CHAPTER TWO

GAS CIRCULATION AND EXCHANGE

2.1. Circulation in animals

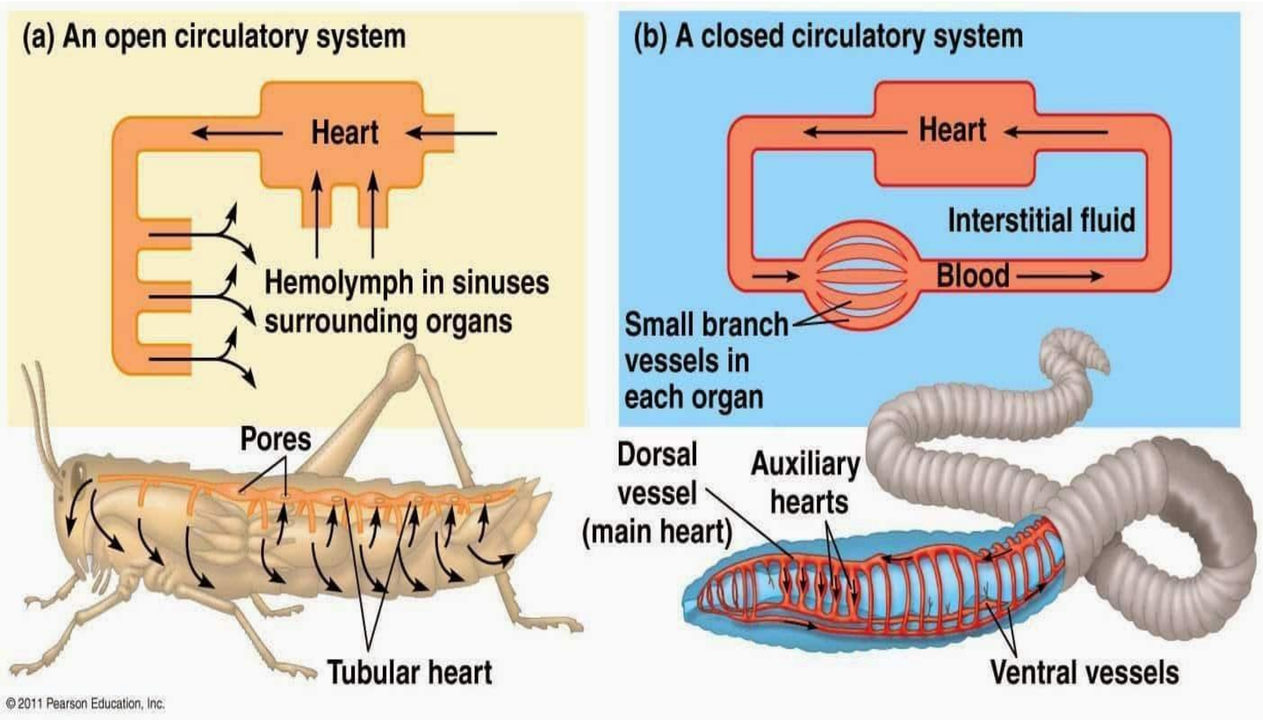
Like unicellular organisms, simple (diploblastic) or multicellular organisms consisting of a small number of cells can carry out their transport of matter by simple diffusion between the external environment and the cells.

On the other hand, in large animals, the phenomenon of diffusion is no longer sufficient for exchanges with the outside world. In these animals, the extracellular medium is compartmentalized in a circulatory system that is more or less agitated.

2.1.1-Setting the indoor environment in motion

A) By simple brewing

In the simplest cases (Triploblastic acelomata), it is the movements of the animal that stir and ensure limited circulation of interstitial liquids (fig. 1 A). The appearance of a circulatory system makes it possible to set in motion only part of the internal fluids.



