Composition and Functions of the Blood

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Objectives;

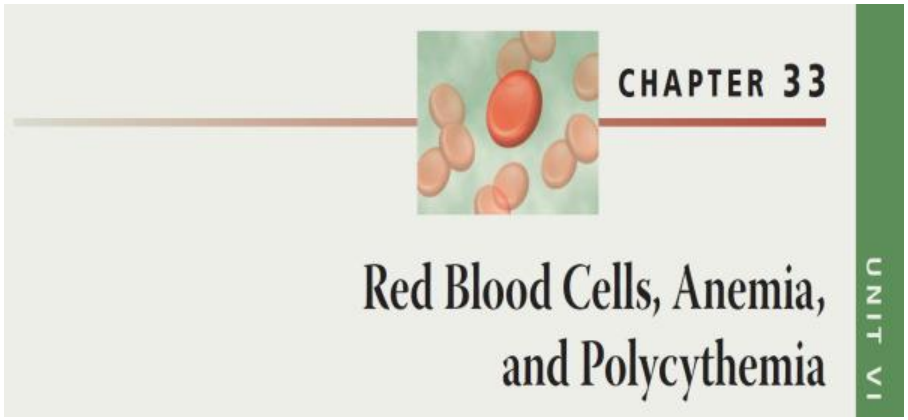
Intended learning outcomes (ILOs)

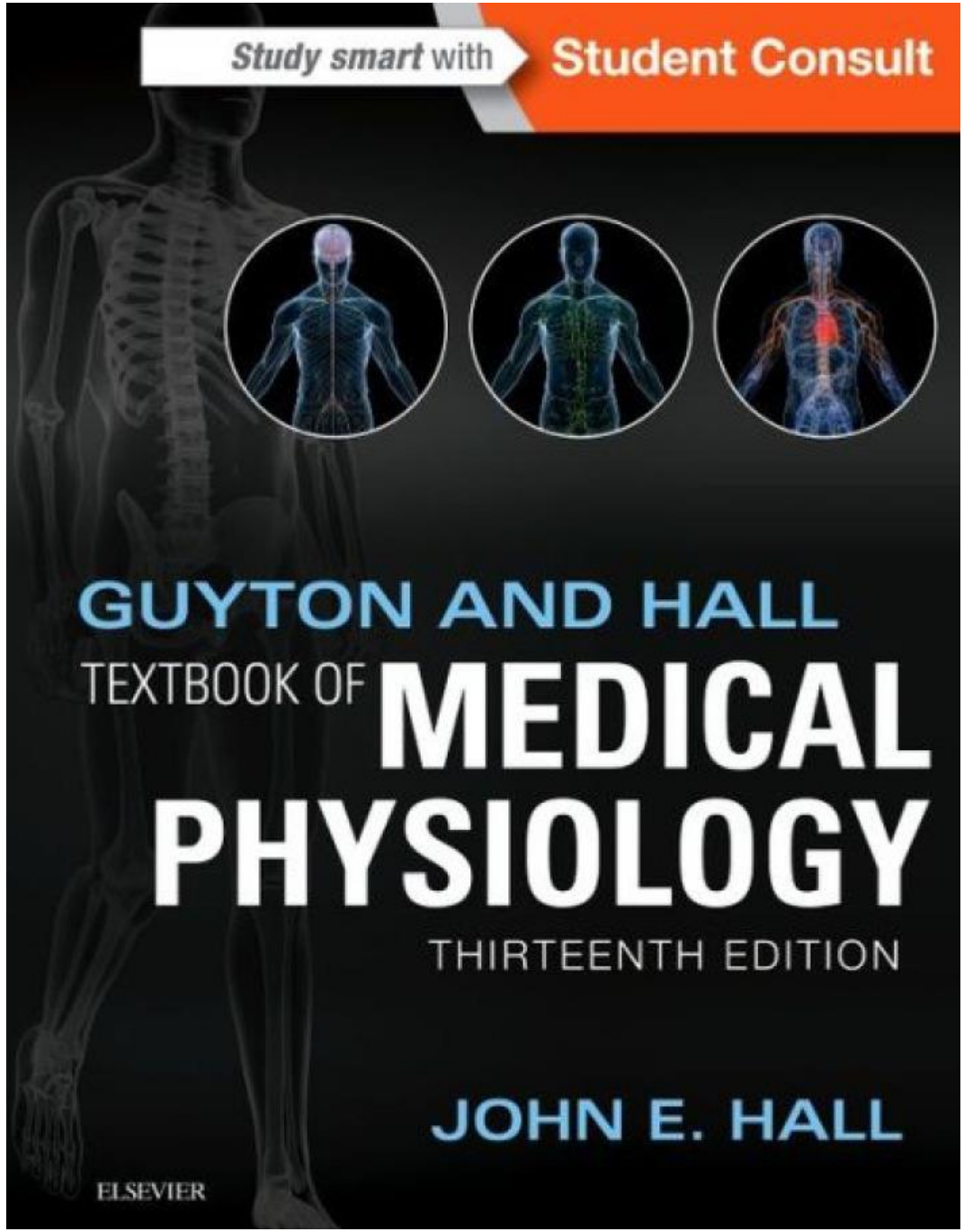
After reviewing the PowerPoint presentation and the associated learning resources, the student should be able to:

- List the functions of the blood
- Describe the physical characteristics of blood
- Discuss the composition of the blood
- Differentiate between the terms formed elements, Packed Cell Volume, plasma and serum
- Outline the functions of the plasma proteins
- Describe the shape of mature red blood cells and explain the advantages of this shape
- Explain what maintains the shape of the normal red blood cell and outline the pathogenesis of hereditary spherocytosis
- Summarize the functions of red blood cells
- Describe the different hematological indices and indicate their physiological significance

Learning Resources

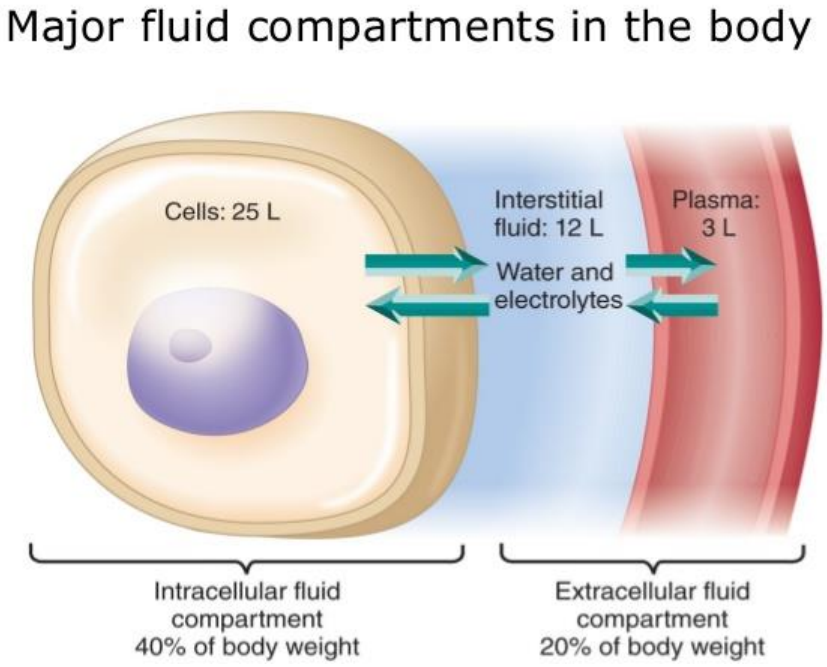
- **Guyton and Hall, Textbook of Medical Physiology; 13th Edition; Unit VI-Chapter 33.**

