CHAPTER X

RESPIRATORY SYSTEM
Objectives

- Define the term gas exchange and list the characteristics of a respiratory surface.
- Identify the structures of the mammalian respiratory system and state their functions.
- Describe the four phases of gas exchange in mammals.
- Explain how body cells obtain oxygen and get rid of carbon dioxide.
Human Respiratory System

Figure 10.1
Chapter X

Respiratory System
Most protists and animals need to remove carbon dioxide from their bodies.

- The oxygen is needed for aerobic cellular respiration.
Protists

- Eukaryotes – have a nucleus
- Most have mitochondria for cellular respiration
- Most have chloroplasts to make their own food
- Most live in water
## Comparison of Cellular Processes

<table>
<thead>
<tr>
<th>Photosynthesis</th>
<th>Cellular Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>In photosynthetic organisms like some bacteria, plantlike protists (<em>Euglena</em>) &amp; all plants</td>
<td>All animals, fungi, and animal-like protists</td>
</tr>
<tr>
<td>Requires CO₂</td>
<td>Use oxygen → aerobic respiration</td>
</tr>
<tr>
<td>Occurs in the chloroplasts</td>
<td>No oxygen → anaerobic respiration like lactic acid fermentation or alcoholic fermentation</td>
</tr>
<tr>
<td></td>
<td>Occurs in the mitochondria</td>
</tr>
<tr>
<td><strong>Aerobic respiration</strong></td>
<td><strong>Anaerobic respiration</strong></td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Use oxygen</td>
<td>does not use oxygen</td>
</tr>
<tr>
<td>No alcohol or lactic acid made</td>
<td>alcohol (in yeast and plants) or lactic acid (in animals) is made</td>
</tr>
<tr>
<td>Large amount of energy release from each molecule of glucose</td>
<td>much less energy released from each molecule of glucose</td>
</tr>
<tr>
<td>Carbon dioxide made</td>
<td>carbon dioxide is made by yeast and plants, but not by animals</td>
</tr>
</tbody>
</table>
Anaerobic Respiration

- Cell respiration **WHEN OXYGEN IS NOT PRESENT**!
- Only **two** ATP produced due to the **incomplete breakdown** of **glucose**
- Occurs in the **cytoplasm** of yeast cells and muscle cells

Two types of anaerobic respiration (fermentation)

- **Alcohol Fermentation**
  - occurs in yeast cells

- **Muscle Fermentation**
  - Occurs in muscle cells

Skeletal muscle cell
Cellular respiration is a chemical process that allows organisms to release energy from substance such as glucose.

During aerobic cellular respiration, carbon dioxide is produced.

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{Energy} \]
Protist and animal cells must get rid of the excess **carbon dioxide** that has been produced.

Gas exchange refers to the physical methods that organisms have for obtaining **oxygen** from their surroundings and removing excess **carbon dioxide**.
The Respiratory Surface

- When **oxygen** and **carbon dioxide** are exchanged **between an organism and its environment** the gases pass through a **boundary surface**.

- The surface through which gas exchange take place is called the **respiratory surface**.
This diagram shows the main constituents of alveolus, and the interalveolar wall. The thickness of the alveolar-capillary barrier varies from 0.2 to 2.5 μm. The wall of the capillary endothelial cell is fused to that of the alveolar cell with only a very thin basement membrane between these two cells. This produces a very narrow gap across which oxygen and carbon dioxide can rapidly diffuse.
1. The surface must be thin-walled so that diffusion across it can occur rapidly.

2. It must be moist because the oxygen and carbon dioxide must be in the solution.
3. It must be in contact with a source of oxygen that exists in the surroundings.

4. In most multicellular organisms, it must be in contact with the transport system that carries dissolved materials to and from the cells of the organism.
Gas exchange through the respiratory surface take place by diffusion.

The direction of the gas exchange depends on the amounts of the gases on each side of the respiratory surface.
- For example, when oxygen is used up inside an organism’s tissues, more oxygen diffuses into the tissues.

- When carbon dioxide builds up within tissues, the excess diffuses out of the tissues.
The larger the area of the respiratory surface, the greater the amount of gas exchange that can occur during a given time period.

