

## CHAPTER 2. CIRCULATORY SYSTEM

### Introduction

Circulatory systems ensure the transport of gases, nutrients, hormones, and wastes when diffusion alone is insufficient. **Invertebrates** show diverse designs:

- **Open systems** (arthropods, most mollusks) let hemolymph flow in body cavities at low pressure and energy cost.
- **Closed systems** (annelids, cephalopods) keep blood in vessels for higher pressure and efficient delivery.  
Some simple forms still rely mainly on diffusion.

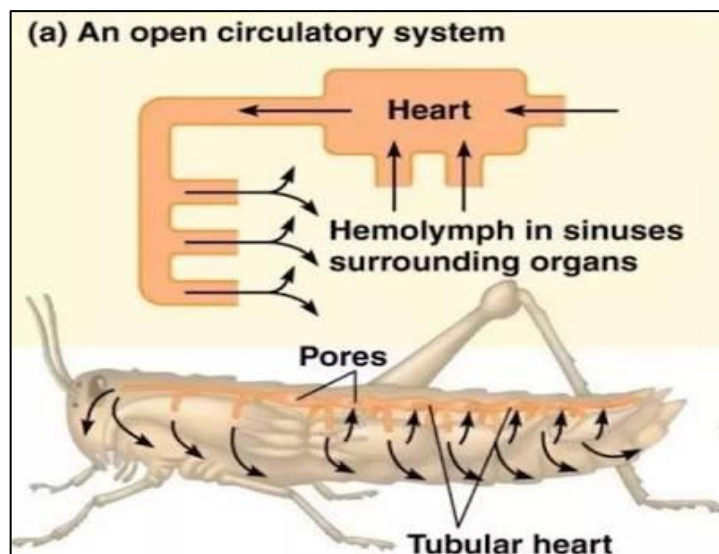
**Vertebrates** always have a **closed system** with a muscular heart. Fish use a **single circuit**, while amphibians and reptiles have a **double circuit** with partial separation. Birds and mammals possess a **four-chambered heart**, ensuring complete separation of oxygen-rich and oxygen-poor blood to support high metabolic demands.

### 1. Types of Circulatory Systems in Invertebrates:

#### A. Open Circulatory System

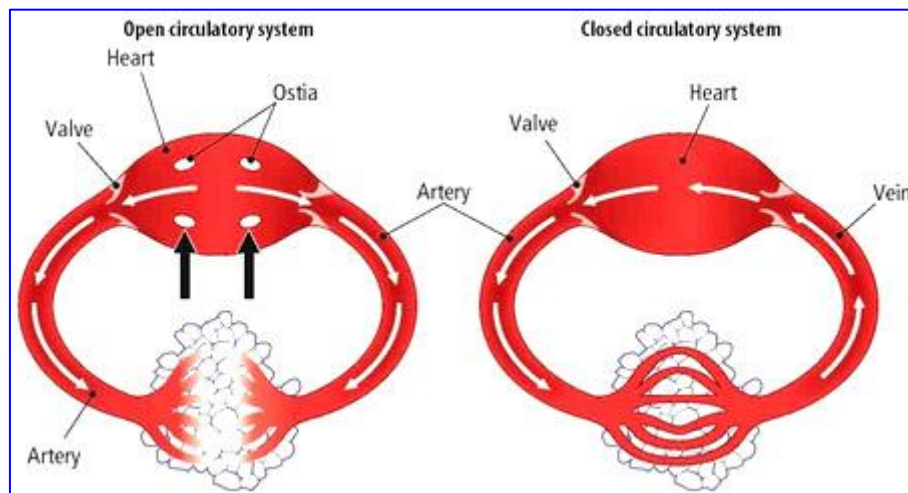
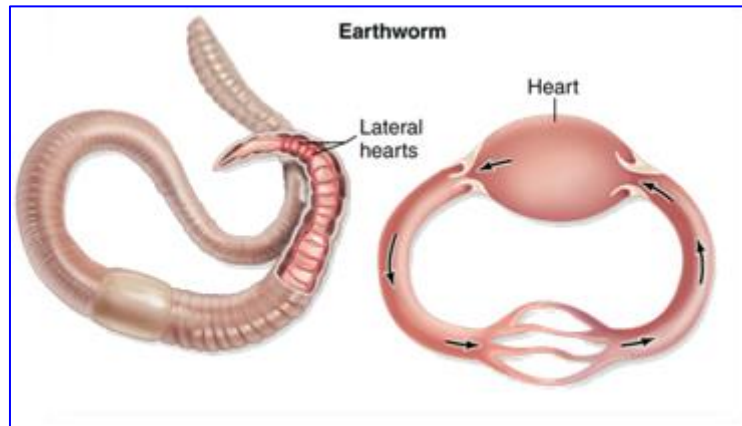
The open circulatory system is the most widespread form among invertebrates, particularly in **insects, bivalve mollusks, and many arthropods**. In this system, the circulatory fluid, known as **hemolymph**, is not confined entirely within blood vessels. Instead, the heart pumps hemolymph into a series of cavities and open spaces, termed **sinuses** or **lacunae**, where it comes into direct contact with the tissues and internal organs. This arrangement allows for the direct exchange of gases, nutrients, and wastes between the hemolymph and the cells.

