Blood and Blood Gas Transport

A. Composition of Blood
1. plasma
   - water + electrolytes (Na⁺, Cl⁻, K⁺, HCO₃⁻, Ca²⁺), plasma proteins, glucose, urea, etc.
2. formed elements
   a. erythrocytes (RBCs) ~ 5,000,000/µL
   b. leukocytes (WBCs) ~ 5,000-10,000/µL
   c. platelets

RBCs are anucleated cells, filled with hemoglobin. The hematocrit is % by volume of RBCs (normally ~ 45%).

Blood cells are produced in red bone marrow from hematopoietic stem cells. Erythropoietin - hormone produced by kidneys, stimulates production and differentiation of RBCs. Polycythemia - high RBC count (high hematocrit). Anemia - low O₂ carrying capacity of blood (low hemoglobin concentration).

B. Hemoglobin Structure and Function
- protein composed of 4 polypeptide (globin) subunits (2 α, 2 β)
- each subunit contains a heme group with iron (Fe²⁺) at the center
- each heme reversibly binds O₂ (→ 4 O₂ binding sites)

C. Oxygen Transport by Blood
1. O₂ Dissolved in Plasma
   - low solubility of O₂ in plasma at PO₂ = 100 mm Hg, plasma: 3 mL O₂ / L blood
2. O₂ Carried by Hemoglobin
   - whole blood: 200 mL O₂ / L blood
   - ~ 99% of O₂ in blood is carried by hemoglobin
   - O₂ carrying capacity of blood depends on hemoglobin concentration

Hemoglobin-O₂ Binding:
- deoxyhemoglobin (Hb) + O₂ ⇌ oxyhemoglobin (Hb O₂)
- binding and release of O₂ depends on:
  a. PO₂ of the blood
  b. affinity of hemoglobin for O₂

3. Oxygen-Hemoglobin Dissociation Curve
- relationship between PO₂ of blood and percent O₂ saturation of hemoglobin
- S-shaped curve results from interactions among hemoglobin subunits
  - promotes loading of O₂ in the lungs and unloading of O₂ in the tissues

Normal values (resting, sea level):
- arterial PO₂ = 100 mm Hg, 98% O₂ saturation
- venous PO₂ = 40 mm Hg, 75% O₂ saturation

In lungs (PO₂ = 100 mmHg): flat part of curve → nearly 100% saturated
In tissues (PO₂ < 60 mmHg): → rapid unloading of oxygen as PO₂ decreases

During exercise, tissue PO₂ ↓→ more O₂ released from Hb → ↓ O₂ sat. of venous blood
Pulmonary disease → ↓ arterial PO₂ → ↓ O₂ sat. (hypoxemia)
At high altitude, ↓ arterial PO₂ → ↓ O₂ sat.
4. Factors That Affect O₂ Affinity of Hemoglobin
   a. ↑ temperature → decreases affinity (rightward shift of O₂ dissociation curve)
   b. ↓ pH (↑ [H⁺]) → decreases affinity - (Bohr shift)
   c. ↑ PCO₂ → decreases affinity
   d. ↑ 2,3-DPG → decreased affinity
   - rightward shift means more O₂ will be unloaded from Hb at a given P_O₂
   - in active tissues, ↑ temperature, ↓ pH and ↑ PCO₂ promote unloading of O₂

D. Carbon Dioxide Transport by Blood
1. Dissolved CO₂ in Plasma (~10%)
2. Bicarbonate (~70%)
   \[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \]
   - carbonic anhydrase in RBC catalyzes conversion of CO₂ to carbonic acid
   - CO₂ is a major source of H⁺ in the body: ↑ PCO₂ → ↓ pH
   - hemoglobin acts as a buffer of H⁺ formed by the reaction
   - HCO₃⁻ transported from RBC out to plasma in exchange for Cl⁻
     In tissues, high PCO₂ drives reaction forward to form HCO₃⁻
     In lungs, lower PCO₂ pulls reactions in reverse, HCO₃⁻ is converted back into CO₂
3. Carbamino Hemoglobin (~20%)
   - binding of CO₂ to amino end of hemoglobin chains