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MZO-003: Comparative Animal Physiology and Biochemistry
Guess Paper-1

Q1. Describe the difference between open and closed circulatory system.

Ans. Open Circulation: Many invertebrates have an open circulation, that is, a system in which blood pumped by the heart empties via an artery into an open fluid space, the hemocoel, which lies between the ectoderm and endoderm. The fluid contained within the hemocoel, referred to as hemolymph, or blood, is not circulated through capillaries but bathes the tissues directly. The hemocoel is often large and may constitute 20%-40% of body volume. In some crabs, for instance, blood volume is about 30% of body volume. Open circulatory systems have low pressures, with arterial pressures seldom exceeding 0.6- 1.3 kilopascals (kPa),or 4.5-9.7 rnm Hg (1kPa = 7.5 rnrn Hg). Higher pressures have been recorded in portions of the open circulation of the terrestrial snail Helix, but these are exceptional. In snails, these high pressures are generated by contractions of the heart, whereas in some bivalve molluscs high pressures in the foot are generated by contractions of surrounding muscles rather than of the heart.

Animals with an open circulation generally have a limited ability to alter the velocity and distribution of blood flow. As a result, in bivalve molluscs and other animals that have an open circulation and use blood for gas transport, changes in oxygen uptake are usually slow and maximal rates of oxygen transfer low per unit weight. Nonetheless, such animals exert some control over both the flow and distribution of hemolymph; moreover, the blood is distributed throughout the tissues in many small channels in animals with an open circulation. In the absence of such features, even moderate rates of oxygen consumption would be impossible because of the large diffusion distances for oxygen between the hemolymph and the active tissue.

Insects have an open circulation but do not depend on it for oxygen transport and thus can achieve high rates of oxygen transfer. They have evolved a tracheal system in which direct gas transport to tissues occurs through air-filled tubes that bypass the blood, which plays a negligible role in oxygen transport. Consequently, although insects have an open circulation, they have a large capacity for aerobic metabolism.

Closed Circulation: In a closed circulation, blood flows in a continuous circuit of tubes from arteries to veins through capillaries. All vertebrates and some invertebrates, such as cephalopods (octopuses, squids), earthworm, have this type of circulation. In general, there is a more complete separation of functions in closed circulatory systems than in open ones. The blood volume in the closed circulation of vertebrates typically is about 5%- 10% of body volume, much smaller than that of open-circulation invertebrates. The extracellular volume in vertebrates, expressed as a percentage of body volume is similar to the hemocoel volume in invertebrates. The closed circulatory system of vertebrates is a specialized portion of their extracellular space.

In a closed circulation, the heart is the main propulsive organ, pumping blood into the arterial system and maintaining a high blood pressure in the arteries. The arterial system, in turn, acts as a pressure reservoir forcing blood through the capillaries. The capillary walls are thin, thus allowing high rates of transfer of material between blood and tissues by diffusion, transport, or filtration. Each tissue has many capillaries, so that each cell is no more than two or three cells away from a capillary. Capillary networks are in parallel, allowing fine control of blood distribution and, therefore, oxygen delivery to tissues. Animals with a closed circulation can increase oxygen delivery to a tissue very rapidly. For this reason, squid, unlike many other invertebrates, can swim rapidly and maintain high rates of oxygen uptake; that is, their closed circulation permits sufficient flow and efficient distribution of hemolymph to the muscles to support short bursts of high-level activity.

Also, the blood is under sufficiently high pressure in a closed circulation to permit the ultra filtration of blood in the tissues, especially the kidneys. Ultra filtration refers to the separation of an ultra filtrate, devoid of colloidal particles, from plasma by filtration though a semi permeable membrane (capillary wall) using pressure (blood pressure) to force the fluid through the membrane. Ultra filtration occurs in most vertebrate kidneys, resulting in the net movement of a protein-free plasma from the blood into the kidney tubule. In general, all capillary walls are permeable and as pressures are high, so fluid slowly filters across the walls and into the space between cells. A lymphatic system has evolved in conjunction with the high-pressure, closed circulatory system of vertebrates to recover fluid lost to tissues from the blood. The extent of filtration depends largely on the blood pressure and the permeability of the capillary wall. Filtration across capillary walls can be decreased either by a reduction in the permeability of the capillary walls or in the pressure of the blood. For example, the vessels in some tissues have less permeable walls than those found in other tissues. And in the liver and lung, where permeability is high for other reasons, pressures are lower than those in the rest of the body.

