TRANSPORT IN HUMANS

Competency: The learner appreciates the mechanisms of transport of substances in the blood, and the immune system's role in protecting the human body by analysing the processes and their role in the maintenance of human health, to prevent diseases in everyday life.

- Assess the role of the human heart in blood circulation and the role of haemoglobin in the transportation of gases in blood under various physiological conditions.
- The transportation of oxygen and carbon dioxide in the body and understanding of the importance of chloride shift in carbon dioxide transportation.
- Effect of different factors on the amount of oxygen in the blood and understanding of oxygen dissociation in the respiring tissue
- The effect of carbon dioxide concentration on the heartbeat rate.
- The responses of athletes versus non-athletes, and low land dwellers versus high land dwellers, to exercise.
- Explaining the effect of carbon monoxide on transportation of oxygen.
- The myogenic action of the heart and nervous control of heartbeat rate and the role played by the brain, sinoatrial node, and atrioventricular node during regulation of the heartbeat.

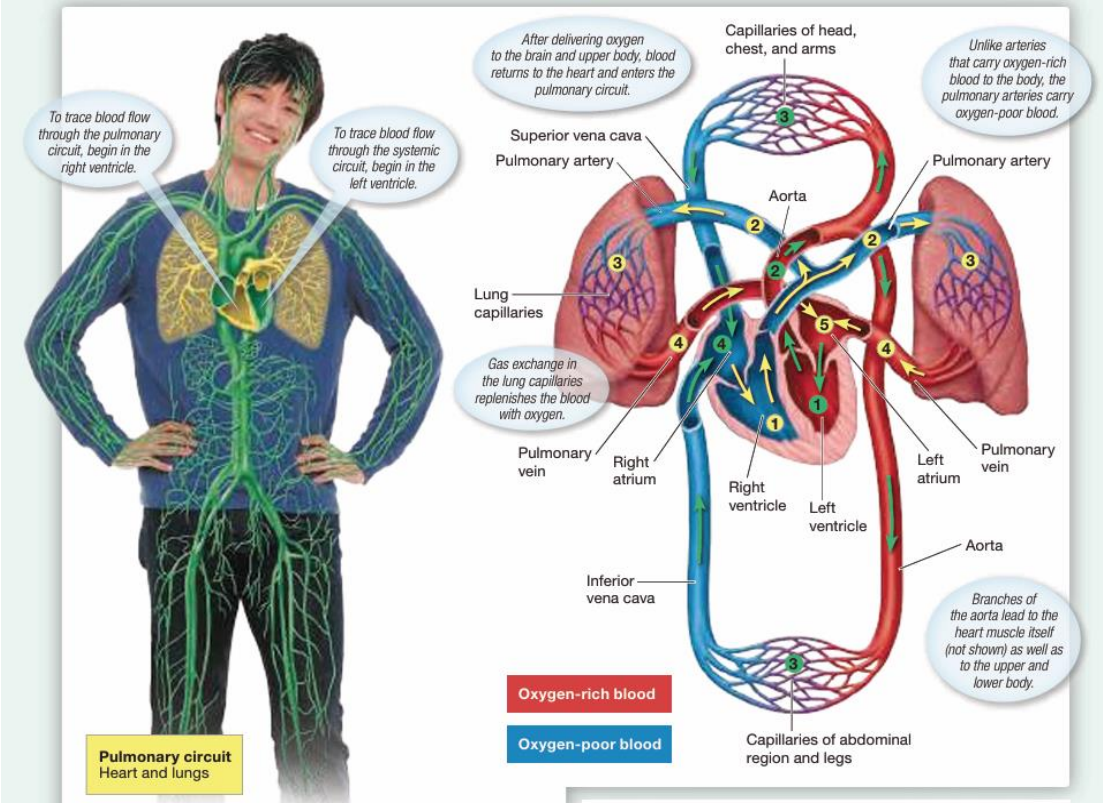


Figure 1 structure and function of the circulatory system

TRANSPORT IN ORGANISMS

Transport refers to the movement of materials from one part of the organism to another. The major processes involved in. the transport of materials in organisms are diffusion, osmosis, active transport in simple and small organisms, circulatory systems in complex and large animals.
The necessity for transport systems in large complex multicellular organisms is based on the following facts:

(i) That neither the organism nor its cells can live in total independence of their environments for they need metabolites for their metabolism and have to eliminate the resulting metabolic wastes.
(ii) The fact that diffusion alone can no longer suffice in large organisms to move such materials (wastes and metabolites) to and from the cells let alone at a rate commensurate-to (as fast as) body needs.
(iii) That in large multicellular organisms most of the cells are detouched from the environment and the great distance between them and the environment is certainly a hindrance to diffusion and other means of movement in and out of cells.
(iv) That quicker movement of materials in the organism can only be achieved if the materials in transit are separated from other materials within the organism.
(v) That a large part of the external body surface must often be kept impermeable to conserve water particularly in terrestrial organisms.
(vi) This is exactly what vascular systems and circulatory systems have been evolved to do and thus they share the following similarities.

VASCULAR SYSTEMS IN HUMANS

Vascular systems in man is made up of:
1. A circulatory fluid: most common one is blood though higher organisms contain lymph as an addition
2. A pump organ: the heart
3. A system of tubes through which the circulatory fluid can move

Functions of circulatory system

The circulatory system in man carries out the following basic functions.
1. **Transport of nutrients**. It transports all soluble food compounds from the area of absorption to different parts of the body for storage, assimilation or synthesis of new components.
2. **Transport of waste products**: it transports all the excretory products produced as a result of cellular activities from all over the body to the organs of excretion (like kidney in man)
3. **Transport of intermediate metabolites**: it transports all the byproducts or intermediate products from the tissues they are produced to the organs where they can be metabolized (like lactic acid produced in muscles is transported to the live for oxidation.
4. **Transport of hormones**: since hormones are produced by ductless glands, they are transported through the circulatory fluid to their target organs.
5. **Uniform distribution of heat**: since circulatory fluid connects to all parts of the body it picks up heat from one part and dissipates it on the surface bringing about the uniform distribution.
6. Transport of **water**, **inorganic ions** and various chemicals is also done by the circulatory fluid so as to maintain a uniform distribution
7. **Defense against diseases**: the circulating fluid contains blood cells responsible for body defense
8. **Transport of respiratory gases**: it contains haemoglobin which contains haemoglobin which

may be dissolved in plasma. The oxygen is transported from respiratory organs to respiring tissues while carbon dioxide is carried from tissues to respiratory organs.

Transport of carbondioxide

Carbon dioxide is readily soluble in water and is carried both by plasma and red blood cells. As an active cell gives out CO_2, it enters the blood where only about 5-8% forms the solution in the blood plasma and the rest 92-95% enters the red blood cells where it is transported by two means. In all carbon dioxide is carried by three different means.

