Key Terms: Circulatory system, heart, blood vessel, blood, open circulatory system, closed circulatory system, pulmonary artery, pulmonary vein, aorta, atrioventricular valve, semilunar valve, pulmonary circulation, systemic circulation, vasodilation, and vasoconstriction.

As organisms evolved, the method to transport materials into and around the organism also had to evolve.

A single celled organism, such as; an amoeba, is dependent on direct diffusion to move materials into and out of the cell.

For more multicellular organisms, the exchange of materials is more complex process.

Complex multicellular organisms are made up of trillions of specialized cells, which are organized into functional, structural units, such as; tissue, and organs. Each cell requires nutrients, and oxygen and produce metabolic wastes and carbon dioxide. There must be a mechanism to transport these materials to and from the cells. This is done by a specialized system, called the circulatory system.

Circulatory system: the system that transports blood, nutrients, and wastes around the body.
Main Function of the Circulatory System

1. It transports gases (from the respiratory system), nutrients molecules, and waste materials (from the digestive system)
2. It regulates internal temperature and transports chemical substances that are vital to health from one part of the body to another.
3. It protects against blood loss from injury and against disease-causing microbes or toxic substances introduced into the body.

Major Components of the Circulatory System

1. Pump – Heart
2. Blood Vessels – Artery, veins, and capillaries
3. Blood – a fluid that transports materials throughout the body
4. Valves – maintain one way directional flow
5. Exchange Area – where diffusion occurs (capillaries)

Heart: the muscular organ that pumps blood via the circulatory system to the lungs and body.

Blood vessels: a hollow tube that carries blood to and from body tissues.

Blood: the bodily fluid in which blood cells are suspended.
The Two Types of Circulatory Systems

*Open circulatory system*: a circulatory system in which vessels open into the animal’s body cavity.

An open circulatory system allows the blood to flow freely from the vessels into body cavities, where the blood mixes with interstitial fluids and baths various organs. Nutrients and wastes are exchanged by diffusion. This type of system is seen in many invertebrates, such as; grasshopper and crustaceans. The blood and fluids that surround the cells is called *hemolymph*.

*Figure 12.1 (A)* A grasshopper has an open circulatory system. The heart pumps hemolymph through a single tubular vessel into a body cavity. The fluid re-enters the vessel through small pores called *ostia*. The arrows show the movement of hemolymph.
**Closed circulatory system**: is a circulatory system, in which the circulating blood is contained within vessels, and kept separate from the interstitial fluid.

Vertebrates require a closed system to circulate blood, maintaining blood pressure and blood rate to supply the needs of all the cells of the body. The blood never leaves the blood vessels and follows a continuous path keeping the blood separate from the interstitial fluid.

![Closed Circulatory Systems](image)

**Figure 12.1 (B)** The earthworm has a simple closed circulatory system. Five *aortic arches* near the heart act as hearts to pump the blood around the body.

**The Human Circulatory System: The Heart**

Location: slightly to the left of the mid line, and is about the size of your fist.
The heart is made up of Cardiac muscle which is arranged in a network, that allows contact and relax rhythmically and involuntarily.
The heart has valves, this ensures that blood flows in one direction, and chambers so that oxygenated and deoxygenated blood will not mix.
The Structure of the Heart

Mammal and bird heart is a four chambered heart, two chambers on the top and two on the bottom. (Atrium and Ventricles) The heart is also divided into a left and right sides by a muscular wall called a septum.

Figure 12.2: The Human Heart has four chambers. The arrows show the directions in which blood moves into, through, and out of the heart.
The Four Chambers of the Heart

The four chambers of the heart create two separate pathways in which blood flows.

Blood returns from the body and enters the heart through the superior and inferior vena cava. The blood enters the Right Atrium. When the atrium contracts the blood is forced out of the right atrium and into the Right Ventricle, while passing through the atrioventricular valve. The ventricles contract and blood flows from the right ventricle into the pulmonary artery, passing through the Semilunar Valve. The blood travels to the lungs where gases exchange takes place. The blood returns to the heart on the left side, traveling from the lungs to the heart in the pulmonary veins. The blood enters the Left Atrium. When the Atriums contract and the blood enters the Left Ventricle, while passing through the Left Atrioventricular valve. The blood in the ventricle is pump out during a contraction. The blood passed through the Semilunar Valve and into the Aorta, where the blood travels to all part of the body.

**Pulmonary Artery**: large blood vessel that carries blood from the heart to the lungs.

**Pulmonary Vein**: blood vessel that carries blood from the lungs to the heart.

**Aorta**: an artery that carries blood directly from the heart to other arteries.

**Atrioventricular valve**: a valve in the heart between the ventricle and atrium.

**Semilunar valve**: a valve between the ventricle and the large arteries; it carries blood away from the heart.
Figure 12.3: This cross section of the human heart shows the four main valves that help maintain blood pressure and keep the blood blowing in one direction.

