Gaseous exchange
&
Respiration in Fishes

Gas Exchange The transfer of oxygen (O_2), carbon-di-oxide (CO_2) and to a lesser extend, ammonia (NH_3) between the environment and the cell/tissue site of use or production

Respiration **Intake** of oxygen (O_2) for metabolism/energy production and **release** of carbon-di-oxide (CO_2) into the environment as a end product of metabolism

Aerobic Respiration

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 32\ ATP$$

Anaerobic Respiration

Alcohol Fermentation

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 + 2\ ATP$$

Lactic Acid Fermentation

$$C_6H_{12}O_6 \rightarrow C_3H_6O_3 + 2\ ATP$$

Respiratory Organs in Fishes

✓The gills are the main organ by which gases are exchanged between the fish and the surrounding water

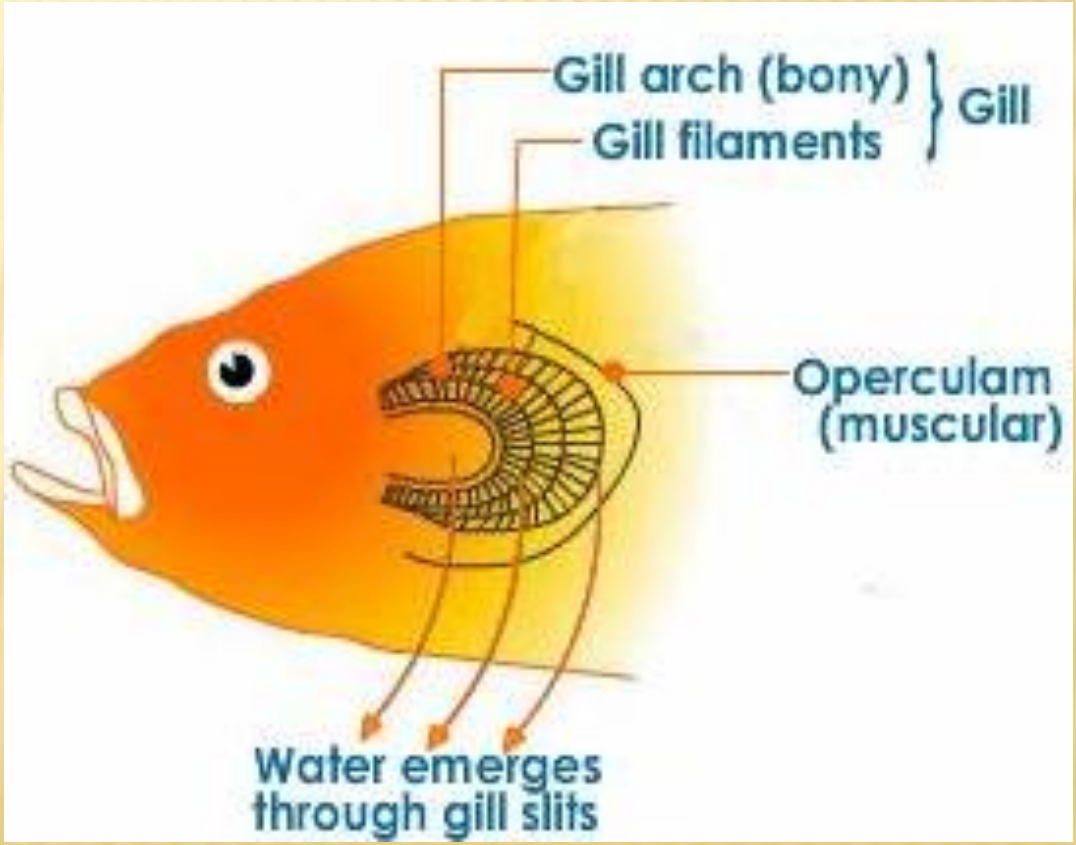
✓Through the gills, fish are able to absorb oxygen and give off carbon dioxide

✓Like the lungs, the gills have a large area for gaseous exchange

✓Some species have altered gills and other organs so that they can atmospheric air and extract the oxygen like skin, air bladder etc

Structure of Bony fish gill

The region between the buccal cavity (mouth) and the oesophagus is called the pharynx. In the pharyngeal region, the wall on either side shows slits which open to the exterior. These slits are called the gill slits. The gill slits are separated by a tissue called the gill arch or the branchial arch.



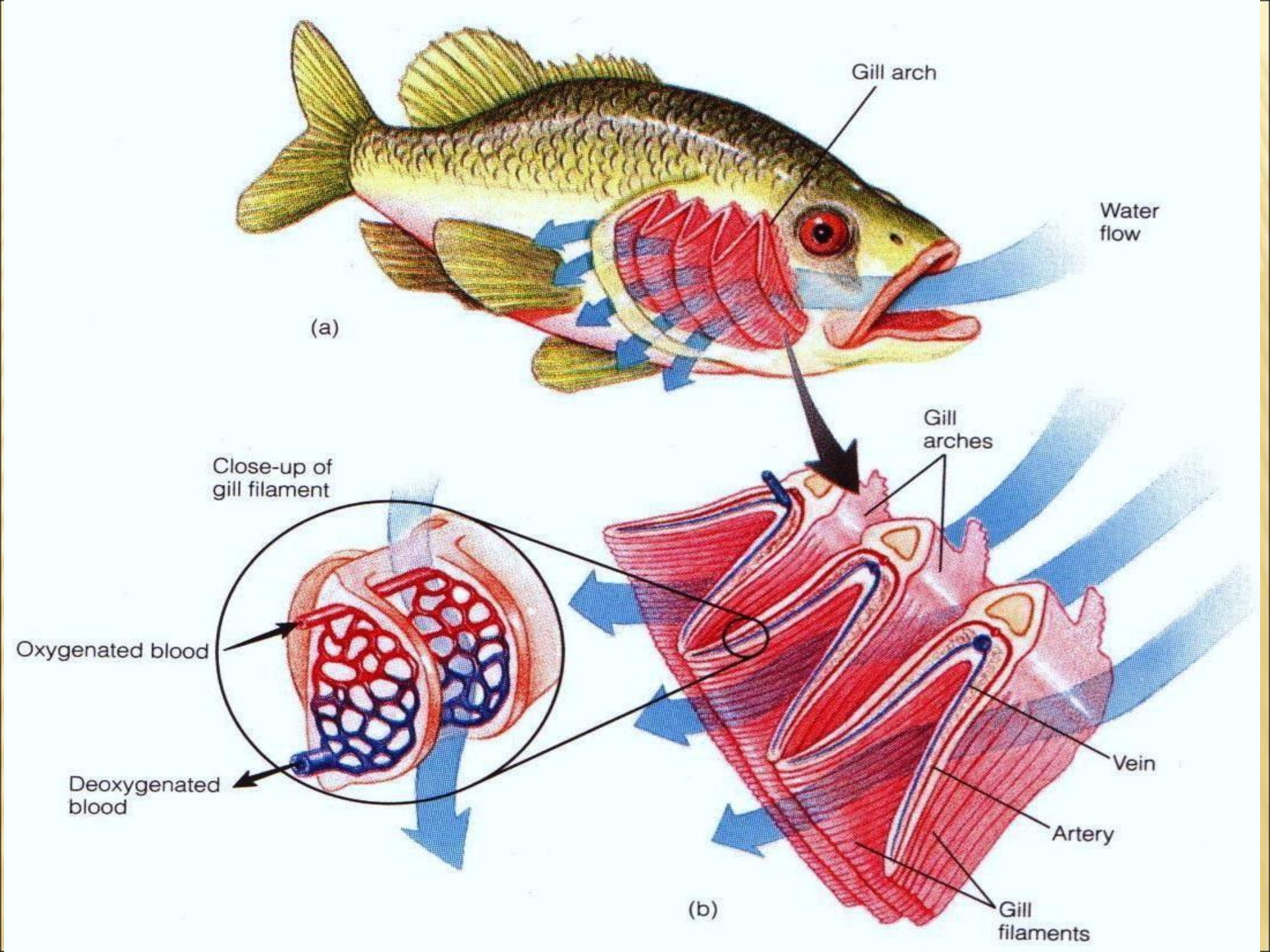
✓Gills are formed by filamentous outgrowth from the anterior and posterior wall of each gill silt