- **By plasma in solution form** (5-8%)

Carbon dioxide combines with water to form carbonic acid. It is a very slow process and hence a very small amount is carried this way.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

- **By the R.B.C as compounds with proteins of haemoglobin (l5 %.).**

Some carbon dioxide that enters the R. B. C forms a reversible compound with amino (-NH2) group of the globin (protein) part of reduced haemoglobin. The reaction is similar to that with oxygen but is not with the heme part but is with the protein part of the haemoglobin. The compound formed is called as carbamino-haemoglobin.

$$\underset{\text{Reduced haemoglobin}}{HHbNH_2} + CO_2 \longrightarrow \underset{\text{Carbaminohaemoglobin}}{HbNHCOOH} + H^+$$

As sodium bicarbonate (80%).

As carbon dioxide diffuses into the blood plasma, only a part combines with water to form carbonic acid because it is a very slow reaction. A large part enters the R.B.C where a zinc enzyme carbonic anhydrase speeds up the formation of carbonic acid tremendously. The carbonic acid thus formed dissociates into bicarbonate $HC0_3^-$ and hydrogen ionsH^+. The hydrogen ions are buffered by the hemoglobin itself to form HHb as shown below. The bicarbonate ions diffuse out into the plasma where they combine with sodium ions to form sodium bicarbonate. At the same time the loss of bicarbonate ions is balanced by chloride ions diffusing into the R. B.C. from the plasma. This is called **chloride shift. Sodium** bicarbonate in plasma forms an important buffering system and helps to neutralize any acids or bases formed.

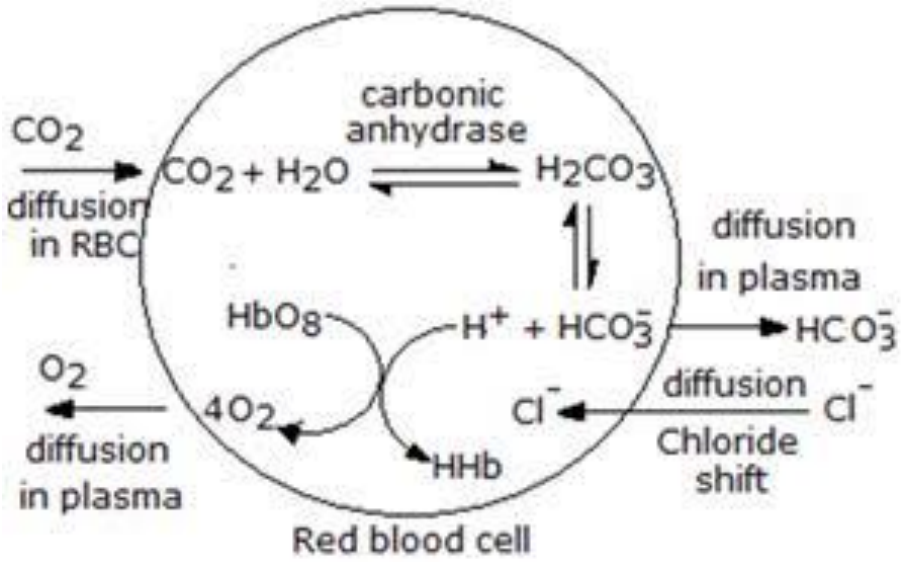


Figure 2 effect of the chloride shift in oxygen transportation

Release of carbondioxide from all the body at the lungs

All the processes described above in transport of carbon dioxide are reversible. At the lung alveolus the situation is just reverse of what it is at tissue level. At the alveoli. the blood capillaries are subjected to high oxygen and low carbon dioxide concentration. As a result, there is a speedy reversal of chemical events releasing carbon dioxide and picking up oxygen simultaneously. Carbonic anhydrase also rapidly converts carbonic acid back to carbon dioxide and water when blood reaches the lungs.

Release of gases at the tissue and lung level

At the tissue level, oxygen is released from oxyhaemoglobin and carbon dioxide is picked by plasma and red blood cells. At the lung level, carbon dioxide is released from its three states so as to expire it out from blood to the alveoli and oxygen is picked up by haemoglobin.

Release of 02 from oxyhaemoglobin at the tissue level

$$HbO_2 \longrightarrow Hb + O_2$$

The dissociation of oxyhaemoglobin depends on PO_2 and PCO_2 of the cell. Oxyhaemoglobin *gives off its oxygen more readily* in the presence of increased carbon dioxide or PCO_2. Increased CO_2 actually increases acidity and lower the pH value *by* the formation of carbonic acid. All these factors favour the release of oxygen from haemoglobin.

