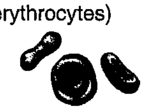
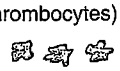
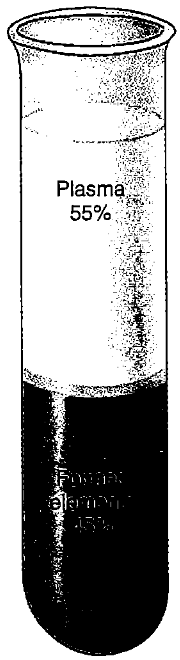
13.4 Blood

Blood is the only liquid tissue in the body. If blood is transferred from a person's vein to a test tube and is prevented from clotting, it separates into two layers (Fig. 13.10). The lower layer consists of the **formed elements** and the upper layer is **plasma.** The formed elements consist of red blood cells (erythrocytes), white blood cells (leukocytes), and

FORMED ELEMENTS	Function and Description	Source
Red Blood Cells (erythrocytes)  4 million–6 million per mm^3 blood	Transport O_2 and help transport CO_2 7–8 μm in diameter Bright-red to dark-purple biconcave disks without nuclei	Red bone marrow
White Blood Cells (leukocytes) 4,000–11,000 per mm^3 blood	Fight infection	Red bone marrow
Granular leukocytes		
• Basophils  20–50 per mm^3 blood	10–12 μm in diameter Spherical cells with lobed nuclei; large, irregularly shaped, deep-blue granules in cytoplasm; release histamine which promotes blood flow to injured tissues	
• Eosinophils  100–400 per mm^3 blood	10–14 μm in diameter Spherical cells with bilobed nuclei; coarse, deep-red, uniformly sized granules in cytoplasm; phagocytize antigen-antibody complexes and allergens	
• Neutrophils  3,000–7,000 per mm^3 blood	10–14 μm in diameter Spherical cells with multilobed nuclei; fine, pink granules in cytoplasm; phagocytize pathogens	
Agranular leukocytes		
• Lymphocytes  1,500–3,000 per mm^3 blood	5–17 μm in diameter (average 9–10 μm) Spherical cells with large round nuclei; responsible for specific immunity	
• Monocytes  100–700 per mm^3 blood	10–24 μm in diameter Large spherical cells with kidney-shaped, round, or lobed nuclei; become macrophages which phagocytize pathogens and cellular debris	
• **Platelets** (thrombocytes)  150,000–300,000 per mm^3 blood	Aid clotting 2–4 μm in diameter Disk-shaped cell fragments with no nuclei; purple granules in cytoplasm	Red bone marrow



PLASMA	Function	Source
Water (90–92% of plasma)	Maintains blood volume; transports molecules	Absorbed from intestine
Plasma proteins (7–8% of plasma)	Maintain blood osmotic pressure and pH	Liver
Albumin	Maintain blood volume and pressure	
Globulins	Transport; fight infection	
Fibrinogen	Clotting	
Salts (less than 1% of plasma)	Maintain blood osmotic pressure and pH; aid metabolism	Absorbed from intestine
Gases		
Oxygen	Cellular respiration	Lungs
Carbon dioxide	End product of metabolism	Tissues
Nutrients	Food for cells	Absorbed from intestine
Lipids Glucose Amino acids		
Nitrogenous wastes	Excretion by kidneys	Liver
Urea Uric acid		
Other		
Hormones, vitamins, etc.	Aid metabolism	Varied

• with Wright's stain

Figure 13.10 Composition of blood.
When blood is transferred to a test tube and prevented from clotting, it forms two layers. The transparent, yellow top layer is plasma, the liquid portion of blood. The formed elements are in the bottom layer. This table describes these components in detail.

blood platelets (thrombocytes). Formed elements make up about 45% of the total volume of whole blood. Plasma, which accounts for about 55% of the total volume of whole blood, contains a variety of inorganic and organic substances dissolved or suspended in water.