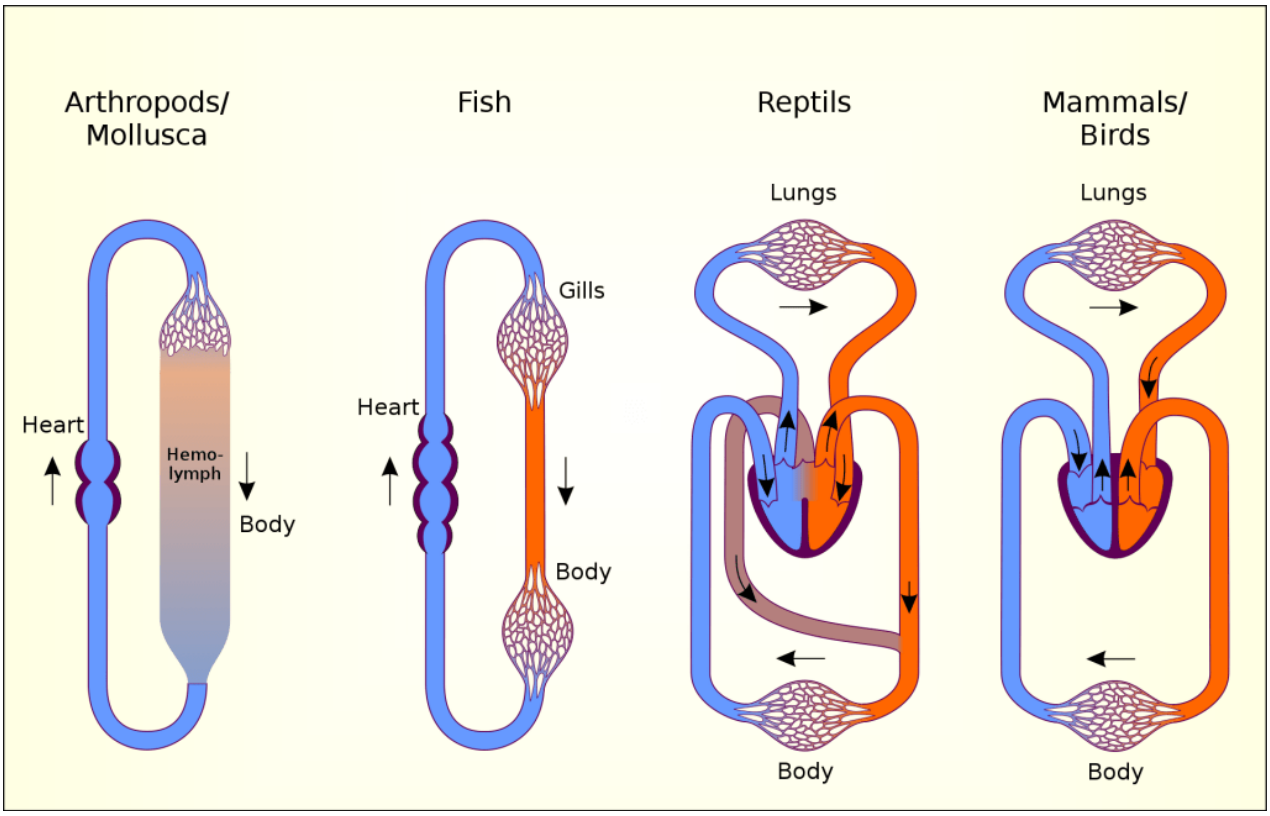


Fig.01 :The appearance of a circulatory system makes it possible to set in motion only part of the internal fluids.

B) Circulatory System

Most Arthropods and Molluscs have a circulatory system in which blood circulates in vessels that open to the coeloma and interstitial spaces (fig. 1 B). The return to the heart is via interstitial space sinuses. Open circulatory systems are inefficient when they do not have a propellant. The presence of a core allows an increase in efficiency, but the opening of the system limits both the irrigation pressure and the circulation speed, thus the supply of nutrients.

C) Circulatory System

In a closed circulatory system, blood is set in motion by one or more hearts. One circulates under pressure in a system of vessels and returns to the heart through other vessels in continuity with the first. The exchanges are carried out at the level of thin-walled vessels, the capillaries.

Complete containment of circulating fluid is already present in relatively primitive phyla such as annelids or cephalopod molluscs, but develops mainly in vertebrates (fig. 1 C).

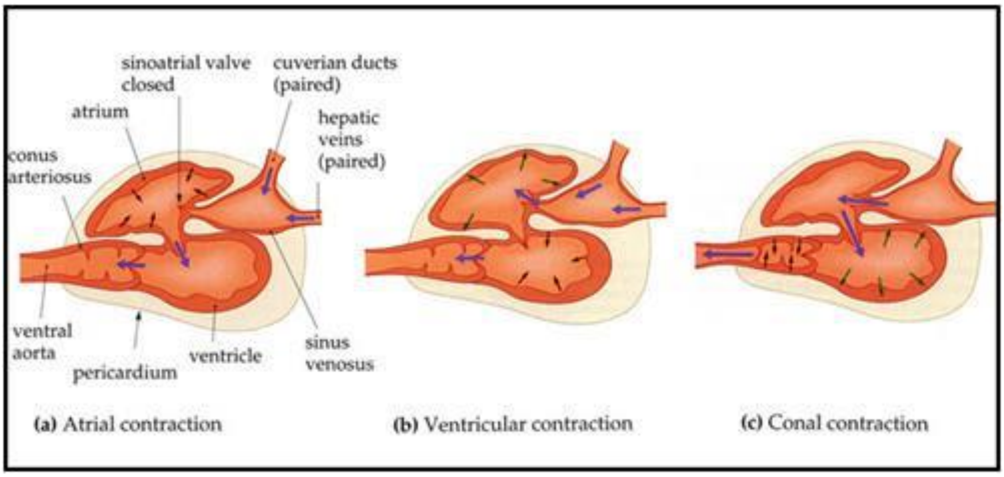
This system allows, on the one hand, rapid circulation and high blood pressure and, on the other hand, the ability to fine-tune and quickly adjust local blood flows by varying the vascular diameter.

2.1.1. Hearts: brewing organs

The movement of the contained fluid is due either to the movements of the body (Annelids), or to the contraction of certain vascular segments (Insects), or to the rhythmic movements of a heart (Vertebrates). The latter type of pump has many variations but the most important change is the appearance of partitioning. The degree of partitioning is to be related to the evolution of the respiratory system and the development of lungs

a) Non-partitioned hearts

Non-partitioned cores have a variable number of chambers (from one to four) placed in series. In Teleostans, for example, there is a non-contractable venous sinus upstream of the atrium and an arterial bulb (Teleostans) or arterial cone (Elasmobranches) downstream of the ventricle (fig. 2 B). The circulation of blood is the result of successive contractions of the atrium, ventricle and arterial bulb.