In protists and small multicellular animals, the exchange of gases take place directly between the cells and the environment.
Protozoa – Unicellular Organism

The respiratory surface of an unicellular organism is through **plasma membrane**.
(a) Single cell

(b) Two layers of cells

Exchange

Mouth

Gastrovascular cavity

Exchange
In larger animals, however, the majority of the body cells are not near the outside environment. Therefore, gas exchange cannot take place directly between all the cells and the environment.
Furthermore, larger animals often have an outer protective layer, such as scales, feather, or dry skin, that prevents direct gas exchange through the skin.

Therefore, most large, multicellular animals have respiratory surface in specialized organs or organ systems.
Specialized structures

- Structures specialized for gas exchange include:
  - gills (aquatic animals)
  - spiracles (terrestrial insects)
  - lungs (most terrestrial vertebrates)
Gills in aquatic animals

- Outfoldings of the body surface suspended in water
- Sea stars
- Segmented worms or polychaetes
- Molluscs and crustaceans
- Fishes
- Young amphibians
- Total surface area is greater than the rest of the body
Sea star

Segmented worm

Molluscs

crustaceans
• **Tracheal** system of insects – network of tubes that bring O2 to every cell
Lungs

• Found in spiders, terrestrial snails, vertebrates
The human respiratory system is made up of the lungs and the system of air tubes that carry air to and from the lungs.

Lungs

Lungs are the gas exchange organ in air-breathing vertebrates and some other animals.
- They are **made up of** many small chambers.
- Each chamber is surrounded by **capillaries**.
- Inside these small chambers is **a huge respiratory surface for the diffusion of oxygen into the blood and the diffusion of carbon dioxide out of the blood.**
Mammalian respiration
- The **lungs** fill a large part of the chest cavity in humans.

- They are **separated** from the abdominal cavity by the **diaphragm**.

- The **diaphragm** is a **muscle** that forms the **floor** of the chest cavity.

- Each lung is completely **enclosed** by a two-**layered membrane**, which is called the **pleura**.
- One layer of the pleura covers each lung, while the other layer is in contact with the diaphragm and the other organs of the chest cavity.
- A lubricating fluid between the two layers allows the lungs to move freely in the chest during breathing.
• Air passes from the environment to the respiratory surface in the lungs.

• It goes through the nose, pharynx, larynx, trachea, bronchi, bronchial, bronchial tubes, bronchioles and alveoli.
The Nose

- Air normally enters the respiratory system through the nostrils.
- These lead into hollow spaces in the nose called the **nasal passages**.
• **Hairs** at the openings of the nostrils stop various foreign particles from entering.

• The wall of the nasal passages and other air passageways are lined with a mucous membrane.

• Many of the cells that make up this membrane have **cilia**.
The Respiratory Epithelium

(a) Superficial view

(b) Lamina propria
Ciliated columnar epithelial cell
Stem cell
Goblet cell
Cilia
Mucus layer

(c) Sectional view
Cilia
Goblet cell
Nucleus of columnar epithelial cell
Lamina propria
Stem cell
Basal lamina

Movement of mucus toward pharynx
• Others secrete mucus, which is a sticky fluid.
• The mucus and the cilia trap bacteria, dust and other particles in the air.
• The mucus also moistens the air.
• Just below the mucous membrane are a large number of capillaries.
• As air passes through the nose, it is warmed by the blood in these capillaries.

• Thus, the nasal passages serves to filter, moisten, and warm the air before it reaches the delicate lining of the lungs.

• When you breathe through your mouth, you lose these advantages.
Pharynx and larynx

- From the nasal passages, air travels through the **pharynx or throat**.
- After leaving the pharynx, air passes into the **larynx or voice box**.
• The **voice box** is made mainly of cartilage, which is a flexible connective tissue.

• The **vocal cords** are two pairs of membranes that are stretched across the inside of the larynx.

