Structure and function of hemoglobin

Objectives

By the end of this lecture, the students should be able to know:

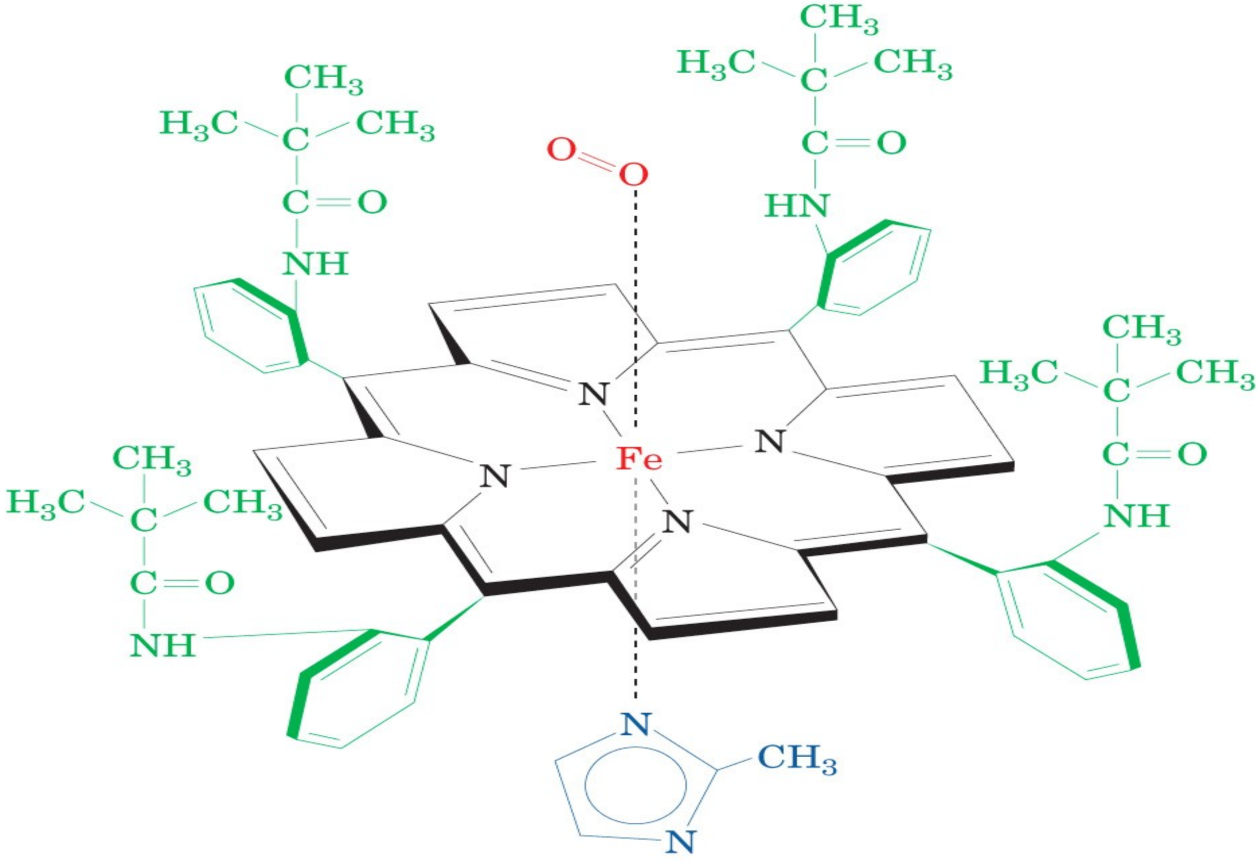
- the structure and function of hemoglobin.
- the factors affecting oxygen binding to hemoglobin.
- examples of normal and abnormal hemoglobin structures.

Hemoglobin (Hb)

- A hemeprotein found only in red blood cells
- Oxygen transport function
- Contains heme as prosthetic group
- Heme reversibly binds to oxygen

The heme group

- A complex of protoporphyrin IX and ferrous iron (Fe^{2+})
- Fe^{2+} is present in the center of the heme
- Fe^{2+} binds to four nitrogen atoms of the porphyrin ring
- Forms two additional bonds with:
  - Histidine residue of globin chain
  - Oxygen