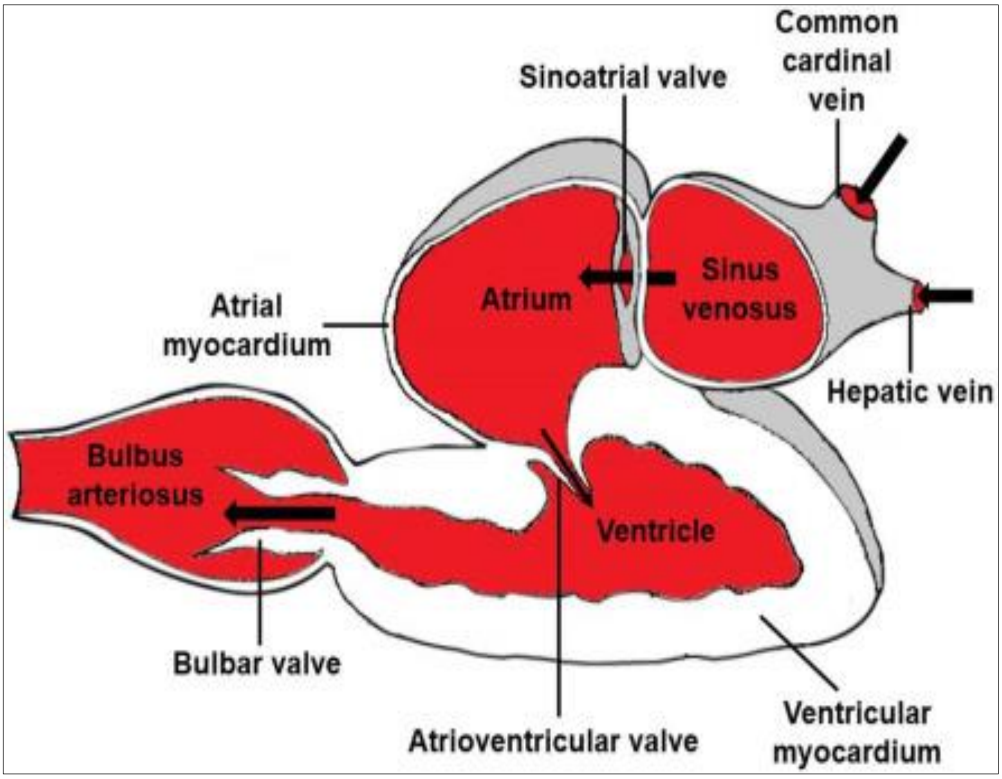
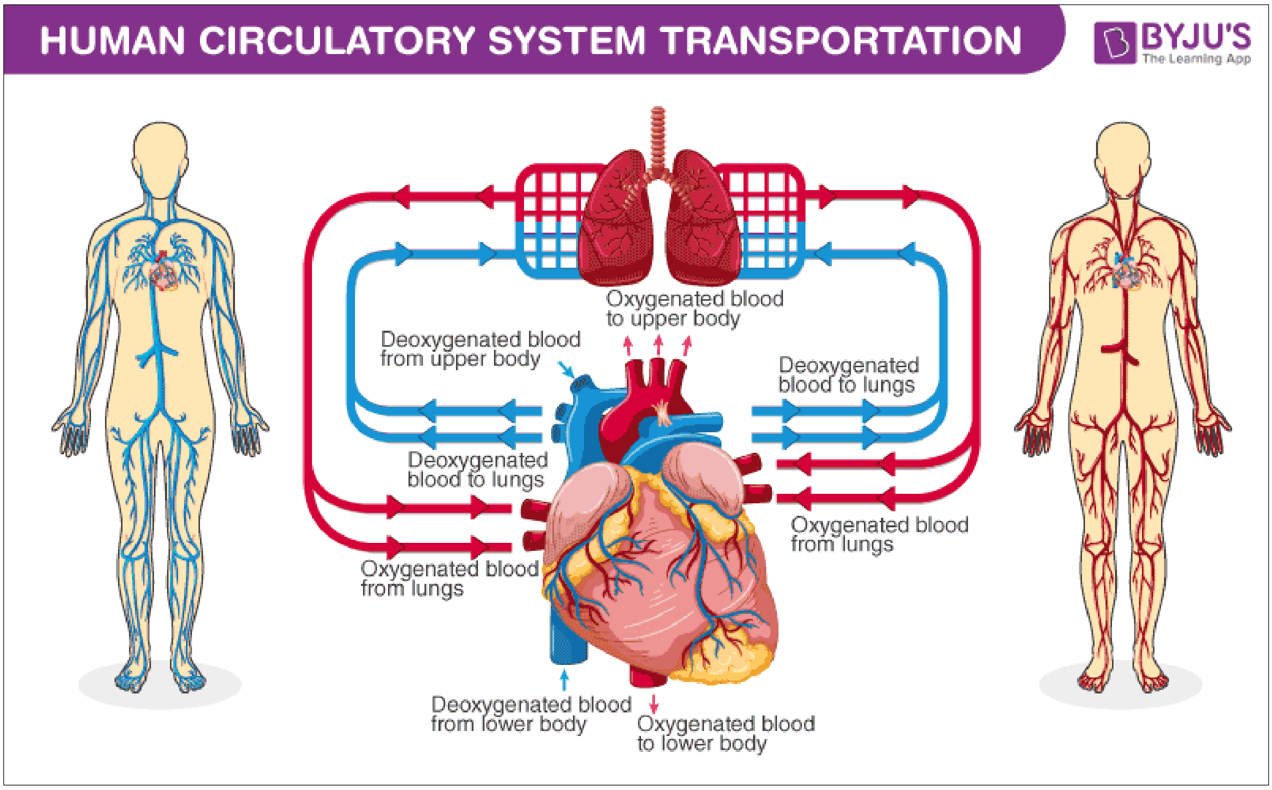


Figure 2: circulatory system

b) Partitioned hearts

In Crocodile Reptiles, Birds and Mammals, the partitioning is total, there are two atriums and two ventricles (fig. 3 A).



2.1.3- The human circulatory system

In the closed circulatory system, the human cardiovascular system provides the link between the different organs. Blood, the circulating phase of the internal environment, is propelled into the system by means of a pump, the heart, a hollow muscle at the origin of blood movements in the

vascular circuit. The distribution of blood throughout the body is ensured by a

Figure 2:

dense network of vessels. Arteries, through which blood leaves the heart, veins that bring blood back to the heart and capillaries that connect arteries and veins and allow exchanges with interstitial fluids (fig. 4). In mammals, and in humans, the heart is partitioned,which determines two functional hearts, the left heart and the right heart, each formed by two cavities, an atrium and a ventricle, communicating with each other *via* an atrioventricular valve. This partitioning imposes a blood path according to two circuits placed in series: the systemic circulation, which starts from the left heart, and the pulmonary circulation, which starts from the right heart. All the blood therefore passes successively into the two hearts, each time respecting an atrium-ventricular path.