Plasma proteins, which make up 7–8% of plasma, assist in transporting large organic molecules in blood. For example, **albumin** transports bilirubin, a breakdown product of hemoglobin. The lipoproteins that transport cholesterol contain a type of protein called globulins. Plasma proteins also maintain blood volume because their size prevents them from readily passing through a capillary wall. Therefore, capillaries are always areas of lower water concentration compared to tissue fluid, and water automatically diffuses into capillaries. Certain plasma proteins have specific functions. As discussed later in the chapter, fibrinogen is necessary to blood clotting, and immunoglobulins are antibodies, which help fight infection.

We shall see that blood has transport functions, regulatory functions, and protective functions. Blood transports oxygen and nutrients to the capillaries and takes carbon dioxide and wastes away from the capillaries. It also transports hormones. Blood helps regulate body temperature by dispersing body heat and blood pressure because the plasma proteins contribute to the osmotic pressure of blood. It also helps regulate pH by means of the buffers it contains. It helps guard the body against invasion by **pathogens** (e.g., disease-causing viruses and bacteria), and it clots, preventing a potentially life-threatening loss of blood.

The Red Blood Cells

Red blood cells are continuously manufactured in the red bone marrow of the skull, the ribs, the vertebrae, and the ends of the long bones. Normally, there are 4 to 6 million red blood cells per mm^3 of whole blood.

Red blood cells are biconcave disks (Fig. 13.11). Their shape increases their flexibility for moving through capillary beds and their surface area for the diffusion of gases. Red blood cells carry oxygen because they contain **hemoglobin,** the respiratory pigment. Since hemoglobin is a red pigment, the cells are red. A hemoglobin molecule contains four polypeptide chains that make up the protein globin. Each chain is associated with heme, a complex iron-containing group. The iron portion of hemoglobin acquires oxygen in the lungs and gives it up in the tissues. Plasma carries only about 0.3 ml of oxygen per 100 ml of blood, but whole blood carries 20 ml of oxygen per 100 ml of blood. This shows that hemoglobin increases the oxygen-carrying capacity of blood more than 60 times.

Carbon monoxide is an air pollutant that comes primarily from the incomplete combustion of natural gas and gasoline. Unfortunately, carbon monoxide combines with hemoglobin more readily than does oxygen, and it stays combined for several hours, making hemoglobin unavailable for oxygen transport. Some homes are equipped with carbon monoxide detectors because you can neither smell nor see this deadly gas.

Possibly because they lack nuclei, red blood cells live only about 120 days. They are destroyed chiefly in the