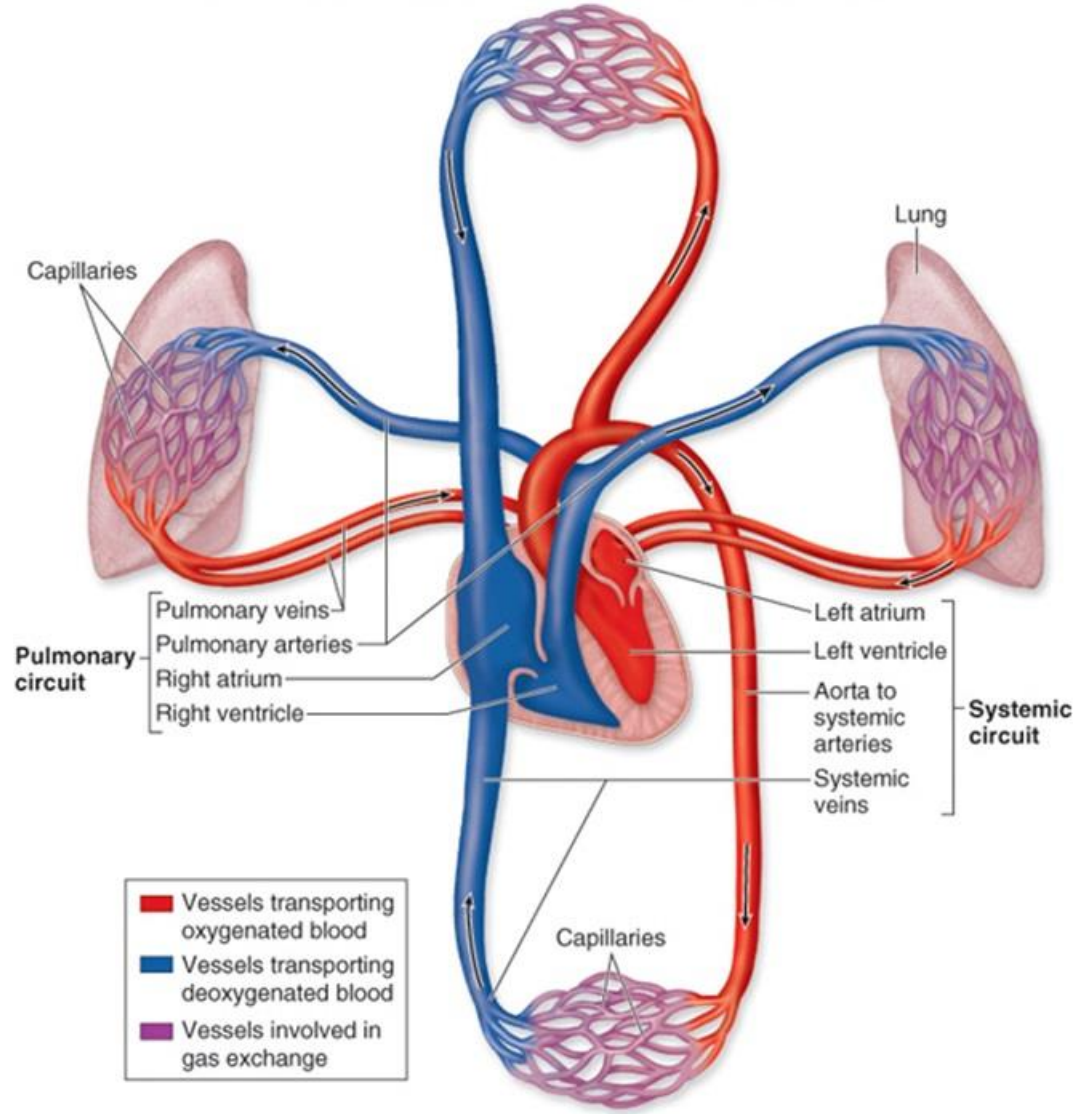




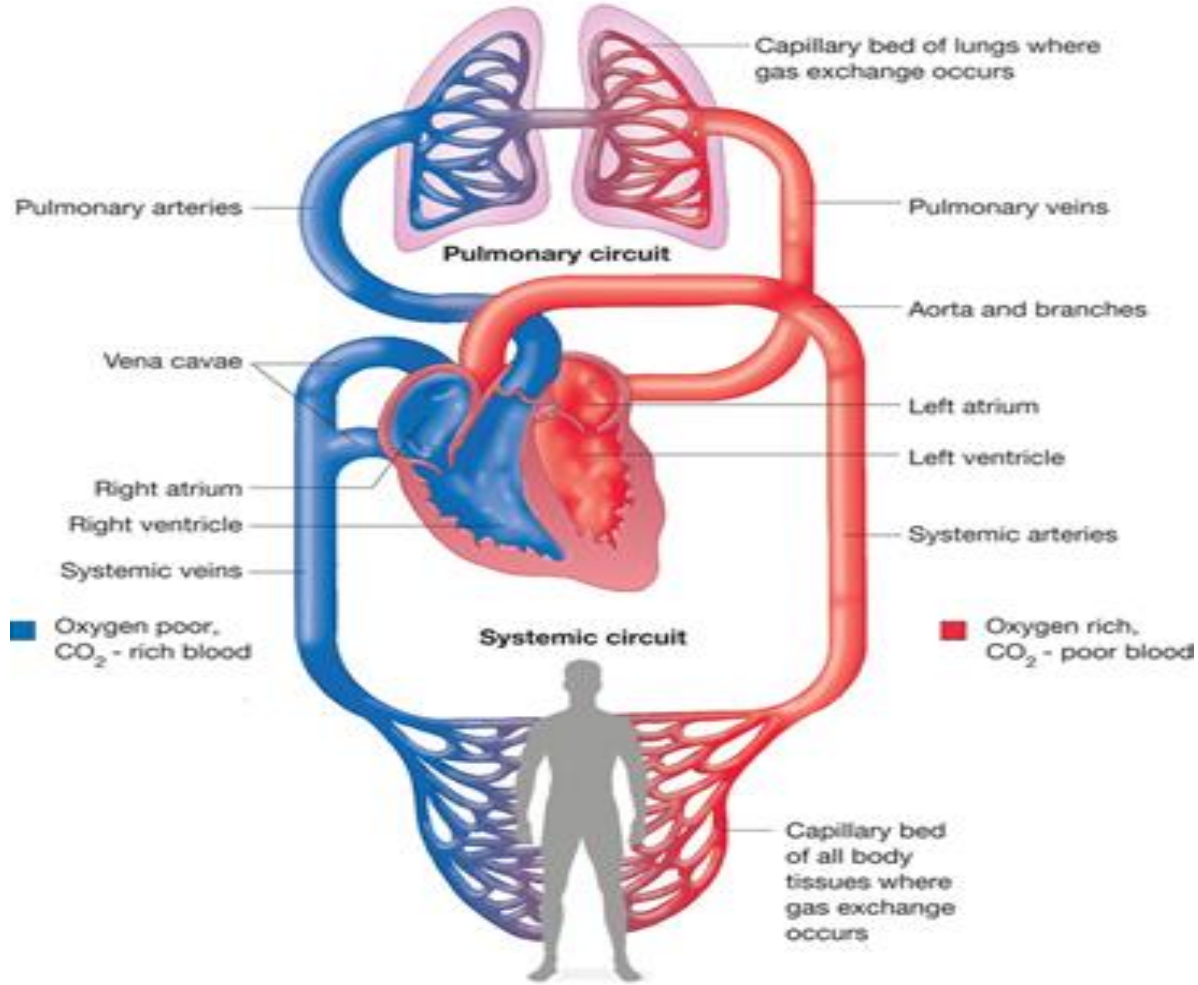
Major Components of the Circulatory System

- Heart
- Blood vessels
- Blood





Blood circulation



Some Physical Characteristics of Blood

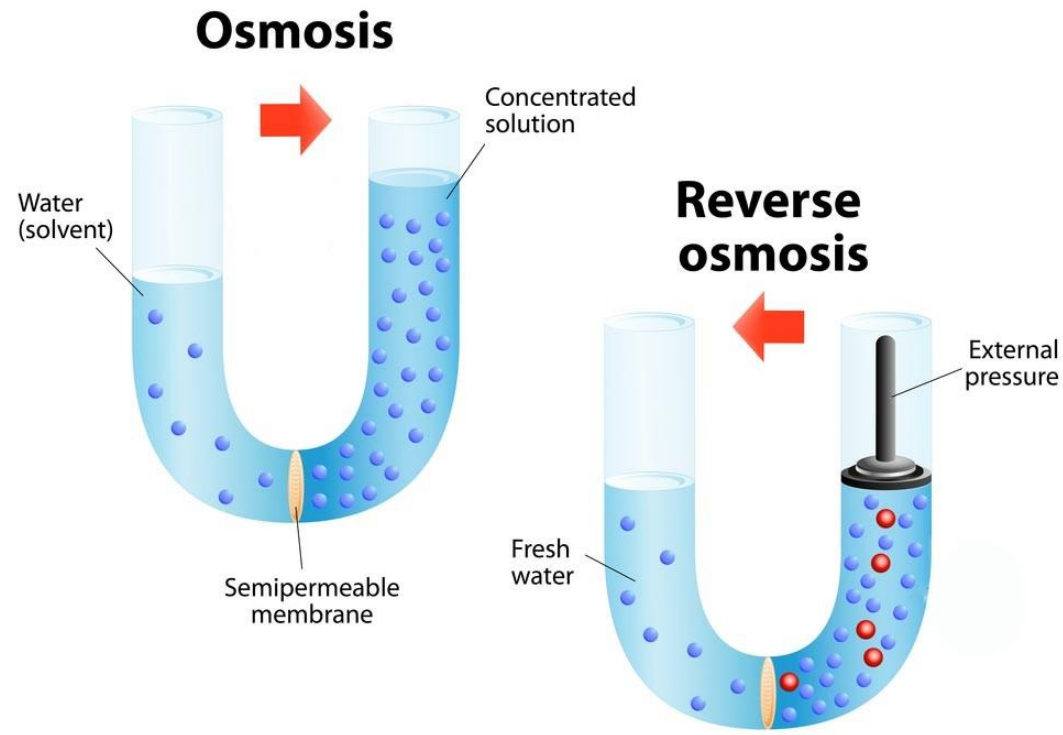
- **Blood volume**
  - Blood makes up 7-9% of body weight
  - Blood volume is 5 to 6 liters in adult males
    4 to 5 liters in adult females

- **Viscosity (thickness and stickiness of blood)**
  - Blood is thicker (more viscous) than water and flows more slowly than water
  - Plasma at 37°C is about 1.8-times more viscous than water; therefore, the relative viscosity of plasma (compared to water) is about 1.8
  - Whole blood viscosity (relative to water) = 4.5-5.5

- **pH**
  - Slightly alkaline: 7.4
  - Ranges from 7.35 to 7.45

Some Physical Characteristics of Blood

- **Color**
  - Bright red = O_2 rich
  - Dull red = O_2 poor
- **Osmolarity**
  - Plasma osmolarity is about 300 mOsmol/L
  - Plasma osmolarity is equal to the osmolarity of Normal Saline = 0.9% NaCl Solution. Hence, Normal Saline is an Isotonic solution
- **Osmotic Pressure**
  - Osmotic pressure is the pressure necessary to prevent net movement of water (in osmosis)
  - In other words, osmotic pressure is the pressure developed by solutes dissolved in water working across a selectively permeable membrane.
  - At normal plasma osmolarity of about 300 mOsmol/L, the total plasma osmotic pressure is about 5540 mmHg.

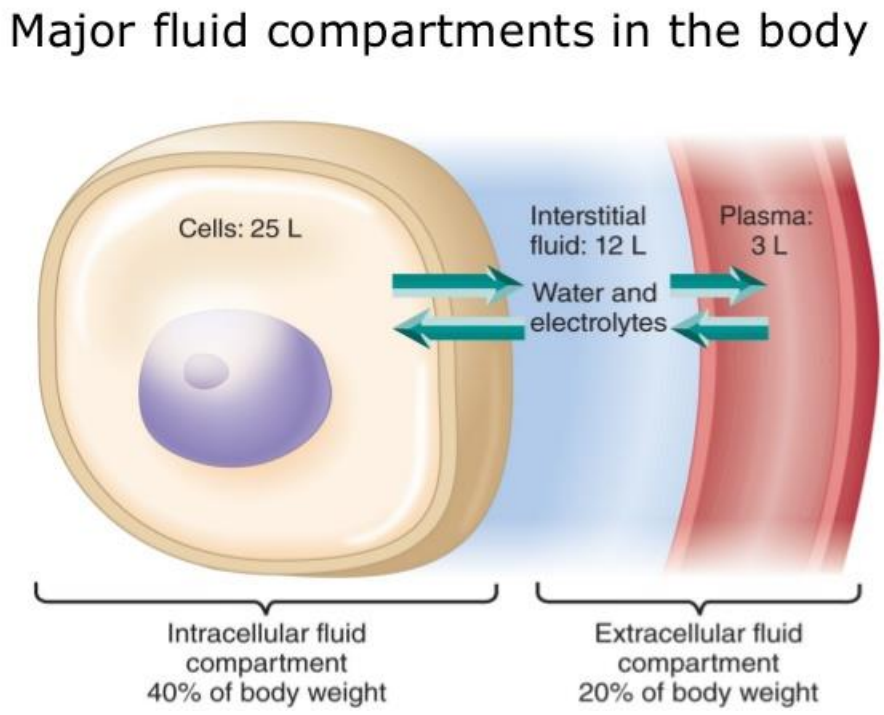


Some Physical Characteristics of Blood

❑ Plasma Osmotic Pressure

❑ **Crystalloid osmotic pressure:** **is the pressure generated by all crystal substances, particularly electrolytes (mainly NaCl). This pressure modulates water distribution between inside and outside of cells. Hence, it is important in maintaining fluid balance across cell membranes.**

❑ **Colloid osmotic pressure:** **is the pressure generated by plasma proteins, particularly albumin. This pressure modulates water distribution between inside and outside of blood capillaries. Hence, it is important in fluid transfer across capillaries. It is normally about 25 mmHg, which represents about 0.5% of the total plasma osmotic pressure.**



Functions of Blood

- **Blood transports:**
  - Oxygen from the lungs and nutrients from the digestive tract
  - Metabolic wastes from cells to the lungs and kidneys for elimination
  - Hormones from endocrine glands to target organs