The heart valves orient the blood in a unidirectional manner. Heart rate (pulse) is the number of heartbeats per minute. The cardiac revolution is a cycle that includes a phase of ejection of blood, during a contraction called *systole*, and a phase of filling the heart, during a relaxation called *diastole*. Cardiac output is the volume of blood ejected into the systemic circulation per minute. The frequency of contractions of the heart muscle is coordinated by an electrical conduction network, which originates in the sinus node (or rhythmogenic center) of the right atrium. This node reacts according to the stimulation produced by nerves or hormones, body temperature and physical exercise.

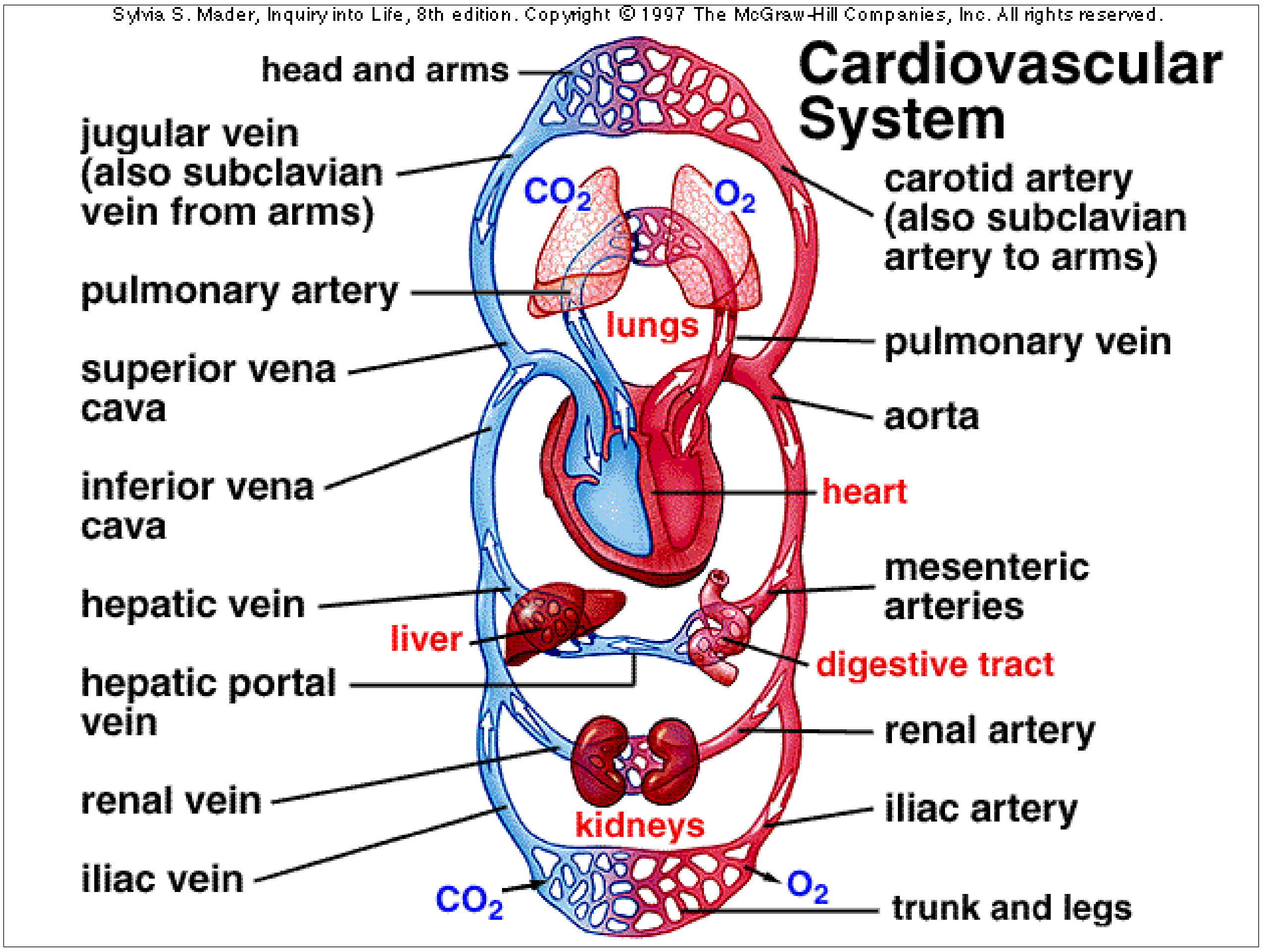


Figure 4: Diagram of the cardiovascular system

Structural differences between arteries, veins and capillaries correlate with the functions of these vessels. An endothelium is the inner tunic of all blood vessels, and the only tissue layer of the capillaries. Arteries and veins have two other tunics: the outer tunic and the middle tunic. The first is made of connective tissue containing collagen fibers; the second consists of smooth muscle tissue, elastic fibers, and collagen fibers. Arteries have the thickest, strongest and most elastic wall. This is an adaptation to the increase in blood pressure and rapid blood movement. Body movements help bring blood back to the heart through the veins; the large veins are equipped with unidirectional valves.

The blood supply to the different organs is determined by the variable constriction of the arterioles and precapillary sphincters. The substances pass through the endothelium of the capillaries in various ways: by endocytosis and exocytosis, by diffusion, or by dissolution in liquids expelled by intercellular slits under the effect of blood pressure at the arterial end of the capillary.

The fluids re-enter the circulation directly, at the venous end of the capillary, and indirectly, thanks to the lymphatic system.