✓Gill arch bears two rows of gill filaments (V shape) forms a complete gill or holobranch. Individual row is called hemibranch

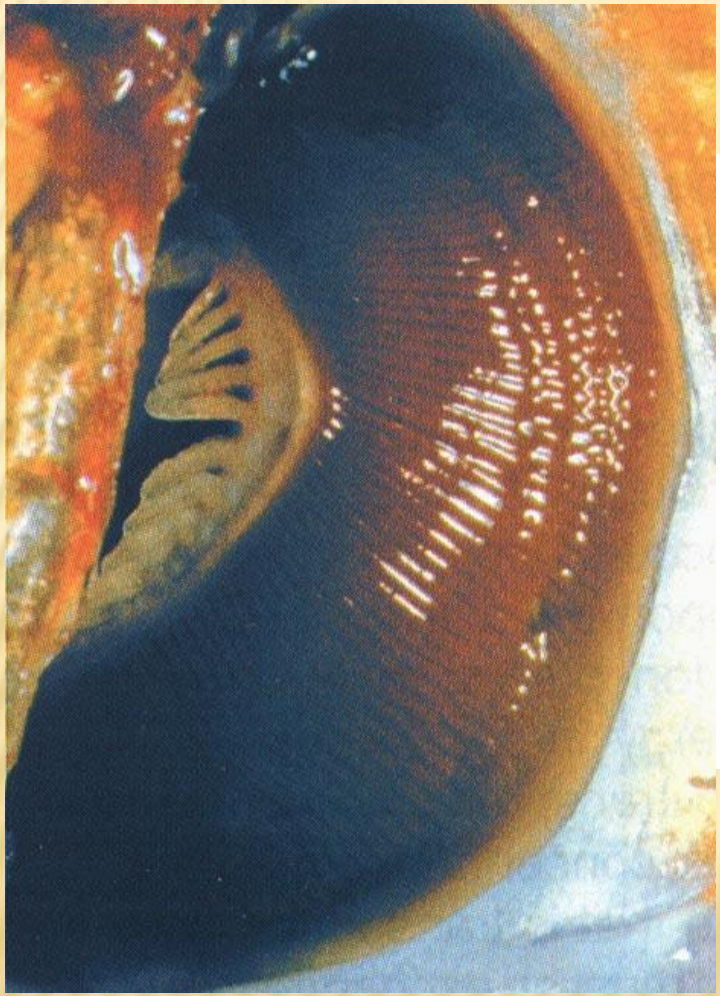
✓Most teleost have four holobranches (8 hemibranches) on each side while elasmobranchs have five holbranchs (10 hemibranches) on each side

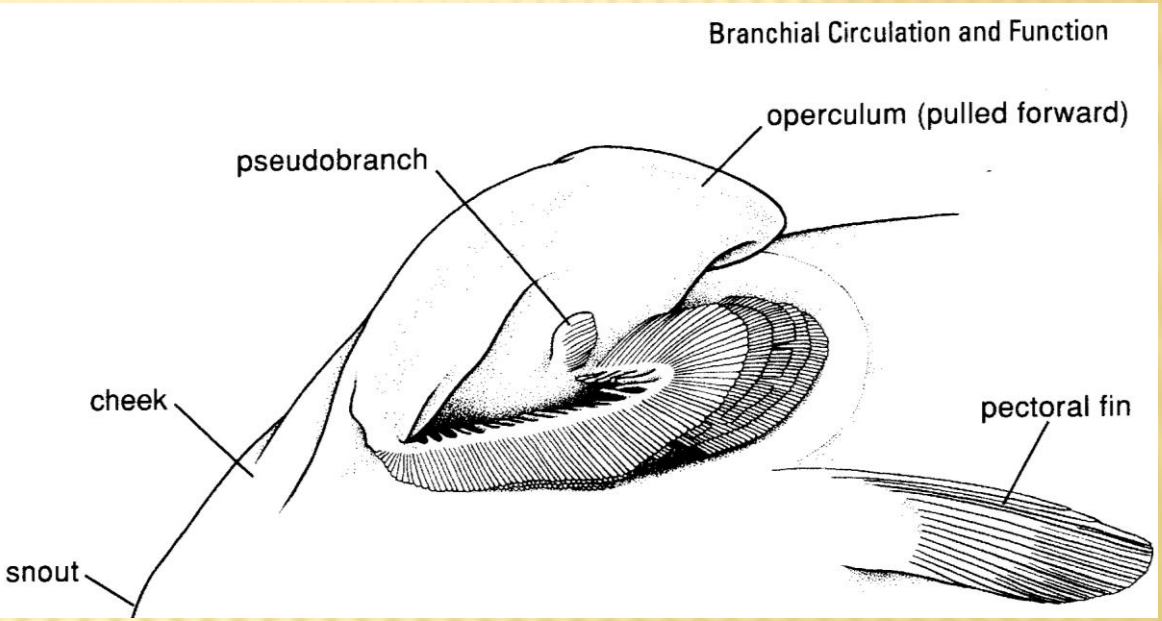
✓Gill arch bears gill rakers towards the inner (buccal) side and gill filaments towards the outer (opercular) side