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Different pressures can be maintained in the systemic (body) and pulmonary (lung) circulations of mammals because the mammalian circulatory system is equipped with a completely divided heart. The right side of the heart pumps blood in the pulmonary circulation, and the left side pumps blood in the systemic circulation. This means, however, that the flows in the pulmonary and systemic circuits must be equal because blood returning from the lung is pumped around the body. In other vertebrates the heart is not completely divided and flow to the lung can be varied independently of body blood flow.

The venous system collects blood from the capillaries and delivers it to the heart via the veins, which are typically low-pressure, compliant structures in which large changes in volume have little effect on venous pressure. Thus, the venous system contains most of the blood and acts as a large-volume reservoir. Blood donors give blood from this reservoir, and since there is little change in pressure as the venous volume decreases, the volumes and flow in other regions of the circulation are not markedly altered.

Q2. Describe gas transfer mechanisms in air and water.

Ans. Many small organisms obtain oxygen by diffusion through their body surfaces. They do not have any specialized respiratory organs nor do they have blood circulation. Larger and more complex organisms, however, need specialized surfaces for gas exchange and a circulatory system that transports oxygen more readily than that possible by simple diffusion across the body surface.

Calculations based on metabolic demands and rate of diffusion in protoplasm show that simple diffusion is sufficient only to meet the demands of organisms not larger than 1 mm in diameter. These calculations appear reasonable when we see that animals like protists (protozoans) and flatworms that meet their respiratory requirements through diffusion are either quite small or have very low metabolic rates (Fig. 2.1 a). Giant land planarians which are 50 cm long are exceptions as they are flat with very large surfaces in relation to mass, therefore, diffusion is sufficient to meet their oxygen demand. Coelentrates like corals and sponges often reach very large sizes but have very modest metabolic demands. They maintain a circulation of water over the surfaces of cells by means of cilia which line their canal systems. Thus, sufficient gas exchange takes place without the aid of a circulatory system or respiratory pigments.

In animals that have inefficient circulatory system and readily permeable vascular skins, gas exchange occurs through the integument. Thus we find that animals like earthworms, flatworms (planarians) (Fig. 2.1 a), leeches and many larval fishes are among the many animals that obtain the oxygen they need across their general body surface. Even larger animals such as many amphibians and fish may rely on cutaneous respiration during emergencies or use it as a supplement to gills or lungs.

The ability to respire through the integument is most developed in eels, and amphibians that have moist and highly vascularized skins. The integumentary contribution to respiration may be as high as 90 per cent in the giant salamander (Cryptobranchus alleganiensis) and as low as 20 per cent in dryskinned toads. The giant salamander is 25 to 60 cm in length and may weigh over 1 kg. It lacks gills and the unspecialized lungs play little or no part in respiration. This aquatic amphibian is the largest animal relying exclusively on cutaneous breathing (breathing by skin).

Animals that are large and have higher metabolic rates have specialized respiratory organs. These organs have a thin respiratory surface to help in gas exchange.