The heme group: Fe^{2+}– porphyrin complex with bound O_2

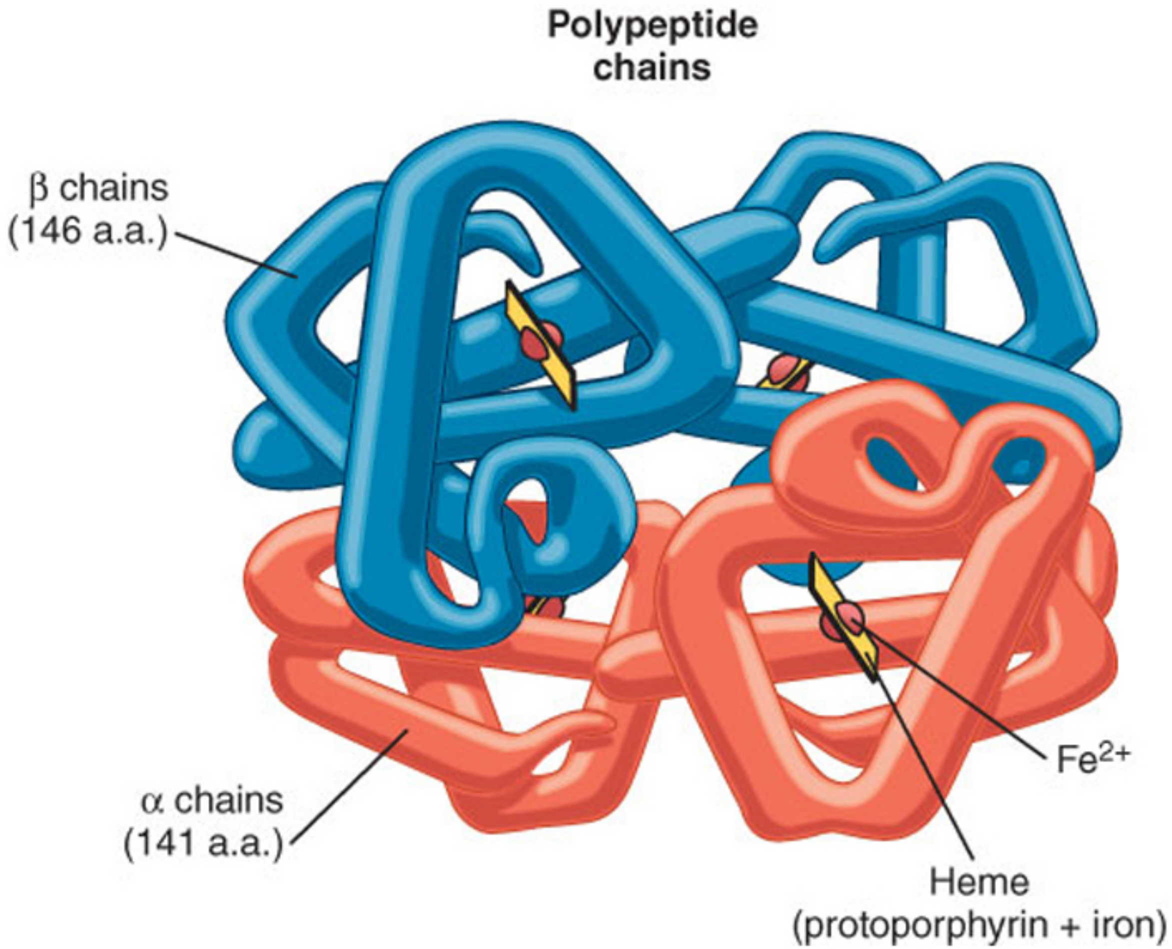
Types of Hb

Form	Chain composition	Fraction of total hemoglobin
HbA	$\alpha_2\beta_2$	90%
HbF	$\alpha_2\gamma_2$	<2%
HbA_2	$\alpha_2\delta_2$	2%–5%
HbA_{1c}	$\alpha_2\beta_2$-glucose	3%–9%