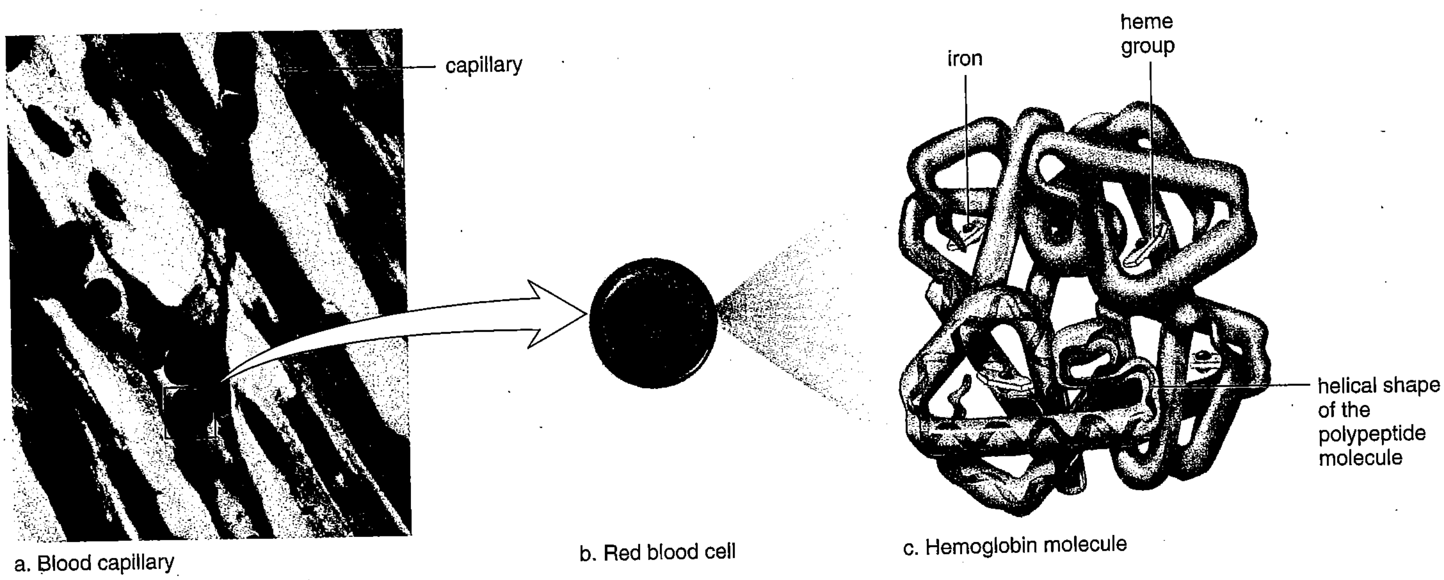


Figure 13.11 Physiology of red blood cells.
a. Red blood cells move in single file through the capillaries. **b.** Each red blood cell is a biconcave disk containing many molecules of hemoglobin, the respiratory pigment. **c.** Hemoglobin contains four polypeptide chains (blue). There is an iron-containing heme group in the center of each chain. Oxygen combines loosely with iron when hemoglobin is oxygenated. Oxyhemoglobin is bright red, and deoxyhemoglobin is a dark maroon color.

liver and the spleen, where they are engulfed by large phagocytic cells. When red blood cells are broken down, the hemoglobin is released. The iron is recovered and returned to the bone marrow for reuse. The heme portion of hemoglobin undergoes chemical degradation and is excreted as bile pigments by the liver into the bile.

When the body has an insufficient number of red blood cells or the red blood cells do not contain enough hemoglobin, the individual suffers from **anemia** and has a tired, rundown feeling. In iron-deficiency anemia, the most common type, the hemoglobin level is low, probably due to a diet that does not contain enough iron. Usually, the number of red blood cells increases whenever arterial blood carries a reduced amount of oxygen, as happens when an individual first takes up residence at a high altitude. Under these circumstances, the kidneys increase their production of a hormone called **erythropoietin,** which speeds the maturation of red blood cells in the bone marrow.

The White Blood Cells

White blood cells (leukocytes) differ from red blood cells in that they are usually larger, have a nucleus, lack hemoglobin, and without staining appear translucent. White blood cells are not as numerous as red blood cells, with only 5,000–11,000 cells per mm^3. White blood cells fight infection and play a role in the development of immunity, the ability to resist disease.

On the basis of structure, it is possible to divide white blood cells into **granular leukocytes** and **agranular leukocytes.** Granular leukocytes are filled with spheres that contain various enzymes and proteins, which help white blood cells defend the body against microbes. **Neutrophils** are granular leukocytes with a multilobed nucleus joined by nuclear threads. They are the most abundant of the white blood cells and are able to phagocytize and digest bacteria. The agranular leukocytes (monocytes and lymphocytes) typically have a spherical or kidney-shaped nucleus. **Monocytes** are the largest of the white blood cells, and after they take up residence in the tissues, they differentiate into the even larger **macrophages** (Fig. 13.12). Macrophages phagocytize microbes and stimulate other white blood cells to defend the body. The **lymphocytes** are of two types, B lymphocytes and T lymphocytes, and each type plays a specific role in immunity.