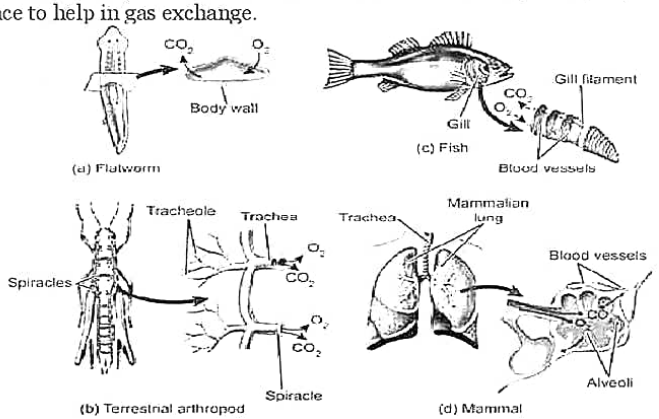

Fig. 2.1: Respiratory System of a) flatworm; b) insect; c) fish; and d) humans.

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Insects have a special respiratory system (Fig.2.1b). Small openings present on the insect's body surface are connected to small tubes or trachea that branch and spread throughout the body. The gases diffuse through these branches directly into the cells.

Generally gills are for aquatic breathing (Fig. 2.1 c) and lungs (Fig. 2.1 d) for breathing air. Gills are highly vascularised extensions of gas exchange membranes. Gill surface area must be large enough to provide adequate exchange of gases. Therefore, highly active fish have the largest relative gill area.

Gas exchange in fishes takes place in the gill lamellae as water flows between them in one direction and blood within them in the other direction. This is known as countercurrent flow. This type of flow permits the blood leaving the fish gills to have the highest possible oxygen levels.

We know that air has more oxygen than water. The atmosphere provides a constant supply of oxygen almost everywhere. The greatest disadvantage however, is that air tends to dry out membranes involved in gas exchange. To overcome this, terrestrial animals have to live in extremely moist environments or find some ways to keep their respiratory surfaces moist. In order to accomplish this, water loss in terrestrial animals has been minimized evolutionarily by turning the respiratory membranes into lungs located inside the body as seen in amphibians, reptiles, birds and mammals, and into trachea as in insects. These structures which are contained within the body are bathed by body fluid both internally and externally and so are kept moist.

Table 2.1 compares oxygen availability in respiration using air and water.

Table 2.1: Major advantages of breathing air.

Properties	Air	Water
Solubility of oxygen at 15°C	Air contains 209 ml of oxygen per litre	7 ml of oxygen per litre
Energy needed to move medium (air or water) over the respiratory surface	Less energy needed to move air over the respiratory surface	More energy needed to move water over the respiratory surface as water is much more viscous than air.
Diffusion of Oxygen	Oxygen diffuses some 10,000 times more rapidly in air than in water and so can diffuse in lungs over several millimeters	Oxygen diffusion is slow from water to the respiratory surface in fish gill as it takes place only in a small area constituting a tiny fraction of a millimeter.

As you must have studied in your graduation course that lungs are of two types i) diffusion lungs which are characterized by air exchange with the surrounding environment by means of only diffusion, are present in small animals such as pulmonate snails, small scorpions, some spiders and some isopods; ii) ventilation lungs which are typical of vertebrates. The air passes through a tube into inflatable lungs where gas exchange takes place and not the oxygen poor air, but carbon dioxide rich air is then forced out usually through the same tube. This is known as tidal flow of air.

You have already studied details of mammalian lungs as they are the best representatives of a respiratory surface adapted for terrestrial respiration. In the next section of this unit you will study about gas exchangers and transport of gases.

Q3. Explain the Neural Regulation of Respiration.

Ans. The rhythmic contractions of the diaphragm and of the intercostal muscles are controlled by respiratory centre which consists of clusters of neurons located in the area of the medulla oblongata and pons of the brain.

There are four respiratory groups that regulate respiration in the body - two in the medulla and two in the pons. The two groups in the pons are known as the pontine respiratory group. The respiratory group are as follows:

- Dorsal respiratory group - in the medulla
- Ventral respiratory group - in the medulla
- Pneumotaxic center - various nuclei of the pons
- Apneustic center - nucleus of the pons

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Chemoreceptors that are located in the respiratory centers are sensitive to increased carbon dioxide levels and increased acidity of the blood and the cerebrospinal fluid and respond by increasing the lung ventilation so that more CO_2 is able to leave the lungs and its levels return to normal. Chemoreceptors that are sensitive to changes in arterial carbon dioxide, oxygen, and pH (resulting from changes in the levels of carbon dioxide) transmit the information of these changes to the centres in the brain by nerve impulses which transmit the information to respiratory centres so that they can respond appropriately by sending impulses to increase or decrease ventilation. Whenever the need for oxygen in the body increases, ventilation of the respiratory organs also increases. The respiratory muscles in particular the diaphragm and intercostal muscles as a result become activated and cause air to move in and out of the lungs.