However, due to the absence of a continuous vascular network, the circulation operates under **low hydrostatic pressure**, which results in **relatively slow and less efficient transport** compared with closed systems. Despite these limitations, the open circulatory system is well adapted for animals with lower metabolic demands and is energetically less costly to maintain.



## B. Closed Circulatory System

In contrast, certain groups of invertebrates, such as **annelids** and **cephalopod mollusks** (e.g., **squids and octopuses**), exhibit a **closed circulatory system**. In this more advanced arrangement, blood is completely enclosed within a continuous network of **arteries, veins, and capillaries**, thereby preventing direct contact with tissues. This system allows the circulatory fluid to be maintained at **higher pressure**, enabling **faster and more efficient transport** of oxygen, nutrients, and metabolites. Such efficiency is particularly advantageous for organisms with **high metabolic rates**, such as cephalopods, which require rapid oxygen delivery to sustain active predation and complex behaviors.



## 2. Hemolymph: Composition and Functions

Hemolymph is the circulatory fluid of invertebrates with an **open circulatory system**, combining the roles of blood and lymph. Unlike vertebrate blood, it generally does **not transport respiratory gases**, except in species with pigments such as **hemocyanin** or rarely **hemoglobin**. It flows through the **hemocoel**, directly bathing tissues.

### A. Composition

- **Plasma (84–92% water, pH ~6.7):** Contains inorganic ions ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ), carbohydrates (mainly trehalose), proteins (lipoproteins, enzymes, immune and clotting factors), lipids, amino acids, organic acids, nitrogenous wastes (e.g., uric acid), and cryoprotectants in cold-adapted insects.
- **Hemocytes (blood cells):** Nucleated cells involved in **immunity, clotting, and tissue repair**. Major types include **plasmatocytes** (phagocytosis), **granular hemocytes** (encapsulation), **oenocytoids** (melanization), **coagulocytes** (clotting), and various storage or structural cells.

## B. Key Functions

1. **Transport & Storage:** Distributes nutrients, hormones, wastes, and water; stores sugars and lipids for energy during growth, molting, reproduction, or stress.
2. **Immune Defense:** Hemocytes perform phagocytosis, encapsulation, melanization, and secrete antimicrobial peptides.
3. **Coagulation & Wound Repair:** Rapid clot formation seals injuries and prevents infection.
4. **Hydraulic Role:** Generates pressure for molting, wing expansion, organ eversion, and body-shape maintenance in soft-bodied forms.
5. **Osmoregulation & pH Buffering:** Regulates ion balance and acid–base equilibrium (pH 6–7.5) via Malpighian tubules and gut transport.
6. **Thermoregulation (limited):** Distributes heat in endothermic insects like honeybees during flight.
7. **Reflex Bleeding (Defense):** Some insects exude toxic or foul-smelling hemolymph to deter predators.
8. **Metabolic Medium:** Supports nutrient conversion (e.g., trehalose  $\rightarrow$  glucose), lipid mobilization, hormone transport, and detoxification.