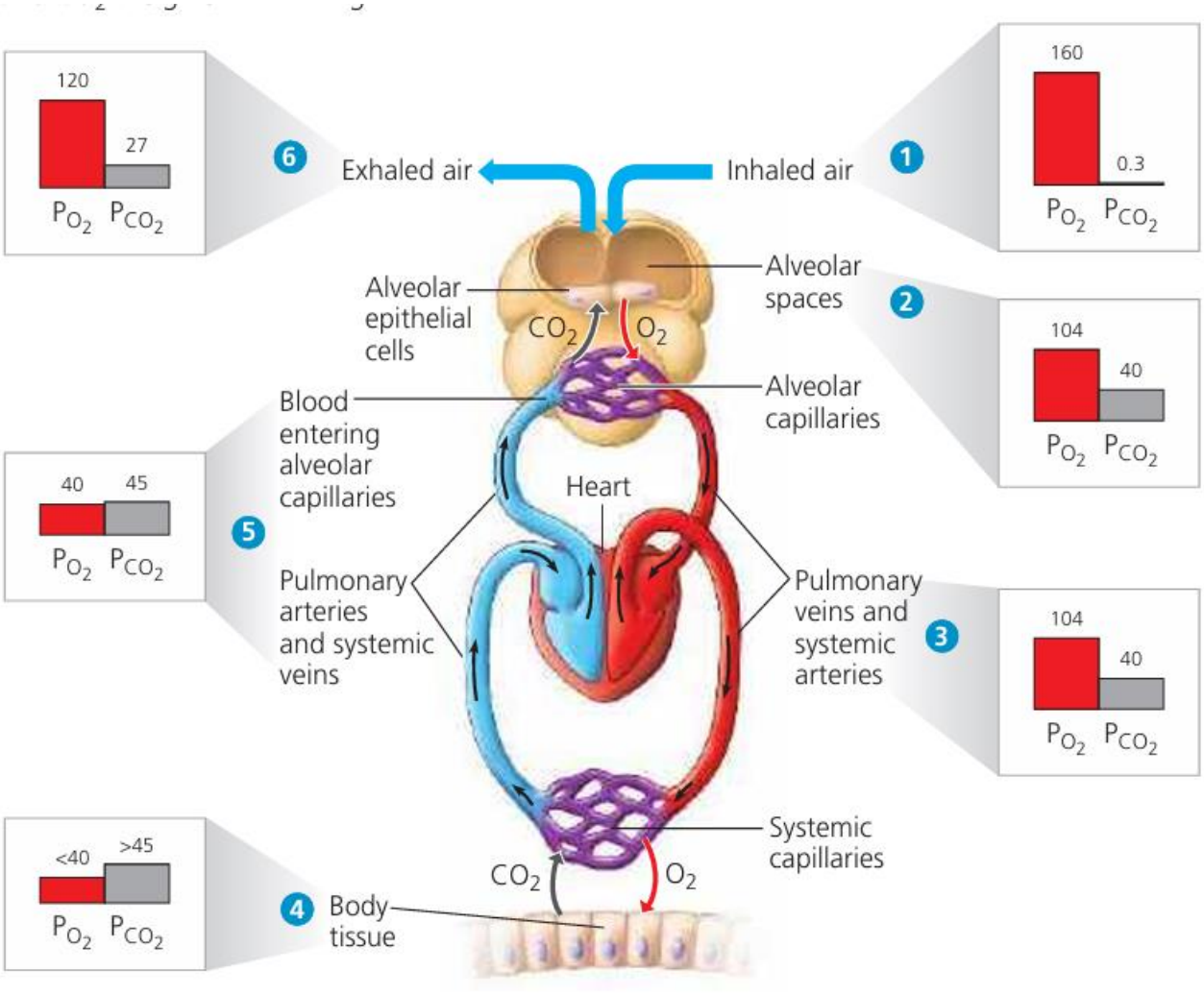


Figure 3 the various partial pressures of oxygen and carbondioxide in different body parts

Transport of oxygen

Since oxygen is not very soluble in water under normal atmospheric conditions, most of itis carried by red blood cells. Red blood cells contain a complex protein hemoglobin which on combination with oxygen forms a reversible compound oxyhemoglobin.

Structure of haemoglobin

Haemoglobin is a tetrameric protein, meaning it's made up of four subunits. These subunits are two alpha chains (α) and two beta chains (β). The subunits are arranged in two αβ dimers, with each dimer interacting with the other to form the tetramer. Each subunit is a globular protein, similar in structure to myoglobin. Each subunit contains a heme group, a prosthetic group that binds oxygen. The heme group consists of an iron atom (Fe) bound to a proto-porphyrin ring. The iron atom in the heme group is in the ferrous (Fe2+) state, which is essential for its ability to bind oxygen reversibly. The iron atom is linked to the nitrogen atom of a histidine residue in the polypeptide chain. The porphyrin ring is held in place by interactions with amino acids in the subunit.

Hemoglobin's primary function is to transport oxygen from the lungs to the tissues and carbon dioxide back to the lungs.

The cooperative binding of oxygen to the four subunits allows for efficient oxygen delivery to tissues.

The structure of haemoglobin allows it to exist in two conformations: a tense (T) state (deoxygenated) and a relaxed (R) state (oxygenated).

The transition between these states is crucial for the efficient loading and unloading of oxygen in the lungs and tissues.

A molecule of hemoglobin can carry 1-4 oxygen molecules (one with each heme group) according to its degree of saturation which depends upon

(i) Partial pressures of oxygen in alveolus

(ii) Partial pressures of carbondioxide in the blood. (PCO_2)

Hemoglobin molecule on combining with oxygen forms oxyhemoglobin in the lungs. These oxygen molecules are quickly released in the tissues.

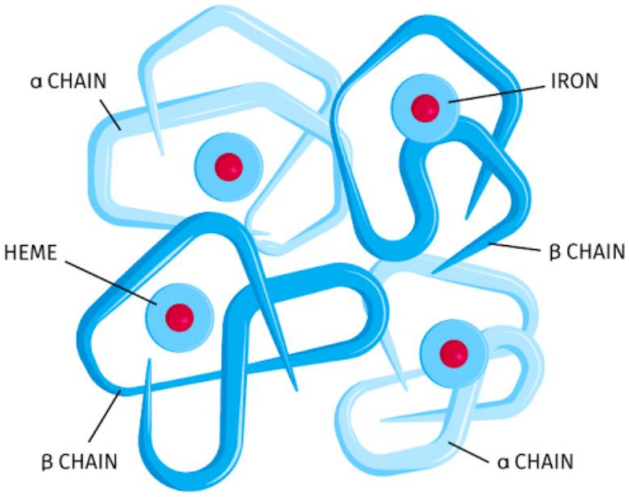


Figure 4 molecular structure of a haemoglobin molecule

Hemoglobin has high affinity for oxygen and this affinity is enhanced by fall PCO_2 in of blood. At the alveolus in lungs, venous blood has low oxygen and it is exposed to high PCO_2 of alveolus and so oxygen diffuses into red blood cells and forms oxyhemoglobin. As carbon dioxide diffuses from blood to alveolus, blood PCO_2 falls enhancing further uptake of oxygen. Oxyhemoglobin remains unchanged till it reaches the tissues where it dissociates readily to release its oxygen.

Describe the structure of haemoglobin and discuss how it is suited to its functions

OXYGEN DISSOCIATION CURVE

The oxygen dissociation curve shows the rate at which oxygen associates, and also dissociates, with haemoglobin at different partial pressures of oxygen.

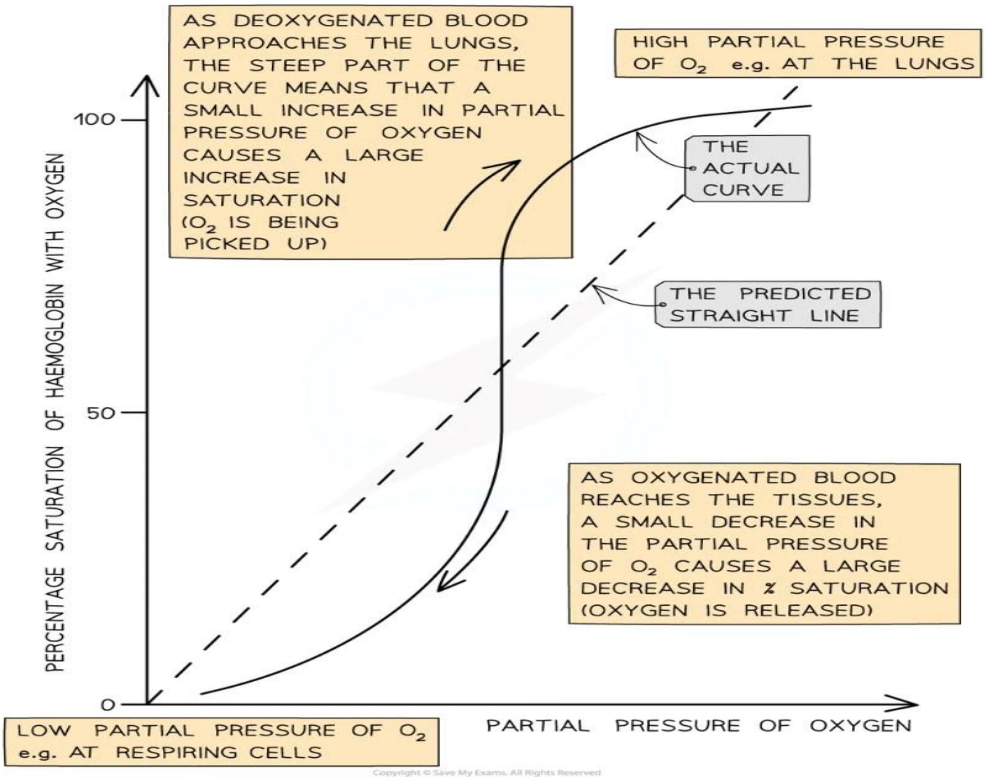
Partial pressure of oxygen refers to the pressure exerted by oxygen within a mixture of gases or it is a measure of oxygen concentration