Central chemoreceptors are located on the medulla oblongata, near the medullary respiratory groups of the respiratory center. They are mainly sensitive to changes in the pH in the blood, (resulting from changes in the levels of carbon dioxide).

The peripheral chemoreceptors are present in the carotid bodies and aortic arch near the heart and are sensitive to changes in arterial carbon dioxide, oxygen, and pH. Chemoreceptors located in the carotid bodies and aortic arches respond to decreased PO_2 levels by increasing the depth and frequency of breathing. The carotid bodies in general are more important in mediating this response and provide the principal mechanism by which mammals sense decreased levels of oxygen. Information from the peripheral chemoreceptors is conveyed along nerves to the respiratory groups of the respiratory center.

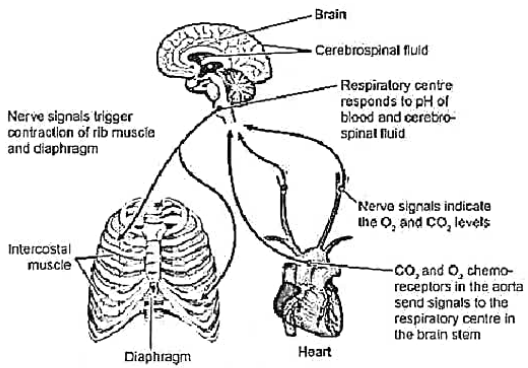

Fig.: Respiratory centre in brain.

Q4. Discuss the Chemical Regulation of Respiration.

Ans. Chemical regulation refers to the effect of blood pH and blood levels of oxygen and carbon dioxide on breathing. This is shown in Fig. 2.8. Chemoreceptors that detect changes in blood gases and pH are located in the carotid and aortic bodies and in the medulla itself.

A decrease in the blood level of oxygen (hypoxia) is detected by the chemoreceptors in the carotid and aortic bodies. The sensory impulses generated by these receptors travel along the glossopharyngeal and vagus nerves to the medulla, which responds by increasing respiratory rate or depth (or both). This response will bring more air into the lungs so that more oxygen can diffuse into the blood to correct the hypoxic state.

Carbon dioxide becomes a problem when it is present in excess in the blood, because excess CO_2 (hypercapnia) lowers the pH when it reacts with water to form carbonic acid (a source of H+ ions). That is, excess CO_2 makes the blood or other body fluids less alkaline (or more acidic). The medulla contains chemoreceptors that are very sensitive to changes in pH, especially decreases. If accumulating CO_2 lowers blood pH, the medulla responds by increasing respiration. This is not for the purpose of inhaling, but rather to exhale more CO_2 to raise the pH back to normal.

Of the two respiratory gases, which is the more important as a regulator of respiration? Our guess might be oxygen, because it is essential for energy production in cell respiration. However, the respiratory system can maintain a normal blood level of oxygen even if breathing decreases to half the normal rate or stops for a few moments. This oxygen did not enter the blood but was available to do so if needed. Also, the residual air in the lungs supplies oxygen to the blood even if breathing rate slows.

Therefore, carbon dioxide must be the major regulator of respiration, and the reason is that carbon dioxide affects the pH of the blood. As was just mentioned, an excess of CO_2 causes the blood pH to decrease, a process

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that must not be allowed to continue. Therefore, any increase in the blood CO_2 level is quickly compensated for by increased breathing to exhale more CO_2. If, for example, you hold your breath, what is it that makes you breathe again? Have you run out of oxygen? Probably not, for the reasons mentioned. What has happened is that accumulating CO_2 has lowered blood pH enough to stimulate the medulla to start the breathing cycle again.

