

UNIT FOUR

RESPIRATION SYSTEM IN ANIMALS

Introduction

Breathing is an involuntary event. How often a breath is taken and how much air is inhaled or exhaled are tightly regulated by the respiratory center in the brain. Under normal breathing conditions, humans will breathe approximately 15 times per minute on average. A respiratory cycle consists of an inhalation and an exhalation: with every normal inhalation, oxygenated air fills the lungs, while with every exhalation, deoxygenated air rushes back out. The oxygenated air crosses the lung tissue, enters the bloodstream, and travels to organs and tissues. Oxygen (O_2) enters the cells where it is used for metabolic reactions that produce ATP, a high-energy compound. At the same time, these reactions release carbon dioxide (CO_2) as a by-product. CO_2 is toxic and must be eliminated; thus, CO_2 exits the cells, enters the bloodstream, travels back to the lungs, and is expired out of the body during exhalation.

The primary function of the respiratory system is to deliver oxygen to the cells of the body's tissues and remove carbon dioxide. The main structures of the human respiratory system are the nasal cavity, the trachea, and the lungs. All aerobic organisms require oxygen to carry out their metabolic functions.

Along the evolutionary tree, different organisms have devised different means of obtaining oxygen from the surrounding atmosphere. The environment in which the animal lives greatly determines how an animal respire. The complexity of the respiratory system correlates with the size of the organism. As animal size increases, diffusion distances increase and the ratio of surface area to volume drops. In unicellular (single-celled) organisms, diffusion across the cell membrane is sufficient for supplying oxygen to the cell. Diffusion is a slow, passive transport process. In order to be a feasible means of providing oxygen to the cell, the rate of oxygen uptake must match the rate of diffusion across the membrane. In other words, if the cell were very large or thick, diffusion would not be able to provide oxygen quickly enough to the inside of the cell. Therefore, dependence on diffusion as a means of obtaining oxygen and removing carbon dioxide remains feasible only for small organisms or those with highly-flattened bodies,

such as flatworms (platyhelminthes). Larger organisms have had to evolve specialized respiratory tissues, such as gills, lungs, and respiratory passages, accompanied by a complex circulatory system to transport oxygen throughout their entire body.

The Respiratory System and Direct Diffusion

Respiratory processes that help organisms exchange O_2 and CO_2 range from simple direct diffusion to complex respiratory systems.

Direct diffusion: This flatworm's process of respiration works by diffusion across the outer membrane.



Direct Diffusion

For small multicellular organisms, diffusion across the outer membrane is sufficient to meet their oxygen needs. Gas exchange by direct diffusion across surface membranes is efficient for organisms less than 1 mm in diameter. In simple organisms, such as cnidarians and flatworms, every cell in the body is close to the external environment. Their cells are kept moist so that gases diffuse quickly via direct diffusion. Flatworms are small, literally flat worms, which 'breathe' through diffusion across the outer membrane. The flat shape of these organisms

increases the surface area for diffusion, ensuring that each cell within the body is close to the outer membrane surface and has access to oxygen. If the flatworm had a cylindrical body, then the cells in the center would not be able to get oxygen.

Most animal respiration involves four steps:

1. Taking air in (inspiration) and pushing air out (expiration). The term breathing refers to the processes of inspiration and expiration in humans and many other animals.
2. Circulating gases throughout the body.
3. Exchanging needed gases for unnecessary gases.
4. Using the needed gases.

Depending on the complexity of their bodies and the environment in which they live, animals evolved respiratory surfaces to achieve respiration. Four basic types of gas-exchange systems occur in animals:

- **Integumentary exchange** occurs through the outer respiratory surface of some small animals that constantly stay moist.e.g. Earthworms exchange oxygen and carbon dioxide directly through their skin. The oxygen diffuses into tiny blood vessels in the skin surface, where it combines with the red pigment **hemoglobin**. Hemoglobin binds loosely to oxygen and carries it through the animal's bloodstream. Carbon dioxide is transported back to the skin by the hemoglobin.
- **Gills** are respiratory structures that extend outward from an animal's body to exchange gases in watery environments. E.g. Fishes use outward extensions of their body surface called gills for gas exchange. **Gills** are flaps of tissue richly supplied with blood vessels. As a fish swims, it draws water into its mouth and across the gills. Oxygen diffuses out of the water into the blood vessels of the gill, while carbon dioxide leaves the blood vessels and enters the water passing by the gills.
- **Tracheal exchange systems** rely on a network of respiratory tubes that end in holes to move oxygen and carbon dioxide throughout the bodies of certain types of insects. E.g. Terrestrial arthropods have a series of openings called **spiracles** at the body surface.