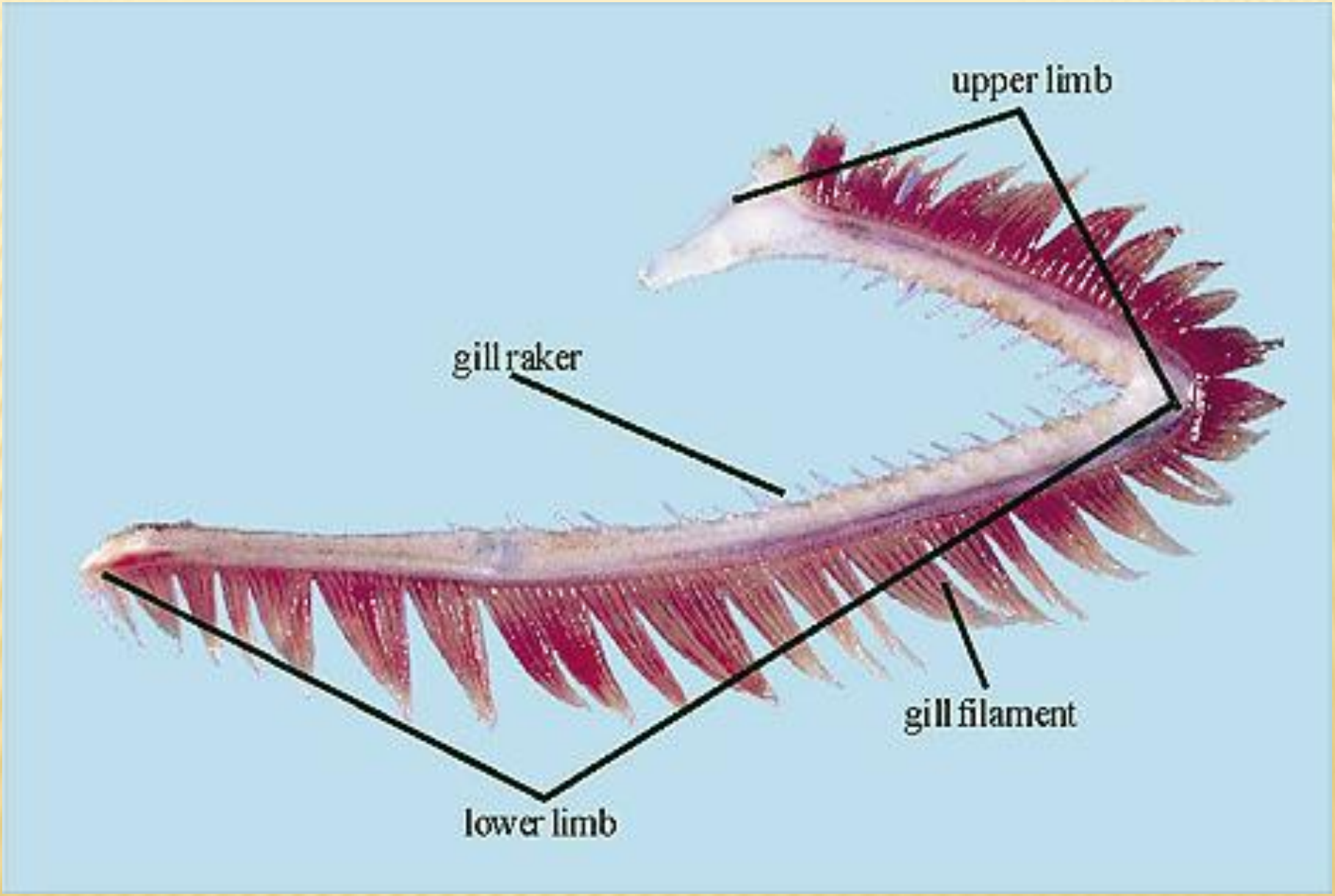
✓Gill rakers are covered by an epithelial layer bearing taste buds and mucus secreting cells


Gill arch
Water flow
(a)
Gill arches
Close-up of gill filament
Oxygenated blood
Deoxygenated blood
Vein
Artery
Gill filaments
(b)

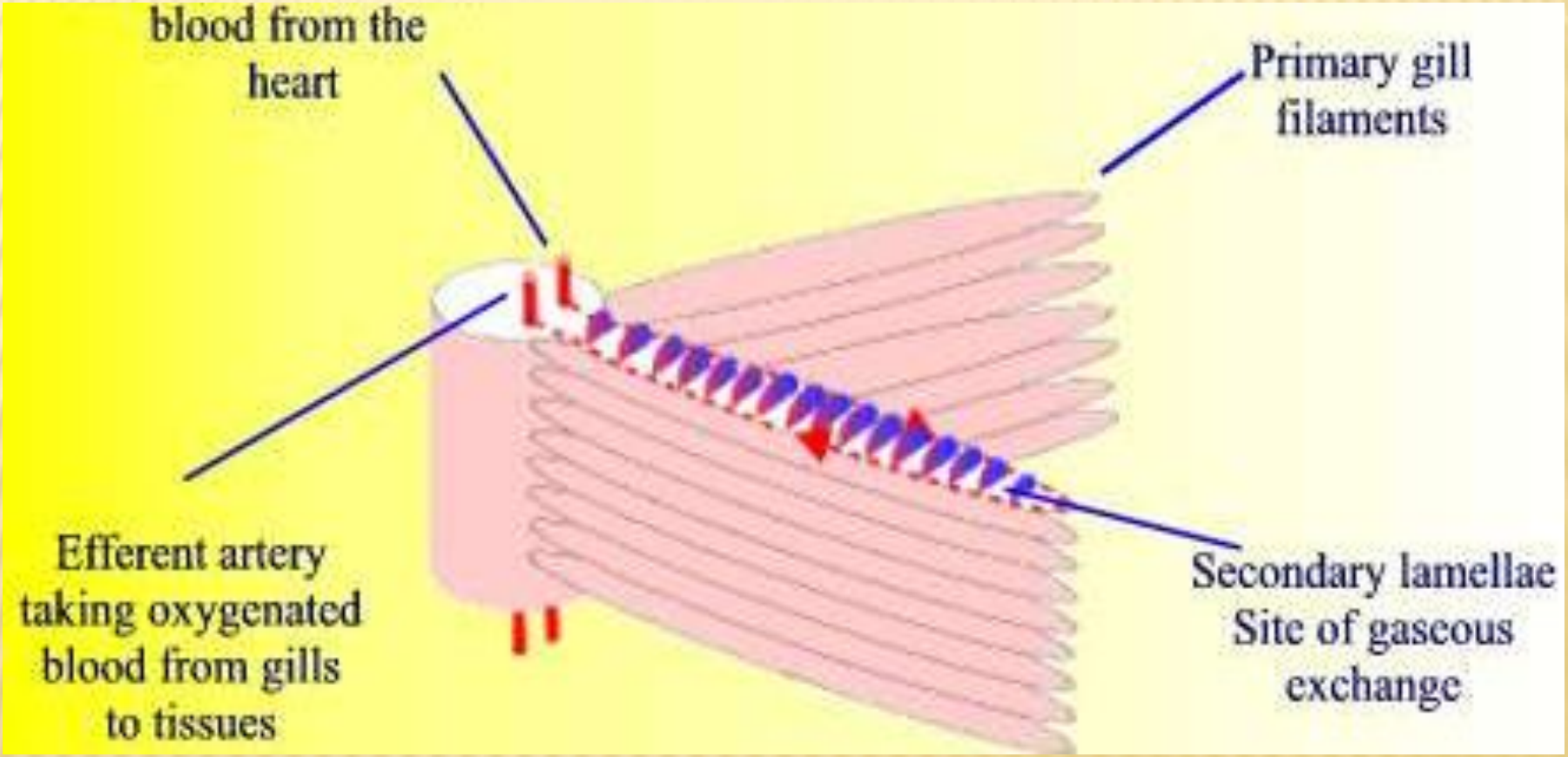
Teleost gill structure






upper limb
gill raker
gill filament
lower limb

From each gill arch arise two rows of filaments, which are arranged in a V-shaped manner. Each gill filament bears a large number of tiny folds on both the sides. these flat leaf like structures are called the lamellae and serve to further increase the surface area of filament



Lamellae have a rich supply of blood capillaries. Thus the barrier between the blood capillaries and the water is only few cells thick.