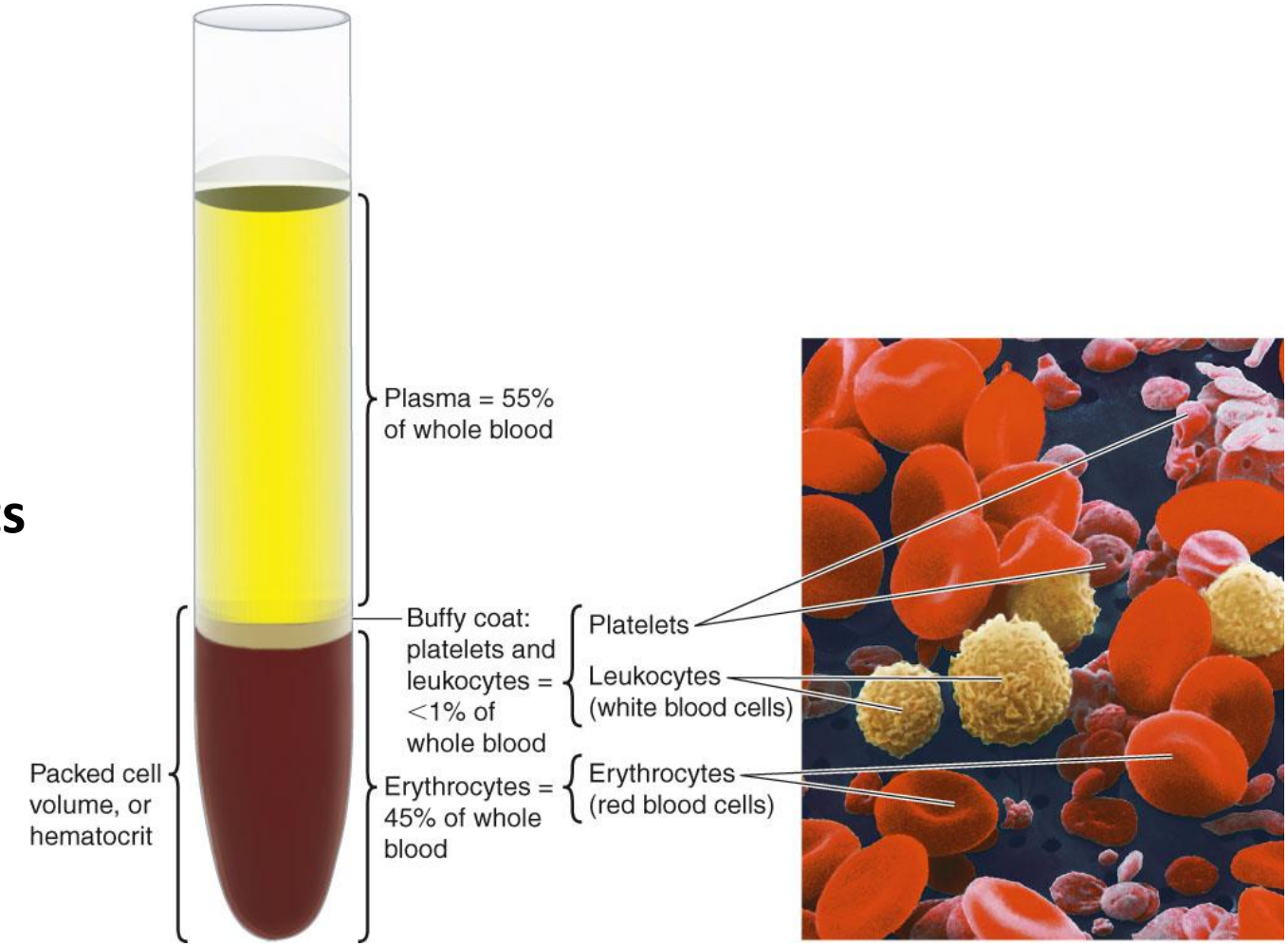
- **Blood maintains:**
  - Appropriate body temperature by absorbing and distributing heat
  - Normal pH in body tissues using buffer systems
  - Adequate fluid volume in the circulatory system

- **Blood prevents blood loss by:**
  - Activating plasma proteins and platelets
  - Initiating clot formation when a vessel is broken

- **Blood prevents infection by:**
  - Synthesizing and utilizing antibodies
  - Activating complement proteins
  - Activating WBCs to defend the body against foreign invaders

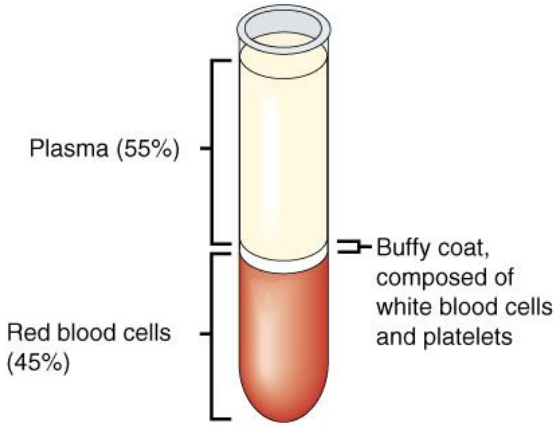
Composition of Blood

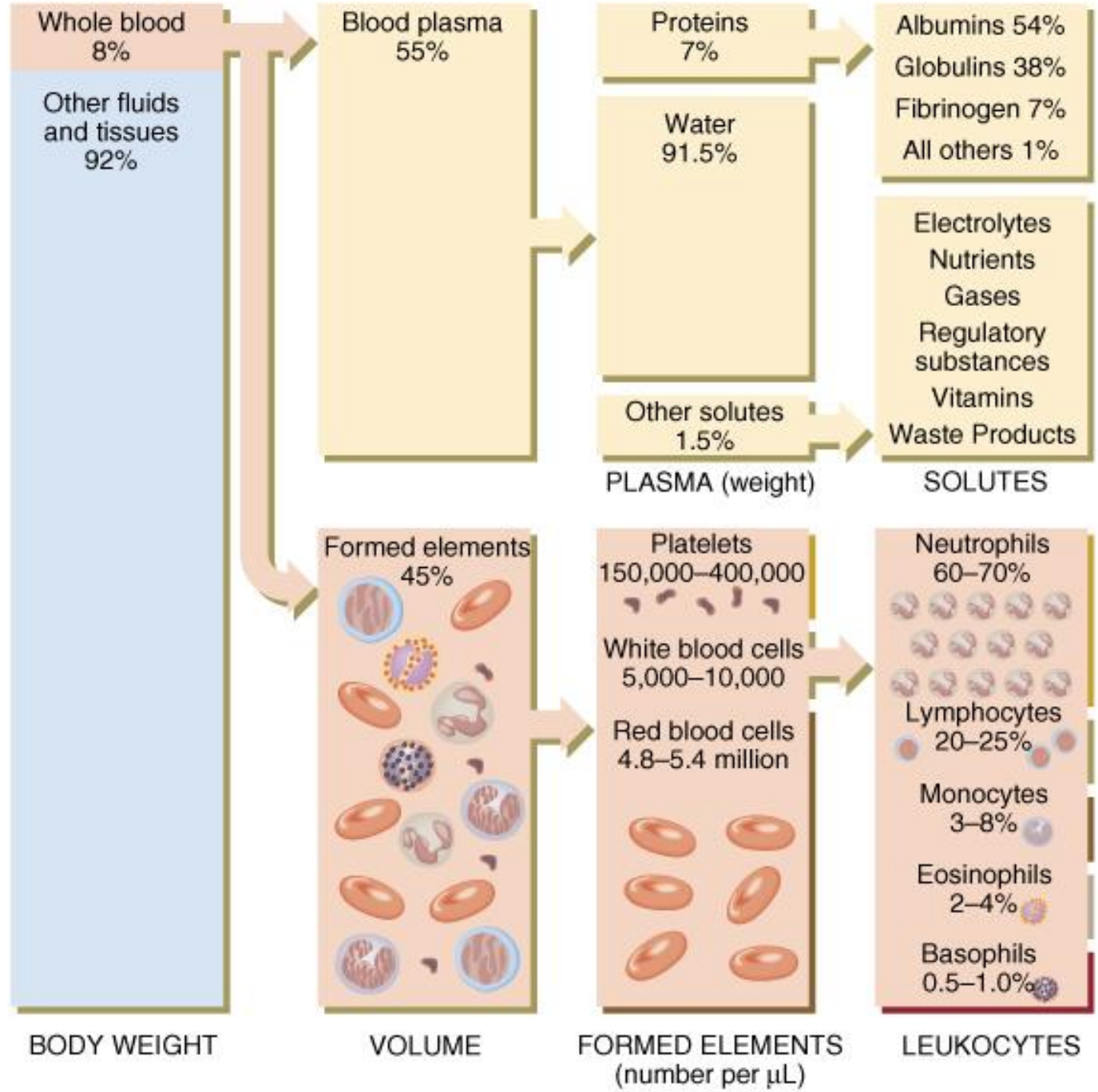
- **Cells and cell fragments = "formed elements": 45%**
  - **Erythrocytes = RBCs**
  - **Leukocytes = WBCs**
  - **Thrombocytes = platelets (cell fragments)**
- **Matrix (plasma): makes up 55% of blood volume**



Composition of Blood

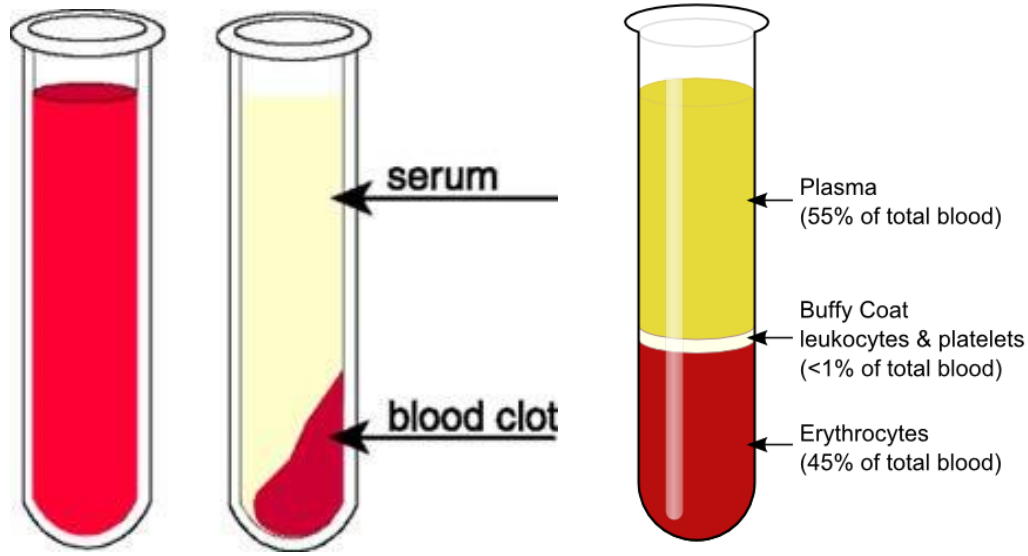
- **45% cells**
  - **99% RBCs**
  - **< 1% WBCs and platelets**
- **55% plasma**



