Human Phys PCB4701

Lecture 22: Respiration part 2

T. Houpt, Ph.D.
houpt@bio.fsu.edu

Hemoglobin and Hemoglobin Dissociation Curves

Transport of CO_2

Respiratory Challenge:
    Fetus In Utero (in the uterus)

Hemoglobin

Respiratory pigment that picks up oxygen from lungs, releases oxygen into tissues: increases oxygen carrying capacity of blood

Consists of 4 protein subunits (2 x alpha, 2 x beta subunits) and 4 **heme molecules** (centered around **iron atom** that binds O_2 molecule). Iron gives blood reddish hue.

oxyhemoglobin: when carrying oxygen; **deoxyhemoglobin**: when not carrying oxygen.

Dissociation curve: proportion of hemoglobin that is carrying oxygen as a function of oxygen concentration in the blood (or as a function of pH, or temperature, etc.)

Hemoglobin associates with oxygen at high oxygen concentrations (in lungs); oxygen dissociates from hemoglobin at low oxygen concentrations (in tissues).

Bohr Shift: oxygen dissociates from hemoglobin at low pH (reflects high CO_2 in tissues).

2,3 DPG: molecule that is produced when oxyhemoglobin low; causes more oxygen release from hemoglobin.

hemo- blood
globin - protein

Dissolved O_2 Content of Blood

Henry's Law: $[O_2]$ ml/L = 0.031 x P_{O2}

at P_{O2} in lungs = 100 mmHg

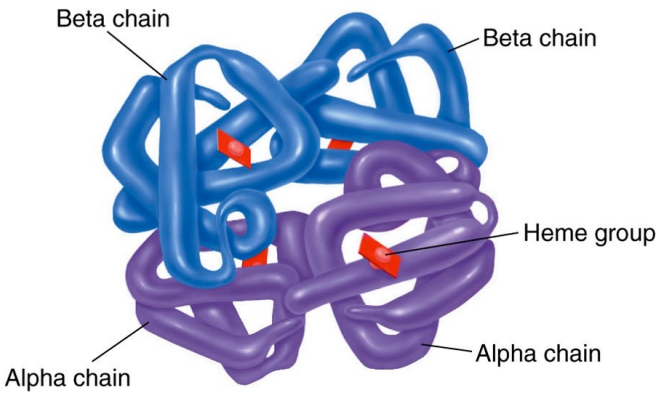
$[O_2]$ in blood = 3.0ml/L

So to find total dissolved oxygen in human blood (5 L)

= 3.0 ml/L x 5 L blood = 150 ml O_2 (dissolved)

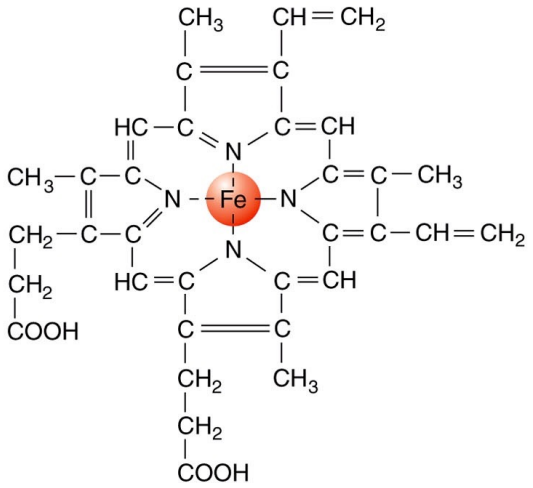
but human uses 250 ml O_2 per minute….

Hemoglobin



(a)

Heme



(b)