In some situations, oxygen does become the major regulator of respiration. People with severe, chronic pulmonary diseases such as emphysema have decreased exchange of both oxygen and carbon dioxide in the lungs. The decrease in pH caused by accumulating CO_2 is corrected by the kidneys, but the blood oxygen level keeps decreasing. Eventually, the oxygen level may fall so low that it does provide a very strong stimulus to increase the rate and depth of respiration.

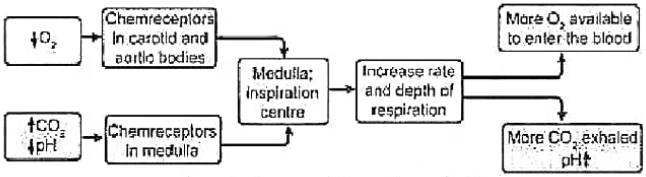

Fig.: Chemical regulation of respiration.

Q5. Explain the Respiration and Acid Base Balance.

Ans. As you have already studied in previous sections that respiration affects the pH of body fluids because it regulates the amount of carbon dioxide in these fluids. Remember that CO_2 reacts with water to form carbonic acid (H_2CO_3), which ionizes into H+ ions and HCO– ions. The more hydrogen ions present in a body fluid, the lower the pH, and the fewer hydrogen ions present, the higher the pH.

The respiratory system may be the cause of a pH imbalance, or it may help correct a pH imbalance created by some other cause.

Respiratory Acidosis and Alkosis

Respiratory acidosis occurs when the rate or efficiency of respiration decreases, permitting carbon dioxide to accumulate in body fluids. The excess CO_2 results in the formation of more H+ ions, which decrease the pH. Holding one's breath can bring about a mild respiratory acidosis, which will soon stimulate the medulla to initiate breathing again. More serious causes of respiratory acidosis are pulmonary diseases such as pneumonia and emphysema, or severe asthma. Each of these impairs gas exchange and allows excess CO_2 to remain in body fluids.

Respiratory alkalosis occurs when the rate of respiration increases, and CO_2 is very rapidly exhaled. Less CO_2 decreases H+ ion formation, which increases the pH. Breathing faster for a few minutes can bring about a mild state of respiratory alkalosis. Babies who cry for extended periods (crying is a noisy exhalation) put themselves in this condition. In general, however, respiratory alkalosis is not a common occurrence. Severe physical trauma and shock, or certain states of mental or emotional anxiety, may be accompanied by hyperventilation and also result in respiratory alkalosis. In addition, traveling to a higher altitude (less oxygen in the atmosphere) may cause a temporary increase in breathing rate before compensation occurs.

Respiratory Compensation: If a pH imbalance is caused by something other than a change in respiration, it is called metabolic acidosis or alkalosis. In either case, the change in pH stimulates a change in respiration that may help restore the pH of body fluids to normal.

Metabolic acidosis may be caused by untreated diabetes mellitus (ketoacidosis), kidney disease, or severe diarrhea. In such situations, the H+ ion concentration of body fluids is increased. Respiratory compensation involves an increase in the rate and depth of respiration to exhale more CO to decrease H+ ion formation, which will raise the pH toward the normal range.

Metabolic alkalosis is not a common occurrence but may be caused by ingestion of excessive amounts of alkaline medications such as those used to relieve gastric disturbances. Another possible cause is vomiting of stomach contents only. In such situations, the H+ ion concentration of body fluids is decreased. Respiratory compensation involves a decrease in respiration to retain CO_2 in the body to increase H+ ion formation, which will lower the pH toward the normal range.

Respiratory compensation for an ongoing metabolic pH imbalance cannot be complete, because there are limits to the amounts of CO_2 that may be exhaled or retained. At most, respiratory compensation is only about 75% effective.

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