Haemoglobin is referred to as being **saturated** when all of its oxygen binding sites are taken up with oxygen or when it contains four oxygen molecules.
The ease with which haemoglobin binds and dissociates with oxygen can be described as its **affinity for oxygen.**

When haemoglobin has a high affinity it binds easily and dissociates slowly. When haemoglobin has a low affinity for oxygen it binds slowly and dissociates easily. In other liquids, such as water, we would expect oxygen to becomes associated with water, or to dissolve, at a constant rate, providing a straight line on a graph, but with haemoglobin oxygen binds at different rates as the partial pressures of oxygen changes; hence the resulting curve. It can be said that haemoglobin's affinity for oxygen changes at different partial pressures of oxygen.

Oxygen dissociation curve diagram

The oxygen dissociation curve is a sigmoidal shape. Oxygen dissociation curve with labels describing the diagram.



Interpreting the curve

When the curve is read from left to right, it provides information about the rate at which haemoglobin binds to oxygen at different partial pressures of oxygen

At low partial pressures of oxygen, in the bottom left corner of the graph, oxygen binds slowly to haemoglobin; this means that haemoglobin cannot pick up oxygen and become saturated as blood passes through the body's oxygen-depleted tissues. Haemoglobin has a low affinity for oxygen at low partial pressures of oxygen, so saturation percentage is low.

At medium partial pressures of oxygen, in the central region of the graph, oxygen binds more easily to haemoglobin and saturation increases quickly at this point on the graph a small increase in partial pressures of oxygen causes a large increase in haemoglobin saturation.

At high partial pressures of oxygen, in the top right corner of the graph, oxygen binds easily to haemoglobin this means that haemoglobin can pick up oxygen and become saturated as blood passes

through the lungs. Haemoglobin has a high affinity for oxygen at high partial pressures of oxygen, so **saturation percentage is high.**

Note that at this point on the graph increasing the partial pressures of oxygen by a large amount only has a small effect on the percentage saturation of haemoglobin; this is because most oxygen binding sites on haemoglobin are already occupied.

N.B: When read from right to left, the curve provides information about the rate at which haemoglobin dissociates with oxygen at different partial pressures of oxygen

In the lungs, where partial pressures of oxygen are high, there is very little dissociation of oxygen from haemoglobin.

At medium partial pressures of oxygen, oxygen dissociates readily from haemoglobin, as shown by the steep region of the curve; this region corresponds with the partial pressures of oxygen present in the respiring tissues of the body, so ready release of oxygen is important for cellular respiration.

At this point on the graph a small decrease in partial pressures of oxygen causes a large decrease in percentage saturation of haemoglobin, leading to easy release of plenty of oxygen to the cells

At low partial pressures of oxygen dissociation slows again; there are few oxygen molecules left on the binding sites, and the release of the final oxygen molecule becomes more difficult, in a similar way to the slow binding of the first oxygen molecule.

Explaining the Oxygen Dissociation Curve

The curved shape of the oxygen dissociation curve for haemoglobin can be explained as follows:

Due to the shape of the haemoglobin molecule it is **difficult** for the first oxygen molecule to bind to haemoglobin; this means that binding of the first oxygen occurs **slowly**, explaining the **relatively shallow curve at the bottom left corner of the graph**. After the first oxygen molecule binds to haemoglobin, the haemoglobin **protein changes shape**, or conformation, making it easier for the next oxygen molecules to bind; this **speeds up binding** of the remaining oxygen molecules and explains the steeper part of the curve in the middle of the graph. The shape change of haemoglobin leading to easier oxygen binding is known as **cooperative binding**. As the haemoglobin molecule approaches saturation it takes longer for the fourth oxygen molecule to bind due to the shortage of remaining binding sites, explaining the levelling off of the curve in the top right corner of the graph.

Note: In man the arterial blood has Partial pressure of oxygen is about 95 mm of Hg and so hemoglobin is about 95%saturated. In the venous blood, partial pressure of oxygen is about 40 mm of Hg and so blood is about 70% saturated.

Bohr Effect

Bohr effect describes how changes in carbondioxide and pH affect haemoglobin's ability to bind with oxygen. It is the shifting of the oxygen dissociation curve to the right due to increase in partial pressures of carbondioxide.

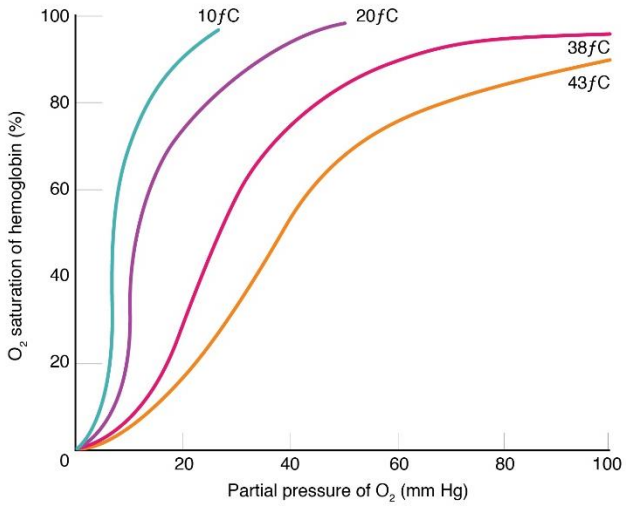
Figure above shows that increase in partial pressures of carbondioxide shifts the oxygen dissociation curve downwards. Since $PCO_2$is lower in lungs than in tissues, hemoglobin has higher affinity for oxygen. In the tissues, $P0_2$ is between 10 and 40 mm of Hg and $PC0_2$is comparatively very high around 46 mm of Hg. An active tissue has a relatively high $PC0_2$, low pH and raised temperature and all these changes lead to more dissociation of oxygen. Oxygenated blood passing through **inactive** cells does not give up oxygen even if its $P0_2$ is low but in *active* cells it readily gives oxygen as $PC0_2$ is very high.

