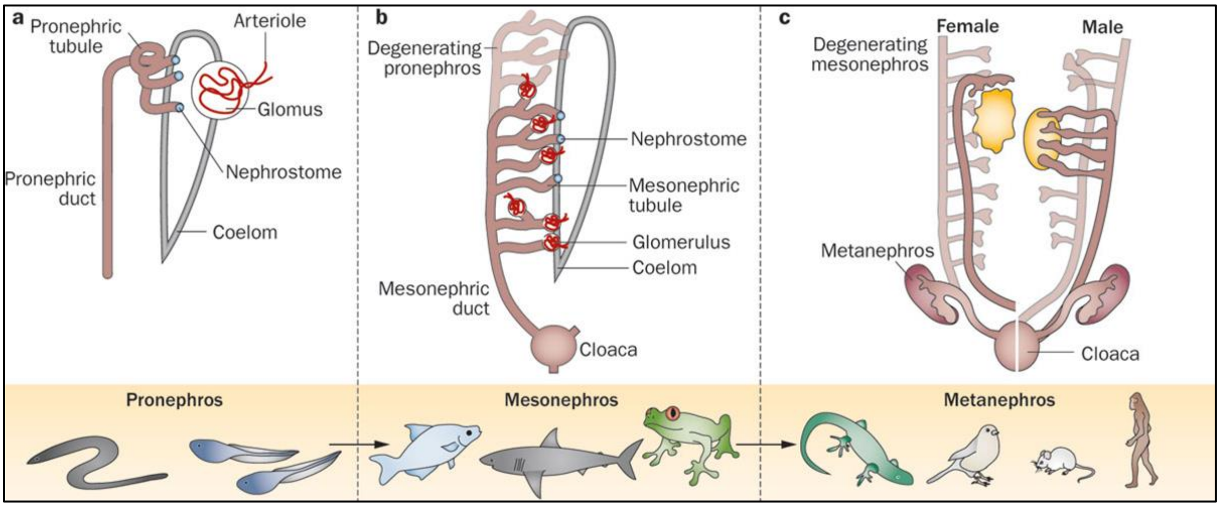
- On **land**: they are **ureotelic**, excreting **urea** to **conserve water**.
- In **water**: they become **ammonotelic**, excreting **ammonia** that diffuses easily into the environment.

The **urinary bladder** and **skin** also aid in **osmoregulation**. The bladder serves as a **water reservoir**, allowing **water reabsorption** during dry conditions. The **skin** assists in eliminating small amounts of **salts** and **urea** and also participates in **respiration**. The **liver** converts toxic ammonia into urea via the **urea cycle**.

In summary, amphibians show **remarkable adaptability** in excretion, enabling efficient regulation of **water balance** and **nitrogenous waste** in both **aquatic** and **terrestrial** habitats.

2.3. Reptiles

Amphibians, such as **frogs**, **toads**, and **salamanders**, possess **intermediate excretory adaptations** that allow them to live both in **water** and on **land**. The main excretory organs are the **mesonephric (opisthonephric) kidneys**, located dorsally on either side of the **vertebral column**. From each kidney, a **ureter** arises and opens into the **cloaca**, a common chamber for the **digestive**, **urinary**, and **reproductive** systems. The kidneys contain many **nephrons**, each consisting of a **glomerulus**, **Bowman's capsule**, and **tubules** (**proximal**, **distal**, and **collecting ducts**) that carry out **filtration**, **reabsorption**, and **secretion** to form **urine**.