Spiracles open into tiny air tubes called **tracheae**, which expand into fine branches that extend into all parts of the arthropod body.

- **Lungs** are respiratory structures that extend into an animal's body, creating moist internal surfaces that use diffusion to transport gases into and out of the body. e.g. Terrestrial vertebrates such as amphibians, reptiles, birds, and mammals have well-developed respiratory systems with lungs.
- Frogs swallow air into their lungs, where oxygen diffuses into the blood to join with hemoglobin in the red blood cells. Amphibians can also exchange gases through their skin.
- Reptiles have folded lungs to provide increased surface area for gas exchange. Rib muscles assist lung expansion and protect the lungs from injury.
- Birds have large air spaces called *air sacs* in their lungs. When a bird inhales, its rib cage spreads apart and a partial vacuum is created in the lungs. Air rushes into the lungs and then into the air sacs, where most of the gas exchange occurs. This system is birds' adaptation to the rigors of flight and their extensive metabolic demands.
- The lungs of mammals are divided into millions of microscopic air sacs called **alveoli** (the singular is *alveolus*). Each alveolus is surrounded by a rich network of blood vessels for transporting gases. In addition, mammals have a dome-shaped diaphragm that separates the thorax from the abdomen, providing a separate chest cavity for breathing and pumping blood. During inhalation, the diaphragm contracts and flattens to create a partial vacuum in the lungs. The lungs fill with air, and gas exchange follows.
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Gas Exchange Mechanisms in Fish, Toad, Mammals and Plants

Skin, Gills, and Tracheal Systems

Respiration can occur using a variety of respiratory organs in different animals, including skin, gills, and tracheal systems.

Skin and Gills

There are various methods of gas exchange used by animals. As seen in mammals, air is taken in from the external environment to the lungs. Other animals, such as earthworms and amphibians, use their skin (integument) as a respiratory organ. A dense network of capillaries lies just below the skin, facilitating gas exchange between the external environment and the circulatory system. The respiratory surface must be kept moist in order for the gases to dissolve and diffuse across cell membranes.

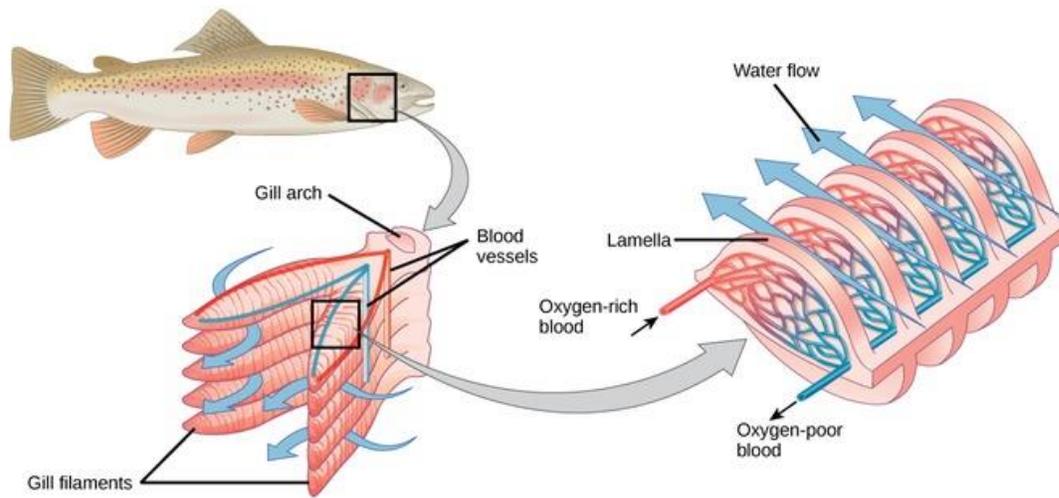
Organisms that live in water also need a way to obtain oxygen. Oxygen dissolves in water, but at a lower concentration in comparison to the atmosphere, which has roughly 21 percent oxygen. Fish and many other aquatic organisms have evolved gills to take up the dissolved oxygen from water. Gills are thin tissue filaments that are highly branched and folded. When water passes over the gills, the dissolved oxygen in the water rapidly diffuses across the gills into the bloodstream. The circulatory system can then carry the oxygenated blood to the other parts of the body. In animals that contain coelomic fluid instead of blood, oxygen diffuses across the gill surfaces into the coelomic fluid. Gills are found in mollusks, annelids, and crustaceans.