Effect of different factors on the amount of oxygen in the blood and understanding of oxygen dissociation in the respiring tissue

- **Blood temperature**

Increased body temperature shifts the oxygen dissociation curve to the right, reducing hemoglobin's affinity for oxygen and promoting oxygen unloading in tissues. Conversely, lower temperatures shift the curve to the left, increasing affinity and hindering oxygen release. This rightward shift facilitates oxygen delivery to metabolically active, warmer tissues. When temperature increases, hemoglobin becomes less likely to bind to oxygen and more likely to release it into the tissues. Lower temperatures cause a leftward shift, making hemoglobin's affinity for oxygen higher. This means more oxygen is bound to hemoglobin, making it less readily available for release into the tissues.

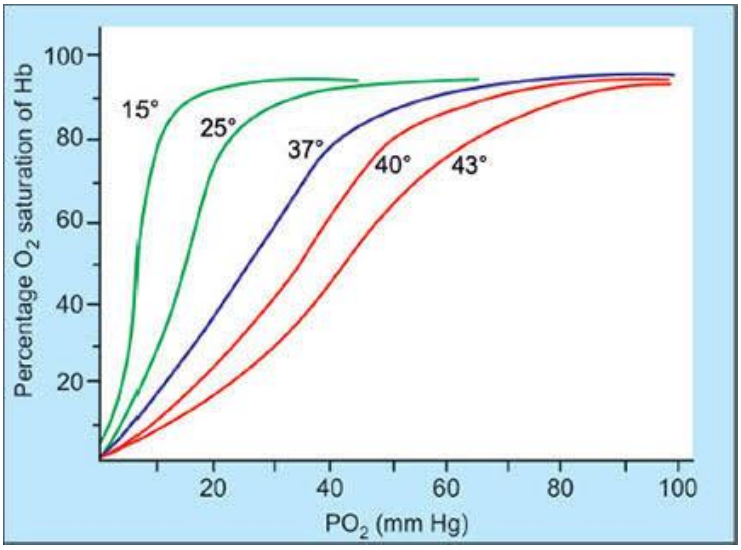
The rightward shift at higher temperatures **is crucial for delivering oxygen to metabolically active** tissues, which have higher oxygen demands and are typically warmer. For example, during exercise, increased temperature and other factors shift the curve to the right, facilitating oxygen delivery to working muscles.



- **Blood PH**

A change in pH shifts the oxygen dissociation curve, impacting hemoglobin's affinity for oxygen. A decrease in pH (acidity) shifts the curve to the right, reducing the affinity and promoting oxygen release, while an increase in pH (alkalinity) shifts the curve to the left, increasing affinity and reducing oxygen release. This phenomenon is known as the Bohr effect. A decrease in pH (more acidic) leads to a rightward shift of the curve. This means that at a given partial pressure of oxygen, hemoglobin will have a lower affinity for oxygen, and more oxygen will be released to the tissues. This is advantageous in active tissues where metabolic activity increases CO_2 production, lowering the pH and promoting oxygen unloading. An increase in pH (more alkaline) shifts the curve to the left. This indicates a higher affinity for oxygen, and less oxygen will be released at a given PO_2. This is beneficial in the lungs, where the pH is relatively high and oxygen loading is favored.

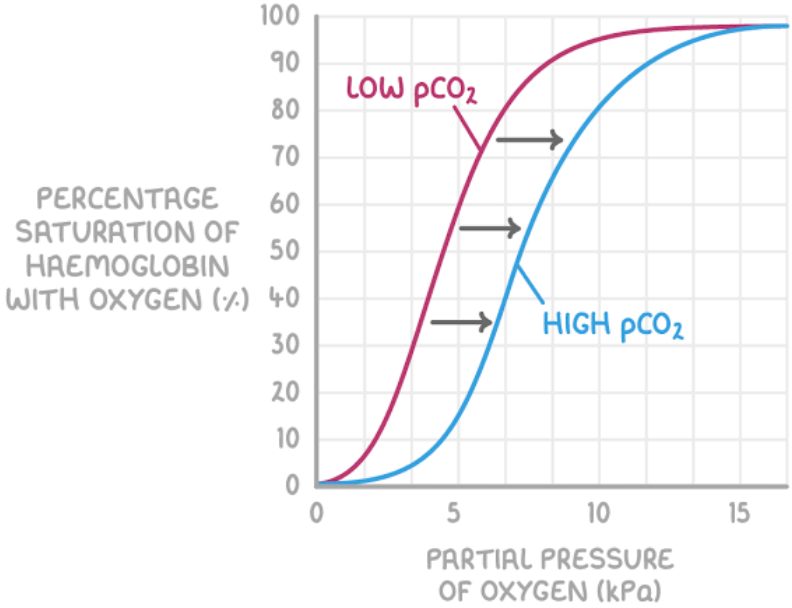
The hydrogen ion concentration (H+) is directly related to pH. A higher H+ concentration (lower pH) favors the deoxyhemoglobin state, which has a lower affinity for oxygen.



- **Carbon dioxide concentration**

Exercise 1

Using the curve above explain the effect of carbondioxide concertation on the Oxygen dissociation curve.



The effect of carbon monoxide on transportation of oxygen.

Nature of carbon monoxide

It is a colorless, odorless, tasteless gas which makes it difficult to detect and it is a product of incomplete combustion of fuels.

Exercise 2

Look out for any five sources of carbon monoxide in our environment and list them down.

Effect of carbon-monoxide

Hemoglobin has much more about 250 times more affinity for carbon monoxide than for oxygen. In the presence of carbon monoxide, it readily combines to form a stable compound called **carboxyhemoglobin**. The oxygen combining power decreases and as a result tissues suffer from oxygen starvation. It leads to cellular hypoxia (oxygen deprivation) and in extreme cases to death. The person needs to be administered with pure oxygen-carbon dioxide mixture to have a very high PO_2 level to dissociate carbon monoxide from hemoglobin.

Vulnerable Groups

- Infants
- pregnant women,
- individuals with heart or respiratory conditions
- elderly

Exercise 3

As a biology student what are some of the signs and symptoms of carbon monoxide poisoning and suggest ways how we could address the problems it causes to the environment.

The responses of athletes versus non-athletes, and low land dwellers versus high land dwellers, to exercise.

ATHLETES VS NON -ATHLETES

Athletes typically exhibit enhanced physiological and psychological responses to exercise compared to non-athletes.

athletes	Non –athletes
Have greater cardiovascular fitness, Higher stroke volume, lower resting heart rate, increased cardiac output, greater blood volume, and enhanced oxygen extraction by muscles. **These adaptations allow for more efficient oxygen delivery and utilization during exercise.** Increased muscle mass and strength, and improved respiratory capacity allows them to perform at higher intensity and volume of exercise.	Higher resting heart rate, lower stroke volume, lower cardiac output. During exercise, they experience a more rapid increase in heart rate and blood pressure compared to athletes.