If the total number of white blood cells increases beyond normal, disease may be present. Sometimes an increase or decrease of only one type of white blood cell, as detected with a differential white blood cell count, is a sign of infection. A person with **infectious mononucleosis,** caused by the Epstein-Barr virus, has an excessive number of lymphocytes of the B type. A person with AIDS, caused by an HIV infection, has an abnormally low number of lymphocytes of the T type. **Leukemia** is a form of cancer characterized by uncontrolled production of abnormal white blood cells.

White blood cells live different lengths of time. Many live only a few days and are believed to die combating invading pathogens. Others live months or even years.

Red blood cells, which are more numerous and smaller than white blood cells, contain hemoglobin and carry oxygen. White blood cells, which are translucent when not stained, all fight infection but are varied as to their specific characteristics and functions.

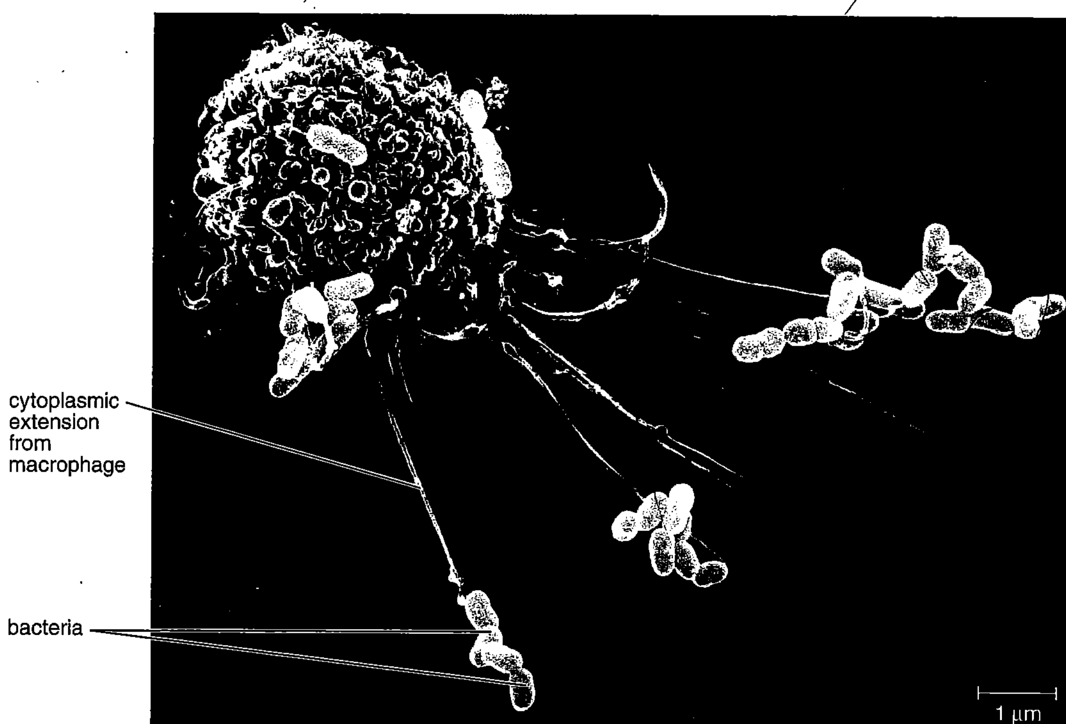


Figure 13.12 Macrophage (red) engulfing bacteria (green). Monocyte-derived macrophages are the body's scavengers. They engulf microbes and debris in the body's fluids and tissues, as illustrated in this colorized scanning electron micrograph.

The Platelets and Blood Clotting

Platelets (thrombocytes) result from fragmentation of certain large cells, called **megakaryocytes,** in the red bone marrow. Platelets are produced at a rate of 200 billion a day, and the blood contains 150,000–300,000 per mm^3. These formed elements are involved in the process of blood **clotting,** or coagulation.