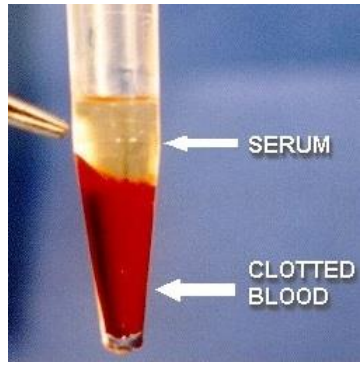


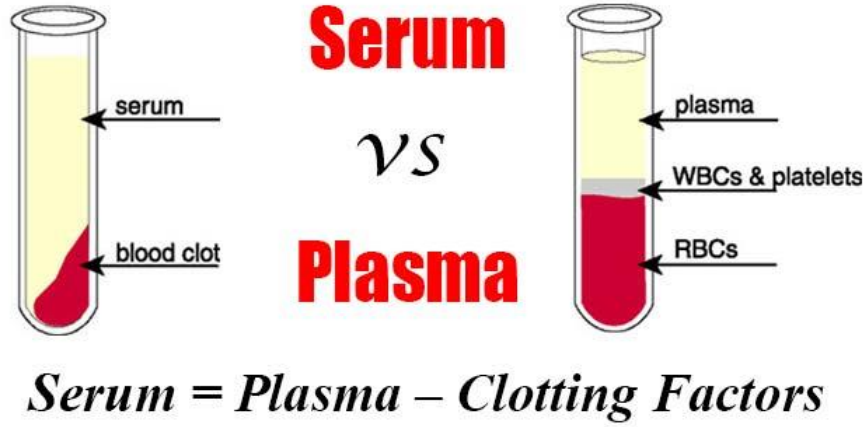
Plasma: Definition and Composition

- **Plasma =** whole blood minus cells
- **Serum =** plasma minus clotting proteins
  - If whole blood is allowed to clot
  - Then, clot is removed, the remaining fluid is SERUM
  - Thus, serum does not contain coagulation factors



- **Constituents of plasma**
  - 91.5% water
  - 7% plasma proteins
  - 1.5% other solutes including:
    - Electrolytes
    - Organic nutrients and wastes
    - Respiratory gases
    - Vitamins

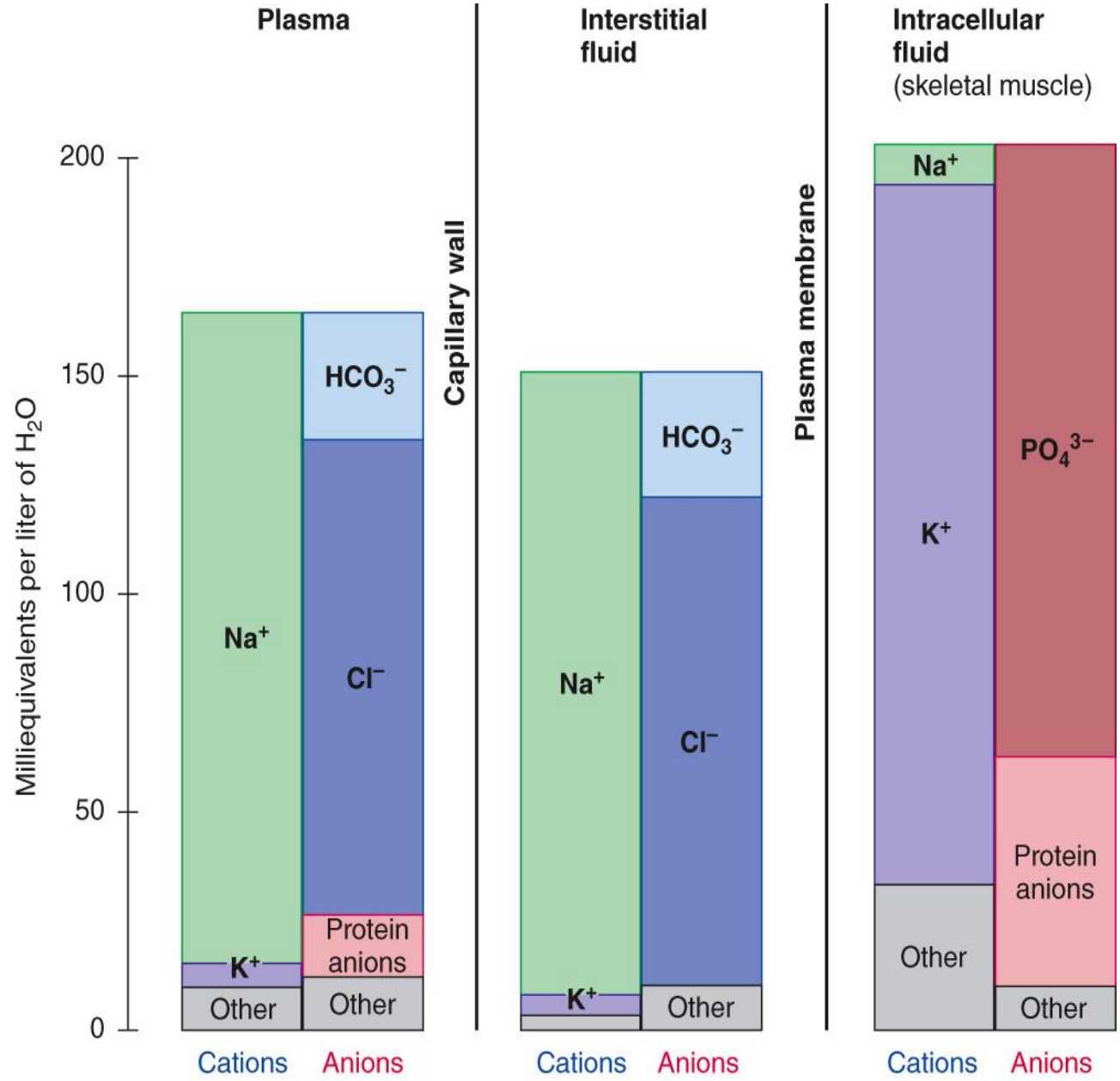




Serum = Plasma – Clotting Factors

Ionic Composition of the Plasma

Ionic composition of the plasma is very similar to that of the interstitial fluid



Functions of Plasma Proteins

- **Generation of plasma colloid osmotic pressure (oncotic pressure):** most capillary walls are relatively impermeable to the proteins in plasma, and the proteins therefore exert an osmotic force of about 25 mm Hg across the capillary wall (oncotic pressure that pulls water into the blood.) Albumin is the most abundant protein in plasma: about half of all plasma protein. It provides about 80% of plasma oncotic pressure.

- **Buffering function of plasma proteins:** the plasma proteins are also responsible for 15% of the buffering capacity of the blood.

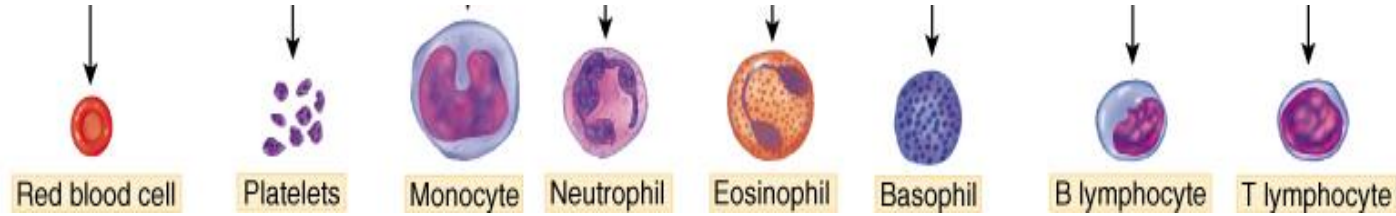
- **Plasma proteins function as nonspecific carriers** for various hormones (e.g., cortisol, thyroxin), other solutes (e.g., iron, cupper), and drugs.

- **Defense:** Gamma globulins are antibodies

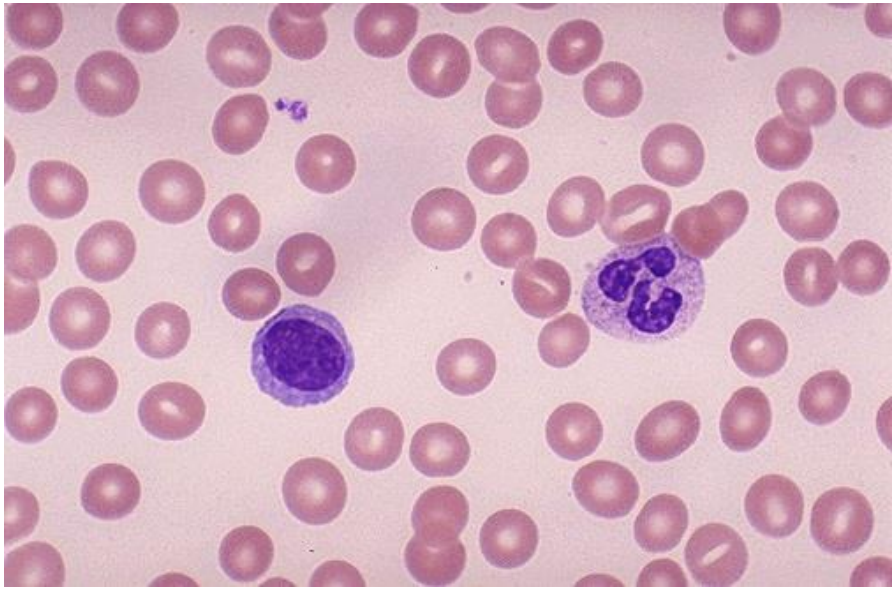
- **Plasma proteins include proteins concerned with blood clotting.**

