Systemic 2[B]

Chapter 16: EXCRETORY SYSTEMS AND MECHANISMS

Learning Objectives: Upon completion of this chapter, students should be able to:

- Define excretion and differentiate it from egestion and secretion.
- Explain the need for excretion in living organisms.
- Describe the different forms of nitrogenous waste.
- Outline excretory mechanisms in simple organisms (e.g., *Amoeba*, *Hydra*, Earthworm).
- Detail the structure and function of the human excretory system (kidneys, skin, lungs, liver).
- Explain the process of urine formation in the kidney.
- Discuss osmoregulation and thermoregulation in mammals.
- Describe excretory and regulatory mechanisms in plants.

16.1 Definition and Importance of Excretion

- **Excretion:** The removal of metabolic waste products from the body or cells. These wastes are produced by cellular activities (metabolism) and can be toxic if allowed to accumulate.
    - *Examples of metabolic wastes:* Carbon dioxide, urea, uric acid, ammonia, excess water, excess salts.
- **Differentiation:**
    - **Excretion vs. Egestion:**
        - **Excretion:** Removal of *metabolic* waste products (e.g., urine, sweat, carbon dioxide).
        - **Egestion (Defecation):** Removal of *undigested and unabsorbed food material* (feces) from the alimentary canal. This is not a metabolic waste product.
    - **Excretion vs. Secretion:**
        - **Excretion:** Removal of waste products *out of the body*.
        - **Secretion:** Production and release of useful substances by cells or glands (e.g., hormones, enzymes, mucus) *into or out of the body* for a specific function.
- **Need for Excretion:**
    1. **Prevent Toxicity:** Metabolic wastes are often toxic and can interfere with cellular processes if they accumulate.

2. **Maintain Homeostasis (Internal Balance):** Regulates water potential, salt balance, and pH of body fluids.
3. **Remove Excess Substances:** Eliminates excess water, salts, or nutrients.

16.2 Forms of Nitrogenous Waste

Nitrogenous wastes are by-products of protein and nucleic acid metabolism.

1. **Ammonia (NH_3):**
    - **Characteristics:** Highly toxic, highly soluble in water.
    - **Excreted by:** Aquatic animals (fish, aquatic invertebrates). They can excrete it quickly and dilute it with plenty of water.
2. **Urea:**
    - **Characteristics:** Less toxic than ammonia, moderately soluble in water.
    - **Excreted by:** Mammals, amphibians, some marine fish. Requires water for excretion, but less than ammonia.
    - **Formation:** Ammonia is converted to urea in the liver (urea cycle).
3. **Uric Acid:**
    - **Characteristics:** Least toxic, almost insoluble in water (excreted as a paste or solid).
    - **Excreted by:** Birds, reptiles, insects. Adapted for water conservation, as it requires very little water for excretion.

16.3 Excretory Mechanisms in Simple Organisms

- **A. *Amoeba* (Unicellular Protozoan):**
    - **Mechanism:** Gaseous wastes (CO_2) and nitrogenous wastes (ammonia) diffuse directly across the cell membrane into the surrounding water.
    - **Osmoregulation:** The **contractile vacuole** actively pumps out excess water that enters the cell by osmosis (due to the cell being hypertonic to freshwater), preventing the cell from bursting.
- **B. *Hydra* (Simple Multicellular Coelenterate):**
    - **Mechanism:** Excretion occurs by diffusion of metabolic wastes directly from individual cells into the surrounding water or into the gastrovascular cavity. No specialized excretory organs.
- **C. Earthworm:**
    - **Specialized Organs:** Possesses pairs of segmentally arranged excretory organs called **nephridia** (specifically metanephridia).
    - **Mechanism:** Each nephridium has a ciliated funnel (nephrostome) that collects fluid from the coelom. The fluid passes through a convoluted tubule where useful substances (water, salts, glucose) are reabsorbed, and wastes (nitrogenous wastes like urea, excess salts, water) are concentrated. The dilute urine is then expelled through an excretory pore (nephridiopore) on the body surface.
    - **Overall:** Maintains water balance and removes nitrogenous wastes.

16.4 Human Excretory System (Mammalian Excretory Organs)

The human body has several organs involved in excretion:

1. **Kidneys:**
    - **Primary Excretory Organs:** Filter blood to produce urine, removing nitrogenous wastes (urea), excess salts, and water.
    - **Function:** Maintain water and salt balance (osmoregulation), regulate blood volume and pressure, remove metabolic wastes.
    - **Structure:** Two bean-shaped organs located in the abdominal cavity. Consist of an outer **cortex**, inner **medulla**, and a central **pelvis** leading to the ureter.
        - **Nephron:** The functional unit of the kidney (millions per kidney). Each nephron consists of a renal corpuscle (glomerulus and Bowman's capsule) and a renal tubule (proximal convoluted tubule, loop of Henle, distal convoluted tubule, collecting duct).
    - **Urine Formation (in Nephron):**
        1. **Glomerular Filtration (Ultrafiltration):** Blood enters the glomerulus (a capillary knot) under high pressure. Water, salts, glucose, amino acids, urea, and other small molecules are filtered from the blood into Bowman's capsule, forming **glomerular filtrate**. Large molecules (proteins) and blood cells are retained.
        2. **Selective Reabsorption:** As the filtrate passes through the renal tubule, useful substances are reabsorbed back into the blood.
            - **Proximal Convoluted Tubule:** Most glucose, amino acids, vitamins, and a large proportion of salts and water are reabsorbed actively and passively.
            - **Loop of Henle:** Creates a concentration gradient in the medulla, allowing for the reabsorption of more water and salt.
            - **Distal Convoluted Tubule & Collecting Duct:** Variable reabsorption of water and salts, regulated by hormones (e.g., ADH for water reabsorption).
        3. **Tubular Secretion:** Certain waste products (e.g., some drugs, excess ions like H^+) are actively secreted from the blood into the filtrate in the tubules.
    - **Ureters:** Tubes carrying urine from kidneys to the bladder.
    - **Urinary Bladder:** Stores urine temporarily.
    - **Urethra:** Tube through which urine is expelled from the body.
2. **Skin:**
    - **Excretory Function:** Sweat glands produce **sweat** (water, salts, a small amount of urea).
    - **Primary Function:** Thermoregulation (cooling the body through evaporation of sweat).
3. **Lungs:**
    - **Excretory Function:** Excrete **carbon dioxide** (a major metabolic waste from respiration) and **water vapor** during breathing.
    - **Primary Function:** Gaseous exchange.

4. **Liver:**
    - **Key Metabolic Organ with Excretory Roles:**
        - **Detoxification:** Converts harmful substances (e.g., alcohol, drugs) into less toxic forms for excretion.
        - **Urea Formation:** Converts toxic ammonia (from deamination of excess amino acids) into less toxic urea, which is then transported to the kidneys for excretion.
        - **Breakdown of Old Red Blood Cells:** Breaks down hemoglobin, forming bile pigments (bilirubin), which are excreted in bile (and ultimately in feces).
    - **Primary Function:** Numerous metabolic roles; excretion is a consequence of these.

16.5 Osmoregulation and Thermoregulation in Mammals

- **Osmoregulation:**
    - **Definition:** The control of the water potential and solute concentration (salt balance) of body fluids.
    - **Key Organs:** Kidneys play the primary role in mammals. The hypothalamus (brain) and pituitary gland (releasing ADH) also play crucial roles.
    - **Mechanism:**
        - If body fluids are too concentrated (low water potential, e.g., after sweating a lot), the hypothalamus detects this and stimulates the pituitary gland to release more **Antidiuretic Hormone (ADH)**. ADH makes the collecting ducts in the kidneys more permeable to water, leading to more water reabsorption and production of small volumes of concentrated urine.
        - If body fluids are too dilute (high water potential, e.g., after drinking a lot of water), less ADH is released. Collecting ducts become less permeable, less water is reabsorbed, and a large volume of dilute urine is produced.
- **Thermoregulation:**
    - **Definition:** The maintenance of a stable internal body temperature in mammals (homeothermy).
    - **Key Organs:** Skin (sweat glands, blood flow to surface), hypothalamus (thermoregulatory center in the brain).
    - **Mechanisms to Cool Down (when hot):**
        - **Sweating:** Evaporation of sweat from the skin surface removes latent heat, cooling the body.
        - **Vasodilation:** Arterioles supplying capillaries in the skin dilate, increasing blood flow to the skin surface. More heat is lost by radiation, convection, and conduction.
    - **Mechanisms to Warm Up (when cold):**
        - **Shivering:** Involuntary muscle contractions generate heat.
        - **Vasoconstriction:** Arterioles in the skin constrict, reducing blood flow to the surface, minimizing heat loss.
        - **Piloerection (Goosebumps):** Hairs stand on end to trap a layer of insulating air (less effective in humans than in furry animals).
        - **Increased Metabolism:** Hormones can increase metabolic rate to generate more heat.

16.6 Excretory and Regulatory Mechanisms in Plants

Plants generally have less complex excretory systems than animals because:

- Their metabolic rate is lower.
- They often reuse their waste products.
- Many wastes are stored in harmless ways.
- **A. Excretion of Gaseous Wastes:**
    - **Oxygen:** A by-product of photosynthesis, diffuses out through stomata.
    - **Carbon Dioxide:** A by-product of respiration, diffuses out through stomata (during the night) or used for photosynthesis (during the day).
- **B. Excretion of Liquid Wastes:**
    - **Water (Transpiration):** Excess water is lost as vapor through stomata. This is a form of excretion but also crucial for water transport.
    - **Guttation:** Loss of water droplets from leaf margins (hydathodes) when transpiration is low and root pressure is high.
- **C. Excretion/Storage of Solid Wastes:**
    - **Storage in Vacuoles:** Many waste products (e.g., organic acids, crystals of calcium oxalate) are stored in the central vacuole, often in an insoluble and harmless form.
    - **Storage in Leaves/Bark:** Some wastes are deposited in old leaves or bark, which are then shed (e.g., tannins, resins, gums).
    - **Diffusion into Soil:** Some root cells excrete wastes into the surrounding soil.
- **D. Regulation (Water Balance):**
    - **Stomata Control:** Guard cells regulate the opening and closing of stomata, controlling water loss (transpiration) and gas exchange.
    - **Root Pressure:** Pushes water up the xylem, especially when transpiration is low.
    - **Wilting:** A reversible response to water stress, reducing surface area exposed to sun and wind.