• As air is breathed out, the vocal cords vibrate.
(a) Figure showing the structure of the vocal tract with labels for different anatomical parts:
- Corniculate cartilage
- Cuneiform cartilage
- Vestibular fold
- Vocal fold
- Epiglottis
- Root of tongue

(b) Fiber-optic view of the vocal tract with labels:
- Glottis (open)
- Glottis (closed)
- Aryepiglottic fold
- Vestibular fold
- Vocal fold
- Epiglottis
- Root of tongue

The image illustrates the contrast between the open and closed states of the vocal tract, highlighting the dynamic nature of vocal production.
The Larynx or Voice Box

- Epiglottis
- Hyoid bone
- False vocal cord
- True vocal cord
- Thyroid cartilage
- Cricoid cartilage
- Arytenoid cartilage
- Corniculate cartilage
- Trachea
• By controlling the vibrations of the vocal cords, humans are able to make sounds.

• To prevent choking during swallowing, food and liquids are blocked from entering the opening of the larynx by the epiglottis.
The Epiglottis

- Composed of elastic cartilage
- Ligaments attach to thyroid cartilage and hyoid bone
Sound Production

• Air passing through glottis:
  – vibrates vocal folds
  – produces sound waves

Sound Variation

• Sound is varied by:
  – tension on vocal folds: slender and short = high pitched, thicker and longer = low pitched
  – voluntary muscles (position arytenoid cartilage relative to thyroid cartilage)
Thanks
Trachea
The trachea is kept open by horseshoe shaped rings of cartilage embedded in its walls. Like the nasal passages, the trachea is lined with a ciliated mucous membrane.
• Normally, the cilia move mucus and trapped foreign matter to the pharynx.

• There, they leave the air passage and are usually swallowed.
In the middle of the chest, the trachea divides into two cartilage-ring tubes called bronchi.

Like the trachea, this part of the respiratory system is lined with ciliated cells.
• The bronchi enter the lungs and branch in a tree-like fashion into smaller tubes called bronchial tubes.
• The bronchial tubes divide and subdivide.

• As they do so, their walls become thinner with less and less cartilage.

• Finally, they become a group of tiny tubes called bronchioles.
Each bronchiole ends in a tiny air chamber that looks like a cluster of grapes.

Each chamber contains several cup-shaped cavities called alveoli.

The walls of the alveoli, which are only one cell thick, are the respiratory surface.
Oxygen enters red blood cells

Capillary

Diffusion of oxygen

Diffusion of carbon dioxide

Ventilation

From pulmonary artery

Red blood cell

To pulmonary vein

Epithelium of alveolus

Film of moisture

Carbon dioxide escapes into alveolus
• They are thin, moist and surrounded by a large number of capillaries.

• It is through these walls that the exchange of oxygen and carbon dioxide between blood and air takes place.
Respiratory Membrane
An Alveolus

- Has an extensive network of capillaries
- Is surrounded by elastic fibers

Alveolar Epithelium

- Consists of simple squamous epithelium
- Consists of thin, delicate Type I cells
- Contains alveolar macrophages, also called dust cells
- Contains septal cells (Type II cells) that produce Surfactant- an oily secretion which
  1) Contains phospholipids and proteins
  2) Coats alveolar surfaces and reduces surface tension
Gas Exchange

GAS exchange can be divided into four stages.

1. **Breathing** is the movement of air into and out of the lungs.

2. **External respiration** is the exchange of oxygen and carbon dioxide between the air and the blood in the lungs.
3. **Internal respiration** is the exchange of oxygen and carbon dioxide between the blood in the capillaries and the body cells.

4. **Oxygen and carbon dioxide transport** is the movement between the lungs and other body parts.
These stages of gas exchange are physical processes.

They should not be confused with the chemical processes that take place within cells during cellular respiration.

During cellular respiration, nutrients are broken down, and energy is released.
BREATHING
Air

• Inhaled (Breath In):
  – 79% Nitrogen Gas
  – 20.9% Oxygen
  – 0.04% CO$_2$
  – water

• Exhaled (Breath out):
  – 79% Nitrogen Gas
  – 16.3% Oxygen
  – 4.5% CO$_2$
  – water
Breathing

- moves air into and out of the lungs.
  - two phases of breathing.
  - **Inhalation** draws air into the lungs.
  - **Exhalation** forces air out of the lungs.
• Since the lungs contain no muscle tissue, they cannot move by themselves.

• However, they are elastic.

• During breathing, they are forced to expand or contact as a result of pressure changes movement of the diaphragm, ribs, and rib muscles, as well as the force of air pressure.
Breathing Techniques

- Rib cage expands as rib muscles contract.
- Air inhaled.
- Diaphragm contracts (moves down).
- Inhalation.