2.2. Gas exchanges in animals

Most cells in the body get their energy from the oxidation of organic substrates. This oxidation corresponds to cellular respiration, which results in dioxygen consumption and carbon dioxide release. These mineral compounds are, in this case, referred to as respiratory gases. At the organism level, breathing involves exchanges of these two gases between the internal and external environment. In very small animals or in those with a simple organisational plan (unicellular and Diploblastic), exchanges take place at the level of the body surface. In more complex animals, triploblastic metazoans coelomates in particular, these exchanges take place through precisely localized and most often specialized surfaces. Inside the body, the gases are generally conveyed, between tissues and respiratory exchanger, via the circulation and the internal environment.

TYPES OF GAS EXCHANGE SYSTEMS

System	Animal	Example
Moist skin	Adult amphibians Cnidarians	Frogs Jellyfish
Tracheal system	Insects Arachnids	Grasshopper Redback spider
Lungs	Mammals Reptiles	Humans Lizards
Lungs with air sacs	Birds	Chickens
Gills	Fish Crustacean Juvenile amphibians	Goldfish Crabs Tadpoles

2.2.1. Respiratory exchange surfaces

Regardless of the medium, gas exchanges between an organism and the outside take place through a simple diffusion mechanism. The diffusion is proportional to the partial pressure gradient of the gases and to the surface of the exchanger, and inversely proportional to the thickness of the respiratory epithelium (Fick's law).

Air and water environments bring certain constraints that respiratory exchangers must also meet.

- Oxygen from the environment is available in different states depending on the type of medium. In the air, oxygen, which is in gaseous form, is readily available to organisms. In an aquatic environment, the gases are dissolved and, depending on their solubility, they vary in quantity: water contains much less dioxygen than air, whereas it contains the same amount of CO_2.
- **The aquatic environment** is a medium of high density and high viscosity compared to the aerial environment, so it is a medium that is energetically expensive to set in motion.
- **The aerial environment** is poor in water, it is a drying environment that requires the internalization of respiratory exchangers.

All these constraints lead to the existence of several types of arrangement of respiratory surfaces according to the living environments and the organization plan of the organisms (fig. 6).

2.2.2. The main types of breathing apparatus and how they work

In very small animals or in those with a simple organisational plan (unicellular and Diploblastic), exchanges take place at the level of the body surface. In more complex animals, metazoan triploblastic coelomates in particular, these exchanges take place through precisely localized and most often specialized surfaces, **gills**, **lungs** or **tracheas**.

a) **The branchial system**

The gills are localized evaginations of the surface of the body, specialized in respiratory exchanges. These organs are found in a large number of invertebrates (Annelids, Molluscs, Crustaceans, etc.) and aquatic vertebrates (Fish and Amphibian larvae). They make it possible to meet the dioxygen needs of large and highly active organisms.

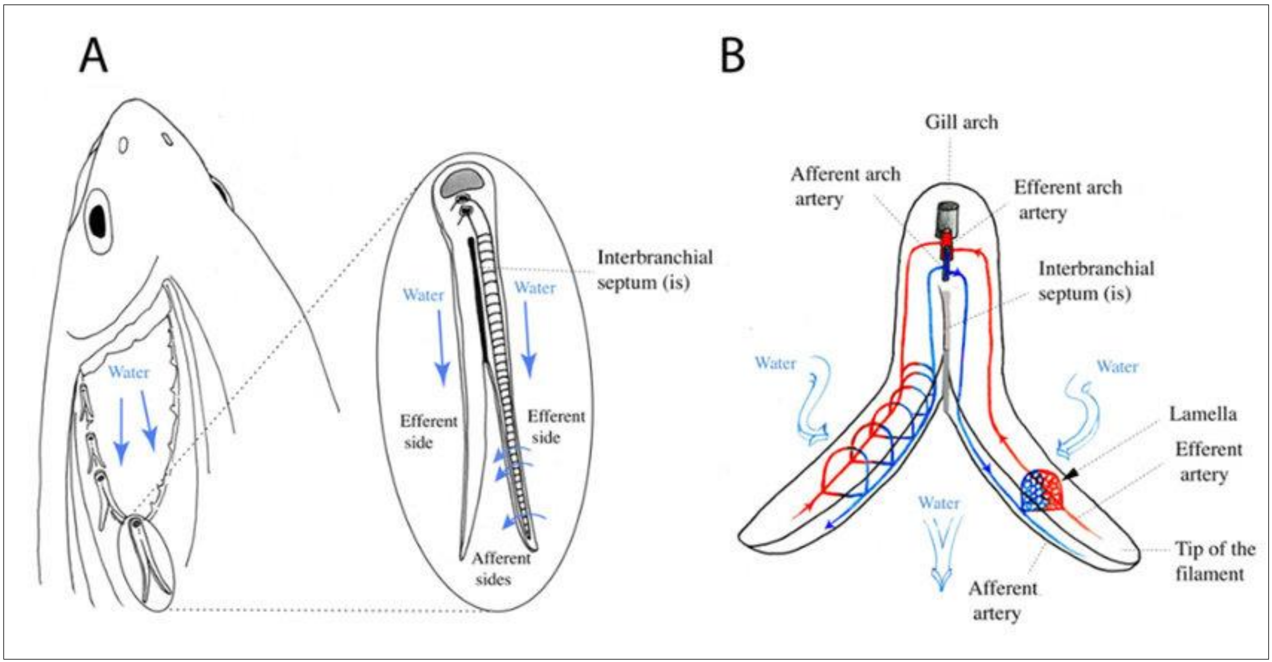
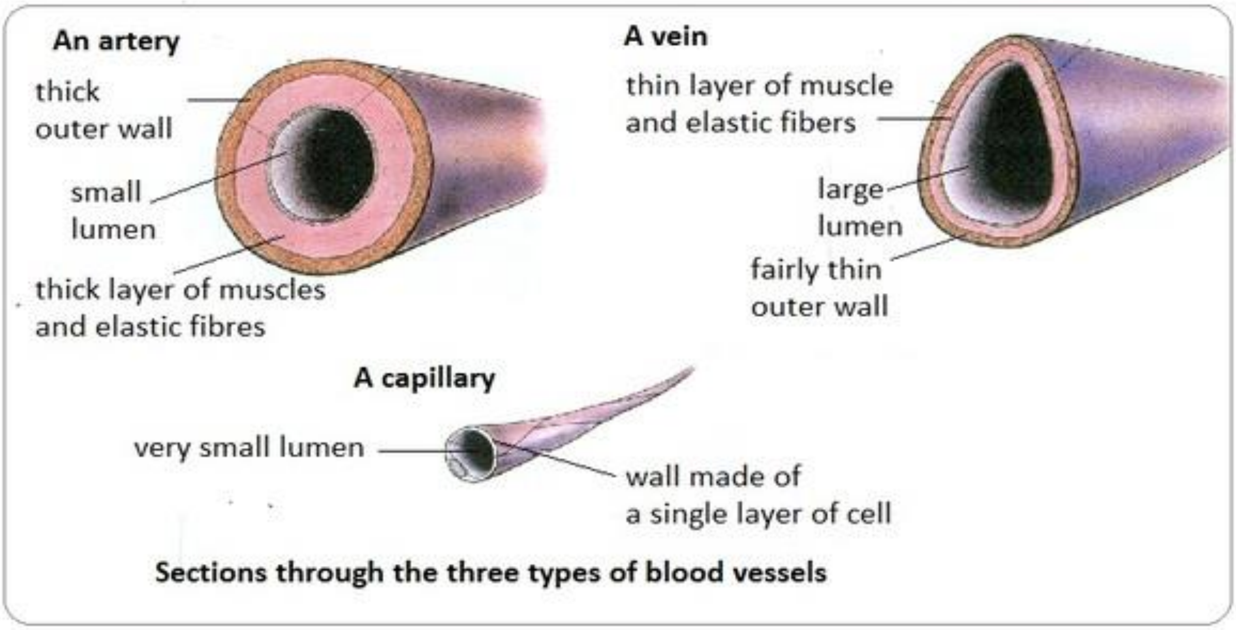