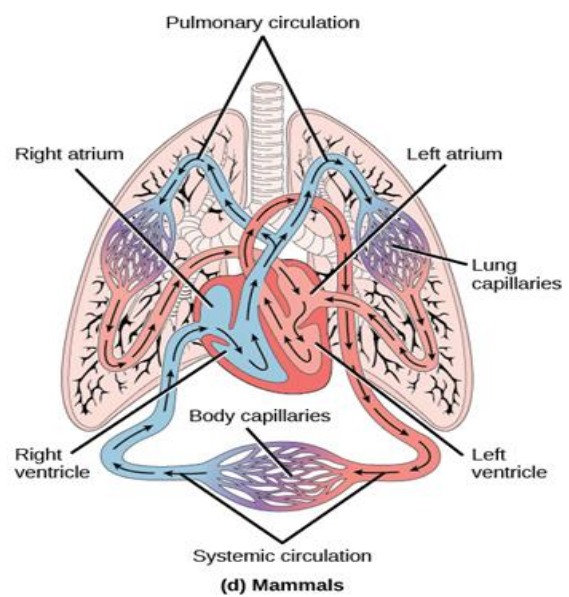
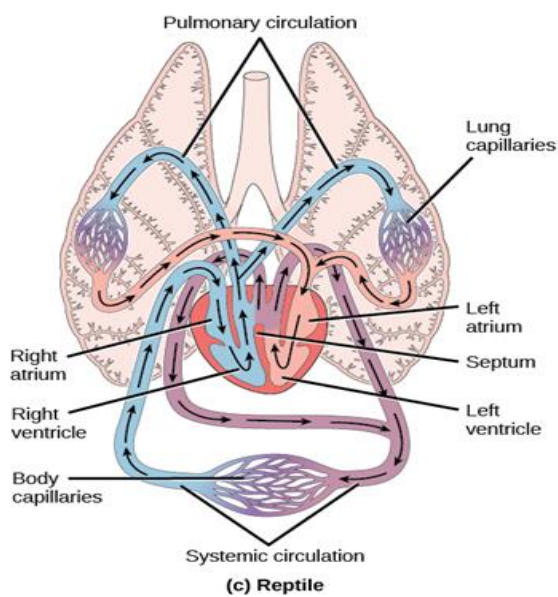
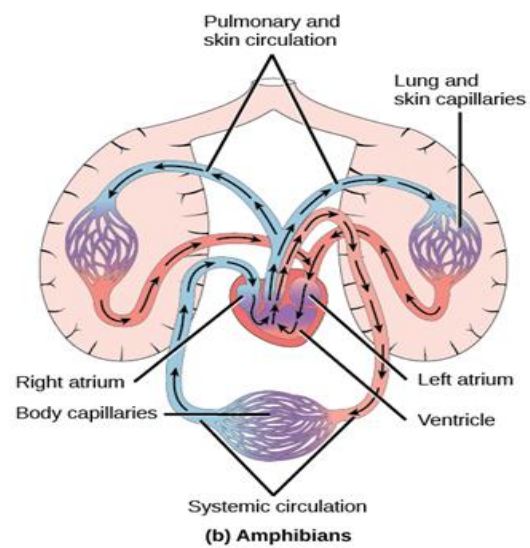
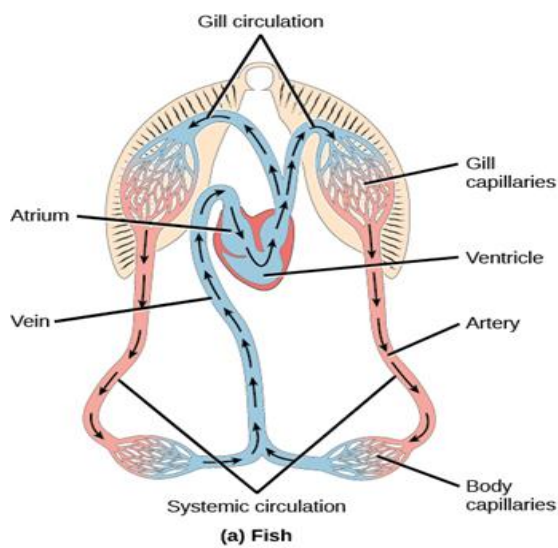
## II. Vertebrate Circulatory System

Vertebrates possess a **closed circulatory system** in which blood is confined to vessels and propelled by a muscular **heart**, allowing **high pressure, rapid flow, and precise regulation** of nutrient and gas exchange. This design supports larger body sizes and high metabolic demands.

### A. Components

- **Heart:** A muscular pump that maintains unidirectional blood flow. Its complexity increases along evolution:
  - **Fish:** 2-chambered heart (1 atrium, 1 ventricle) with a **single circuit** (heart  $\rightarrow$  gills  $\rightarrow$  body).
  - **Amphibians & Most Reptiles:** 3 chambers (2 atria, 1 ventricle) and a **double circuit** (pulmonary + systemic) with partial mixing of blood.

- **Birds & Mammals:** 4 chambers (2 atria, 2 ventricles) ensuring **complete separation** of oxygenated and deoxygenated blood, enabling high metabolic rates and endothermy.
- **Blood Vessels:**
  - **Arteries** carry blood away from the heart under high pressure.
  - **Veins** return blood at lower pressure.
  - **Capillaries** provide exchange of gases, nutrients, and wastes with tissues.
- **Blood:** Contains **plasma** (water, ions, proteins, nutrients, hormones) and **cells** (red blood cells for oxygen transport via hemoglobin, white blood cells for immunity, and platelets for clotting).

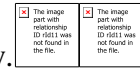


## B. Circulatory Patterns

1. **Single Circulation (Fish):** Blood passes through the heart once per cycle.
2. **Double Circulation (Tetrapods):** Blood passes through the heart twice, separating **pulmonary circulation** (heart–lungs) from **systemic circulation** (heart–body).
3. **Special Adaptations:** Some vertebrates (e.g., diving mammals, ectotherms) exhibit **shunts** or **variable flow** to optimize oxygen use during activity or apnea.

### C. Functions

- **Gas Exchange:** Efficient delivery of oxygen to tissues and removal of carbon dioxide.
- **Transport:** Distribution of nutrients, hormones, and metabolic wastes.
- **Homeostasis:** Regulation of pH, temperature, and osmotic balance.
- **Defense & Repair:** Immune cell circulation and rapid clotting after injury.



### Summary:

The circulatory system ensures the transport of gases, nutrients, hormones, and wastes throughout the body. In invertebrates, it may be **open**, where hemolymph flows freely and contacts tissues directly, or **closed**, where blood circulates within vessels for more efficient transport. Vertebrates always have a **closed system** powered by a **muscular heart**, which evolved from two chambers in fish to four in birds and mammals. Overall, circulatory systems maintain efficient **exchange, regulation, and homeostasis**, supporting the survival and activity of all animals.