There are at least 12 clotting factors in the blood that participate with platelets in the formation of a blood clot. We will discuss the roles played by **fibrinogen** and **prothrombin,** which are proteins manufactured and deposited in blood by the liver. Vitamin K, found in green vegetables and also formed by intestinal bacteria, is necessary for the production of prothrombin, and if by chance this vitamin is missing from the diet, hemorrhagic disorders develop.

Blood Clotting

When a blood vessel in the body is damaged, platelets clump at the site of the puncture and partially seal the leak. They and the injured tissues release a clotting factor called **prothrombin activator,** which converts prothrombin to thrombin. This reaction requires calcium ions (Ca^{2+}). **Thrombin,** in turn, acts as an enzyme that severs two short amino acid chains from each fibrinogen molecule. These activated fragments then join end to end, forming long threads of **fibrin.** Fibrin threads wind around the platelet plug in the damaged area of the blood vessel and provide the framework for the clot. Red blood cells also are trapped within the fibrin threads; these cells make a clot appear red (Fig. 13.13). A fibrin clot is present only temporarily. As soon as blood vessel repair is initiated, an enzyme called plasmin destroys the fibrin network and restores the fluidity of the plasma.

Table 13.1 Body Fluids Related to Blood

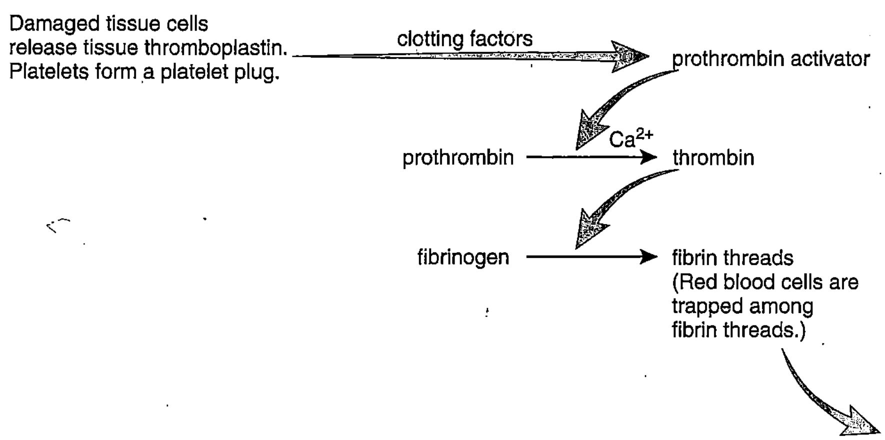
Name	Composition
Blood	Formed elements and plasma
Plasma	Liquid portion of blood
Serum	Plasma minus fibrinogen
Tissue fluid	Plasma minus most proteins
Lymph	Tissue fluid within lymphatic vessels

If blood is allowed to clot in a test tube, a yellowish fluid develops above the clotted material. This fluid is called **serum,** and it contains all the components of plasma except fibrinogen. Table 13.1 reviews the terms used to refer to body fluids related to blood.

Hemophilia

Hemophilia is an inherited clotting disorder caused by a deficiency in a clotting factor. The slightest bump to an affected person can cause bleeding into the joints. Cartilage degeneration in the joints and resorption of underlying bone can follow. Bleeding into muscles can lead to nerve damage and muscular atrophy. The most frequent cause of death is bleeding into the brain with accompanying neurological damage.

Platelets are cell fragments involved in blood clotting, an involved process that is necessary to keep the body in tact following an injury to a blood vessel.



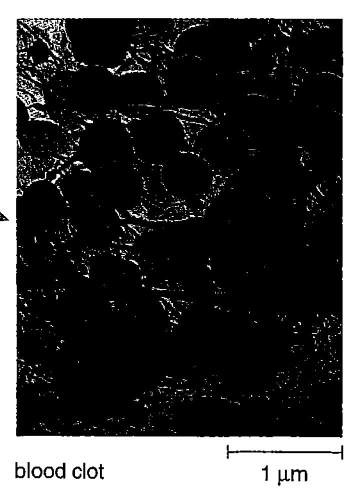


Figure 13.13 Blood clotting.
Platelets and damaged tissue cells release prothrombin activator, which acts on prothrombin in the presence of calcium ions (Ca^{2+}) to produce thrombin. Thrombin acts on fibrinogen in the presence of Ca^{2+} to form fibrin threads. The scanning electron micrograph of a blood clot shows red blood cells caught in the fibrin threads.