Increased lung capacity, stronger respiratory muscles, and improved efficiency of gas exchange. They can sustain higher ventilation rates for longer periods.	Lower lung capacity and less efficient respiratory mechanics. They may experience shortness of breath at lower exercise intensities.
Greater capacity to utilize fat as a fuel source, enhanced glycogen storage in muscles, and improved insulin sensitivity. They can generate more ATP (energy) through aerobic pathways.	Greater reliance on carbohydrate metabolism, lower glycogen stores, and potentially lower insulin sensitivity. They tend to fatigue faster due to lactate accumulation
Increased muscle mass (hypertrophy), greater muscle fiber recruitment, and enhanced strength and power. Their muscles are more resistant to fatigue.	Lower muscle mass and strength. Muscles fatigue more easily.

HIGHLAND SWELLERS VS LOW LAND DWELLERS

Highland dwellers experience physiological adaptations to exercise due to lower oxygen levels, while lowland dwellers may experience initial challenges adapting to high altitudes, but with acclimatization, their bodies can adjust. While total oxygen content may be higher, the partial pressure of oxygen in arterial blood is lower due to the lower atmospheric pressure.

- Living at high altitude stimulates the production of erythropoietin (EPO), leading to increased red blood cell mass and hemoglobin concentration. This enhances oxygen carrying capacity in the blood.
- Cardiac output might be higher at rest and during submaximal exercise in some high-altitude natives compared to lowland natives at altitude. However, maximal cardiac output may be lower.
- Highland dwellers, through long-term exposure to hypoxia (low oxygen), develop adaptations like increased red blood cell production, enhanced lung capacity, and improved blood vessel dilation in the brain and heart. Some long-term high-altitude dwellers exhibit a blunted (Blunted Hypoxic Ventilatory Response) which is a complex adaptation that may help reduce the work of breathing.
- Lowland dwellers initially experience a decline in exercise capacity and efficiency due to hypoxia, leading to fatigue, shortness of breath, and dizziness. Some studies suggest increased pulmonary artery pressure and remodeling of pulmonary vessels in long-term high-altitude residents.

- With acclimatization, lowland dwellers can improve their tolerance to exercise at high altitude through adjustments in respiratory and cardiovascular systems, including increased ventilation and reduced heart rate.
- Highland dwellers may have lower blood pressure compared to lowland dwellers due to decreased blood volume and increased blood vessel dilation.
- Highland dwellers may exhibit blunted cardiovascular responses to exercise compared to lowland dwellers, including reduced heart rate and lower blood pressure. Higher capillary density in muscles can improve oxygen delivery.

Important Considerations for the above observed changes

- ✓ It's crucial to consider the training status of both lowland and highland dwellers. Well-trained lowland athletes may have adaptations that partially offset the advantages of altitude acclimatization in highland natives.
- ✓ There is evidence that genetic differences contribute to the superior exercise performance of some high-altitude populations.
- ✓ Lowland dwellers can acclimatize to altitude over time, which can lead to some of the physiological adaptations seen in native highlanders, but typically not to the same extent.
- ✓ There is significant individual variability in response to exercise and altitude, regardless of athletic status or place of residence.

Exercise 4

Some athletes prepare for competition at sea level by sleeping in a tent in which PO_2 is kept low. When climbing high peaks, some mountaineers breathe from bottles of pure O_2. In a short essay (100–150 words), relate these behaviors to the mechanism of O_2 transport in the human body and to physiological interactions with our gaseous environment

The role of the human heart in blood circulation

The timely delivery of O_2 to the body's organs is critical. Some brain cells, for example, die if their O_2 supply is interrupted for even a few minutes.

How does the mammalian cardiovascular system meet the body's continuous (although variable) demand for O_2?

Let's first examine the overall organization of the mammalian cardiovascular system, beginning with the **pulmonary circuit**. Contraction of the right ventricle pumps blood to the lungs via flows through the pulmonary arteries. As the blood capillary beds in the left and right lungs, it loads O_2 and unloads CO_2. Oxygen-rich blood returns from the lungs via the pulmonary veins to the left atrium of the heart. Next, the oxygen-rich blood flows into the heart's left ventricle, which pumps the oxygen-rich blood out to body tissues through the **systemic circuit**. Blood leaves the **left ventricle** via the **aorta**, which conveys blood to arteries leading throughout the body. The first branches leading from the aorta are **the coronary arteries** which supply blood to the heart muscle itself. Branches further along the aorta lead to capillary beds in the head and arms (fore limbs). The aorta then descends into the abdomen, supplying oxygen-rich blood to arteries leading to capillary beds in the abdominal organs and legs (hind limbs). Within the capillary beds, there is a net diffusion of O_2 from the blood to the tissues and of CO_2 (produced by cellular respiration) into the blood. Capillaries rejoin, forming **venules**, which convey blood to veins. Oxygen-poor blood from the head, neck, and forelimbs is channeled into a large vein, cava. Another large vein, the **superior vena cava** the inferior vena cava, drains blood from the trunk and hind limbs. The two venae cava empty their blood into the right atrium, from which the oxygen-poor blood flows into the right ventricle.

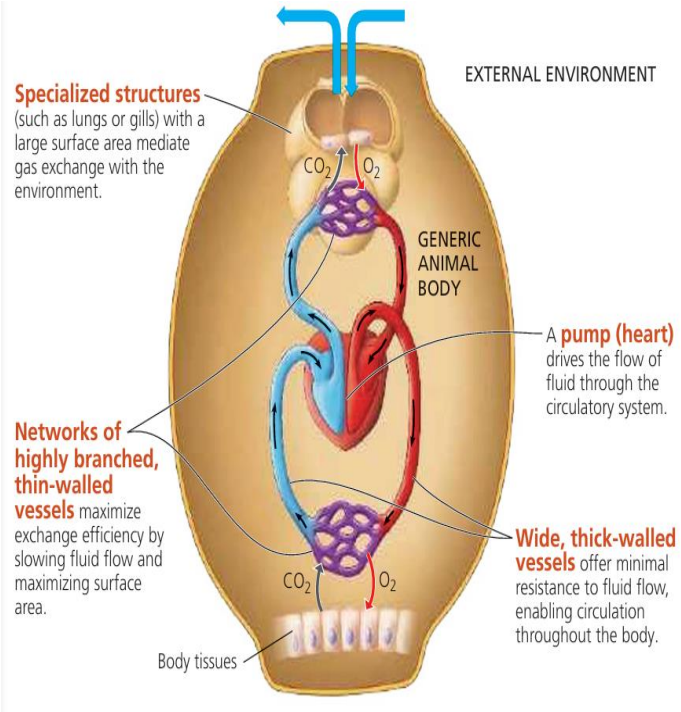
Note: That the dual circuits operate simultaneously, not in the serial fashion that the numbering in the diagram suggests. The two ventricles contract almost in unison and pump the same volume of blood. However, the total volume of blood in the systemic circuit is much greater than that in the pulmonary circuit.