2.4. Birds

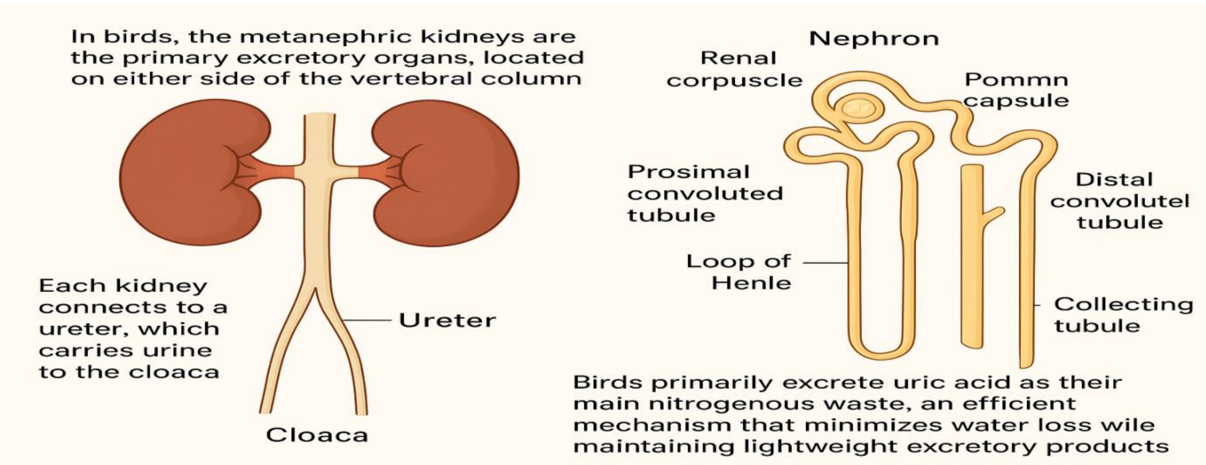
Birds have **metanephric kidneys** located on either side of the vertebral column. **Ureters** carry urine to the **cloaca**, where it mixes with feces and is expelled as a **pasty uric acid** mixture. This adaptation **conserves water** and **reduces body weight**, which is essential for **flight**.

The kidneys contain two types of **nephrons**:

- **Mammalian-type nephrons** (in the **medulla**) with a **Loop of Henle** to **concentrate urine**.
- **Reptilian-type nephrons** (in the **cortex**) that **lack** the Loop of Henle.

Each nephron includes:
Renal corpuscle → Proximal tubule → Loop of Henle (if present) → Distal tubule → Collecting tubule → Ureter.

Birds are **uricotelic**, meaning they excrete **uric acid**, which requires **very little water** and forms a **semi-solid paste**, providing efficient **water conservation** for flight.



2.5. Mammals

Mammals have a highly efficient **excretory system** that removes **metabolic wastes**, regulates **water** and **salt balance**, and maintains **homeostasis**. The main organs are **metanephric kidneys**, located dorsally on either side of the **vertebral column**, with **ureters** carrying urine to the **urinary bladder**, which stores it before expulsion via the **urethra**.

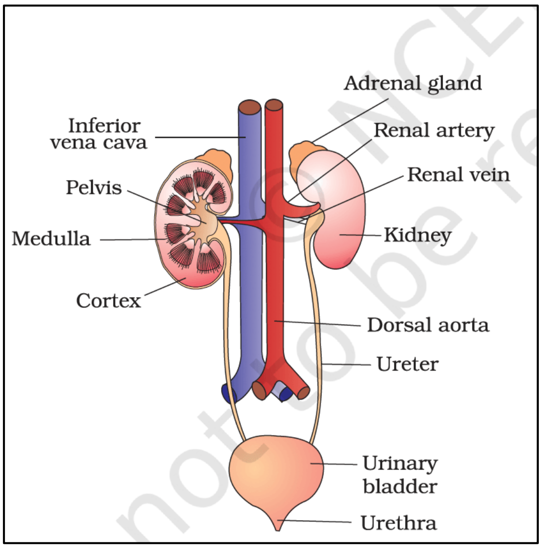
Each kidney contains millions of **nephrons**, composed of a **glomerulus**, **Bowman's capsule**, and **renal tubule** (proximal tubule, **Loop of Henle**, distal tubule, and collecting duct). The