Figure 7: Functional organization of the branchial apparatus of the Teleosteans

In Teleostans, the gills, located at the level of slits in the pharyngeal wall, connect the oral-pharyngeal cavity and two gill cavities, or chambers. These communicate with the external environment through a slit, the hearing (fig. 7 A). Oral and operular movements, controlled by a clean musculature, facilitate in these Pisces the flow of water that bathes the gills.

Each gill develops at the level of a skeletal arch, the gill arch. It consists of a succession of gill leaves or blades, arranged perpendicularly to the gill arch (fig. 7 B).



Blood oxygenation, or hematosis, is carried out at the level of the secondary folds of the branchial blades, and arranged perpendicularly to them. These are traversed by a network of capillaries, often without clean endothelium (blood gaps). The epithelium of the lamellae forms, around these capillaries or gaps, two very thin sheets, held apart by "pillar" cells. Thus, the blood circulating between the pillars is separated from the external environment by only a few micrometers (fig. 8).

b) **The pulmonary system**

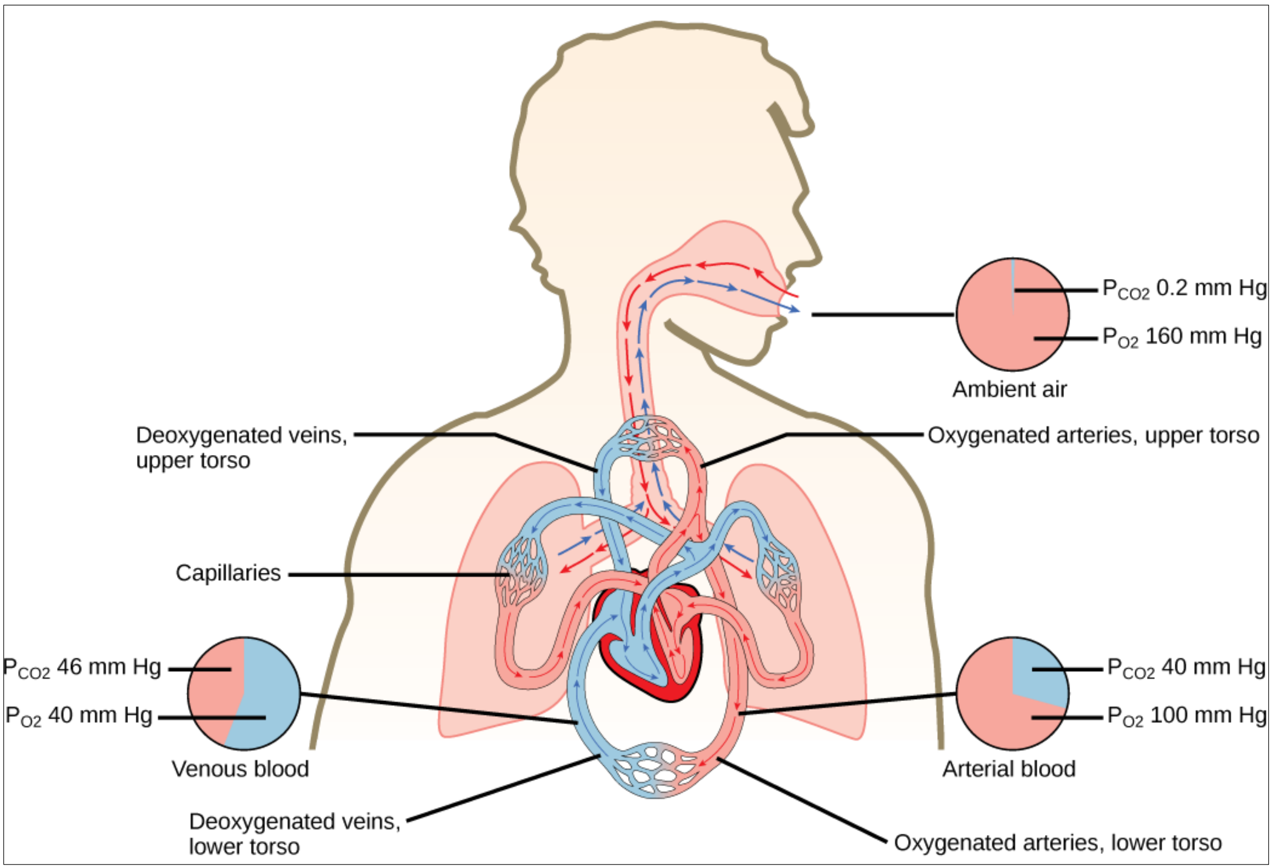
What the lungs have in common is that they are generally highly vascularised cavities. Primitive lungs,with no real ventilatory support, exist in some groups of invertebrates