Bone Marrow Stem Cells

A **stem cell** is a cell that is ever capable of dividing and producing new cells that go on to differentiate into particular types of cells. It's been known for some time that the bone marrow has multipotent stem cells that give rise to other stem cells for the various formed elements (Fig. 13.14). Other tissues of the body also have stem cells. We have already mentioned the ability of the skin to rejuvenate itself. Only recently has it been discovered that several other organs, even the brain, have stem cells. Of particular interest are the so-called mesenchymal stem cells that can give rise to most any type of connective tissue, including cardiac muscle. The hope is that one day these stem cells could be used to repair the heart after a heart attack.

Many scientists want to test the use of embryonic cells to regenerate the various tissues of the adult body. The scientific benefits of using embryonic stem cells versus adult stem cells is not yet known. The use of adult stem cells does not require that an embryo be sacrificed, however.

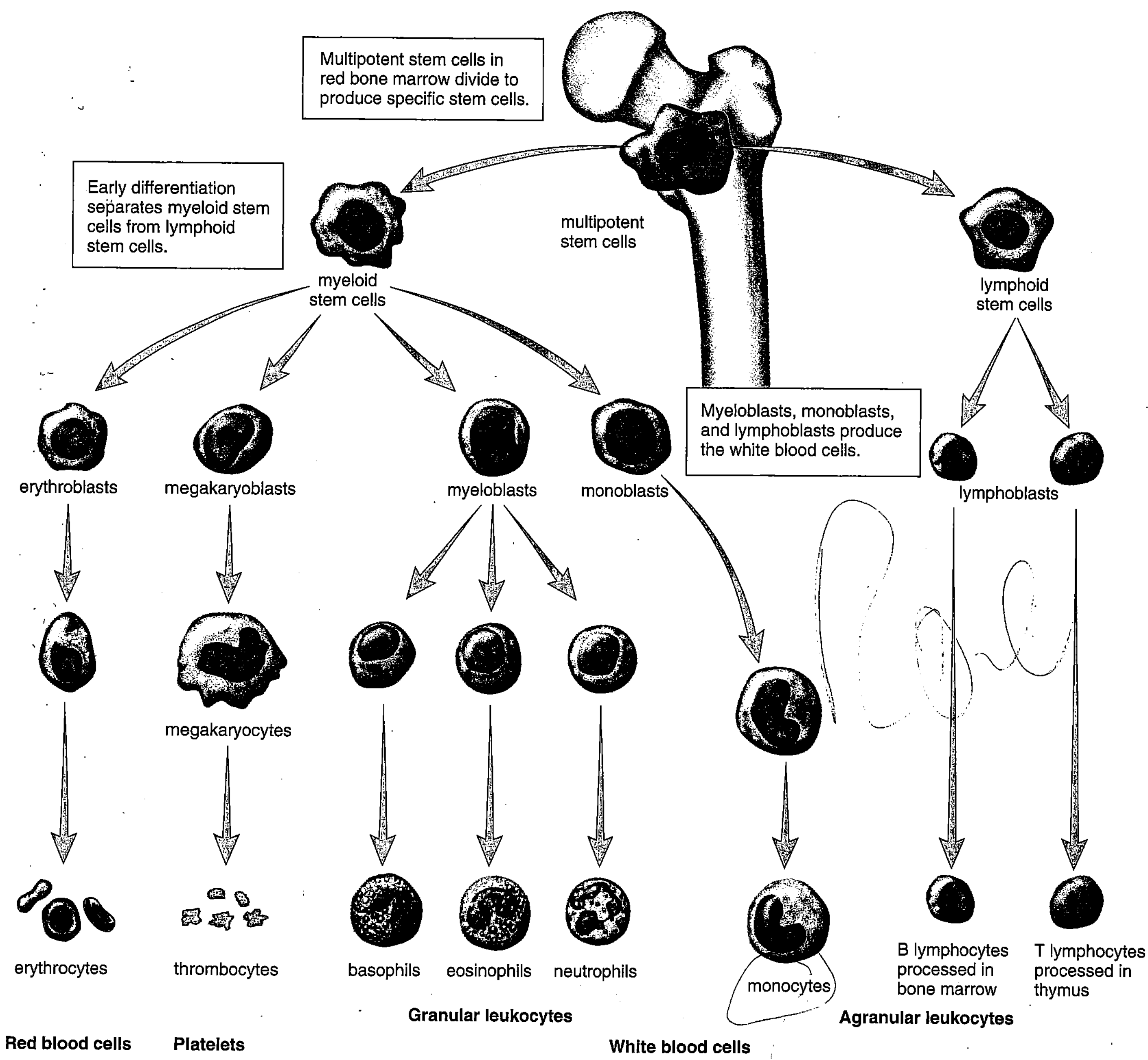


Figure 13.14 Blood cell formation in red bone marrow.
Multipotent stem cells give rise to two specialized stem cells. The myeloid stem cell gives rise to still other cells, which become red blood cells, platelets, and all the white blood cells except lymphocytes. The lymphoid stem cell gives rise to lymphoblasts, which become lymphocytes.

