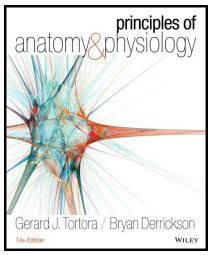


Principles of Anatomy and Physiology

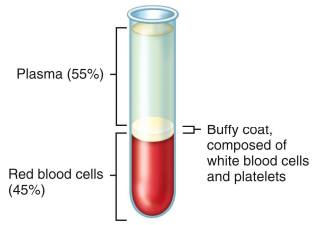
14th Edition

CHAPTER 19

The Cardiovascular System: The Blood

Functions and Properties of Blood

Blood is a **liquid connective tissue** consisting of **cells** surrounded by a liquid matrix (**plasma**).

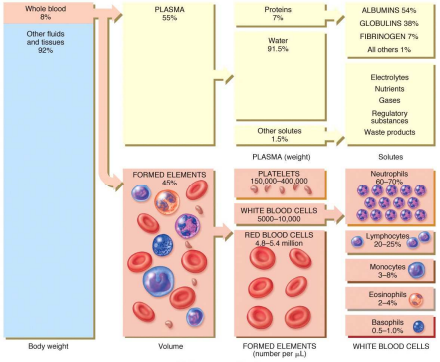


(a) Appearance of centrifuged blood

Functions and Properties of Blood

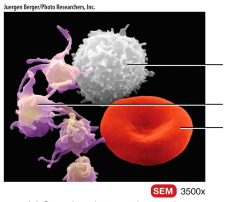
- The **cellular components (formed elements)** of blood include **red blood cells**, **white blood cells** and **platelets**.
- The **plasma** portion of blood consists of **water**, **proteins** and **other solutes**.

Functions and Properties of Blood

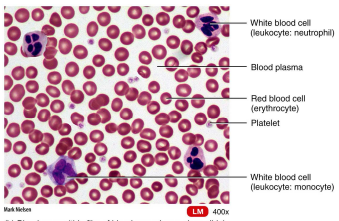


(b) Components of blood

Functions and Properties of Blood



(a) Scanning electron micrograph



(b) Blood smear (thin film of blood spread on a glass slide)

Functions and Properties of Blood

- Blood **transports** oxygen, carbon dioxide, nutrients, hormones, heat and waste products.
- Blood **regulates** homeostasis of all body fluids, pH, body temperature and water content of cells.
- Blood **protects** against excessive loss by **clotting** and against infections through the use of **white blood cells**.

Functions and Properties of Blood

TABLE 19.1

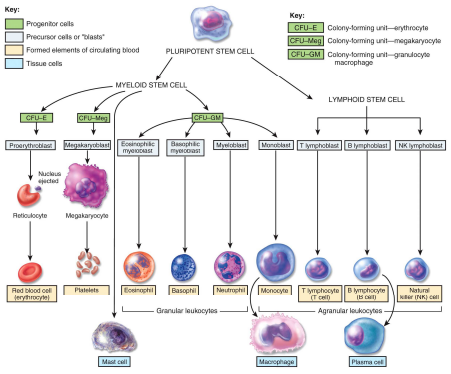
Substances in Blood Plasma

CONSTITUENT	DESCRIPTION	FUNCTION
Water (91.5%)	Liquid portion of blood.	Solvent and suspending medium. Absorbs, transports, and releases heat.
Plasma proteins (7%)	Most produced by liver.	Responsible for colloid osmotic pressure. Major contributors to blood viscosity. Transport hormones (steroid), fatty acids, and calcium. Help regulate blood pH.
Albumins	Smallest and most numerous plasma proteins.	Help maintain osmotic pressure, an important factor in the exchange of fluids across blood capillary walls.
Globulins	Large proteins (plasma cells produce immunoglobulins).	Immunoglobulins help attack viruses and bacteria. Alpha and beta globulins transport iron, lipids, and fat-soluble vitamins.
Fibrinogen	Large protein.	Plays essential role in blood clotting.
Other solutes (1.5%)		
Electrolytes	Inorganic salts; positively charged (cations) Na^+, K^+, Ca^{2+}, Mg^{2+}; negatively charged (anions) Cl^-, HPO_4^{2-}, SO_4^{2-}, HCO_3^-.	Help maintain osmotic pressure and play essential roles in cell functions.
Nutrients	Products of digestion, such as amino acids, glucose, fatty acids, glycerol, vitamins, and minerals.	Essential roles in cell functions, growth, and development.
Gases	Oxygen (O_2).	Important in many cellular functions.
	Carbon dioxide (CO_2).	Involved in the regulation of blood pH.
	Nitrogen (N_2).	No known function.
Regulatory substances	Enzymes.	Catalyze chemical reactions.
	Hormones.	Regulate metabolism, growth, and development.
	Vitamins.	Cofactors for enzymatic reactions.
Waste products	Urea, uric acid, creatine, creatinine, bilirubin, ammonia.	Most are breakdown products of protein metabolism that are carried by the blood to organs of excretion.