- Rib cage gets smaller as rib muscles relax.
- Air exhaled.
- Diaphragm relaxes (moves up).
- Exhalation.
Inhalation

- **Inhalation** is the **active phase** of breathing.
- As the **ribs** are **pulled up** and **out** and the **diaphragm** is **pulled downward**, the chest cavity becomes **larger**.
• As a result, the pressure within the chest cavity is reduced.

• Air from outside the body rushes down the air passageways into the lungs.

• This forces the lungs to expand.
Inspiration \ Inhalation

- Rib cage moves up and out
- Diaphragm contracts and moves down
- Pressure in lungs decreases, and air comes rushing in
Exhalation

- Exhalation is the passive phase of breathing.
- The diaphragm relaxes and moves upward.
- The rib muscles relax, causing the ribs to drop.
- This causes the chest cavity to become smaller, and the pressure of the lungs to become greater.
- Thus, air is squeezed out of the lungs.
Expiration \ Exhalation

- Rib cage moves down and in
- Diaphragm relaxes and moves up
- Pressure in lungs increases, and air pushed out
• Breathing is, for the most part, an involuntary process.

• It is controlled by the respiratory centre in the brain.

• There are also **special structures** in the aorta and several other larger arteries that can **sense the amount of oxygen and carbon dioxide in the blood**.

• These **chemoreceptors** send messages to the respiratory centre.
• When the amount of **carbon dioxide** in the blood **increases**, the respiratory centre of the brain is **stimulated**.

• Nerves from the respiratory centre carry impulses to the diaphragm and chest muscles that **raise the rate and depth of breathing**.

• This **lowers** the amount of **carbon dioxide** and **raises** the amount of **oxygen** in the blood.
Control centers in the brain regulate breathing.

CO₂ increase / pH decrease in blood

Nerve signal indicating low O₂ level

O₂ sensor in artery
• During heavy exercise, lactic acid is produced by muscle cells.

• This increases the acidity of the blood and stimulates the respiratory centre of the brain.

• Once the respiratory centre is stimulated, the rate of breathing increases.
Thanks
External and Internal Respiration

• **External respiration** is the exchange of oxygen and carbon dioxide between the air and the blood in the lungs.

• After inhalation, the amount of oxygen in the alveoli is **higher than** the amount of oxygen in the blood.
Gas Exchange

- **External Respiration**
  - Alveolus
  - CO₂ exit
  - O₂ entry

- **Internal Respiration**
  - Body Cell
  - CO₂ entry
  - O₂ exit
Gas Exchange Between the Blood and Alveoli
• Oxygen dissolves into the moist lining of the alveoli and diffuses from the region of higher concentration (the alveoli) to the region of lower concentration (the blood).

• As the blood is pumped through the vessels of the body by the heart, oxygen-rich blood from the lungs is carried to the body tissues.
• Blood that is rich in carbon dioxide from the body tissues is returned to the lungs.

• In the lungs, then, the amount of carbon dioxide in the blood is higher than it is in the alveoli.

• Carbon dioxide diffuses out of the blood and into the alveoli – in the opposite direction from oxygen.
Internal respiration

- **Internal respiration** is the exchange of oxygen and carbon dioxide between the blood in the capillaries and the body cells.

- In the capillaries of the **body tissues**, oxygen diffuses from the blood through the intercellular fluid into the **body cells**.
• **Carbon dioxide** diffuses from the **cells** through the intercellular fluid into the **blood**.

• Each gas diffuses down a **concentration gradient**.

• That is, each gas diffuses from a region of **higher** concentration **to** a region of **lower** concentration.
Oxygen transport

- In lungs oxygen combines with Hemoglobin to form oxyhemoglobin
Most oxygen is carried from the lungs to the body tissues by the hemoglobin in the red blood cells.

Little of it is dissolved in the plasma.

Hemoglobin (Hb) is a red, iron-containing protein that combines easily with oxygen.
Hemoglobin Structure

- α
- β
- Heme groups
• Hemoglobin holds the oxygen loosely.

• The amount of oxygen in the surrounding tissues determines whether hemoglobin will combine with oxygen or will release oxygen.