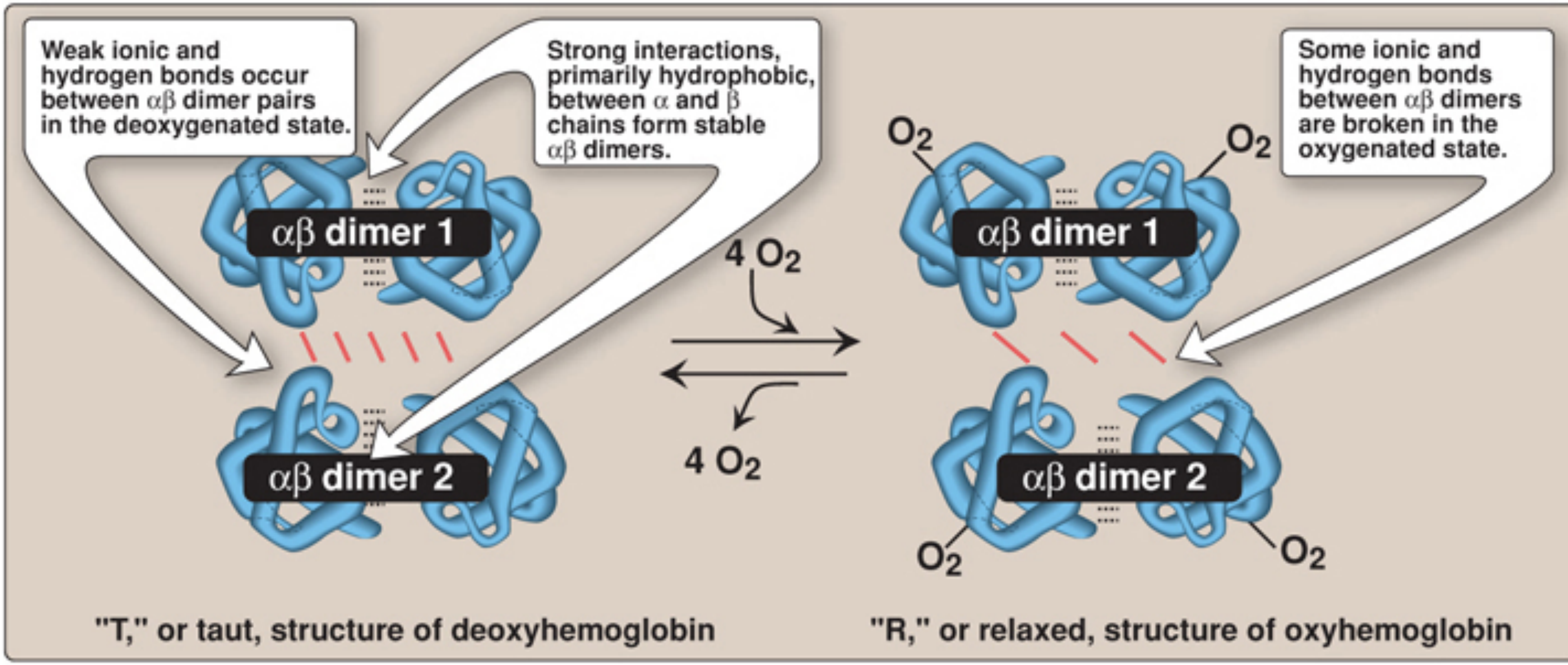
Abnormal:	Carboxy Hb
	Met Hb
	Sulf Hb

Hemoglobin A (HbA)

- Major Hb in adults
- Composed of four polypetide chains:
  - Two α and two β chains
- Contains two dimers of αβ subunits
- Held together by non-covalent interactions
- Each chain is a subunit with a heme group in the center that carries oxygen
- A Hb molecule contains 4 heme groups and carries 4 moelcules of O_2

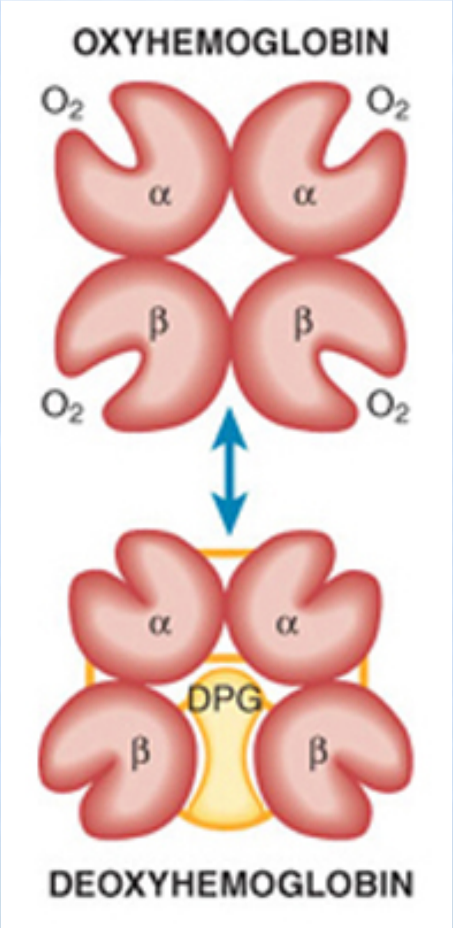

Polypeptide chains
β chains (146 a.a.)
α chains (141 a.a.)
Fe2+
Heme (protoporphyrin + iron)

HbA structure



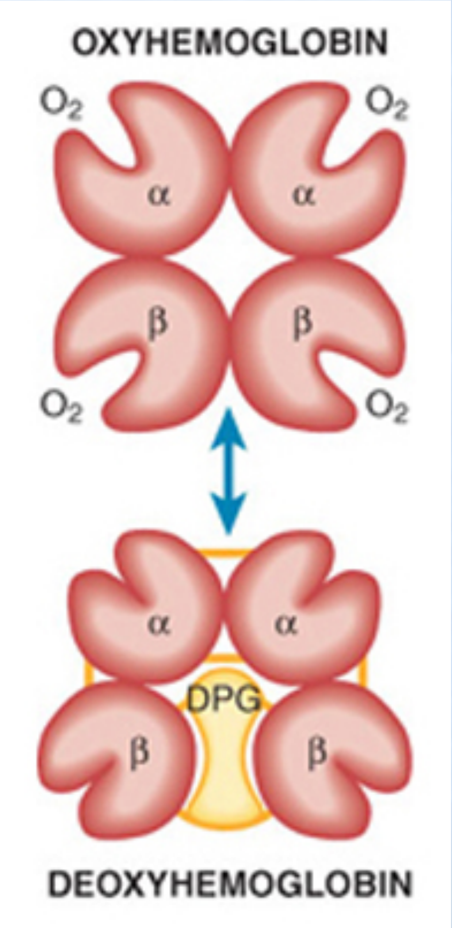
T-form of Hb

- The deoxy form of Hb
- Taut form
- The movement of dimers is constrained
- Low-oxygen-affinity form