Formation of Blood Cells

- **Lymphocytes** are able to live for years while most other blood cells live for hours, days, or weeks.
- The number of red blood cells and platelets remains rather steady while that of white blood cells varies depending on invading pathogens and other foreign antigens.
- The process of producing blood cells is **hemopoiesis (hematopoiesis)**. **Pluripotent stem cells** differentiate into each of the different types of blood cells.

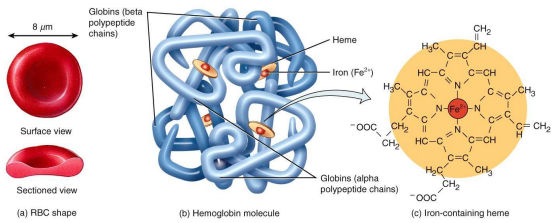
Formation of Blood Cells



Red Blood Cells

- **Red blood cells (erythrocytes)** contain the protein **hemoglobin** that is used to carry oxygen to all cells and to carry 23% of total carbon dioxide to the lungs.
- Each hemoglobin molecule contains an **iron ion** which allows each molecule to bind four oxygen molecules.
- Red blood cells have no nucleus or other organelles and are **biconcave discs**. The lack of a nucleus and the shape allow the cells to efficiently carry oxygen.

Red Blood Cells



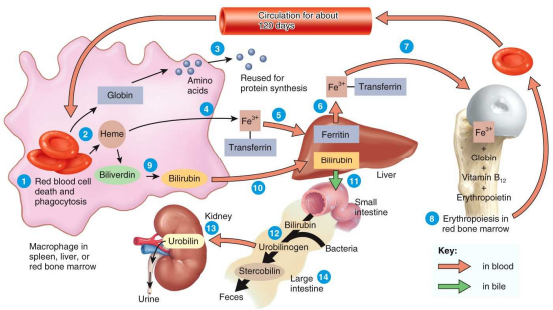
Red Blood Cells

- Hemoglobin is also involved in **regulating blood flow and blood pressure** via the release of **nitric oxide** which causes **vasodilation** that improves blood flow and enhances oxygen delivery.
- Red blood cells also contain **carbonic anhydrase** which catalyzes the conversion of carbon dioxide and water to carbonic acid. This compound transports about 70% oc carbon dioxide in the plasma. It is also a buffer.

Red Blood Cells

- Red blood cells live for only about 120 days. Dead cells are removed from the circulation by the spleen and liver.
- Breakdown products from the cells are recycled and reused.

Red Blood Cells



Red Blood Cells

- **Erythropoiesis** (production of red blood cells) begins in the red bone marrow. **Reticulocytes** (immature red blood cells) enter the circulation and mature in 1 to 2 days.
- **Erythropoietin**, a hormone released by the kidneys in response to **hypoxia** (lowered oxygen concentration) stimulates differentiation of hematopoietic stem cells into erythrocytes.

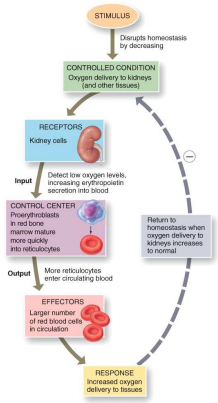
Red Blood Cells

Interactions Animation:

- Erythropoietin

You must be connected to the Internet and in Slideshow Mode to run this animation.

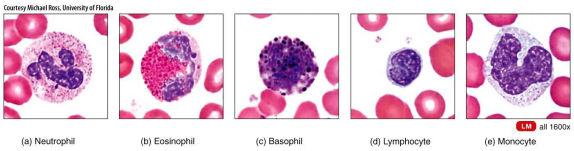
Red Blood Cells



White Blood Cells

- **White blood cells (leukocytes)** contain a nucleus and organelles, but no hemoglobin.
- Leukocytes are classified as either **granular** (containing vesicles that appear when the cells are stained) or **agranular** (containing no granules).
- Granular leukocytes: **neutrophils, eosinophils, basophils**
- Agranular leukocytes: **lymphocytes, monocytes**

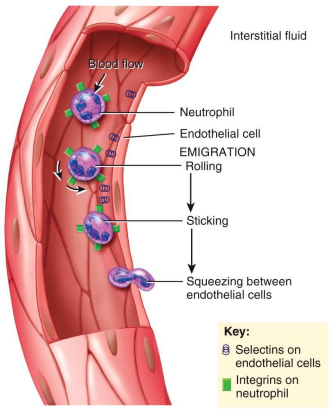
White Blood Cells



White Blood Cells

- White blood cells may live for several months or years. Their main function is to **combat invading microbes**.
- During an **invasion**, many white blood cells are able to **leave the bloodstream and collect at sites of invasion**. The process is called **emigration (diapedesis)**.