• In the lungs, where there is a large amount of oxygen, hemoglobin combines with oxygen to form oxy-hemoglobin ($\text{HbO}_2$)

Oxyhaemoglobin ($\text{Hb} + 4\text{O}_2 \rightarrow \text{HbO}_8$)
• Oxygen-rich blood is a **bright red color** because of the **oxyhemoglobin**.

• When the blood reaches the capillaries of the body tissues, where the **amount of oxygen** in the surrounding tissues is low, the oxy-hemoglobin breaks down into **oxygen** and **hemoglobin**.

• The **oxygen** diffuses from the **blood** into the body cells.
Red blood cell

Oxygen from lungs

Oxygen released to tissue cells

Hemoglobin molecules

Oxygen bonded with hemoglobin molecules
Oxygen from Lungs Bonds with Hemoglobin molecules

Carbon Dioxide Removed from Tissue Cells

Oxygen Released to Tissue Cells
• Once in the cells, the oxygen is used in aerobic respiration.

• The blood, now low in oxygen, is a dark red or dull purple color.

• People who smoke cigarettes have a significantly lower level of oxygen in their blood.

• This is because cigarette smoke contains the gas carbon monoxide.
• Carbon monoxide has a greater attraction for hemoglobin than does oxygen.

• This means that, when carbon monoxide is present, it prevents oxygen from joining with hemoglobin.

• Because their blood contains too little oxygen, smokers often experience a shortness of breath when they are active.
Carbon Dioxide Transport

In tissue cells, CO₂ dissolves in the plasma. CO₂ combines with hemoglobin to form a complex. Carbonic anhydrase facilitates the reaction CO₂ + H₂O → H₂CO₃ → H⁺ + HCO₃⁻. H⁺ combines with hemoglobin.

In alveoli, CO₂ is dissolved in the plasma. CO₂ + H₂O → H₂CO₃ → HCO₃⁻ + H⁺. HCO₃⁻ can be converted back to CO₂ and H₂O, facilitating exhalation.
Carbon Dioxide Transport

• Cellular respiration produces carbon dioxide.

• Thus, the amount of carbon dioxide tends to be greater in the body cells than in the capillary blood.

• Therefore, the carbon dioxide diffuses out of the cells and into the blood.
• Carbon dioxide is carried by the blood to the lungs in three ways.

1. Most (about 70%) of the carbon dioxide that diffuses into the blood combines with water, forming carbonic acid, $\text{H}_2\text{CO}_3$.

\[
\text{CO}_2 + \text{H}_2\text{O} \xrightarrow{\text{Carbonic anhydrase}} \text{H}_2\text{CO}_3
\]
• The \( \text{H}_2\text{CO}_3 \), quickly breaks down into hydrogen ions, \( \text{H}^+ \), and **bicarbonate ions, \( \text{HCO}_3^- \).**

\[
\text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^-
\]

• These two reactions take place quickly because of an enzyme in the red blood cells.

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^-
\]
• Therefore, most of the carbon dioxide from the body cells is carried away in the plasma in the form of bicarbonate ions

\[ CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^- \]
Hydrogencarbonate ions

Carbon dioxide diffuses from body cells to red blood cells.

Carbonic anhydrase combines CO₂ and H₂O to form H₂CO₃.

Carbonic acid dissociates into H⁺ and HCO₃⁻.

H⁺ and HCO₃⁻ form HHb.

Hb + 4O₂ forms HbO₈.

Hydrogencarbonate ions diffuse out of red blood cells.

Chloride shift to maintain charge in red blood cell.

Oxygen released into blood plasma.

Oxyhaemoglobin dissociates under influence of hydrogen ions.
2. Some (about 20%) of the carbon dioxide that diffuses into the blood combines with hemoglobin.

• This carbon dioxide is carried in the red blood cells as carboxyhemoglobin, \( \text{HbCO}_2 \)

\[
\text{CO}_2 + \text{Hb} \rightarrow \text{HbCO}_2
\]
3. A small amount (about 10 percent) of the carbon dioxide that diffuses into the blood is dissolved in the plasma.

- This carbon dioxide is carried away from the body cells to the lungs in the plasma.
- All the reactions are easily reversed.
- In the lungs, carbon dioxide is released from the blood.
Summary: Gas Transport
Thank you