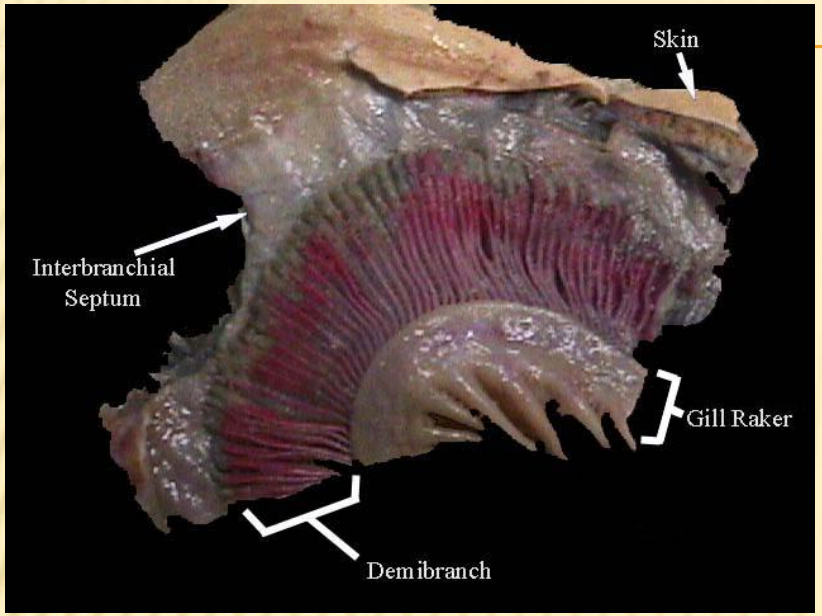
Anatomy of Teleost Gill

T. S. Gill of a teleost

Arrangement of Gill filaments and lamellae

Structure of gill lamellae (pillar cells)

Shark gill structure



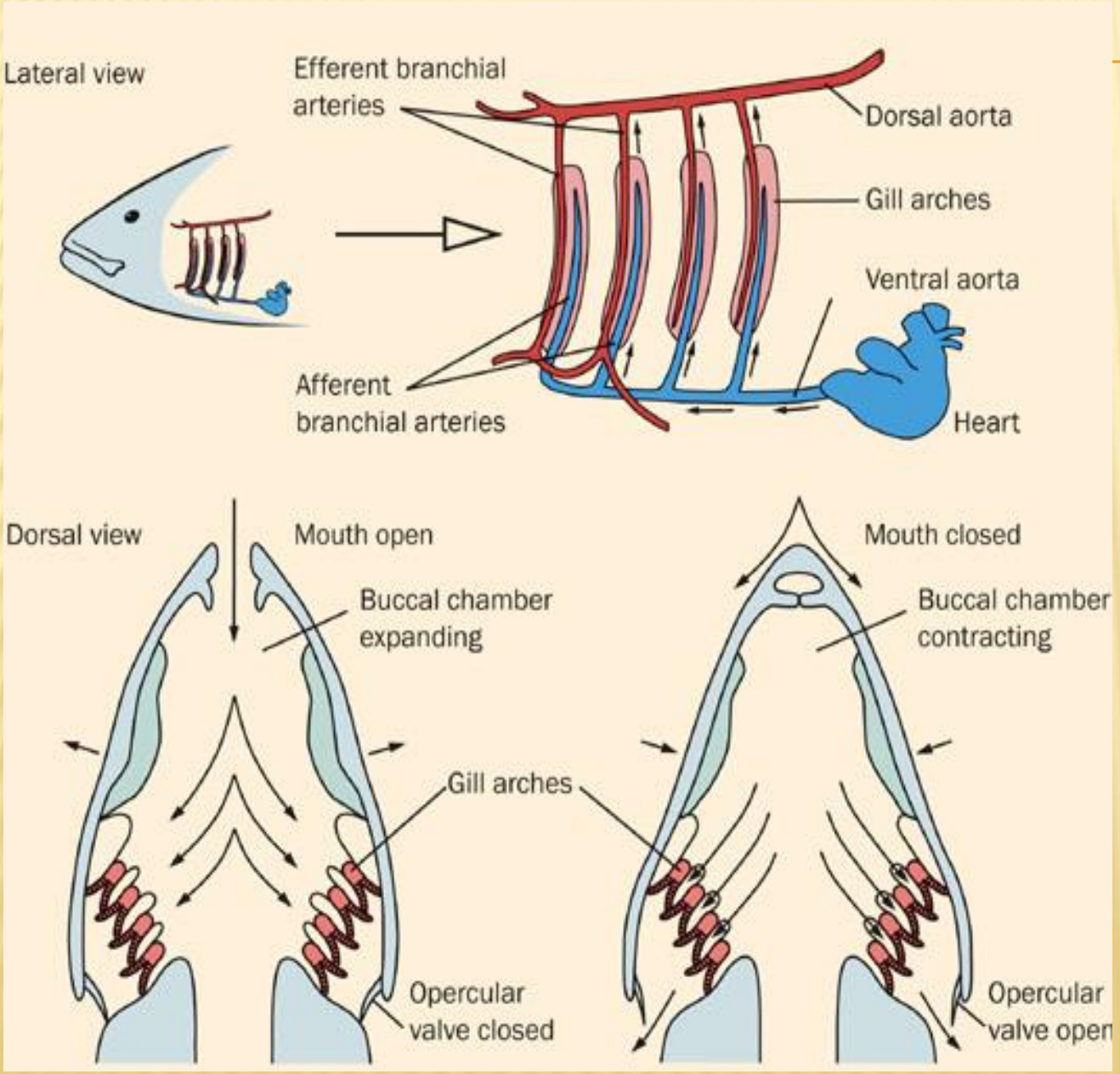
Five pairs of holobranches

Respiratory Pump in Fish

Fish need a more efficient method than terrestrial animals

- Unidirectional system, water always moves one way across gills and out operculum
- No mixing of fresh and respired water maintaining highest possible P_{O2} at gill surface