White Blood Cells



White Blood Cells

- In general, an **elevation in the white blood count** usually indicates an **infection** or **inflammation**.
- A **low white blood cell count** may develop due to several causes.
- A **differential white blood cell count** will help to determine if a problem exists.

White Blood Cells

TABLE 19.2

Significance of High and Low White Blood Cell Counts

WBC TYPE	HIGH COUNT MAY INDICATE	LOW COUNT MAY INDICATE
Neutrophils	Bacterial infection, burns, stress, inflammation.	Radiation exposure, drug toxicity, vitamin B_{12} deficiency, systemic lupus erythematosus (SLE).
Lymphocytes	Viral infections, some leukemias, infectious mononucleosis.	Prolonged illness, HIV infection, immunosuppression, treatment with cortisol.
Monocytes	Viral or fungal infections, tuberculosis, some leukemias, other chronic diseases.	Bone marrow suppression, treatment with cortisol.
Eosinophils	Allergic reactions, parasitic infections, autoimmune diseases.	Drug toxicity, stress, acute allergic reactions.
Basophils	Allergic reactions, leukemias, cancers, hypothyroidism.	Pregnancy, ovulation, stress, hypothyroidism.

Platelets

- **Platelets** are used to **clot the blood**.
- Under the influence of the hormone **thrombopoietin**, hemopoietic stem cells differentiate into **platelets**.
- **Megakaryocytes** in red bone marrow splinter into 2000–3000 fragments to create the platelets that contain many vesicles but no nucleus.
- Platelets survive for only 5 to 9 days.

Platelets

TABLE 19.3

Summary of Formed Elements in Blood

NAME AND APPEARANCE	NUMBER	CHARACTERISTICS*	FUNCTIONS
RED BLOOD CELLS (RBCS) OR ERYTHROCYTES 	4.8 million/μL in females; 5.4 million/μL in males.	7–8 μm diameter, biconcave discs, without nuclei; live for about 120 days.	Hemoglobin within RBCs transports most oxygen and part of carbon dioxide in blood.
WHITE BLOOD CELLS (WBCS) OR LEUKOCYTES	5000–10,000/μL.	Most live for a few hours to a few days.†	Combat pathogens and other foreign substances that enter body.
Granular leukocytes			
Neutrophils 	60–70% of all WBCs.	10–12 μm diameter; nucleus has 2–5 lobes connected by thin strands of chromatin; cytoplasm has very fine, pale lilac granules.	Phagocytosis. Destruction of bacteria with lysozyme, defensins, and strong oxidants, such as superoxide anion, hydrogen peroxide, and hypochlorite anion.
Eosinophils 	2–4% of all WBCs.	10–12 μm diameter; nucleus usually has 2 lobes connected by thick strand of chromatin; large, red-orange granules fill cytoplasm.	Combat effects of histamine in allergic reactions, phagocytize antigen–antibody complexes, and destroy certain parasitic worms.
Basophils 	0.5–1% of all WBCs.	8–10 μm diameter; nucleus has 2 lobes; large cytoplasmic granules appear deep blue-purple.	Liberate heparin, histamine, and serotonin in allergic reactions that intensify overall inflammatory response.

*Colors are those seen when using Wright's stain.
†Some lymphocytes, called T and B memory cells, can live for many years once they are established.