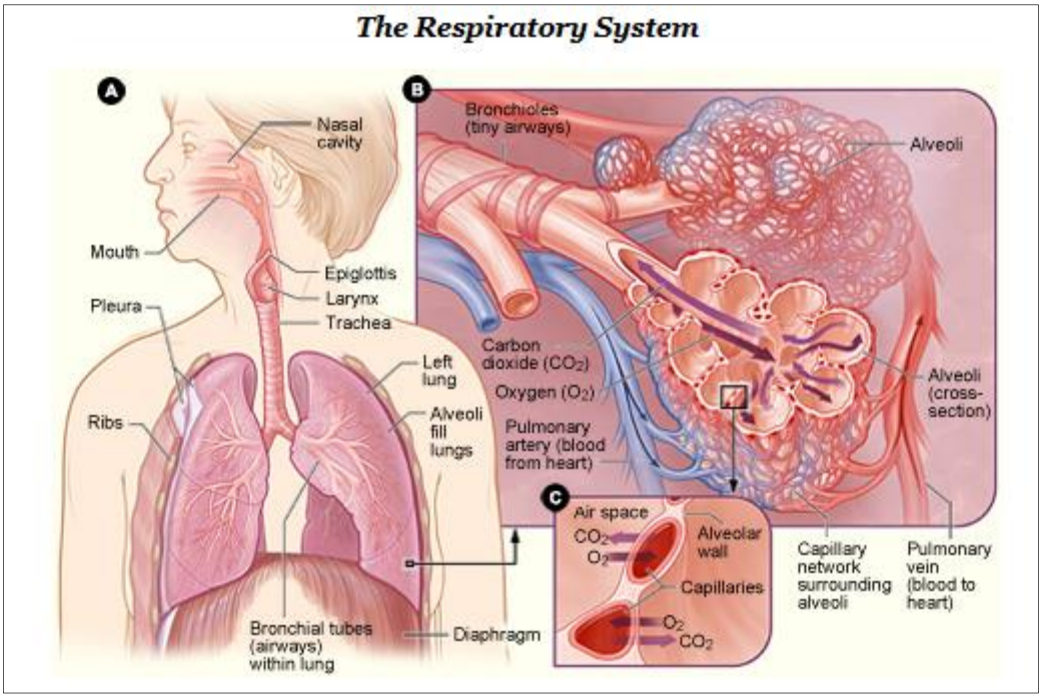
(Pulmonary Gastropods, Terrestrial Isopods, Arachnids). Active ventilation lungs exist in aerial vertebrates. In mammals, the lungs, located in the rib cage, consist of a loose parenchyma, traversed by air ducts and blood vessels.

In the lungs, air-blood contact is made at the level of the alveoli, small bags whose very thin wall is attached to blood capillaries and whose air supply is made through air ducts, bronchi and bronchioles (fig. 9 A).

The large alveolar surface area (80 m^2 per lung in humans) and the thinness of the exchanger (0.2 to 0.4 µm) allow rapid and effective diffusion of respiratory gases (Fig. 9 B and C).

The air in the lungs is renewed by suction and then forced outwards under the effect of pressure variations created by the muscles of the rib cage.





c) **The Tracheal System**

In most terrestrial arthropods, air is conducted directly to the tissues through a set of highly branched tubes, the tracheas (fig. 10a). These tracheas are integumentary invaginations that communicate with the outside through small orifices, the stigmata.

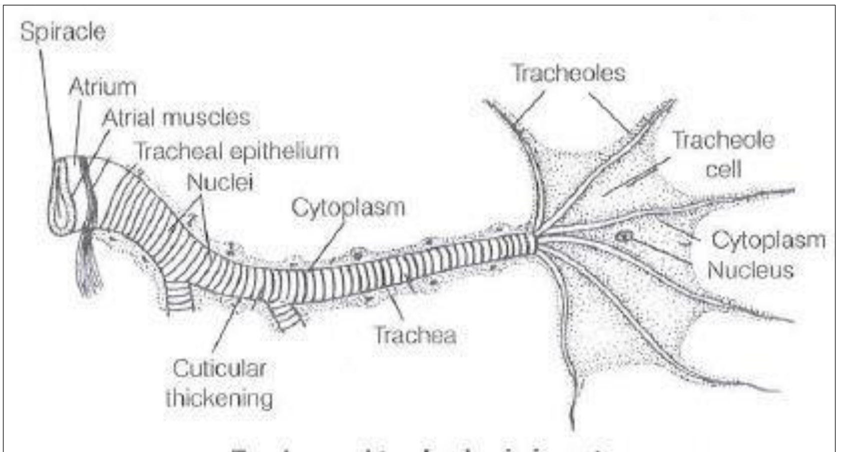
In tracheal systems (fig. 10), the oxygen is brought into the immediate vicinity of the cells in gaseous form: this system requires neither a specialized exchange surface nor an internal medium to distribute the respiratory gases to the tissues (O2) or to ensure their return to the outside (CO2). The air diffuses in the tracheas up to the tracheolar cells, it is at the ends of the tracheolas that exchanges with the surrounding cells (fig. 10 D).