Respiratory Pump in Fish



Dual Pump

Phase I
Expansion of buccal and opercular cavities while opercula are closed

Phase II
Mouth closes, opercula open, forcing water across gills

Counter Current Exchange

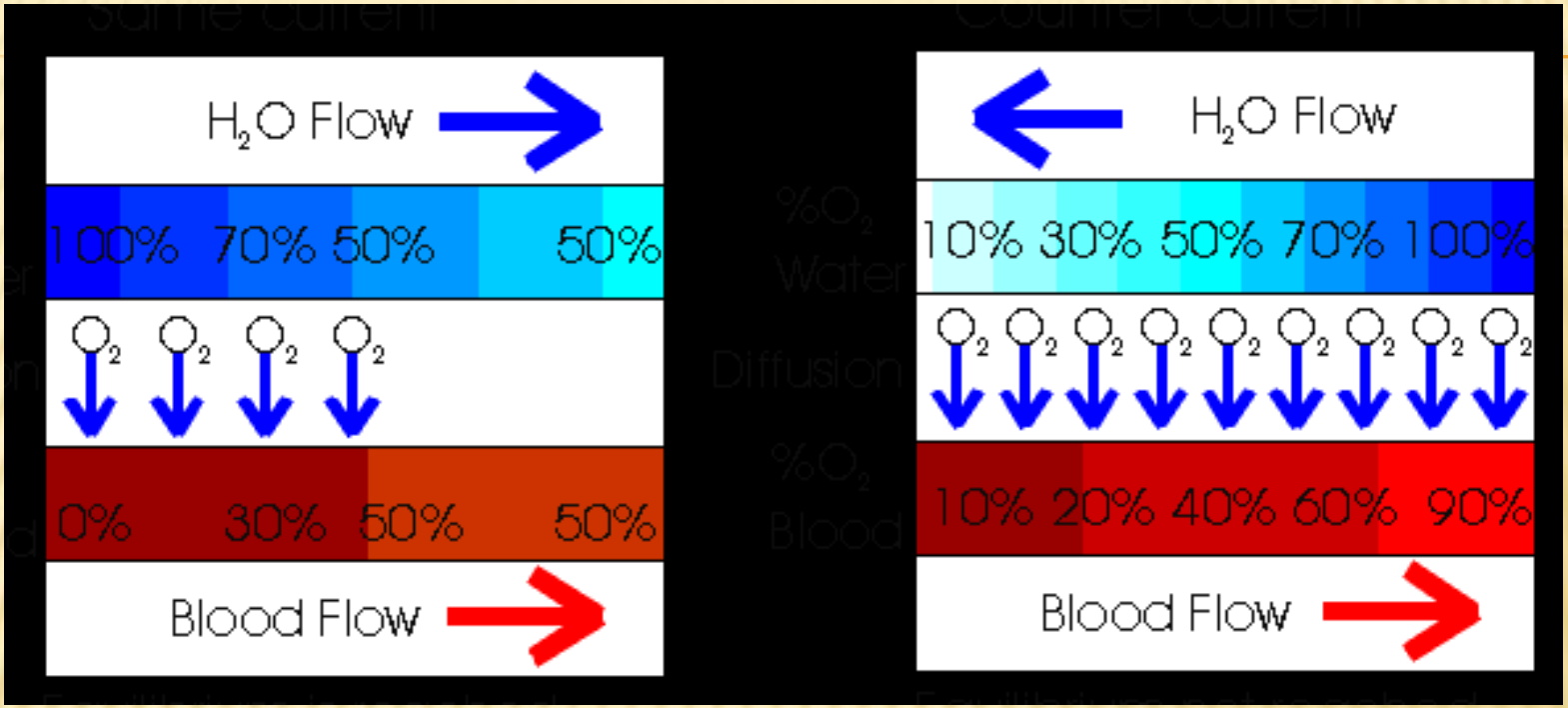
The gills of fish utilize counter-current flow, a very effective mechanism for removing the maximum amount of oxygen from the water flowing over them

During counter-current flow, two types of fluids (in this case blood and water) with different concentrations of one or more dissolved substances flow in opposite directions past one another

These fluids are separated by thin membranes

Counter-current flow promotes diffusion of a substance (such as oxygen) down its concentration gradient from one fluid (water) to the other (blood)

Counter Current Exchange



Blood flows through gill tissue in the opposite direction of water

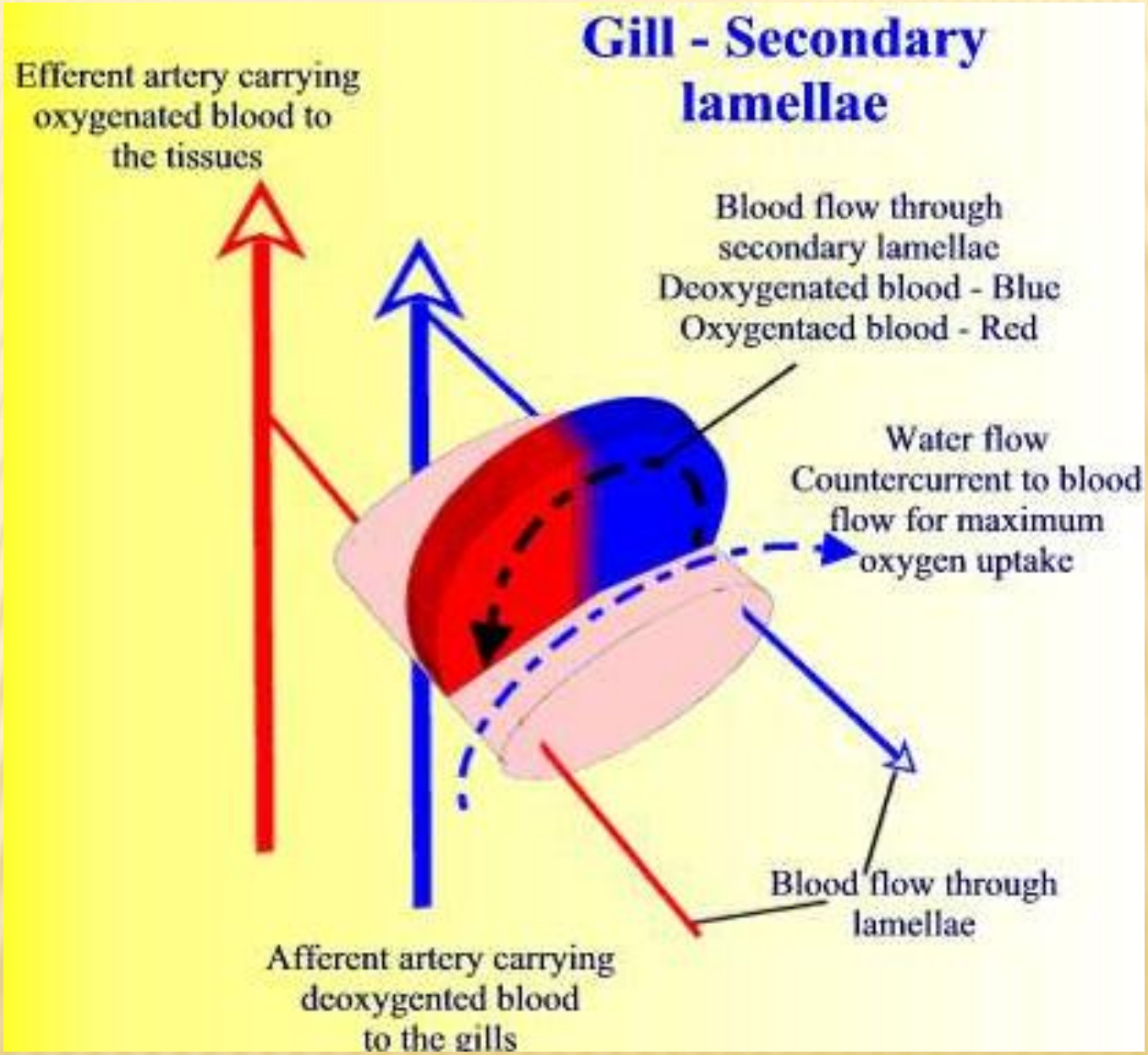
If blood flow were in same direction then blood would only be able to get half of available oxygen

