Systemic 2[A]

Chapter 15: GASEOUS EXCHANGE • RESPIRATORY SYSTEMS

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

- Define respiration and gaseous exchange.
- Describe respiratory surfaces and their characteristics.
- Explain gaseous exchange in simple organisms (e.g., *Amoeba*, *Hydra*).
- Outline the respiratory systems of various animals (e.g., fish, insects, amphibians, mammals).
- Detail the structure and function of the human respiratory system.
- Explain the mechanism of breathing and gaseous exchange in the alveoli.

15.1 Respiration and Gaseous Exchange

- **Respiration:** The metabolic process by which living organisms obtain energy (ATP) by breaking down organic molecules, usually involving the intake of oxygen and release of carbon dioxide. This is a cellular process (covered in Chapter 11).
- **Gaseous Exchange:** The physical process of moving gases (oxygen and carbon dioxide) between the organism and its external environment, across a respiratory surface. It is a prerequisite for aerobic respiration.

15.2 Respiratory Surfaces and Their Characteristics

For efficient gaseous exchange, all respiratory surfaces share common characteristics:

1. **Large Surface Area:** To maximize the rate of diffusion.
2. **Thin Permeable Walls:** Typically one-cell thick, to ensure a short diffusion distance.
3. **Moist Surface:** Gases must dissolve in a thin film of water/mucus before they can diffuse across the membrane.
4. **Rich Blood Supply (Vascularization):** To maintain a steep concentration gradient of gases. In organisms without a circulatory system, a steep gradient is maintained by ventilation and direct contact with the environment.

15.3 Gaseous Exchange in Simple Organisms

- **A. Simple Body Surfaces:**
    - **Unicellular Organisms (e.g., *Amoeba*, *Paramecium*):** Gaseous exchange occurs directly across the entire cell surface (plasma membrane) by diffusion. Their large surface area to volume ratio allows for efficient exchange.

    - **Simple Multicellular Organisms (e.g., *Hydra*, Flatworms):** Gaseous exchange occurs directly across the moist outer body surface by diffusion. These organisms are typically very thin or have a gastrovascular cavity to ensure short diffusion distances to all cells.

15.4 Respiratory Systems in Animals

More complex animals have specialized respiratory organs.

- **A. Gills in Bony Fish:**
    - **Location:** Found under the operculum (gill cover) on each side of the head.
    - **Structure:** Composed of gill arches, from which project numerous gill filaments. Each filament has many lamellae (folds).
    - **Characteristics of Respiratory Surface:**
        - **Large Surface Area:** Provided by numerous filaments and lamellae.
        - **Thin Walls:** Lamellae are one-cell thick.
        - **Rich Blood Supply:** Extensive capillary networks within the lamellae.
        - **Moist Surface:** Always bathed in water.
    - **Mechanism of Gaseous Exchange:**
        - **Ventilation:** Fish constantly pump water over their gills (buccal pumping and opercular movements).
        - **Counter-current Flow:** Blood in the capillaries flows in the opposite direction to the water flowing over the lamellae. This maintains a steep oxygen concentration gradient along the entire length of the exchange surface, maximizing oxygen diffusion into the blood and carbon dioxide diffusion out.
- **B. Tracheal System in Insects (e.g., Grasshopper):**
    - **Description:** A network of air tubes (tracheae) that branch throughout the insect's body, delivering oxygen directly to the cells.
    - **Structure:**
        - **Spiracles:** External openings on the thorax and abdomen, which can be opened and closed to control gas exchange and water loss.
        - **Tracheae:** Larger air tubes branching from spiracles.
        - **Tracheoles:** Fine, dead-end tubes that extend into individual cells or tissues, filled with a small amount of fluid.
    - **Mechanism of Gaseous Exchange:**
        - Air enters through spiracles and travels directly through the tracheal system to the cells.
        - Oxygen dissolves in the fluid at the ends of tracheoles and diffuses into cells.
        - Carbon dioxide diffuses from cells into tracheoles and out through spiracles.
        - Larger insects may use rhythmic body movements (abdominal pumping) to ventilate the tracheal system.
    - **Key Feature:** Does not rely on a circulatory system for oxygen transport.
- **C. Skin and Lungs in Amphibians (e.g., Frog):**
    - **Skin:** Moist, permeable skin allows for significant gaseous exchange, especially when submerged or in moist environments.
        - **Characteristics:** Large surface area relative to body size, thin, moist, richly supplied with capillaries.
    - **Lungs:** Simple, sac-like structures, less efficient than mammalian lungs.
        - **Mechanism:** Frog uses buccal (mouth) pumping to force air into its lungs.