This fish, like many other aquatic organisms, has gills that allow it to obtain oxygen from water.

The folded surfaces of the gills provide a large surface area to ensure that fish obtain sufficient oxygen. Diffusion is a process in which material travels from regions of high concentration to

low concentration until equilibrium is reached. In this case, blood with a low concentration of oxygen molecules circulates through the gills. The concentration of oxygen molecules in water is higher than the concentration of oxygen molecules in gills. As a result, oxygen molecules diffuse from water (high concentration) to blood (low concentration). Similarly, carbon dioxide molecules diffuse from the blood (high concentration) to water (low concentration).

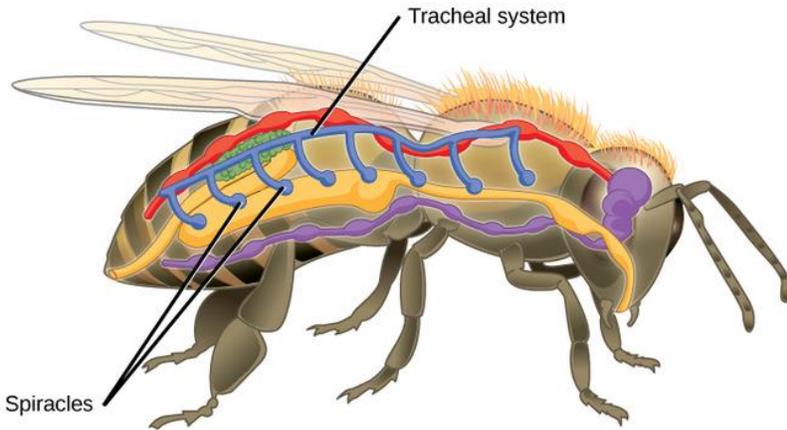


Oxygen transport and gills: As water flows over the gills, oxygen is transferred to blood via the veins.

Tracheal Systems

Insect respiration is independent of its circulatory system; therefore, the blood does not play a direct role in oxygen transport. Insects have a highly-specialized type of respiratory system called the tracheal system, which consists of a network of small tubes that carries oxygen to the entire body. The tracheal system, the most direct and efficient respiratory system in active animals, has tubes made of a polymeric material called chitin.

Insect bodies have openings, called spiracles, along the thorax and abdomen. These openings connect to the tubular network, allowing oxygen to pass into the body, regulating the diffusion of CO_2 and water vapor. Air enters and leaves the tracheal system through the spiracles. Some insects can ventilate the tracheal system with body movements.



Insect respiration: Insects perform respiration via a tracheal system, in which openings called spiracles allow oxygen to pass into the body.

Amphibian and Bird Respiratory Systems

Birds and amphibians have different oxygen requirements than mammals, and as a result, different respiratory systems.

Amphibian Respiration

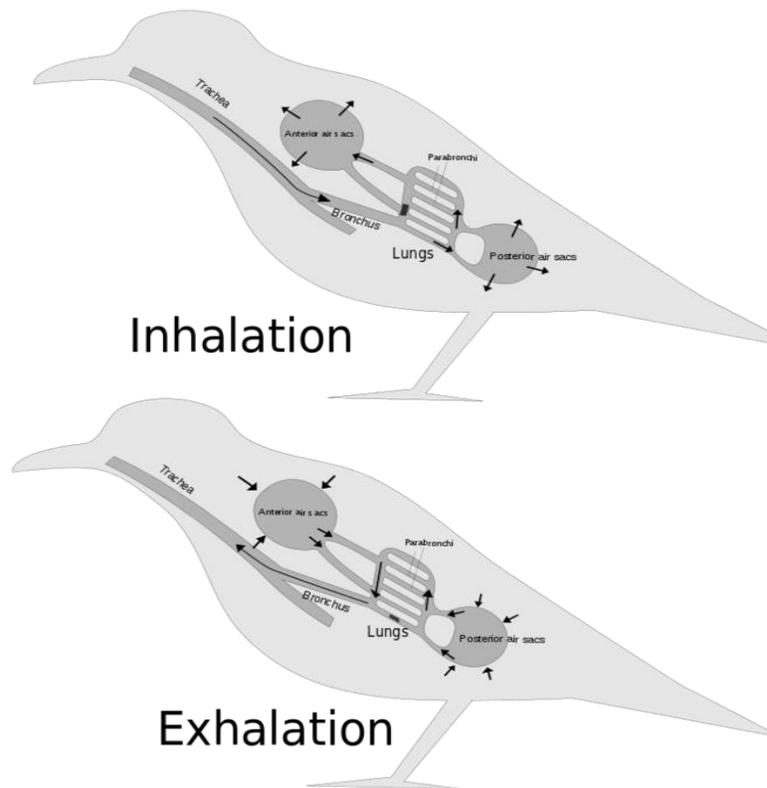
Amphibians have evolved multiple ways of breathing. Young amphibians, like tadpoles, use gills to breathe, and they do not leave the water. As the tadpole grows, the gills disappear and lungs grow (though some amphibians retain gills for life). These lungs are primitive and are not as evolved as mammalian lungs. Adult amphibians are lacking or have a reduced diaphragm, so breathing through the lungs is forced. The other means of breathing for amphibians is diffusion across the skin. To aid this diffusion, amphibian skin must remain moist. It has vascular tissues to make this gaseous exchange possible. This moist skin interface can be a detriment on land, but works well under water.