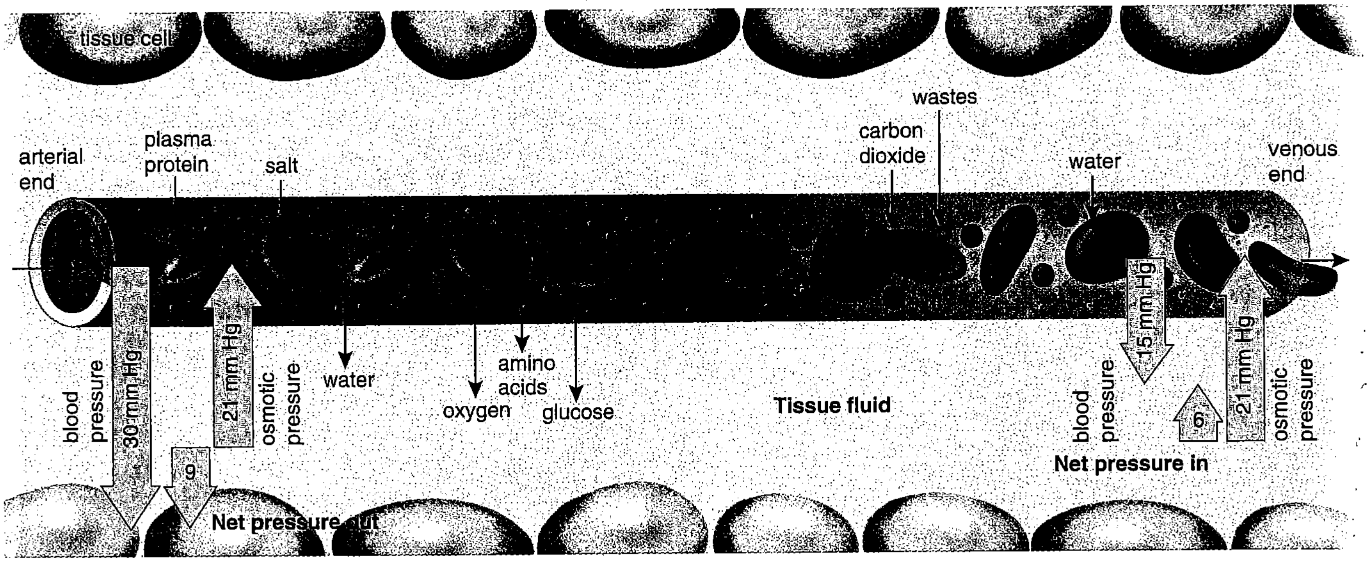


Figure 13.15 **Capillary exchange.**
At the arterial end of a capillary, the blood pressure is higher than the osmotic pressure; therefore, water tends to leave the bloodstream. In the midsection, the gases oxygen and carbon dioxide follow their concentration gradients, as do the nutrients glucose and amino acids. At the venous end of a capillary, the osmotic pressure is higher than the blood pressure; therefore, water tends to enter the bloodstream.

Capillary Exchange

Two forces primarily control movement of fluid through the capillary wall: osmotic pressure, which tends to cause water to move from tissue fluid to blood, and blood pressure, which tends to cause water to move in the opposite direction. At the arterial end of a capillary, blood pressure is higher than the osmotic pressure of blood (Fig. 13.15). Osmotic pressure is created by the presence of salts and the plasma proteins. Because blood pressure is higher than osmotic pressure at the arterial end of a capillary, water exits a capillary at this end.

Midway along the capillary, where blood pressure is lower, the two forces essentially cancel each other, and there is no net movement of water. Solutes now diffuse according to their concentration gradient—nutrients (glucose and oxygen) diffuse