R-form of Hb

- The oxygenated form of Hb
- Relaxed form
- The dimers have more freedom of movement
- High-oxygen-affinity form



Hemoglobin function

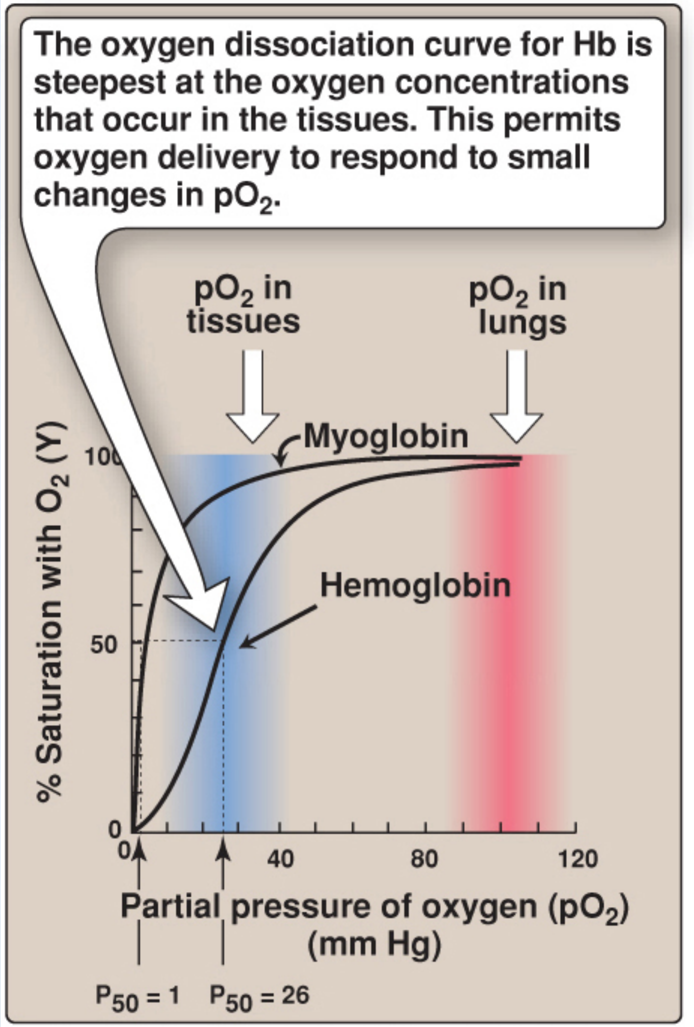
- Carries oxygen from the lungs to tissues
- Carries carbon dioxide from tissues back to the lungs
- Normal level (g/dL):
  - Males: 14-16
  - Females: 13-15

Factors affecting oxygen binding

- Four allosteric effectors:
  - pO_2 (partial oxygen pressure)
  - pH of the environment
  - pCO_2 (partial carbon dioxide pressure)
  - Availability of 2,3-bisphosphoglycerate