Avian (Birds) Respiration

Birds are different from other vertebrates, with birds having relatively small lungs and nine air sacs that play an important role in respiration. The lungs of birds also do not have the capacity to

inflate as birds lack a diaphragm and a pleural cavity. Gas exchange in birds occurs between air capillaries and blood capillaries, rather than in alveoli.

Flight poses a unique challenge with respect to breathing. Flying consumes a great amount of energy; therefore, birds require a lot of oxygen to aid their metabolic processes. Birds have evolved a respiratory system that supplies them with the oxygen needed to sustain flight. Similar to mammals, birds have lungs, which are organs specialized for gas exchange. Oxygenated air, taken in during inhalation, diffuses across the surface of the lungs into the bloodstream, and carbon dioxide diffuses from the blood into the lungs, and is then expelled during exhalation. The details of breathing between birds and mammals differ substantially.



Bird Respiration: The process of inhalation and exhalation in birds. Three distinct sets of organs perform respiration — the anterior air sacs, the lungs, and the posterior air sacs.

In addition to lungs, birds have air sacs inside their body. Air flows in one direction from the

posterior air sacs to the lungs and out of the anterior air sacs. The flow of air is in the opposite direction from blood flow, and gas exchange takes place much more efficiently. This type of breathing enables birds to obtain the requisite oxygen, even at higher altitudes where the oxygen concentration is low. This directionality of airflow requires two cycles of air intake and exhalation to completely get the air out of the lungs.

Mammalian Respiratory System

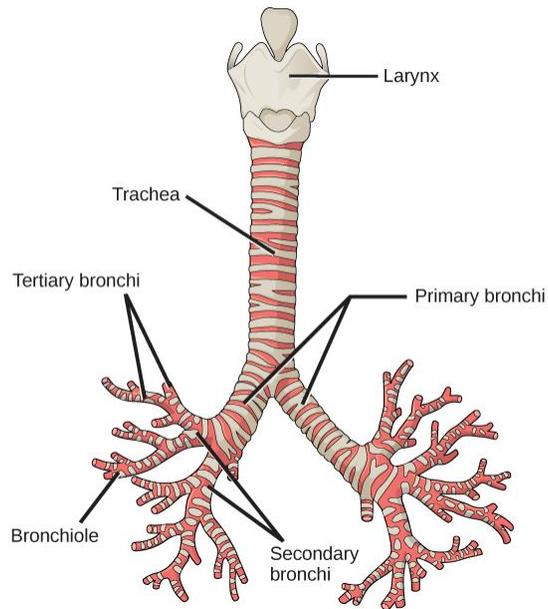
The mammalian respiratory system equilibrates air to the body, protects against foreign materials, and allows for gas exchange.

In mammals, pulmonary ventilation occurs via inhalation when air enters the body through the nasal cavity. Air passes through the nasal cavity and is warmed to body temperature and humidified. The respiratory tract is coated with mucus that is high in water to seal the tissues from direct contact with air. As air crosses the surfaces of the mucous membranes, it picks up water. This equilibrates the air to the body, reducing damage that cold, dry air can cause.