With blood flow opposite the gradient is always such that oxygen will pass to the blood

This gives fish 80 – 90% efficiency in acquiring oxygen

✓**Blood flows across each lamella within a dense network of capillaries. Within each lamella, counter-current flow enhances diffusion by maintaining a concentration gradient of oxygen between the water (which is relatively high in oxygen) and the blood (lower in oxygen). water is deflected over the lamellae in a direction opposite the flow of blood in the capillaries.**

✓**Counter-current flow is so effective that some fish extract 85% of the oxygen from the water that flows over their gills.**


Gill - Secondary lamellae
Efferent artery carrying oxygenated blood to the tissues
Blood flow through secondary lamellae
Deoxygenated blood - Blue
Oxygentaed blood - Red
Water flow
Countercurrent to blood flow for maximum oxygen uptake
Blood flow through lamellae
Afferent artery carrying deoxygented blood to the gills

Circulation of blood through gill filament and lamellae

Teleost gills generally have one afferent unit and one efferent unit

Afferent branchial vessel brings deoxygnated blood

Efferent branchial vessel collect oxygenated blood

Transportation of Respiratory Gases in the Blood

- **The essential function of the gas exchange system is to meet the metabolic requirements of the cells for O_2 and to remove the CO_2 produced by cellular metabolism**

- **Blood carries O_2 to the tissue and remove CO_2 from respiring tissues to the gas exchange surface**

- **The main adaptation of blood for gas transport is the presence of the respiratory pigment hemoglobin (Hb) within the RBCs**

- **Hemoglobin increase the O_2 carrying capacity of blood up to 20 folds in comparison to physically dissolved O_2**