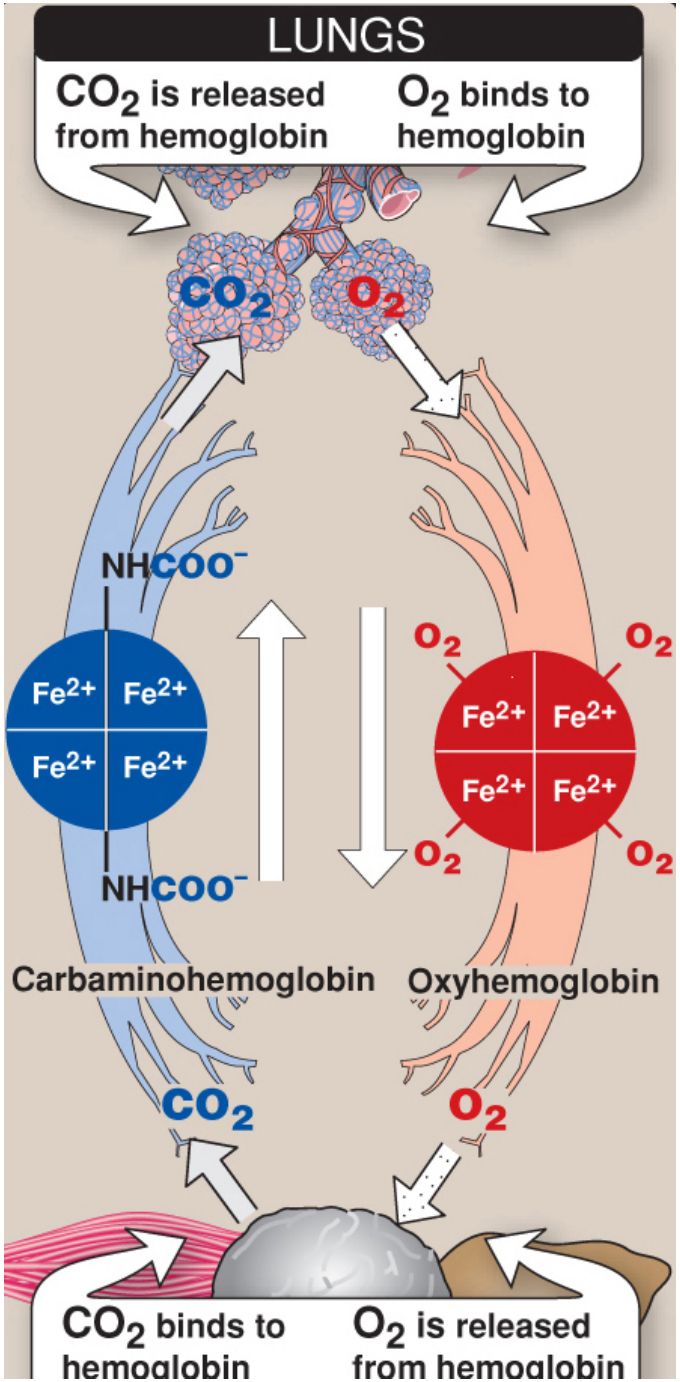
Oxygen Dissociation Curve

- The curve is sigmoidal
- Indicates cooperation of subunits in O_2 binding
- Binding of O_2 to one heme group increases O_2 affinity of others
- Heme-heme interaction



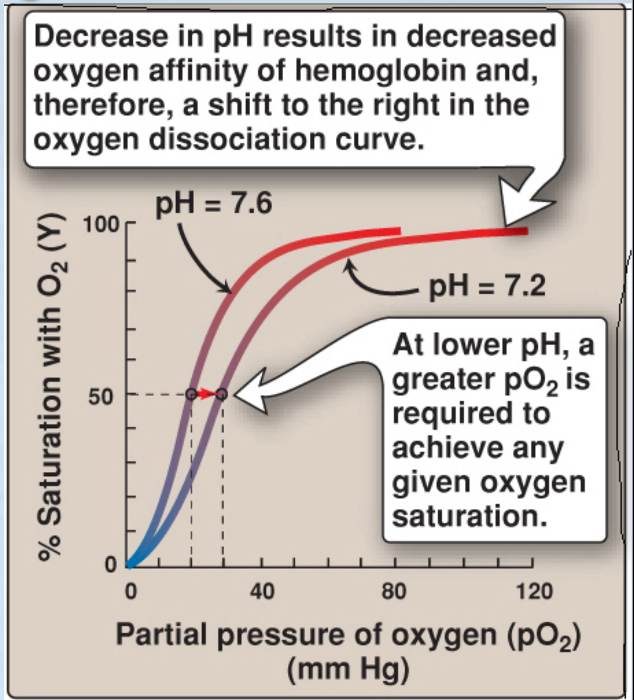
P_{50}

- Indicates affinity of Hb to O_2
- P_{50}(mm Hg): the pressure at which Hb is 50% saturated with O_2
- High affinity → slow unloading of O_2
- Low affinity → fast unloading of O_2
- Lung pO_2 is 100 mm → Hb saturation 100%
- Tissue pO_2 is 40 mm → Hb saturation reduces
- Hence O_2 is delivered to tissues


LUNGS
CO_2 is released from hemoglobin
O_2 binds to hemoglobin
CO_2
O_2
NHCOO⁻
Fe^{2+}
Fe^{2+}
Fe^{2+}
Fe^{2+}
NHCOO⁻
O_2
O_2
Fe^{2+}
Fe^{2+}
Fe^{2+}
Fe^{2+}
O_2
O_2
Carbaminohemoglobin
Oxyhemoglobin
CO_2
O_2
CO_2 binds to hemoglobin
O_2 is released from hemoglobin

The Bohr effect

- It is the shift of the ODC to the right in response to an increase in pCO2 or a decrease in pH
- Effect of pH and pCO_2 on:
  - Oxygenation of Hb in the lungs
  - Deoxygenation in tissues
- Tissues have lower pH (acidic) than lungs
- Due to proton generation (two reactions):
  - $CO_2 + H_20 \rightleftharpoons H_2CO_3$
  - $H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
- Protons reduce O_2 affinity of Hb