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Blood Vessels

There are three types of blood vessels:

a) Arteries (Arterioles) transport blood away from the heart.

b) Veins (Venules) transport blood towards the heart.

c) Capillaries, the area of nutrient and waste exchange.
Figure 12.4: Arteries (A) and veins (B) have three layers. The outer layer is a covering of connective tissue mixed with elastic tissue. The middle layer consists of alternating circular bands of elastic tissue and smooth muscle tissue. The inner layer is only one cell thick and consists of flat smooth cells. The shape and texture of these cells reduce friction as blood moves through the blood vessels. Capillaries (C) consist of a single layer of cells.

Artery: the artery is highly elastic. This allows the arteries to expand as blood passes through under high pressure and return to its original diameter once the blood has passed on. This action forces blood to travel in one direction and maintains pressure on the movement of the blood.

Vein: the vein has thinner walls and is less elastic. The veins can expand their diameter wider than arteries but they do not contract back to their original diameter right away, therefore not creating pressure on the movement of blood. To maintain one way directional flow of blood in these vessels, there are valves which work against gravity.

Capillary: are the smallest vessel in diameter (8μm), it is so small that red blood cells can only pass through one at a time in single file order. There are more capillaries in the body than any other vessel.
Figure 12.6: Pattern of Blood Flow through Vessels.
This diagram shows the pattern of blood flow through vessels in a closed circulatory system.

The Mammalian Circulatory System: A Closer Look

**Pulmonary Circulation**: the path that blood follows from the heart to the lungs and back to the heart.

**Systemic Circulation**: the path that blood follows from the heart to the body and back to the heart.

**Cardiac Circulation**: the movement of blood through the heart tissues.

The Mammalian circulatory system is set up to maximize the delivery of oxygen to support the high energy demands, and the removal of metabolic wastes.

Oxygen rich blood (oxygenated) and oxygen poor blood (deoxygenated) do not have the opportunity to mix. To do this the circulatory system is divided into separate pathways, Pulmonary and Systemic circulation.
The **Pulmonary** circulation starts when the deoxygenated blood leaves the **Right Ventricle** and enters the **Pulmonary Arteries**. The pulmonary arteries deliver blood to the right and left **Lungs**, where gas exchange takes place. The blood leaving the lungs is now **oxygenated** and heads back to the **Heart** passing through the **Pulmonary Veins**. The blood now enters the heart at the **Left Atrium**.

The **Systemic** circulation starts when oxygenated blood leaves the **Left Ventricle**, passing into the **Aorta**. Here blood is transported to all the body cells, where gas exchange takes place. The blood returning to the **Heart** is deoxygenated. The blood passes into the **Right Atrium** via the **Superior** and **Inferior Vena Cava**. At any time 80 to 90 percent of your blood is found in the systemic system.

**Cardiac** circulation is the movement of blood through the heart muscle tissue, via the Coronary Artery.

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**Figure 12.7: The Double Circulatory System**

In a double circulatory system, blood flows from the heart through two different circuits – one passes through the lungs, and the other passes throughout the rest of the body.
**Blood and Its Components**

On average an adult human has about 5 litres of blood passing continuously though the vessels of their body. Blood is also known as *connective tissue* because it links all cells and organs of the body together, yet it is a fluid. Blood can be subdivided into two distinct parts; the fluid portion called *plasma* and the solid portion made up of *blood cells* and *platelets*.

**Plasma and Its Functions**

Plasma is a clear, yellowish fluid. It is composed of 92% water, 7% proteins (albumin, globulins, and fibrinogen), and 1% organic (glucose, fatty acids, and vitamins), and inorganic substances (Na⁺, K⁺, Cl⁻, and HCO₃⁻). The blood also contains dissolved oxygen and carbon dioxide gas. Blood also transports metabolic wastes to the kidneys for disposal.

*Figure 12.8:* The three main components of blood can be separated using a device called a blood centrifuge. When the blood is separated, it briefly settles into layers, as shown here.
Table 12.1: Components of Blood Plasma and Their Functions

<table>
<thead>
<tr>
<th>Component</th>
<th>Major Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Dissolves and transports other substances</td>
</tr>
<tr>
<td>Plasma proteins</td>
<td>Maintain fluid balance in plasma, in cells, and in spaces between cells</td>
</tr>
<tr>
<td></td>
<td>Help maintain slightly alkaline pH</td>
</tr>
<tr>
<td></td>
<td>Fibrinogen helps with blood clotting</td>
</tr>
<tr>
<td></td>
<td>Globulins (antibodies) strengthen immunity</td>
</tr>
<tr>
<td>Salts (ions)</td>
<td>Maintain fluid balance in plasma, in cells, and in spaces between cells</td>
</tr>
<tr>
<td>bicarbonate</td>
<td>Help maintain slightly alkaline pH</td>
</tr>
<tr>
<td>calcium</td>
<td>Assist in nerve and muscle function</td>
</tr>
<tr>
<td>chloride</td>
<td></td>
</tr>
<tr>
<td>magnesium</td>
<td></td>
</tr>
<tr>
<td>potassium</td>
<td></td>
</tr>
<tr>
<td>sodium</td>
<td></td>
</tr>
</tbody>
</table>