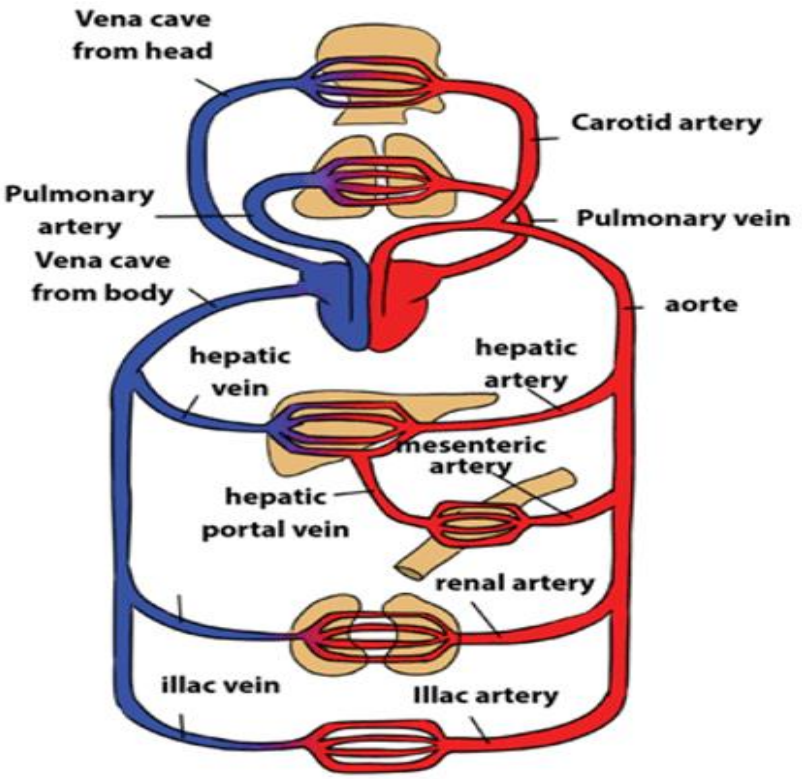
CARDIAC CYCLE

Rhythmic contraction and relaxation of the cardiac chambers i.e. the auricles and the ventricles in a specific manner during one heart beat constitutes a cardiac cycle.

Heart beats continuously without pause in life. Auricles and ventricles show rhythmic contractions and relaxations. On average heart beats 72 times per minute.

Heart pumps about 5 liters of blood per minute. Both auricles contract simultaneously and the blood flows into the ventricles and both ventricles contract together forcing the blood into pulmonary artery and aorta.





INTERNAL STRUCTURE OF THE MAMMALIAN HEART

Located behind the sternum (breastbone), the human heart is about the size of a clenched fist and consists mostly of cardiac muscle. The two **atria** have relatively thin walls and serve as collection chambers for blood returning to the heart from the lungs or other body tissues. Much of the blood that enters the atria flows into the ventricles while all four heart chambers are relaxed. The remainder is transferred by contraction of the atria before the ventricles begin to contract. Compared with the atria, the ventricles have thicker walls and contract much more forcefully— especially the left ventricle, which pumps blood throughout the body via the systemic circuit. Although the left ventricle contracts with greater force than the right ventricle, it pumps the same volume of blood as the right ventricle during each contraction. The heart contracts and relaxes in a rhythmic cycle. When it contracts, it pumps blood; when it relaxes, its chambers fill with blood. One complete sequence of pumping and filling is referred to as the **cardiac cycle**. The contraction phase of the cycle is called **systole**, and the relaxation phase is called **diastole.**

The volume of blood each ventricle pumps per minute is the **cardiac output**. Two factors determine cardiac output: **the rate of contraction**, or **heart rate** *(number of beats per minute),* and the **stroke volume**, *the amount of blood pumped by a ventricle in a single contraction*.

During heavy exercise, the increased demand for O2 is met by an increase in cardiac output that can be as much as fivefold.

Four valves in the heart prevent **backflow** and keep blood moving in the correct direction. Made of flaps of connective tissue, the valves open when pushed from one side and close when pushed from the other. An **atrioventricular (AV) valve** lies between each atrium and ventricle. The AV valves are anchored by strong fibers that prevent them from turning inside out during ventricular systole. Pressure generated by the powerful contraction of the ventricles closes the AV valves, keeping blood from flowing back into the atria.

Semilunar valves are located at the two exits of the heart: where the pulmonary artery leaves the right ventricle and where the aorta leaves the left ventricle. These valves are pushed open by the pressure generated during contraction of the ventricles. When the ventricles relax, blood pressure built up in the pulmonary artery and aorta closes the semilunar valves and **prevents significant backflow**.

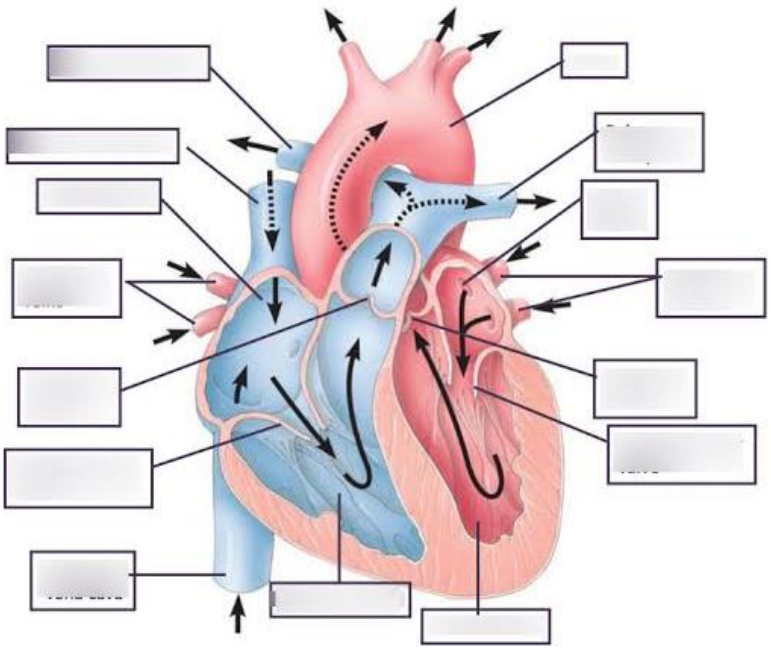
You can follow the closing of the two sets of heart valves either with a **stethoscope** or by pressing your ear tightly against the chest of a friend (or a friendly dog).