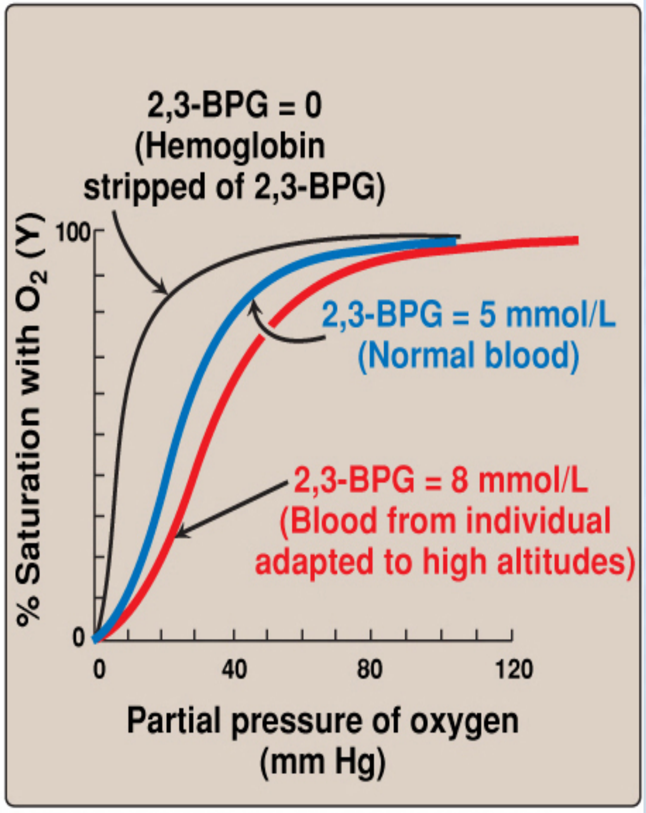


The Bohr Effect

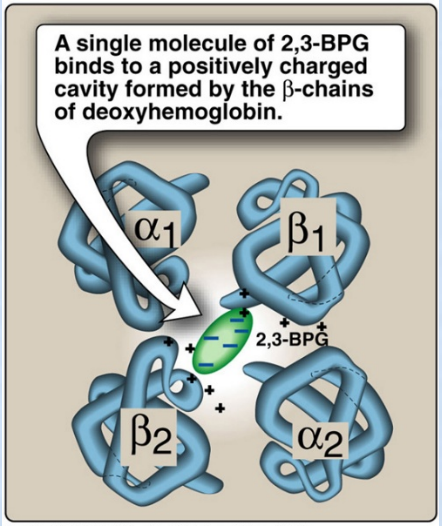
- Causing easier O_2 release into the tissues
- The free Hb binds to two protons
- Protons are released and react with HCO^{3-} to form CO_2 gas ($HCO_3^- + H^+ \rightarrow CO_2 + H_20$)
- The proton-poor Hb now has greater affinity for O_2 (in lungs)
- The Bohr effect removes insoluble CO_2 from blood stream
- Produces soluble bicarbonate

Availability of 2,3 bisphosphoglycerate

- Binds to deoxy-hb and stabilizes the T-form
- When oxygen binds to Hb, BPG is released