Red Blood Cells and Their Functions

Red Blood Cells (erythrocytes) make up 44 % of the total blood volume. Erythrocytes are specialized cells; they do not have a nucleus at maturity, disk-shaped and are responsible for transporting oxygen to the cells. Erythrocytes contain a specialized protein called hemoglobin. Hemoglobin has the ability to increase the carrying capacity of RBC’s to carry oxygen by 70 %. Each cell approximately contains 280 million hemoglobin molecules.

White Blood Cells and Their Functions

White blood cells (leukocytes) are part of your body’s immune system. They respond to infections within your body. Leukocytes make 1 % of the blood volume. This volume may increase when there is an infection present. These cells do have a nucleus, and are colourless.
There are five types of white blood cells, subdivided into two groups:

a) Granulocytes: i) neutrophil ii) eosinophil iii) basophil

b) Agranulocytes: i) lymphocytes ii) monocyte

**Figure 12.10:** Leukocytes move through the interstitial fluid, suspended in the blood plasma. For every white blood cell in normal human blood, there are about 500 to 1000 red blood cells. Neutrophils, eosinophils, and basophils are known as granulocytes due to the grainy appearance of their cytoplasm. Lymphocytes and monocytes because of their smooth cytoplasm.

Some leukocytes can perform phagocytosis, the ability to engulf and kill pathogens. Other leukocytes are responsible for producing antibodies that incapacitate the pathogens so they may be destroyed by macrophages.
Platelets and Their Functions

Platelets (thrombocytes) form a small portion of blood. They do not contain a nucleus, and break down after 7 to 10 days after they form. Platelets are responsible for blood clotting, to prevent blood loss.

The Cellular Components of Blood

Table 12.2: Cellular Components of Blood

<table>
<thead>
<tr>
<th>Point of Comparison</th>
<th>Red blood cells</th>
<th>White blood cells</th>
<th>Platelets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>red bone marrow</td>
<td>Granulocytes</td>
<td>Agranulocytes</td>
</tr>
<tr>
<td>Cells present per mm² of blood (approximate)</td>
<td>5 500 000 (male)</td>
<td>6000</td>
<td>2000</td>
</tr>
<tr>
<td>4 500 000 (female)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative size</td>
<td>small (8 μm diameter)</td>
<td>largest (up to 25 μm)</td>
<td>large (10 μm)</td>
</tr>
<tr>
<td>Function</td>
<td>to carry oxygen and carbon dioxide to and from cells</td>
<td>to engulf foreign particles</td>
<td>to play a role in the formation of antibodies (defence function)</td>
</tr>
<tr>
<td>Life span</td>
<td>120 days</td>
<td>a few hours to a few days</td>
<td>unknown</td>
</tr>
<tr>
<td>Appearance</td>
<td><img src="image" alt="Appearance" /></td>
<td><img src="image" alt="Appearance" /></td>
<td><img src="image" alt="Appearance" /></td>
</tr>
</tbody>
</table>

cell types: eosinophil, basophil, neutrophil, lymphocyte, monocyte

Learning Check:
Questions 7 – 12
The Functions of Blood

Transport:

The blood is responsible for transporting materials from the digestive system and oxygen from the lungs to the body cells. At the same time the blood will transport metabolic wastes to areas of the body for removal. The circulatory system interacts with all the other systems of the body, ensuring they get their nutrients and wastes are removed to maintain homeostasis.

Temperature Regulation:

It is important for the body to maintain a constant temperature. The circulatory system is able to control the heat loss by controlling the volume of blood flow near the surface of the skin. This is under the control of the nervous system. The blood vessels near the surface of the skin can expand or contract, increasing and decreasing blood flow.

Vasodilation: the widening of the blood vessels.

Vasoconstriction: the narrowing of the blood vessels.

When the body becomes hot, vasodilation occurs, more blood flows towards the surface and heat is lost to the surrounding air.

When the body becomes cold, vasoconstriction occurs, less blood reaches the surface, and less heat is lost and more is retained.
Figure 12.12: Thermo Regulation (A) during vasodilation, the blood vessels expand, increasing blood flow near the skin. (B) During vasoconstriction, the blood vessels contract, reducing blood flow nears the skin.

Figure 12.13: Counter-current Heat Exchange In counter-current heat exchange, heat from blood in an artery is conserved by being transferred to a vein that returns blood to the body’s core. Arterial blood is cooled as it moves from the elbow to the hand, and venous blood is warmed as it moves from the hand up the arm. In warmer conditions, more blood flows back to the core through surface veins. The numbers in the figure indicate the temperature of the blood in degrees Celsius.