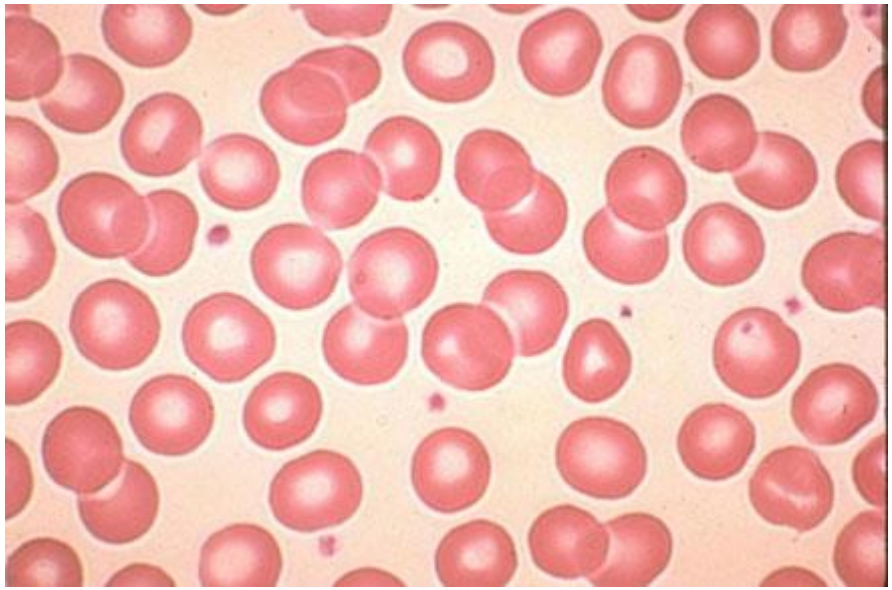
Formed Elements of Blood

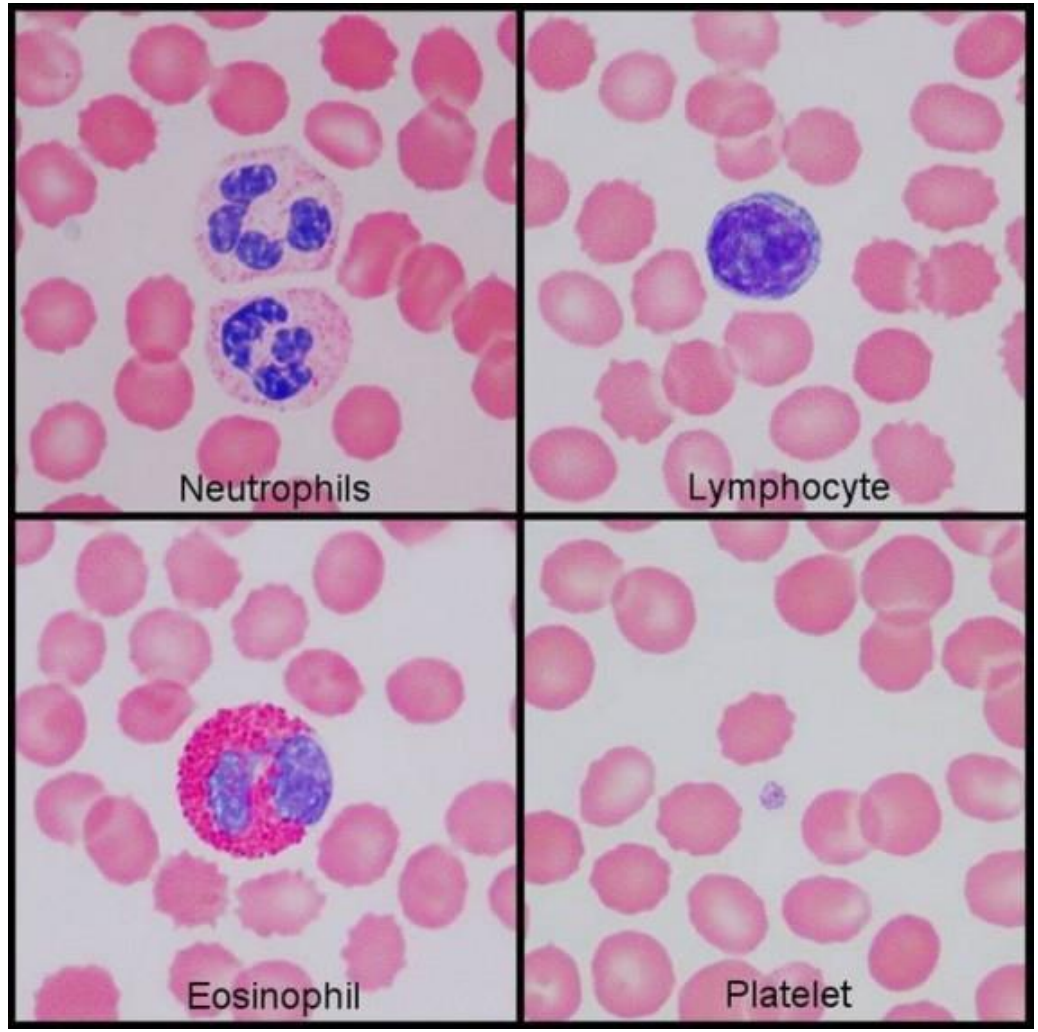
- Red blood cells (erythrocytes)
- White blood cells (leukocytes)
  - granular leukocytes
    - neutrophils
    - eosinophils
    - basophils
  - agranular leukocytes
    - lymphocytes = T cells, and B cells
    - monocytes
- Platelets (special cell fragments)



Blood Film (Blood Smear)

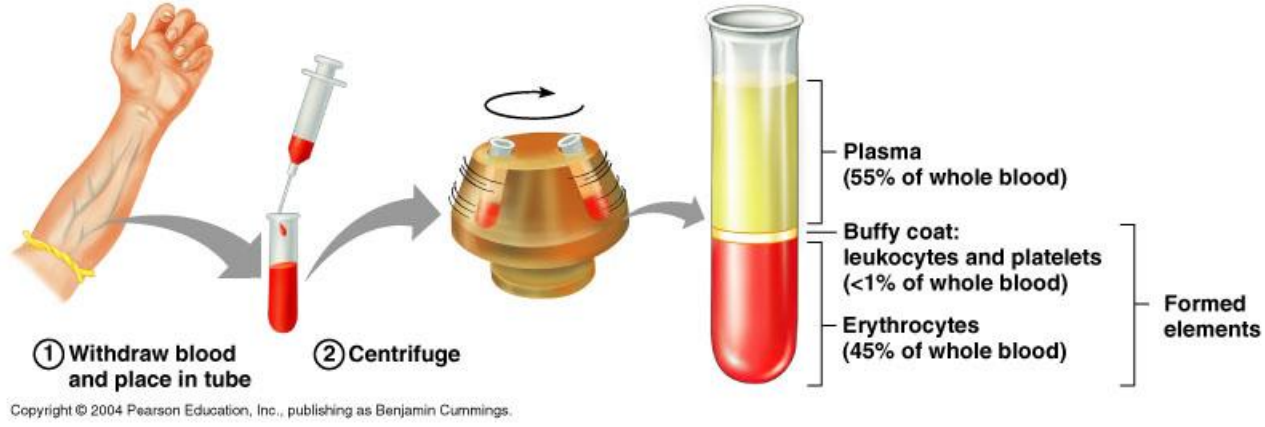






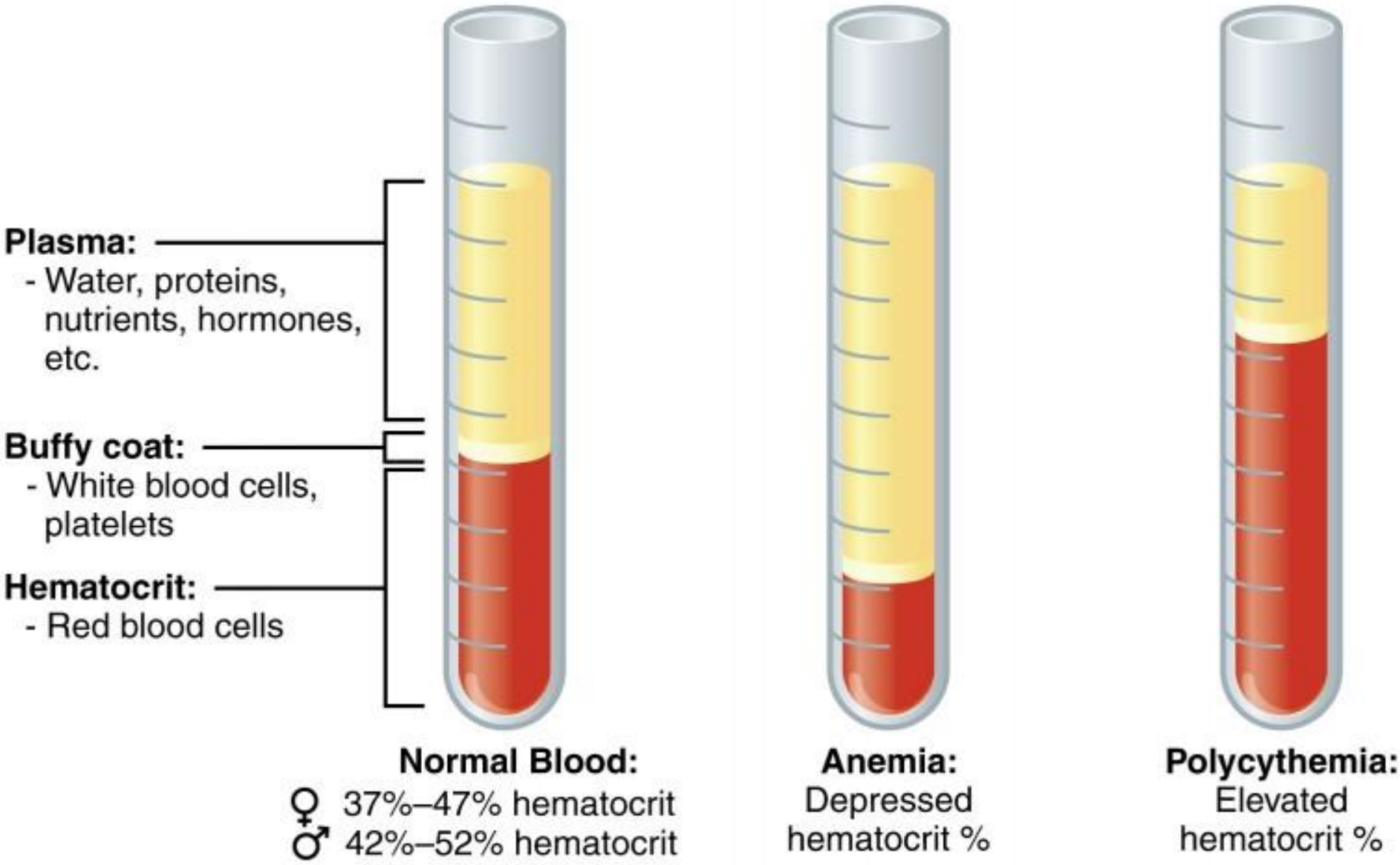
Hematocrit; Hct (PCV)

- Hct is the ratio of formed elements to whole blood
- It is the proportion of blood made up of cells (mainly RBCs)
- It is expressed as percentage
- Percentage of blood made up of cells
- Males: average 47% (range: 42-52%)
- Females: average 42% (range 37-47%)
- Minimum hematocrit to donate blood = 38%



- Hct is measured by centrifuging a tiny sample of blood
- Centrifugation separates formed elements from plasma
- After centrifugation the heavier red blood cells settle to the bottom of the tube. The plasma remains at the top.
- The two layers are separated by a 'buffy coat' of white cells and platelets.