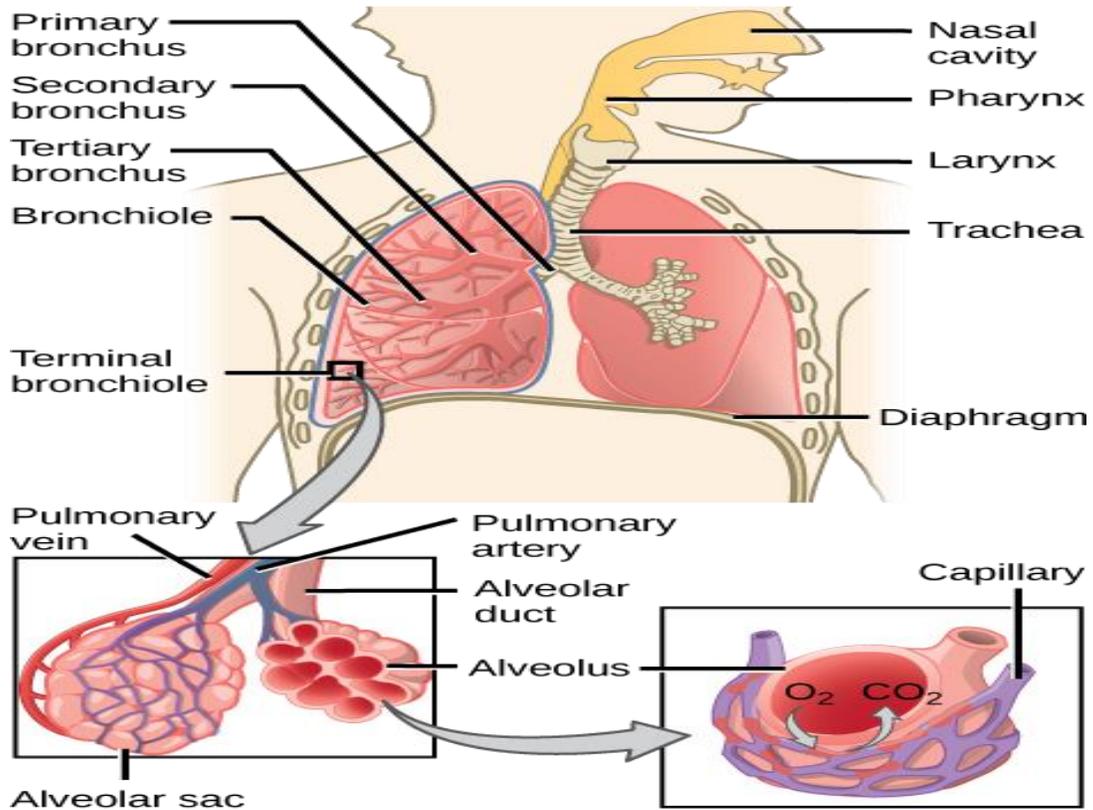
Particulates in the air are also removed in the nasal passages. These processes are all protective mechanisms that prevent damage to the trachea and lungs.

From the nasal cavity, air passes through the pharynx and the larynx to the trachea. The function of the trachea is to funnel the inhaled air to the lungs and the exhaled air out of the body. The human trachea, a cylinder about 10-12cm long, 2cm in diameter found in front of the esophagus, extends from the larynx into the chest cavity. It is made of incomplete rings of hyaline cartilage and smooth muscle that divides into the two primary bronchi at the mid thorax. The trachea is lined with mucus-producing goblet cells and ciliated epithelia that propel foreign particles trapped in the mucus toward the pharynx. The cartilage provides strength and support to the trachea to keep the passage open. The smooth muscle can contract, causing a decrease in the trachea's diameter, which propels expired air upwards from the lungs at a great force. The forced exhalation helps expel mucus when we cough.

Trachea and bronchi structure: The trachea and bronchi are made of incomplete rings of cartilage.