out of the capillary, and wastes (carbon dioxide) diffuse into the capillary. Red blood cells and almost all plasma proteins remain in the capillaries, but small substances leave. The substances that leave a capillary contribute to **tissue fluid,** the fluid between the body's cells. Since plasma proteins are too large to readily pass out of the capillary, tissue fluid tends to contain all components of plasma except lesser amounts of protein.

At the venous end of a capillary, where blood pressure has fallen even more, osmotic pressure is greater than blood pressure, and water tends to move into the capillary. Almost the same amount of fluid that left the capillary returns to it, although some excess tissue fluid is always collected by the lymphatic capillaries (Fig. 13.16). Tissue fluid contained within lymphatic vessels is called **lymph.** Lymph is returned to the systemic venous blood when the major lymphatic vessels enter the subclavian veins in the shoulder region.

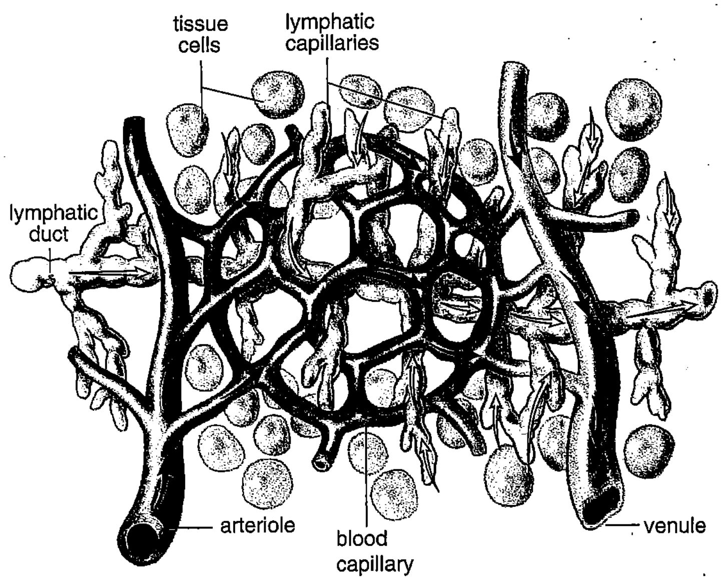


Figure 13.16 **Lymphatic capillaries.**
Arrows indicate that lymph is formed when lymphatic capillaries take up excess tissue fluid. Lymphatic capillaries lie near blood capillaries.

Oxygen and nutrient substances exit; carbon dioxide and waste molecules enter midway along a capillary.