- **H^+ binding capacity of Hemoglobin also help in transportation of CO_2**

Hemoglobin

✓**Hemoglobin is a tetrameric molecule in most teleost fishes**

✓**Agnathans (lampreys & Hag fishes) posses monomeric hemoglobin**

✓**Antartic fishes (Ice fish) do not have hemoglobin**

Teleost

Hag Fish

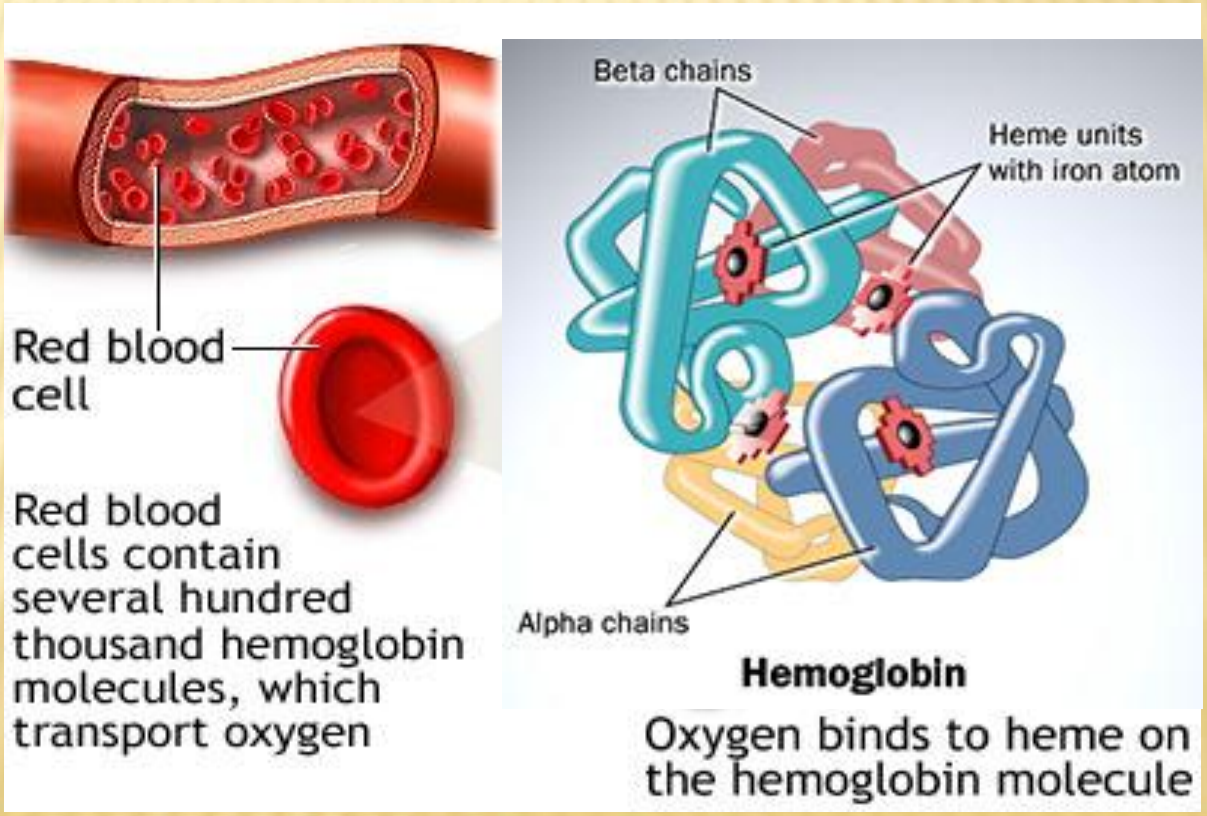
Ice Fish

Hemoglobin

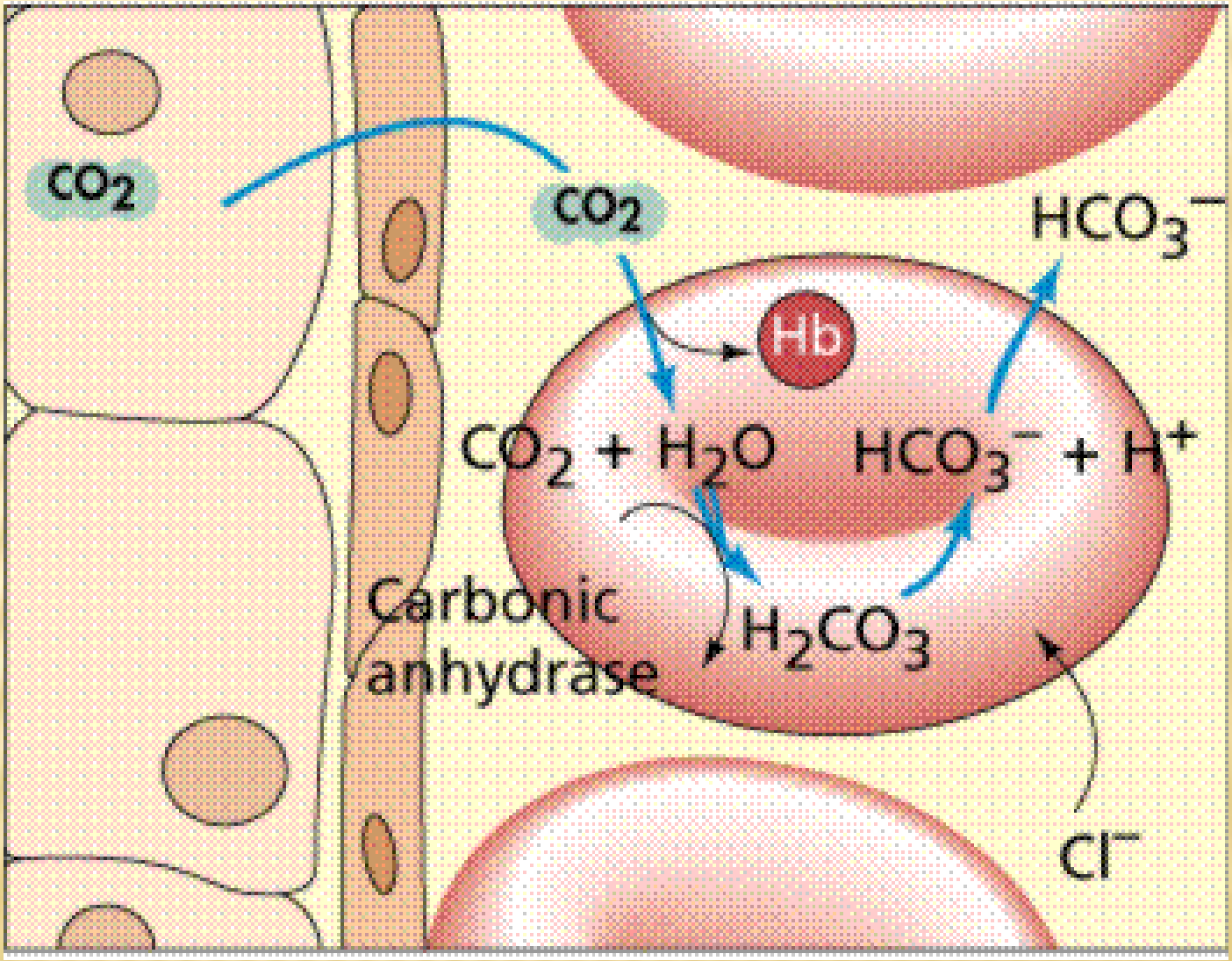
✓Tetrameric hemoglobin has two α and two β chain

✓O_2 bind in reversible and cooperative fashion to four heme group while H+ and CO_2 bind to specific amino acid residues in the globin chains

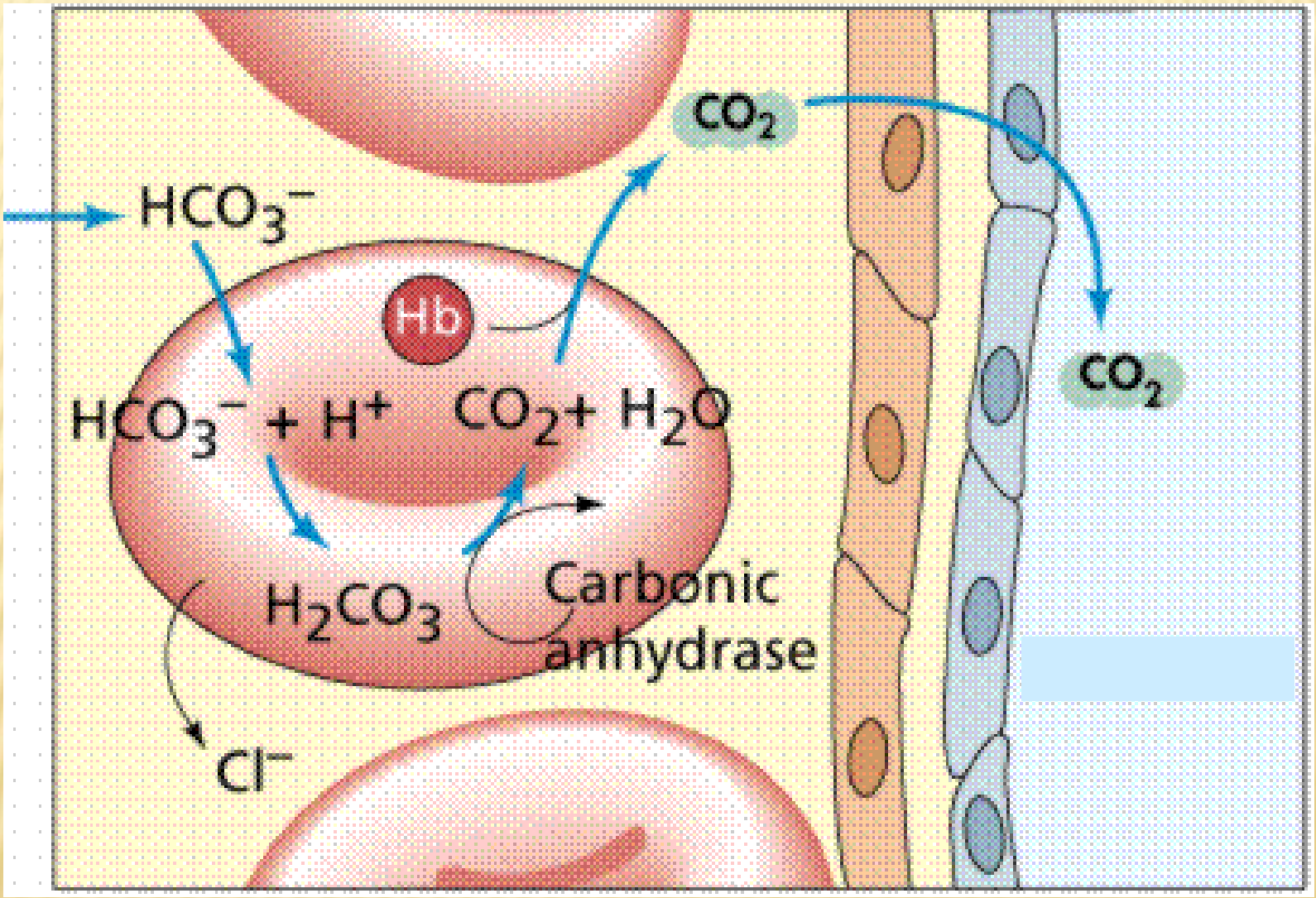
✓But in fishes, due to acetylation of α amino group only β chain available in bind to CO_2