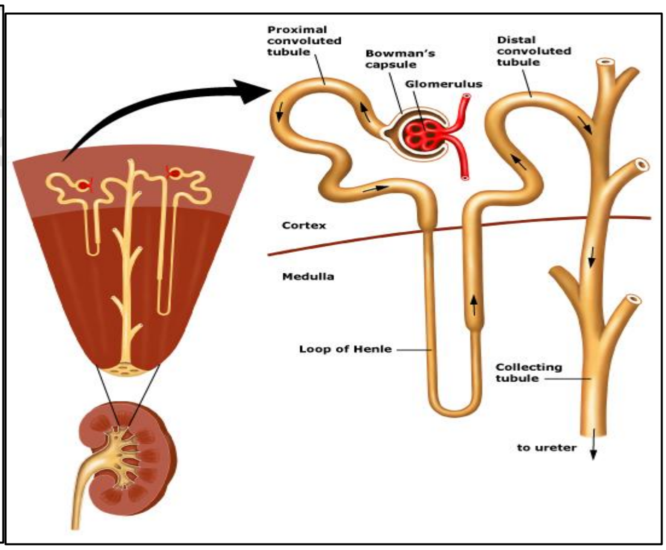
Loop of Henle creates a concentration gradient in the medulla, enabling production of **concentrated urine** and conserving **water**, an important adaptation to terrestrial life.

Mammals are **ureotelic**, excreting **urea**, which is synthesized in the **liver** via the **urea cycle**. Urine concentration varies with habitat: **desert mammals** produce highly concentrated urine, while **aquatic mammals** excrete dilute urine.

The excretory system works with other organs for **osmoregulation** and **acid-base balance**: kidneys regulate **electrolytes**, lungs remove **CO_2**, and skin excretes salts and urea through **sweat**.

In summary, the mammalian excretory system — kidneys, ureters, bladder, and urethra — efficiently removes **nitrogenous wastes**, conserves **water**, and maintains **internal stability**, supporting survival in diverse environments.





4. Kidney and Nephron Function

1. Role of the Kidneys

The **kidneys** are the main organs of the excretory system. Their primary functions are to:

- **Filter blood** to remove metabolic wastes (such as urea)
- **Regulate water balance** (maintain body fluid volume)
- **Control salt and ion concentrations** (electrolyte balance)
- **Regulate blood pH**
- Produce **hormones** such as:

- **Erythropoietin (EPO)** → stimulates red blood cell formation
- **Renin** → helps regulate blood pressure

Each kidney contains about **1–2 million nephrons**, the functional units that perform filtration and urine formation.

2. Structure of the Nephron

A nephron has two main parts:

Part	Structures Included	Function
Renal Corpuscle	**Glomerulus** + **Bowman's Capsule**	**Filtration** of blood
Renal Tubule	**Proximal Tubule**, **Loop of Henle**, **Distal Tubule**, **Collecting Duct**	**Reabsorption & secretion** to form urine

3. Stages of Urine Formation

A. Filtration

- Occurs in the **glomerulus**.
- Blood pressure forces **water and small solutes** (glucose, amino acids, salts, urea) into **Bowman's capsule**.
- Large molecules (proteins, blood cells) **do not pass** → remain in blood.

Result: Formation of **glomerular filtrate**.

B. Reabsorption

- Mostly in the **Proximal Convoluted Tubule (PCT)**.
- Useful substances are **returned to the bloodstream**, such as:
  - **Glucose**
  - **Amino acids**
  - **Water**

- **Ions (e.g., Na^+, Cl^-)**

- The **Loop of Henle** helps **concentrate urine** by reabsorbing water on the descending limb and salts on the ascending limb.

C. Secretion

- Mainly in the **Distal Convoluted Tubule (DCT)**.
- Additional wastes (H^+, K^+, drugs, toxins) are **actively transported** from blood into the filtrate.
- Helps maintain **acid-base balance**.

D. Collection and Concentration

- The **Collecting Duct** adjusts the final concentration of urine.
- Controlled by **ADH (Antidiuretic Hormone)**:
    - **High ADH:** More water reabsorbed → **concentrated urine**
    - **Low ADH:** Less water reabsorbed → **dilute urine**

4. Summary Table

Process	**Location**	**Main Function**
Filtration	Glomerulus → Bowman's Capsule	Forms filtrate from blood
Reabsorption	PCT, Loop of Henle, DCT	Returns useful substances to blood
Secretion	DCT	Removes additional waste and balances ions
Concentration	Collecting Duct	Adjusts final water content of urine