At high altitudes:
-RBC number increases
-Hb conc. increases
-BPG increases



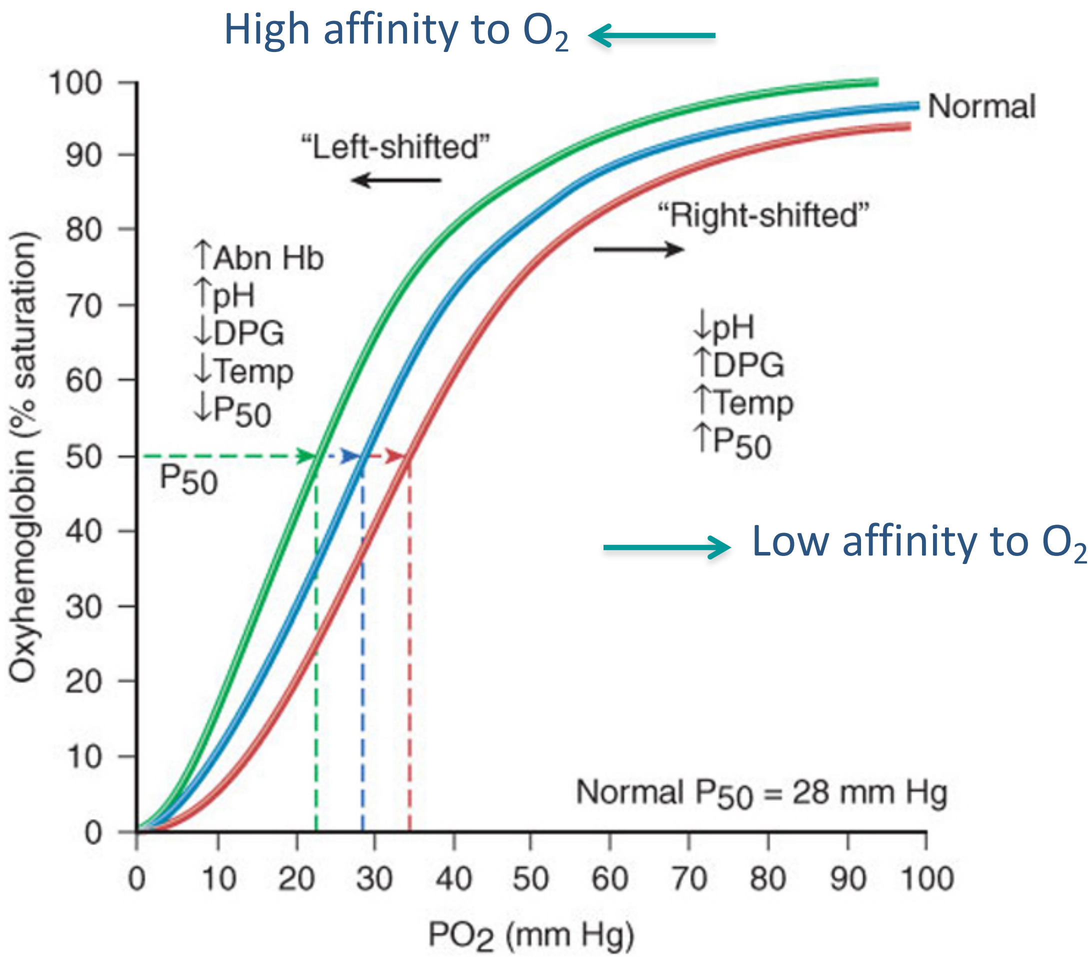
High altitude and O_2 affinity

- In hypoxia and high altitude
  - 2,3 BPG levels rise
  - This decreases O_2 affinity of Hb
  - Thus increases O_2 delivery to tissues

High O_2 affinity

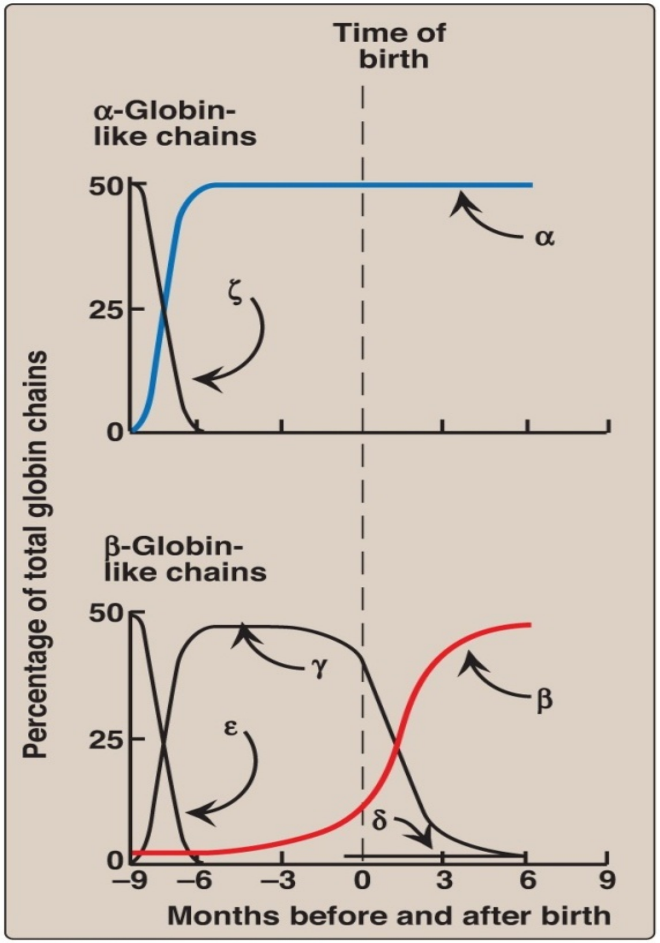
High O_2 affinity is due to:

- Alkalosis
- High levels of Hb F
- Multiple transfusion of 2,3 DPG-depleted blood


High affinity to O_2
100
90
80
70
60
50
40
30
20
10
0
Oxyhemoglobin (% saturation)
"Left-shifted"
"Right-shifted"
Normal
↑Abn Hb
↑pH
↓DPG
↓Temp
↓P_{50}
P_{50}
↓pH
↑DPG
↑Temp
↑P_{50}
Low affinity to O_2
Normal P_{50} = 28 mm Hg
0 10 20 30 40 50 60 70 80 90 100
PO_2 (mm Hg)