Cellular exchange of oxygen and Carbon-di-oxide at respiring tissue



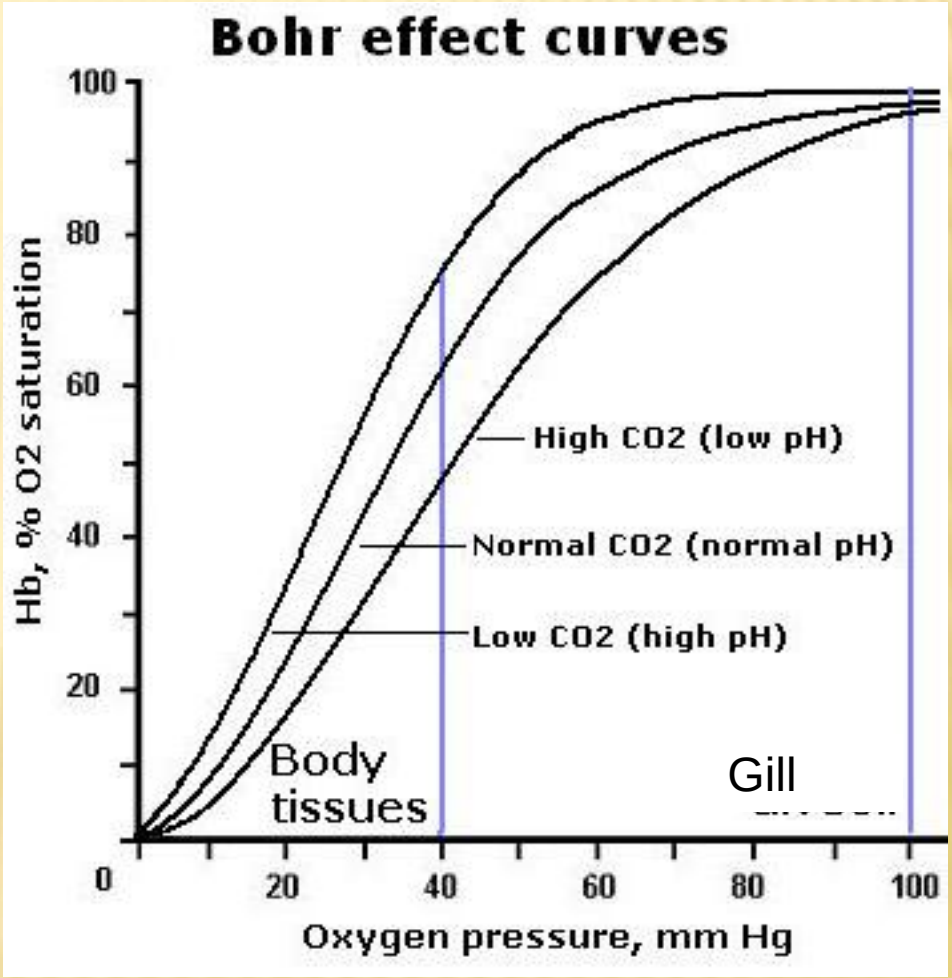
Cellular exchange of oxygen and Carbon-di-oxide at gill



Bohr Effect

The **Bohr effect** is a biological phenomenon first described by Christian Bohr stating that **hemoglobin's oxygen binding affinity is inversely related both to acidity and to the concentration of carbon dioxide**

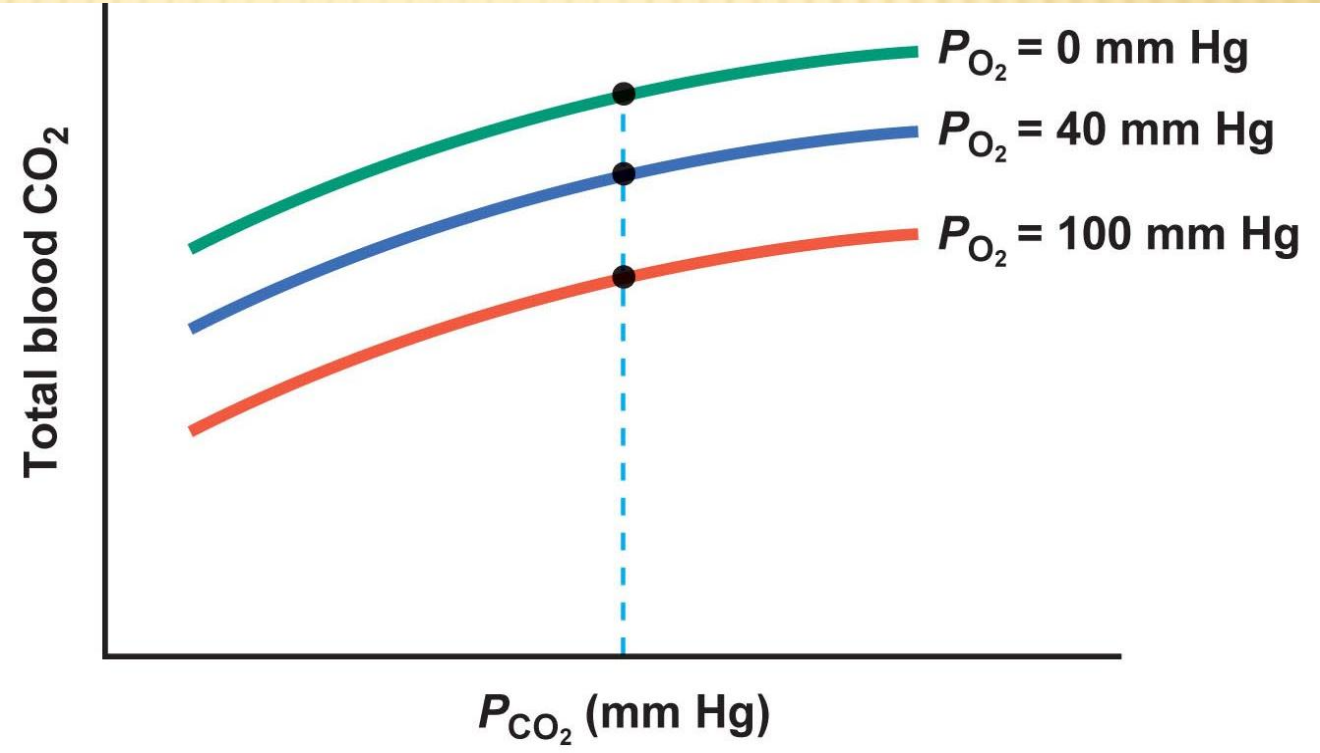
A **decrease in blood pH** or an increase in blood CO_2 concentration will result in hemoglobin proteins releasing their loads of O_2 and a decrease in carbon dioxide or increase in pH will result in hemoglobin picking up more oxygen



Haldane effect

The **Haldane effect** is a property of hemoglobin first described by the John Scott Haldane

Deoxygenation of the blood increases its ability to carry carbon dioxide; this property is the Haldane effect. Conversely, oxygenated blood has a reduced carrying capacity for carbon dioxide



The Root Effect

- **The Root Effect** is a physiological phenomenon that occurs in fish hemoglobin, named after its discoverer R. W. Root

- Hemoglobins showing the root effect show a loss of cooperativity at low pH. This results in the Hb-O_2 dissociation curve being shifted downward and not just to the right. At low pH, hemoglobins showing the root effect don't become fully oxygenated even at oxygen tensions up to 20kPa

- This effect allows hemoglobin in fish with swim bladders to unload oxygen into the swim bladder against a high oxygen gradient

- The effect is also noted in the choroid rete, the network of blood vessels which carries oxygen to the retina

- In the absence of the Root effect, retia will result in the diffusion of some oxygen directly from the arterial blood to the venous blood, making such systems less effective for the concentration of oxygen