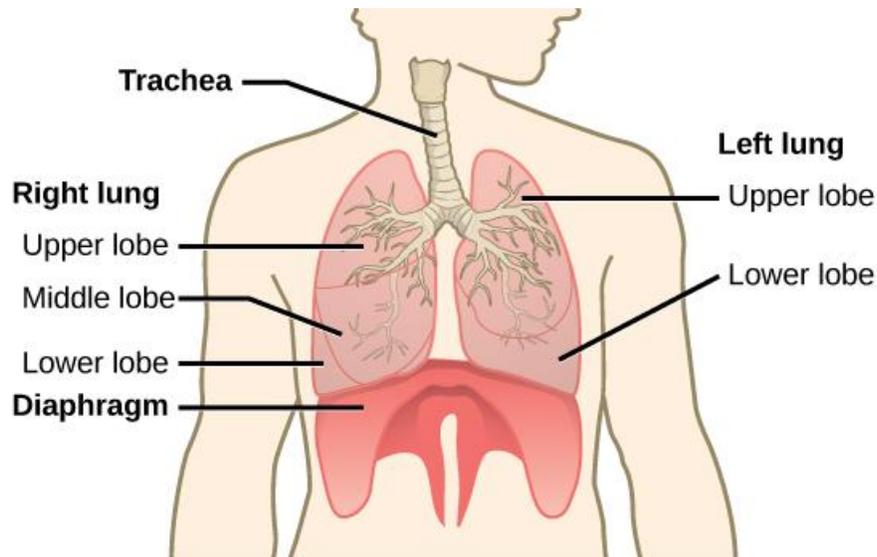


Route of inhalation: Air enters the respiratory system through the nasal cavity and pharynx. It then passes through the trachea and into the bronchi, which bring air into the lungs.



Lungs: Bronchi and Alveoli

The end of the trachea bifurcates to the right and left lungs, which are not identical. The larger right lung has three lobes, while the smaller left lung has two lobes. The muscular diaphragm, which facilitates breathing, is inferior to the lungs, marking the end of the thoracic cavity.

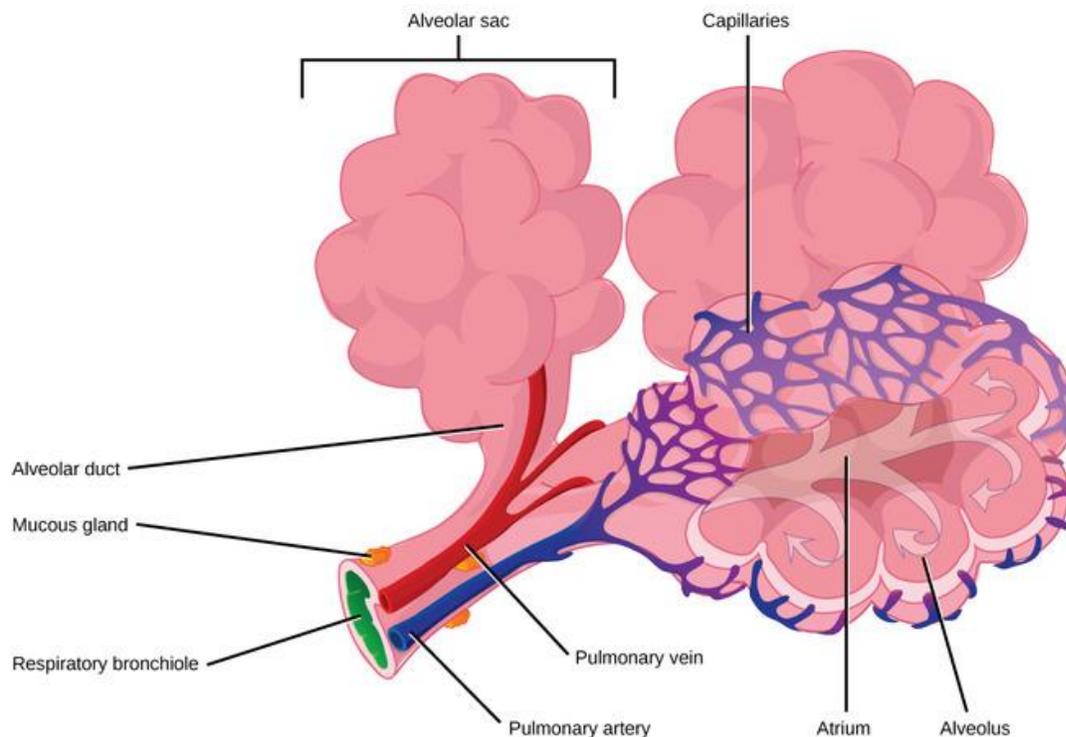


Lung structure: The trachea bifurcates into the right and left bronchi in the lungs. The larger right lung is made of three lobes. To accommodate the heart, the left lung is smaller, having only two lobes.