Hematocrit; Hct (PCV)

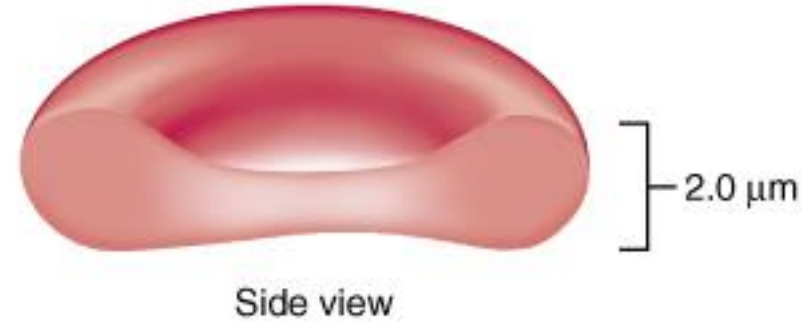


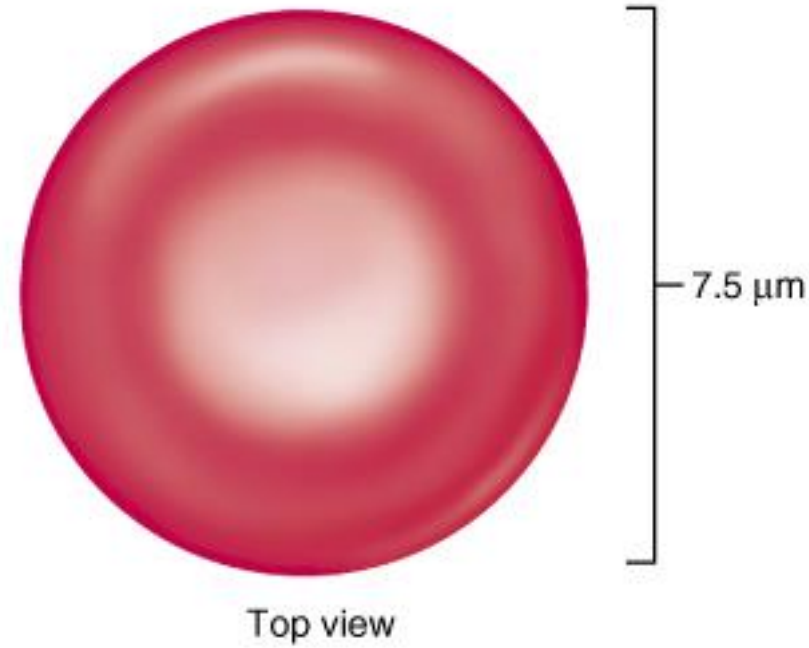
Characteristics of a Mature Erythrocytes (RBC)

- A mature RBC is a biconcave disc having dimensions of (7.5X2X1 µm). The average volume is about 90-95 μm^3.
- It does not have nucleus, mitochondria, ribosomes, endoplasmic reticulum or Golgi apparatus.
- The cytoplasm is filled with hemoglobin (Hb), a protein that functions in gas transport. It also contains the enzyme carbonic anhydrase and the enzymes for glucose metabolism and 2,3 DPG synthesis. Glucose enters RBC by facilitated (carrier-mediated) diffusion. Glycolysis accounts for 90% and hexose monophosphate (HMP) Shunt for 10% of glucose metabolism.
- The plasma membrane contains the protien *spectrin* that:
  - Gives erythrocytes their flexibility
  - Allows them to change shape as necessary with significantly smaller forces
- Erythrocytes are an example of the complementarities of structure and function

Structural characteristics that contribute to its gas transport function are:

- Biconcave shape that has a huge surface area to volume ratio. This is essential for gas exchange
- Discounting water content, erythrocytes are 97% hemoglobin
- ATP is generated anaerobically, so the erythrocytes do not consume the oxygen they transport.



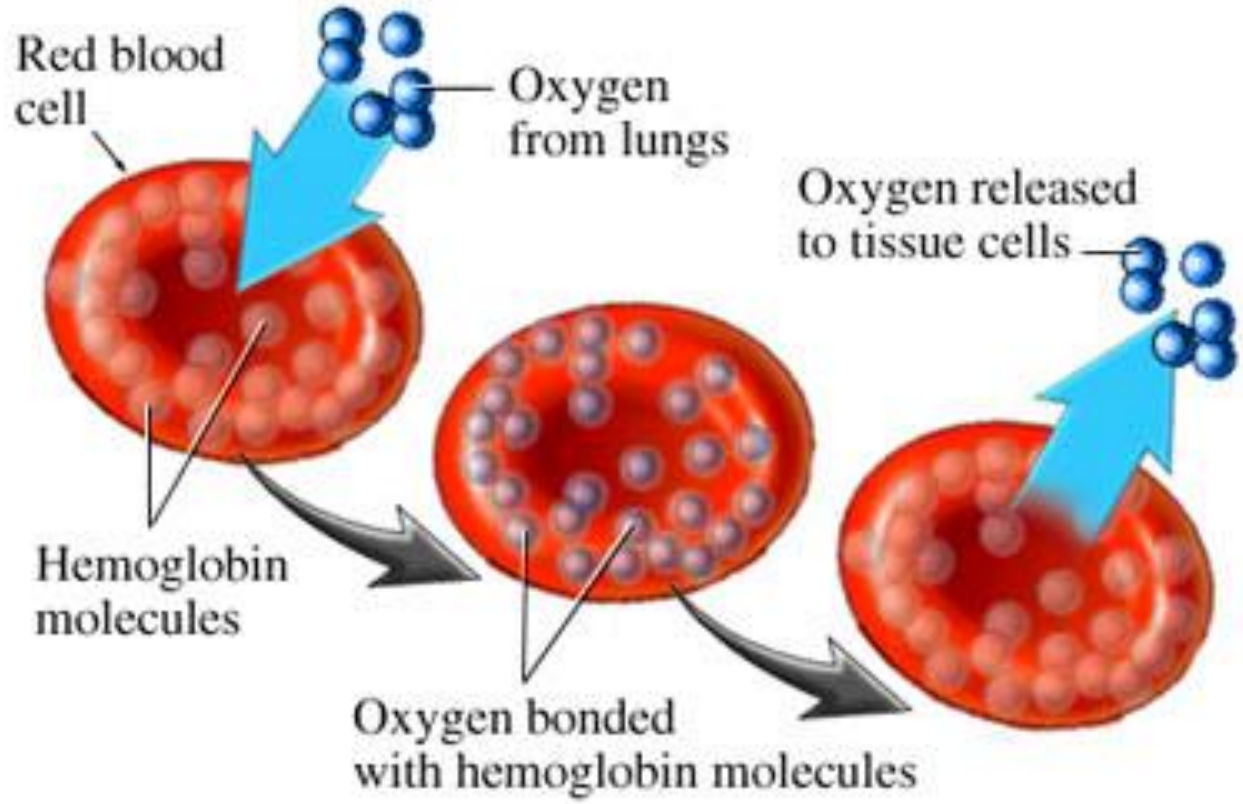


Functions of Red Blood Cells

- A major function of RBCs is to transport hemoglobin, which, in turns, carries oxygen from the lungs to the tissues.

- Hemoglobin combines reversibly with oxygen as blood passes through pulmonary capillaries in the lungs where oxygen is high.

- Hemoglobin releases oxygen as blood passes through systemic capillaries in the tissues where oxygen is low.

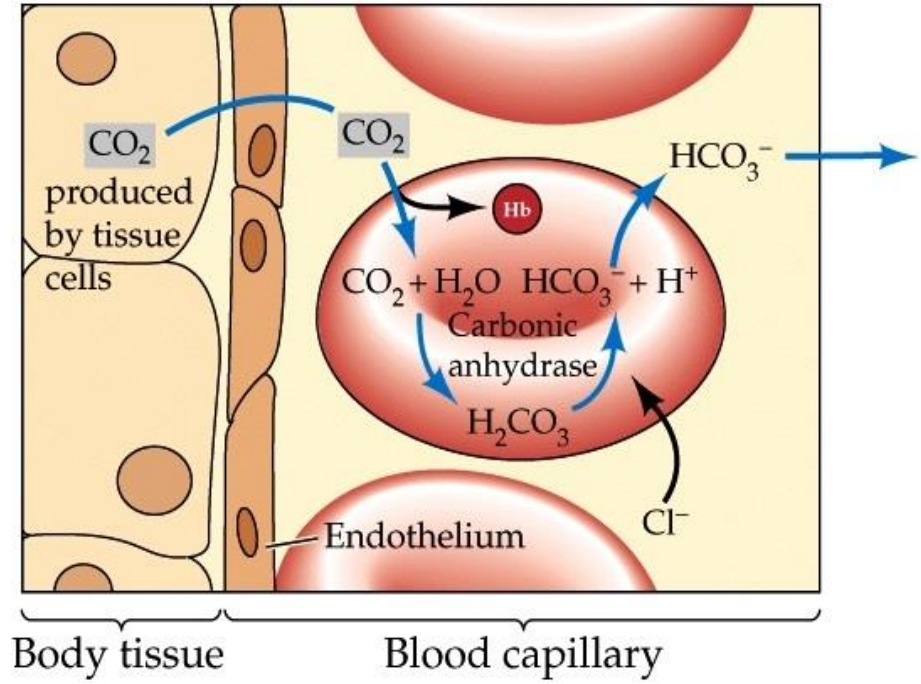


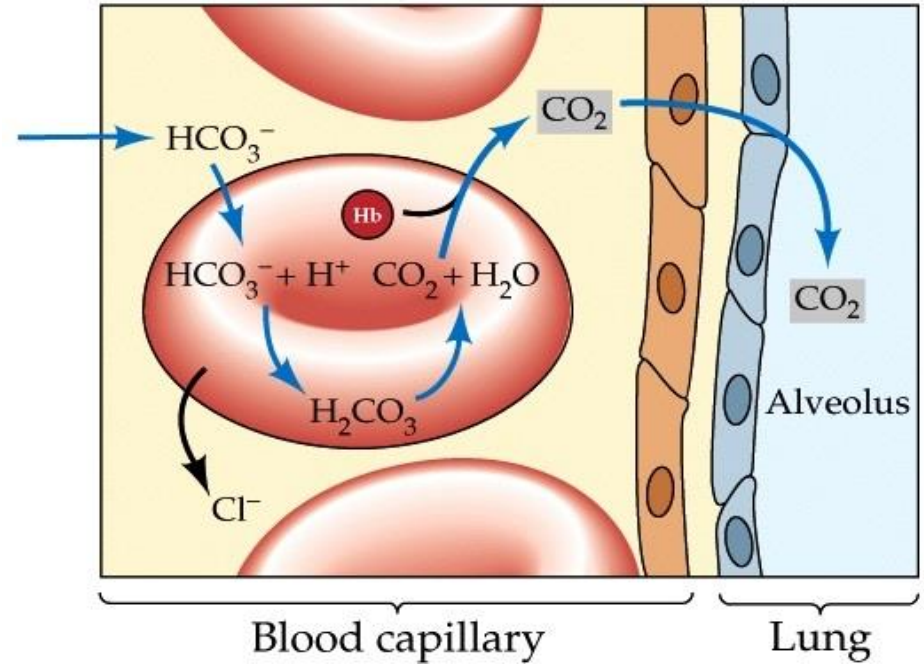
Functions of Red Blood Cells

- RBCs contain the enzyme carbonic anhydrase. This enzyme that catalyzes the reversible reaction between carbon dioxide (CO_2) and H_2O to form carbonic acid (H_2CO_3), increasing the rate of this reaction several thousand fold.