2.2.3. The transport of respiratory gases through the blood

a) Forms of transport of respiratory gases

CO_2 is very soluble in the blood, so it can be transported in a dissolved form. In an aqueous medium, CO_2 combines with water to provide hydrogen carbonate ions HCO^-_3. CO_2 can also combine with plasma proteins or a protein erythrocyte transporter such as hemoglobin.

In contrast, the low solubility of dioxygen requires the presence of specific transporters capable of fixing the dioxygen in the respiratory system, and releasing it at the tissue level. There are several types of respiratory gas transporters in the animal kingdom, all of which are metalloproteins qualified as respiratory pigments: hemoglobins, chlorocruorins, hemerythrins and hemocyanins. These pigments are plasma or erythrocyte. In vertebrates, hemoglobin is contained in erythrocytes.

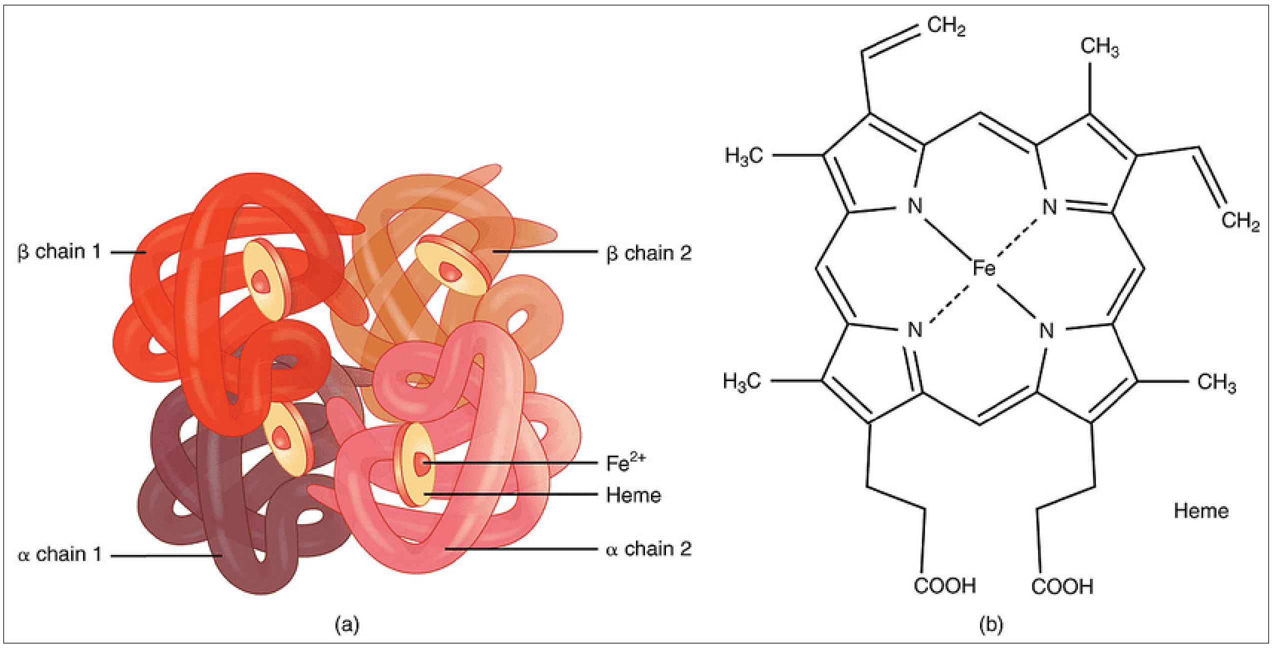


Trachea and tracheoles in insects

- **Hemoglobin: gas transporter**

Hemoglobins are tetrameric molecules consisting of 4 polypeptide chains (globins) that are similar in pairs. Each of these chains has a heme itself consisting of 4 pyrrole nuclei linked to each other and centered on a single ferrous ion ($Fe2^{+}$). This iron atom allows the fixation of a dioxygen, a hemoglobin can thus fix 4 molecules of dioxygen (fig. 11).

The hemoglobin molecule may also bind a $CO2$ but to a site of the globin molecule and not to the heme.



- **Management and release of gases**

Gas exchanges are carried out by diffusion according to partial pressure gradients both at the alveolar and tissue level

- **at the pulmonary level**, the gradient induces a passage of dioxygen to the blood. Solubilized dioxygen binds to hemoglobin and induces a series of reactions that lead to a local increase in the level of dissolved CO 2 (by release of $CO2$ from hemoglobin and by reformation of $CO2$ from HCO^-). The CO 2 gradient is then favorable to a$_3$rd diffusion to the alveolar air.
- **at the tissue level,** the phenomenon is the opposite. The local production of $CO2$ is important. There is therefore a diffusion of $CO2$ to the blood and an increase in the levels of
  $CO2$ and HCO_3^-. This also induces a decrease in local blood pH which modifies the properties of hemoglobin and causes a release of the dioxygen fixed to hemoglobin. The dioxygen thus released passes into dissolved form and then diffuses to the tissues (fig. 12). Regulation centers located in the bridge and spinal bulb

establish the baseline respiratory rate. Chemoreceptors detect changes in blood pH (which is related to CO_2 concentration), as well as changes in dioxygen in the blood. The spinal bulb changes the frequency and amplitude of breathing according to the metabolic needs of the body.