The sound pattern is “lub-dub, lub-dub, lub-dub.” The first heart sound **(“lub”)** is created by the recoil of blood against the closed AV valves. The second sound **(“dub”)** is due to the vibrations caused by closing of the semilunar valves. the blood squirts backward through a defective valve, it may produce an abnormal sound called a **heart murmur**. Some people are born with heart murmurs.

In others, the valves may be damaged as a result of infection (for instance, from **rheumatic fever**, an inflammation caused by infection with certain bacteria).

When a valve defect is severe enough to endanger health, surgeons may implant a mechanical replacement valve. However, not all heart murmurs are caused by a defect, and most valve defects do not reduce the efficiency of blood flow enough to warrant surgery.

Complete the structure of the heart by labelling the missing parts



Exercise 5

Some babies are born with a small hole in the wall between the left and right ventricles. How might this affect the oxygen content of the blood pumped out of the heart into the systemic circuit?

Initiation of the heart beat

The cardiac muscle within the walls of the heart is **myogenic** in nature in a way that the initiation of its contraction is within the muscle itself, but not under the control of the central nervous system (brain and spinal cord). This enables the muscles to contract continuously and rhythmically without fatigue to enable the heart to beat continuously and rhythmically without stopping.

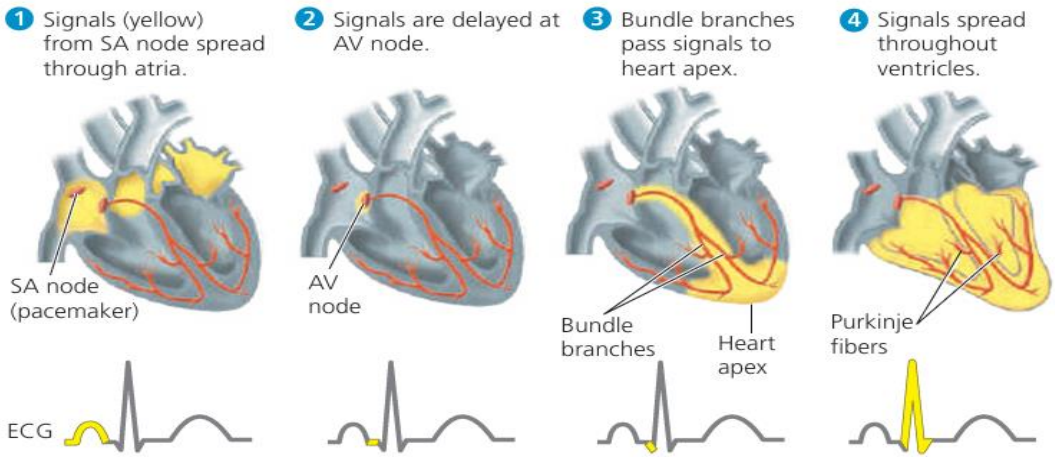
The intrinsic initiation of the heart beat enables the heart to remain beating even it is surgically removed from the body, provided it is under ideal conditions. The rhythmic contraction of the cardiac muscles is initiated by specialized network of fine cardiac muscles network found inside the wall of the right atrium close to the entrance of blood from venacava into the right atrium. This network of fine cardiac muscle fibre is known as **Sino Atrial Node (SAN)** and it serves as a pace maker by giving off a wave of electrical excitations similar to impulses, which spread out very rapidly over both atria causing them to contract and force blood into the ventricles via the open atrial ventricular valves. Because cardiac

muscle cells are electrically coupled through gap junctions, impulses from the SA node spread rapidly within heart tissue.

When the electrical excitations reach the junction at the boundary of the atria, they excite another specialised plexus of other cardiac muscle chambers known as **Atrio Ventricular Node** (AVN). When excited, the AVN sends waves of electrical excitations down to another bundle of cardiac muscle of fibres formed along the inter-ventricular septum called the **Purkinje tissue** or **Bundle of His** to the apex of the heart. This conducts and spreads the excitement to both ventricles which eventually pump blood into the arteries.

Exercise 6

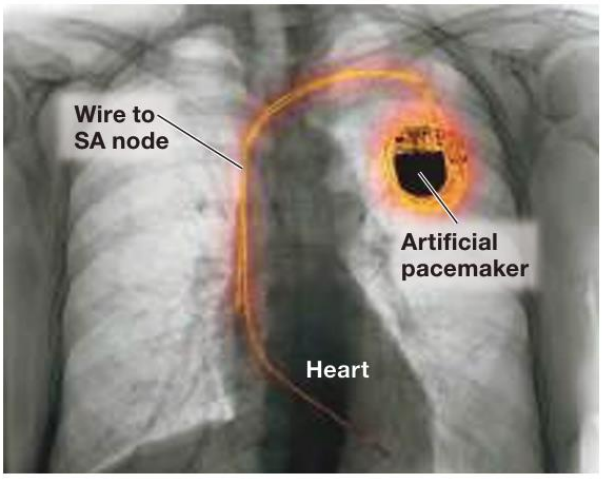
A slight decrease in blood PH causes the SAN to increase the heart rate. How would this control mechanism benefit a person during strenuous exercise?



The electrical impulses in the heart are strong enough to be detected on the skin by electrodes and recorded as an **electrocardiogram (ECG or EKG)**. An ECG can provide data about heart health, such as the existence of **arrhythmias**. These are abnormal heart rhythms, including heart rates that are too slow or too fast and **fibrillation**s (flutterings) of the atria or ventricles.

Fibrillations may occur in a healthy heart when **overstimulation by drugs such as caffeine** cause a group of cells to generate heartbeats outside the SA node.

In certain kinds of heart disease, the heart's self-pacing system fails to maintain a normal heart rhythm. In such cases, doctors can implant in the chest an artificial pacemaker device that emits electrical signals to trigger normal heartbeats.



CONTROL OF HEART BEAT

Physiological cues alter heart tempo by regulating the pacemaker function of the SA node.

NERVOUS SYSTEM

Two portions of the nervous system, the **sympathetic** and **parasympathetic divisions**, are largely responsible for this regulation. They function like the accelerator and brake in a car. For example, when you stand up and start walking, **the sympathetic division speeds up your pacemaker**. The resulting increase in heart rate provides the additional O_2 needed by the muscles that are powering your activity. If you then sit down and relax, **the parasympathetic division slows down your pacemaker**, decreasing your heart rate and thus conserving energy.

HORMONES

Hormones secreted into the blood also influence the pacemaker. For instance, **epinephrine**, the "fight-or-flight" hormone secreted by the adrenal glands, speeds up the pacemaker.

BODY TEMPERATURE

An increase of only 1°C raises the heart rate by about 10 beats per minute. **This is the reason your heart beats faster when you have a fever**.