As air enters the lungs, it is diverted through bronchi beginning with the two primary bronchi. Each bronchus divides into secondary, then into tertiary bronchi, which further divide to create smaller diameter bronchioles that split and spread through the lung. The bronchi are made of cartilage and smooth muscle; at the bronchioles, the cartilage is replaced with elastic fibers. Bronchi are innervated by nerves of both the parasympathetic and sympathetic nervous systems that control muscle contraction or relaxation, respectively. In humans, bronchioles with a diameter smaller than 0.5 mm are the respiratory bronchioles. Since they lack cartilage, they rely on inhaled air to support their shape. As the passageways decrease in diameter, the relative amount of smooth muscle increases.

The terminal bronchioles then subdivide into respiratory bronchioles which subdivide into

alveolar ducts. Numerous alveoli (sing. alveolus) and alveolar sacs surround the alveolar ducts. The alveolar ducts are attached to the end of each bronchiole; each duct ends in approximately 100 alveolar sacs. Each sac contains 20-30 alveoli that are 200-300 microns in diameter. Alveoli are made of thin-walled, parenchymal cells that are in direct contact with capillaries of the circulatory system. This ensures that oxygen will diffuse from alveoli into the blood and that carbon dioxide produced by cells as a waste product will diffuse from the blood into alveoli to be exhaled. The anatomical arrangement of capillaries and alveoli emphasizes the relationship of the respiratory and circulatory systems. As there are so many alveoli (around 300 million per lung) within each alveolar sac and so many sacs at the end of each alveolar duct, the lungs have a sponge-like consistency. This organization produces a very large surface area that is available for gas exchange.



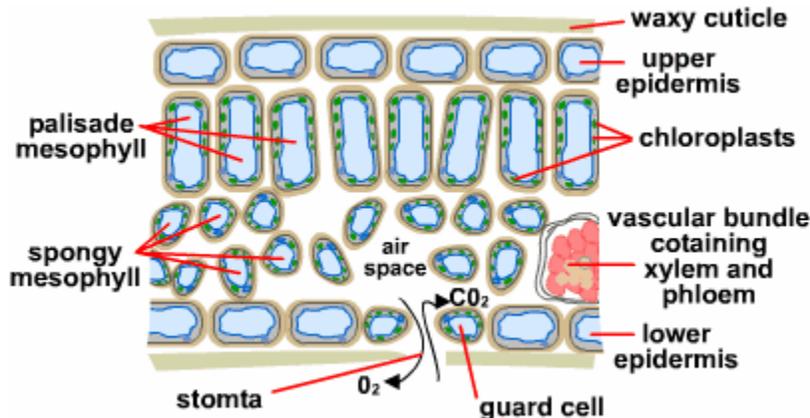
Alveolar structure: Terminal bronchioles are connected by respiratory bronchioles to alveolar ducts and alveolar sacs. Each alveolar sac contains 20 to 30 spherical alveoli and has the appearance of a bunch of grapes. Air flows into the atrium of the alveolar sac, then circulates into alveoli where gas exchange occurs with the capillaries. Mucus glands secrete mucus into the airways, keeping them moist and flexible.

Gas Exchange Mechanism in Plants

Plants obtain the gases they need through their leaves. They require **oxygen for respiration** and **carbon dioxide for photosynthesis**.

The gases diffuse into the intercellular spaces of the leaf through pores, which are normally on the underside of the leaf - **stomata**. From these spaces they will diffuse into the cells that require them.

Stomatal opening and closing depends on changes in the turgor of the guard cells. When water flows into the guard cells by osmosis, their turgor increases and they expand. Due to the relatively inelastic inner wall, the guard cells bend and draw away from each other, so the pore opens. If the guard cells lose water the opposite happens and the pore closes. The guard cells lower their water potential to draw in water from the surrounding epidermal cells, by actively accumulating potassium ions. This requires energy in the form of ATP which, is supplied by the chloroplasts in the guard cells.



Respiration occurs throughout the day and night, providing the plant with a supply of energy.

Photosynthesis can only occur during sunlight hours so it stops at night. A product of respiration is carbon dioxide.

This can be used directly by the plant in photosynthesis. However, during the day, photosynthesis can be going 10 or even 20 times faster than respiration (depending on light

intensity), so the stomata must stay open so that the plant has enough carbon dioxide, most of which diffuses in from the external atmosphere.

For practicals, study the structures and functions of the gas exchange mechanisms in fish, birds plants mammals and amphibians, their similarities and differences, and the need for such exchange mechanism.

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