Platelets

TABLE 19.3

Summary of Formed Elements in Blood

NAME AND APPEARANCE	NUMBER	CHARACTERISTICS*	FUNCTIONS
Agranular leukocytes			
Lymphocytes (T cells, B cells, and natural killer cells) 	20–25% of all WBCs.	Small lymphocytes are 6–9 μm in diameter; large lymphocytes are 10–14 μm in diameter; nucleus is round or slightly indented; cytoplasm forms rim around nucleus that looks sky blue; the larger the cell, the more cytoplasm is visible.	Mediate immune responses, including antigen–antibody reactions. B cells develop into plasma cells, which secrete antibodies. T cells attack invading viruses, cancer cells, and transplanted tissue cells. Natural killer cells attack wide variety of infectious microbes and certain spontaneously arising tumor cells.
Monocytes 	3–8% of all WBCs.	12–20 μm diameter; nucleus is kidney- or horseshoe-shaped; cytoplasm is blue-gray and appears foamy.	Phagocytosis (after transforming into fixed or wandering macrophages).
PLATELETS 	150,000–400,000/μL.	2–4 μm diameter cell fragments that live for 5–9 days; contain many vesicles but no nucleus.	Form platelet plug in hemostasis; release chemicals that promote vascular spasm and blood clotting.

*Colors are those seen when using Wright's stain.
†Some lymphocytes, called T and B memory cells, can live for many years once they are established.

Stem Cell Transplants from Bone Marrow and Cord Blood

- **Bone marrow transplants** are performed to **replace cancerous red bone marrow with normal red bone marrow**. The donor's marrow is usually collected from the **iliac crest** of the hip bone.
- **Stem cells** collected from an umbilical cord after birth are frozen and may also be used and have advantages over bone marrow transplants.

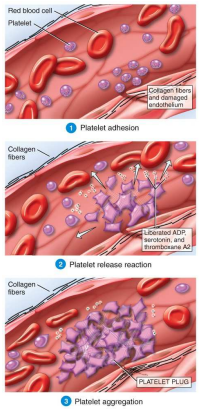
Hemostasis

Hemostasis means to stop bleeding.

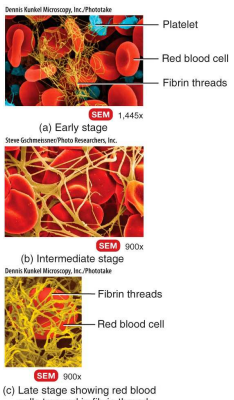
The process involves:

- Vascular spasm
- Platelet plug formation
- Blood clotting (coagulation)

Hemostasis



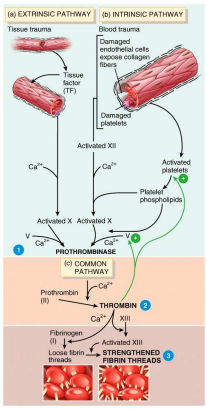
Hemostasis



Hemostasis

- Blood clotting involves several **clotting (coagulation) factors** identified by Roman numerals and divided into three stages.
- The three stages are the **extrinsic pathway**, **intrinsic pathway** and **common pathway**.

Hemostasis



Hemostasis

TABLE 19.4

Clotting (Coagulation) Factors

NUMBER*	NAME(S)	SOURCE	PATHWAY(S) OF ACTIVATION
I	Fibrinogen.	Liver.	Common.
II	Prothrombin.	Liver.	Common.
III	Tissue factor (thromboplastin).	Damaged tissues and activated platelets.	Extrinsic.
IV	Calcium ions (Ca^{++}).	Diet, bones, and platelets.	All.
V	Proaccelerin, labile factor, or accelerator globulin (AcG).	Liver and platelets.	Extrinsic and intrinsic.
VII	Serum prothrombin conversion accelerator (SPCA), stable factor, or proconvertin.	Liver.	Extrinsic.
VIII	Antihemophilic factor (AHF), antihemophilic factor A, or antihemophilic globulin (AHG).	Liver.	Intrinsic.
IX	Christmas factor, plasma thromboplastin component (PTC), or antihemophilic factor B.	Liver.	Intrinsic.
X	Stuart factor, Prower factor, or thrombokinase.	Liver.	Extrinsic and intrinsic.
XI	Plasma thromboplastin antecedent (PTA) or antihemophilic factor C.	Liver.	Intrinsic.
XII	Hageman factor, glass factor, contact factor, or antihemophilic factor D.	Liver.	Intrinsic.
XIII	Fibrin-stabilizing factor (FSF).	Liver and platelets.	Common.

*There is no factor VI. Prothrombinase (prothrombin activator) is a combination of activated factors V and X.

Hemostasis

- Once the clot forms, it **consolidates (tightens)** to pull the edges of the damaged vessel together.
- **Vitamin K** is needed for normal clot formation although it is not directly involved. It is used in the synthesis of 4 clotting factors.
- Small, unwanted clots are usually dissolved by **plasmin (fibrinolysin)**.