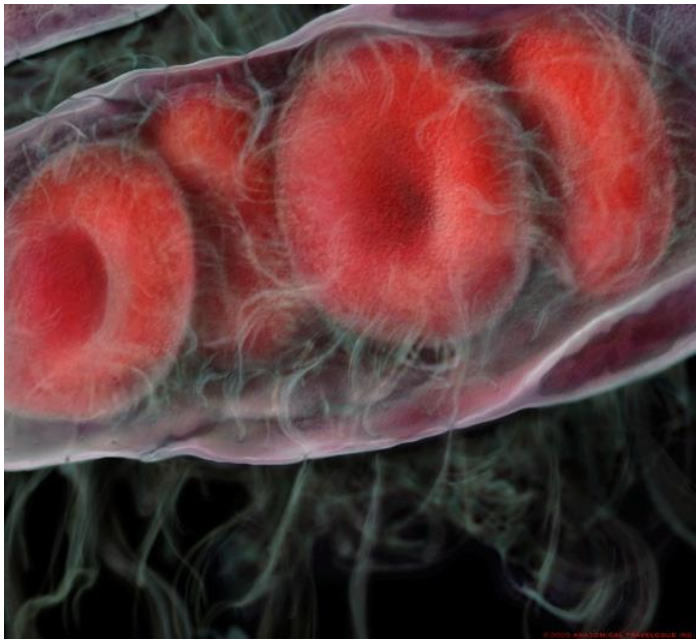
- The rapidity of this reaction makes it possible for the water of the blood to transport enormous quantities of CO_2 in the form of bicarbonate ion ($HCO3^-$) from the tissues to the lungs, where it is reconverted to CO_2 and expelled into the atmosphere as a body waste product.

- The hemoglobin in the cells is an excellent *acid-base buffer* (as is true of most proteins), so the red blood cells are responsible for most of the acid-base buffering power of whole blood.

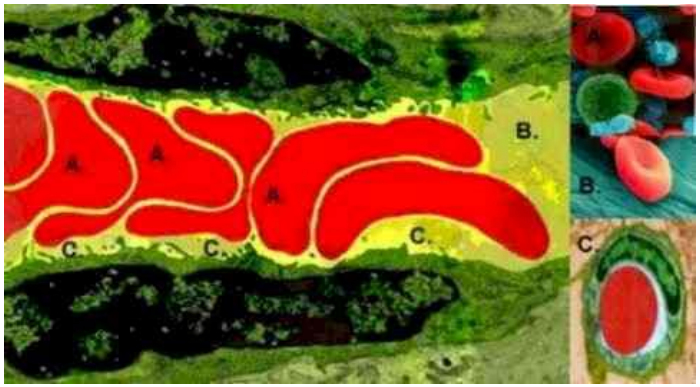




Red Blood Cells in Blood Capillaries

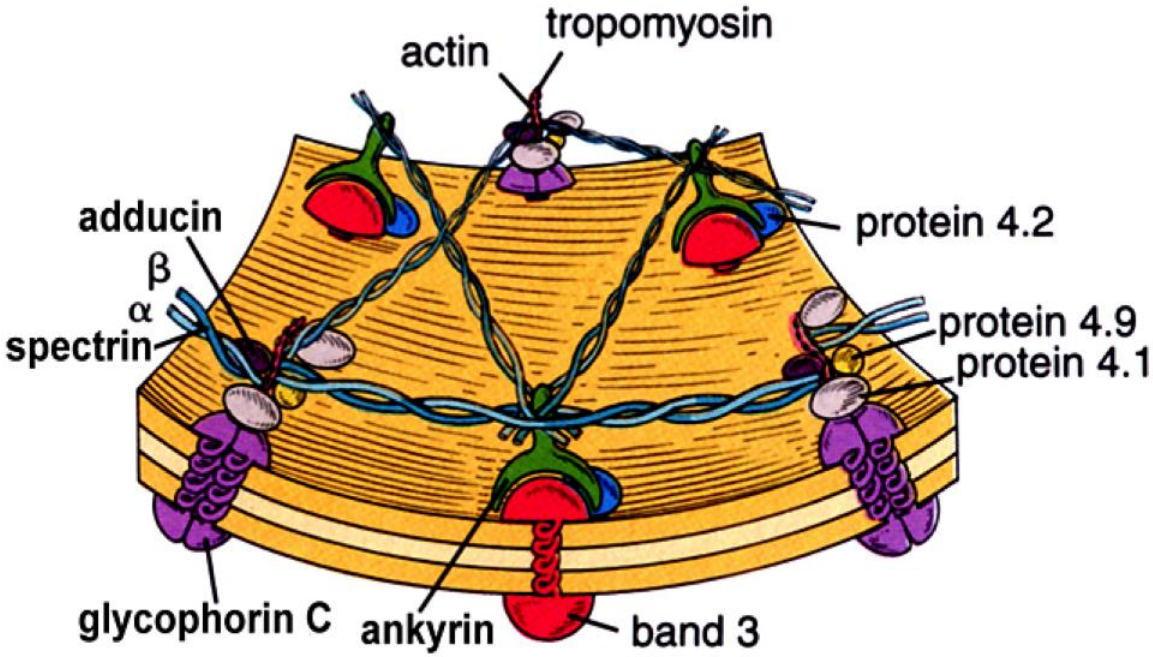


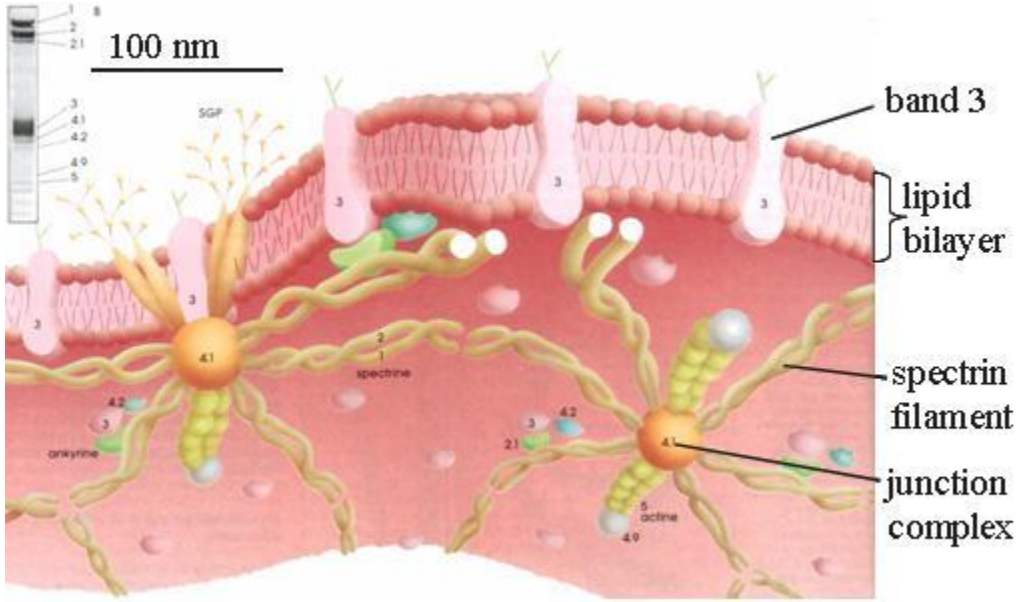
- Blood capillaries are very narrow blood vessels.
- The shapes of RBCs can change dramatically as the cells pass through blood capillaries since they squeeze through capillaries. Actually, the RBC is a bag of hemoglobin that can be deformed into almost any shape.
- This feature keeps them in very close contact with the capillary walls, thereby reducing the diffusion distance for gas exchange with the surrounding tissues.
- Because the normal RBC has a great excess of cell membrane for the quantity of material inside, deformation does not stretch the membrane greatly and, consequently does rupture the cell, as would be the case with many other cells.



- RBCs in single file
- RBCs are flexible and elastic
- They are subject to high amounts of shear stress as they traverse the narrow capillaries of the microvasculature since they squeeze through the narrow capillaries.