    - **Buccal Cavity:** Lining of mouth and throat is also highly vascularized for gaseous exchange.
    - **Combination:** Frogs use a combination of cutaneous (skin) respiration, pulmonary (lung) respiration, and buccal respiration depending on their activity and environment.
- **D. Lungs in Mammals (e.g., Human):**
    - **High Metabolic Rate:** Mammals have a high metabolic rate, requiring a highly efficient respiratory system.

15.5 Human Respiratory System

- **Structure:**
    1. **Nasal Cavity:** Warms, humidifies, and filters incoming air. Lined with mucus and cilia.
    2. **Pharynx (Throat):** Common passageway for air and food.
    3. **Larynx (Voice Box):** Contains vocal cords.
    4. **Trachea (Windpipe):** Reinforced with C-shaped cartilage rings to keep it open. Lined with ciliated epithelium and mucus-producing goblet cells (mucociliary escalator traps particles and sweeps them up).
    5. **Bronchi (Singular: Bronchus):** Trachea branches into two main bronchi, one for each lung. Also reinforced with cartilage.
    6. **Bronchioles:** Bronchi branch into progressively smaller tubes called bronchioles, which lack cartilage.
    7. **Alveoli (Air Sacs):** Tiny, thin-walled air sacs at the end of the bronchioles. The primary site of gaseous exchange. Lungs contain millions of alveoli, providing a vast surface area.
    8. **Lungs:** Spongy organs containing the bronchioles and alveoli. Enclosed by pleural membranes.
    9. **Diaphragm:** A large, dome-shaped muscle beneath the lungs, crucial for breathing.
    10. **Intercostal Muscles:** Muscles between the ribs, also involved in breathing.
- **A. Mechanism of Breathing (Ventilation):**
    - **Inhalation (Inspiration):** Active process.
        - Diaphragm contracts and flattens.
        - External intercostal muscles contract, pulling rib cage up and out.
        - Volume of thoracic cavity increases.
        - Pressure inside lungs decreases (becomes lower than atmospheric pressure).
        - Air rushes into the lungs.
    - **Exhalation (Expiration):** Usually a passive process during quiet breathing.
        - Diaphragm relaxes and domes upwards.
        - External intercostal muscles relax, allowing rib cage to move down and in.
        - Volume of thoracic cavity decreases.
        - Pressure inside lungs increases (becomes higher than atmospheric pressure).
        - Air is forced out of the lungs.
        - *Forced Expiration:* Internal intercostal muscles and abdominal muscles contract to forcefully expel air.
- **B. Gaseous Exchange in the Alveoli:**

- **Structure of Alveoli:**
  - **Large Total Surface Area:** Millions of alveoli provide an immense surface for exchange (e.g., estimated 70-100 m^2).
  - **Thin Walls:** Alveolar walls and capillary walls are each one-cell thick, creating a very short diffusion path (about 0.2-0.6 \mu m).
  - **Moist Surface:** Inner surface of alveoli is lined with a thin film of moisture, allowing gases to dissolve.
  - **Rich Blood Supply:** Each alveolus is surrounded by a dense network of capillaries.
- **Process of Diffusion:**
  - **Oxygen:** Concentration of oxygen is higher in inhaled alveolar air than in the deoxygenated blood in surrounding capillaries. Oxygen diffuses rapidly from alveoli into the blood.
  - **Carbon Dioxide:** Concentration of carbon dioxide is higher in the deoxygenated blood in capillaries than in alveolar air. Carbon dioxide diffuses rapidly from blood into the alveoli.
  - **Maintenance of Gradient:** Continuous blood flow (from pulmonary circulation) and continuous ventilation (breathing) maintain steep concentration gradients, ensuring efficient and continuous gaseous exchange.