Blood Groups and Blood Types

- Blood is characterized into different **blood groups** based on the presence or absence of **glycoprotein and glycolipid antigens (agglutinogens)** on the surface of red blood cells.
- There are 24 blood groups and more than 100 antigens
- Because these antigens are genetically controlled, blood types vary among different populations.
- Classification is based on antigens labeled A, B or AB with O being the absence of the antigens.
- An additional antigen, Rh, is present in 85% of humans.

Blood Groups and Blood Types

TABLE 19.5

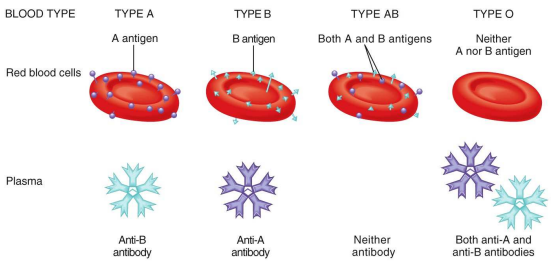
Blood Types in the United States

	BLOOD TYPE (PERCENTAGE)				
POPULATION GROUP	O	A	B	AB	Rh^+
European-American	45	40	11	4	85
African-American	49	27	20	4	95
Korean-American	32	28	30	10	100
Japanese-American	31	38	21	10	100
Chinese-American	42	27	25	6	100
Native American	79	16	4	1	100

Blood Groups and Blood Types

Blood plasma usually contains **antibodies (agglutinins)** that react with A or B antigens. An individual will not have agglutinins against his or her own blood type.

Blood Groups and Blood Types



Blood Groups and Blood Types

TABLE 19.6

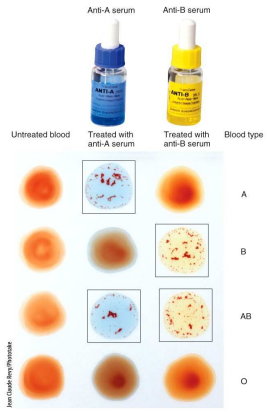
Summary of ABO Blood Group Interactions

	BLOOD TYPE			
CHARACTERISTIC	**A**	**B**	**AB**	**O**
Agglutinogen (antigen) on RBCs	A	B	Both A and B	Neither A nor B
Agglutinin (antibody) in plasma	Anti-B	Anti-A	Neither anti-A nor anti-B	Both anti-A and anti-B
Compatible donor blood types (no hemolysis)	A, O	B, O	A, B, AB, O	O
Incompatible donor blood types (hemolysis)	B, AB	A, AB	—	A, B, AB

Blood Groups and Blood Types

- In order to determine a person's blood type, **typing and cross-matching** are performed.
- A drop of blood is mixed with an **antiserum** that will **agglutinate** blood cells that possess agglutinogens that react with it.

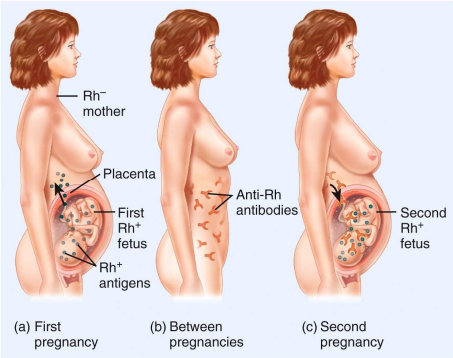
Blood Groups and Blood Types



Hemolytic Disease of the Newborn

- At birth, small amounts of fetal blood leak into the maternal circulation. If the baby is Rh^+ and the mother is Rh^-, she will develop antibodies to the Rh factor.
- During her next pregnancy with an Rh^+ baby, when she transfers antibodies to the fetus (a normal occurrence), transferred **anti Rh antibodies** will attack some of the fetus' red blood cells causing **agglutination and hemolysis**.

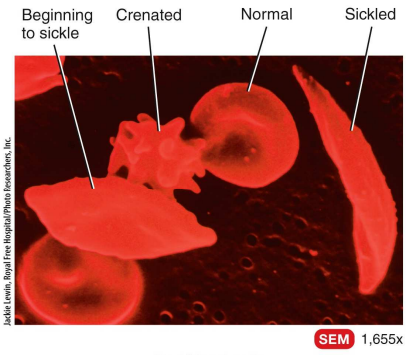
Hemolytic Disease of the Newborn



Disorders: Homeostatic Imbalances

- **Sickle cell disease** is a **genetic anemia (oxygen-carrying capacity of the blood is reduced)**.
- The red blood cells of individuals with this disease contain **hemoglobin-S (Hb-S)** that causes red blood cells to bend into a sickle shape when it gives up oxygen to the interstitial fluid.

Disorders: Homeostatic Imbalances



Red blood cells

End of Chapter 19