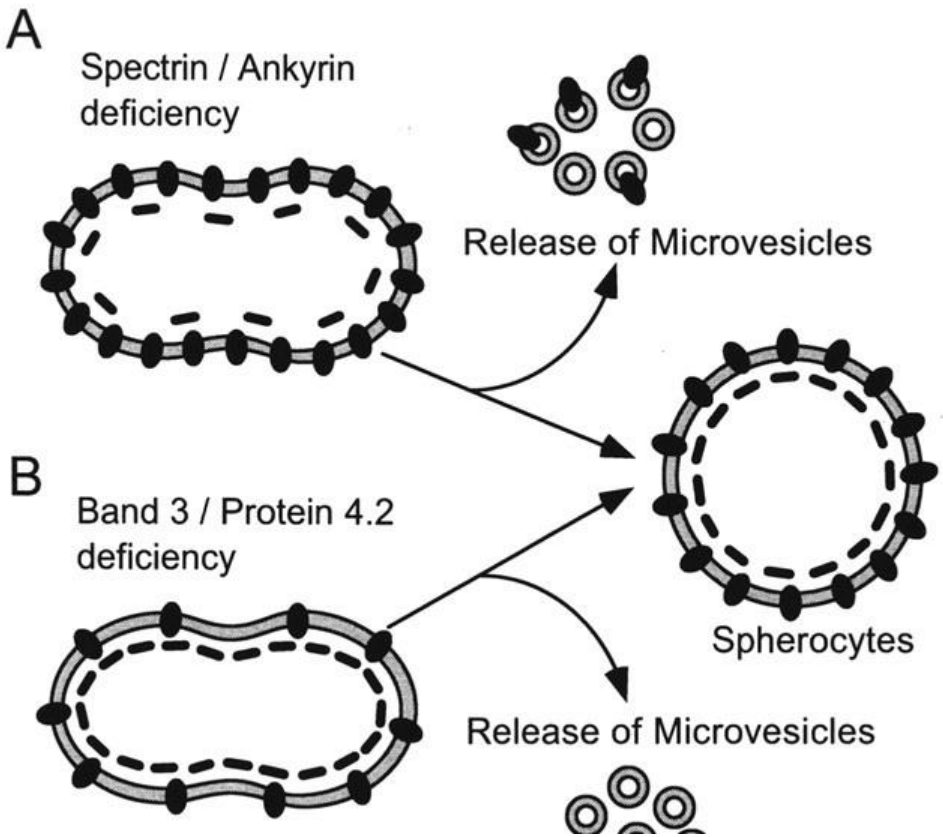
Red Blood Cell Cytoskeleton

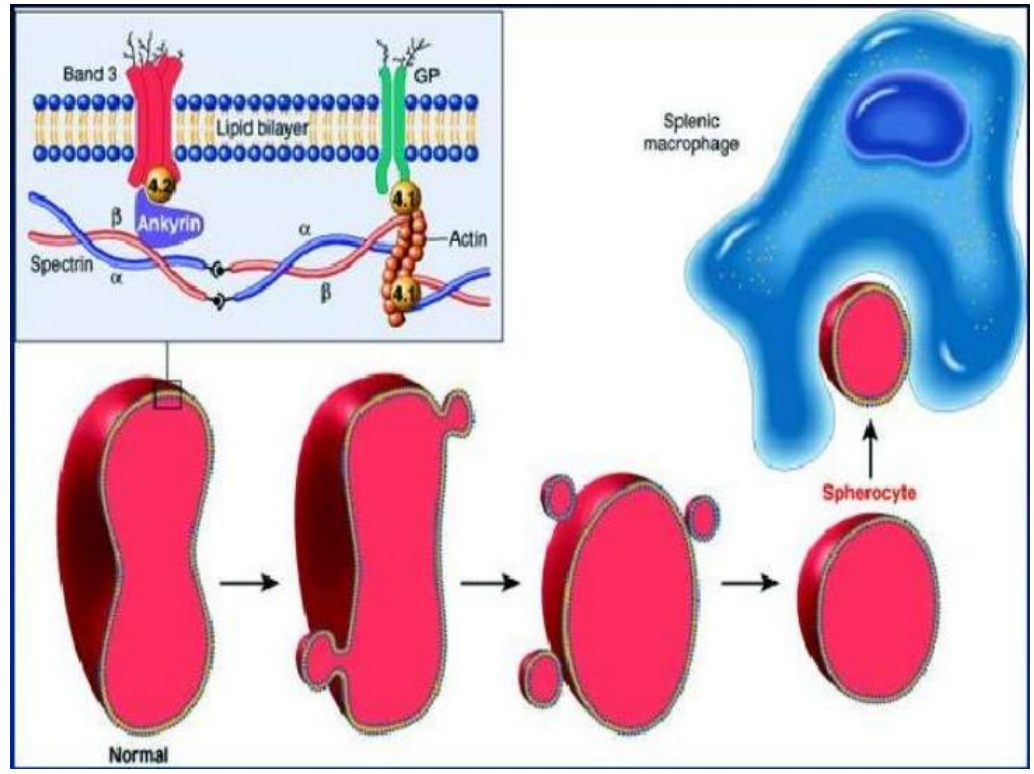


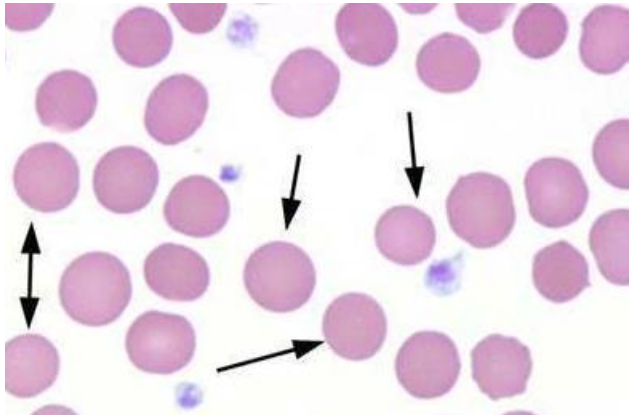


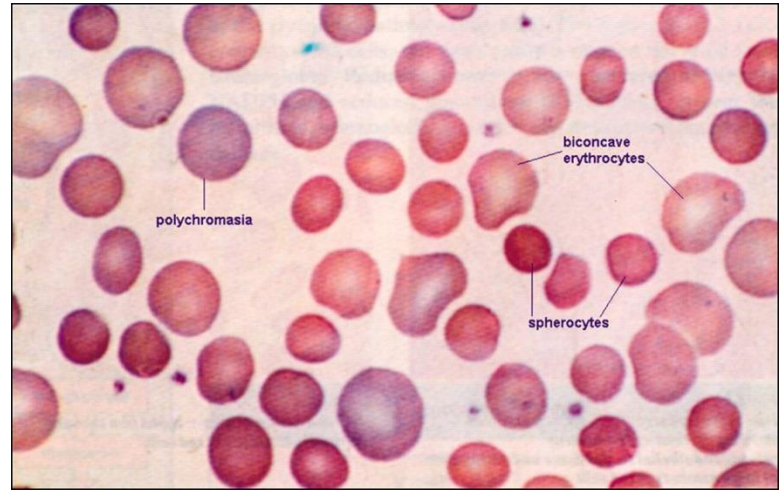
- The RBC, as it continuously Circulates the narrow capillaries of the microvasculature, must be able to undergo extensive passive deformation and to resist fragmentation..
- This requires a highly deformable yet remarkably stable membrane.
- The cytoskeletal proteins are responsible for these important characteristics of the plasma membrane and give the red blood cell the unique biconcave shape.
- Cytoskeletal protein network
  - Spectrin
  - Actin
  - Ankyrin
  - Tropomyosin
  - Proteins 4.1 , 4.2 and 4.9
  - Band 3

Hereditary Spherocytosis









Hemoglobin (Hb)

- Globular protein
- Heme + Globin

Accounts for > 95% of protein in RBC

Main functions: transportation of respiratory gases. It carries ~ 98.5% of all O_2

Hb Content of Blood

Concentration of Hb in the Blood

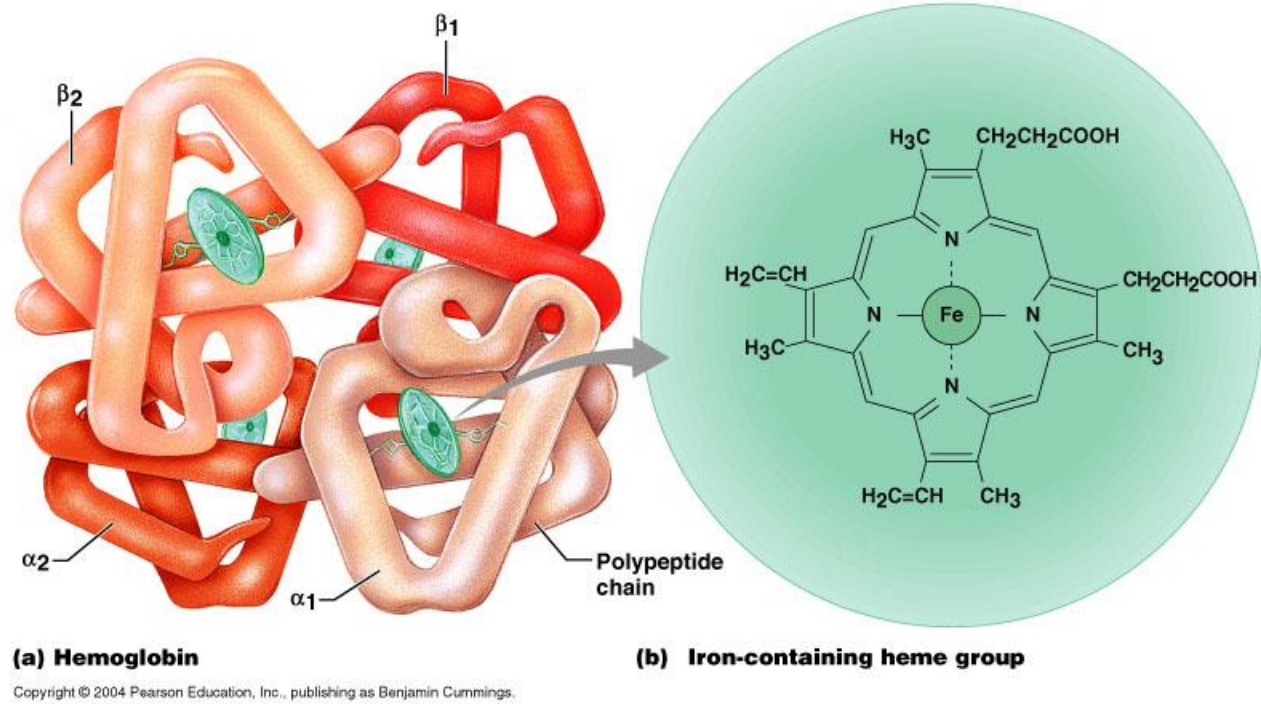
Measured as g/dl (grams per deciliter, or per 100 ml)

Average values:

Male: 13.5 – 17.5 g/dl (16 g/dl)

Female: 12.0 – 15.5 g/dl (14 g/dl)

Infants: 14.0 – 19.0 g/dl



- Each gram of pure hemoglobin is capable of combining with 1.34 ml of oxygen.
- Therefore, in a normal man a maximum of about 20 milliliters of oxygen can be carried in combination with hemoglobin in each 100 milliliters of blood, and in a normal woman 19 milliliters of oxygen can be carried.

Haematological indices

Mean corpuscular volume (MCV): **The average volume of the red blood cells expressed in femtoliters (fl) or cubic micrometers.**

$$= \frac{\text{Hct} \times 10}{\text{RBC } (10^6/\mu\text{L})}$$

Normal value: 90-95 femtoliters (10^{-15} liters) abbreviated fl.

- ❑ **Macrocytic anemias– larger than normal cells**
- ❑ **Normocytic anemias – cells are normal in volume.**
- ❑ **Microcytic anemias– cells are smaller than normal.**

Mean corpuscular Hb (MCH):

The average amount of hemoglobin inside a RBC expressed in picograms (pg).

$$= \frac{\text{Hb} \times 10}{\text{RBC } (10^6/\mu\text{L})}$$

Normal value: 27-33 pg (10^{-12} gram)

- ❑ **Normochromic**
- ❑ **Hypochromic**
- ❑ **Hyperchromic**

Haematological indices

Mean corpuscular Hb concentration (MCHC):

The average concentration of hemoglobin in the RBCs expressed as (gm/dl).

- Normal value: 32- 35 g/dl of RBCs

$$= \frac{Hb \times 100}{Hct}$$

Indices		Males	Females
Hematocrit (Hct) (%)		47	42
Red blood cells (RBC) (10^6/L)		5.4	4.8
Hemoglobin (Hb) (g/dL); dL = 100 milliliters		16	14
Mean corpuscular volume (MCV) (fL) [a]	$= \frac{Hct \times 10}{RBC\ (10^6/\mu L)}$	90 - 95	90 - 95
Mean corpuscular hemoglobin (MCH) (pg)	$= \frac{Hb \times 10}{RBC\ (10^6/\mu L)}$	29	29
Mean corpuscular hemoglobin concentration (MCHC) (g/dL of cells) [b]	$= \frac{Hb \times 100}{Hct}$	34	34
Mean cell diameter (MCD) (µm)	= Mean diameter of 500 cells in smear	7.5	7.5

[a] Cells with MCVs > 95 fL are called macrocytes; cells with MCVs < 80 fL are called microcytes.

[b] Cells with MCHs < 25 g/dL are called hypochromic.

Thank You