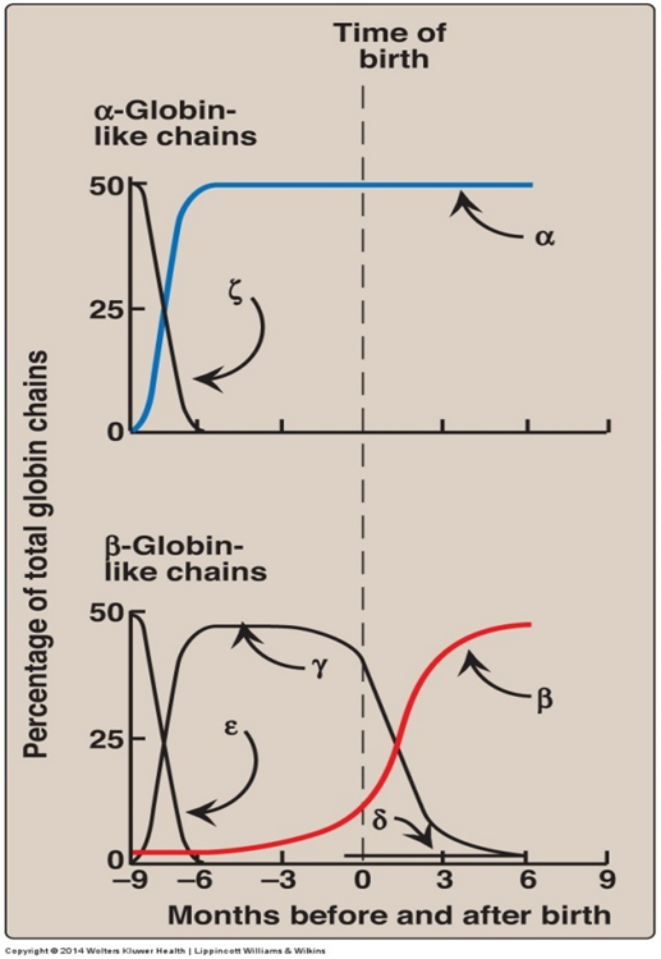
Fetal Hemoglobin (HbF)

- Major hemoglobin found in the fetus and newborn
- Tetramer with two α and two γ chains
- Higher affinity for O_2 than HBA
- Transfers O_2 from maternal to fetal circulation across placenta



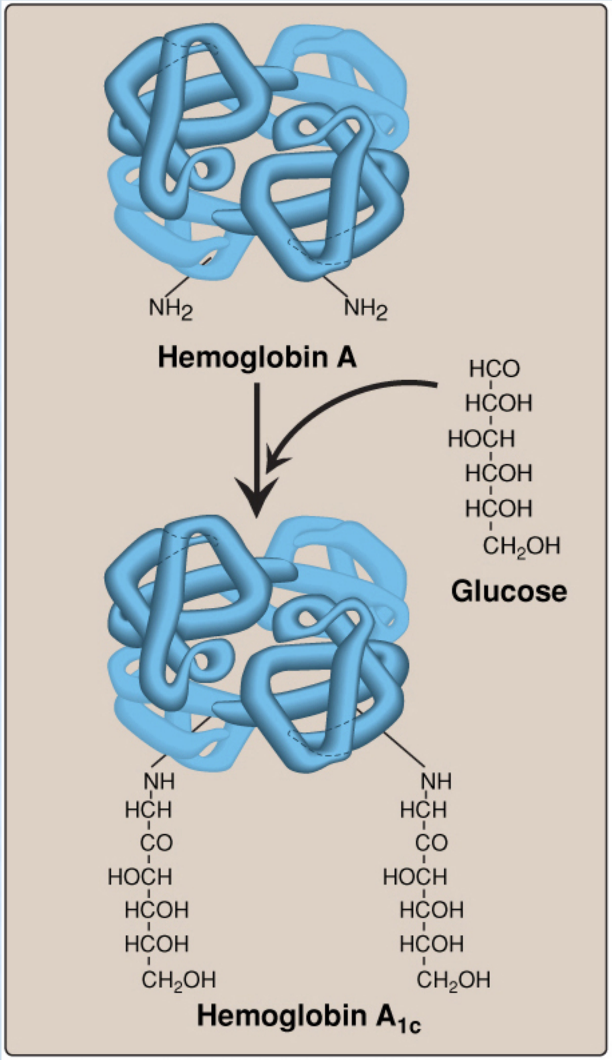
HbA_2

- Appears shortly before birth.
- Constitutes ~2% of total Hb
- Composed of two α and two δ globin chains



HbA_{1c}

- HbA undergoes non-enzymatic glycosylation
- Glycosylation depends on plasma glucose levels
- HbA1c levels are high in patients with diabetes mellitus



Abnormal Hbs

Unable to transport O_2 due to abnormal structure

- Carboxy-Hb: CO replaces O_2 and binds 220X tighter than O_2 (in smokers)
- Met-Hb: Contains oxidized Fe^{3+} (~2%) that cannot carry O_2
- Sulf-HB: Forms due to high sulfur levels in blood (irreversible reaction)

Reference

Lippincott's Illustrated Reviews Biochemistry: Unit I, Chapter 3, Pages 25 -42.