Figure 16.32

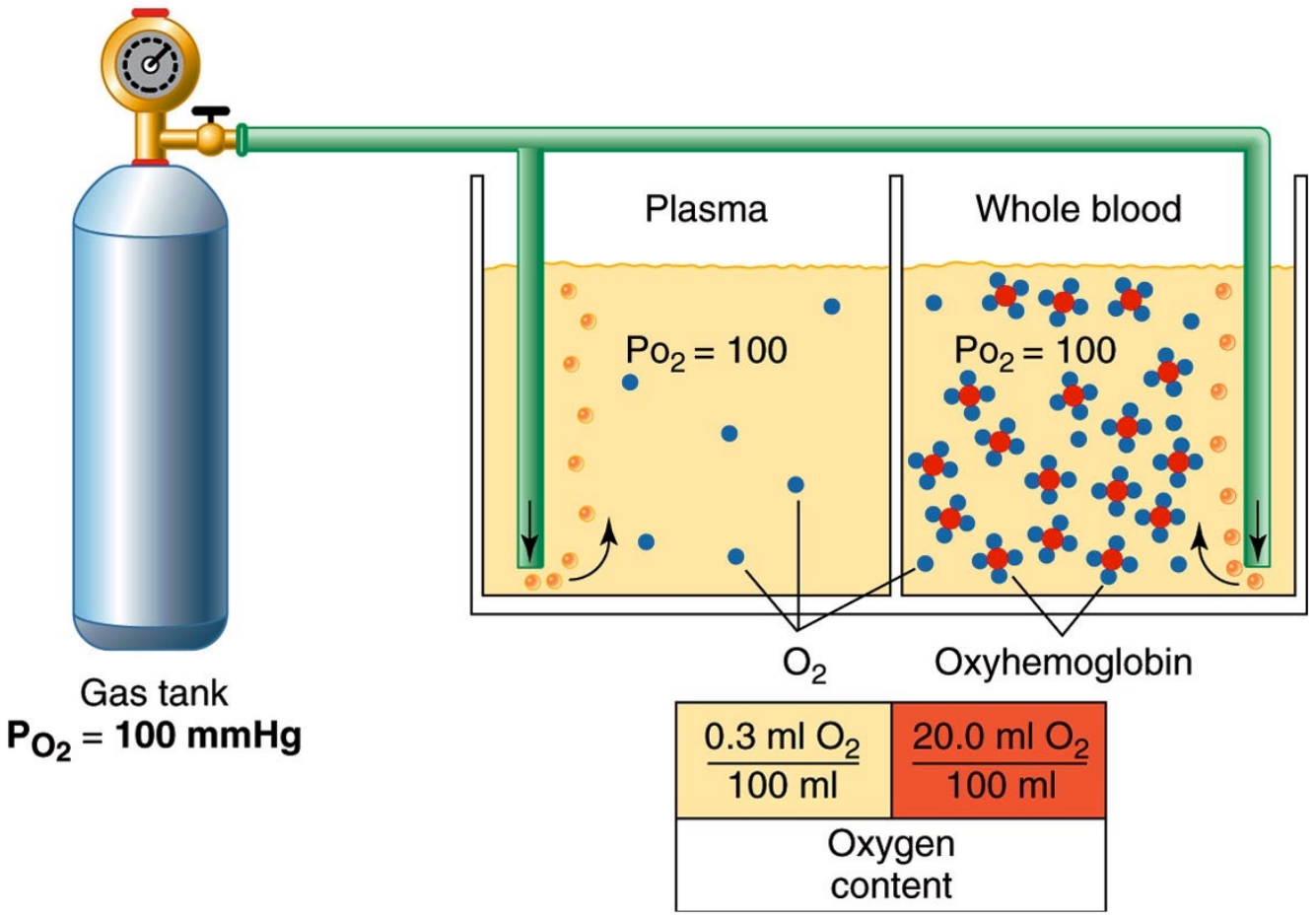
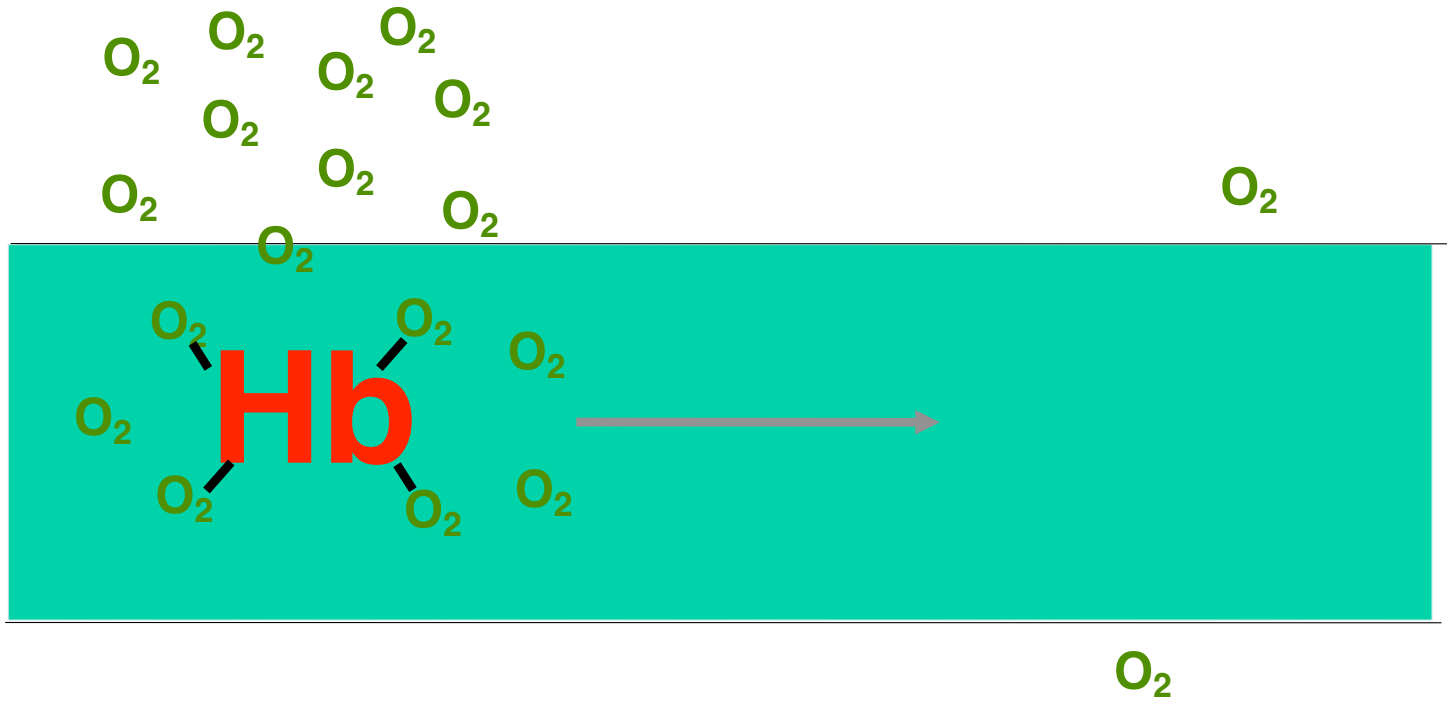
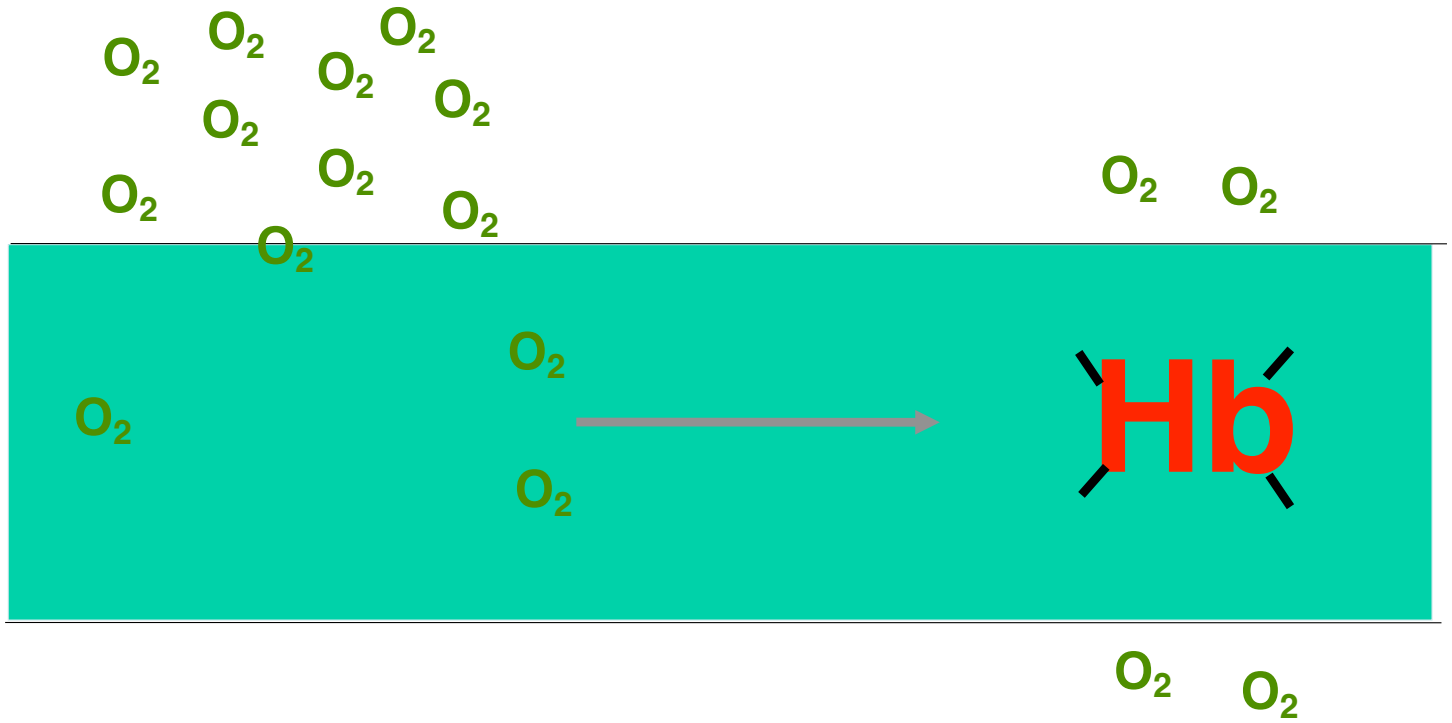

Plasma
Whole blood
$Po_2 = 100$
$Po_2 = 100$
O_2
Oxyhemoglobin
Gas tank
P_{O_2} = 100 mmHg
0.3 ml O_2 / 100 ml
20.0 ml O_2 / 100 ml
Oxygen content

Figure 16.31


O2
O2
O2
O2
O2
O2
O2
O2
O2
O2
O2
Hb
O2
O2
O2
O2
O2
O2
O2
Lungs
PO2 = 100
Tissue
PO2 = 40


O2
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O2
O2
O2
O2
O2
Hb
Lungs
PO2 = 100
Tissue
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O_2 Content of Oxyhemoglobin in Blood

[O_2] bound to saturated oxyhemoglobin = 1.36 ml/g Hb

[Hb] = 150 g / L of blood

So to find total O_2 in human blood (5 L)

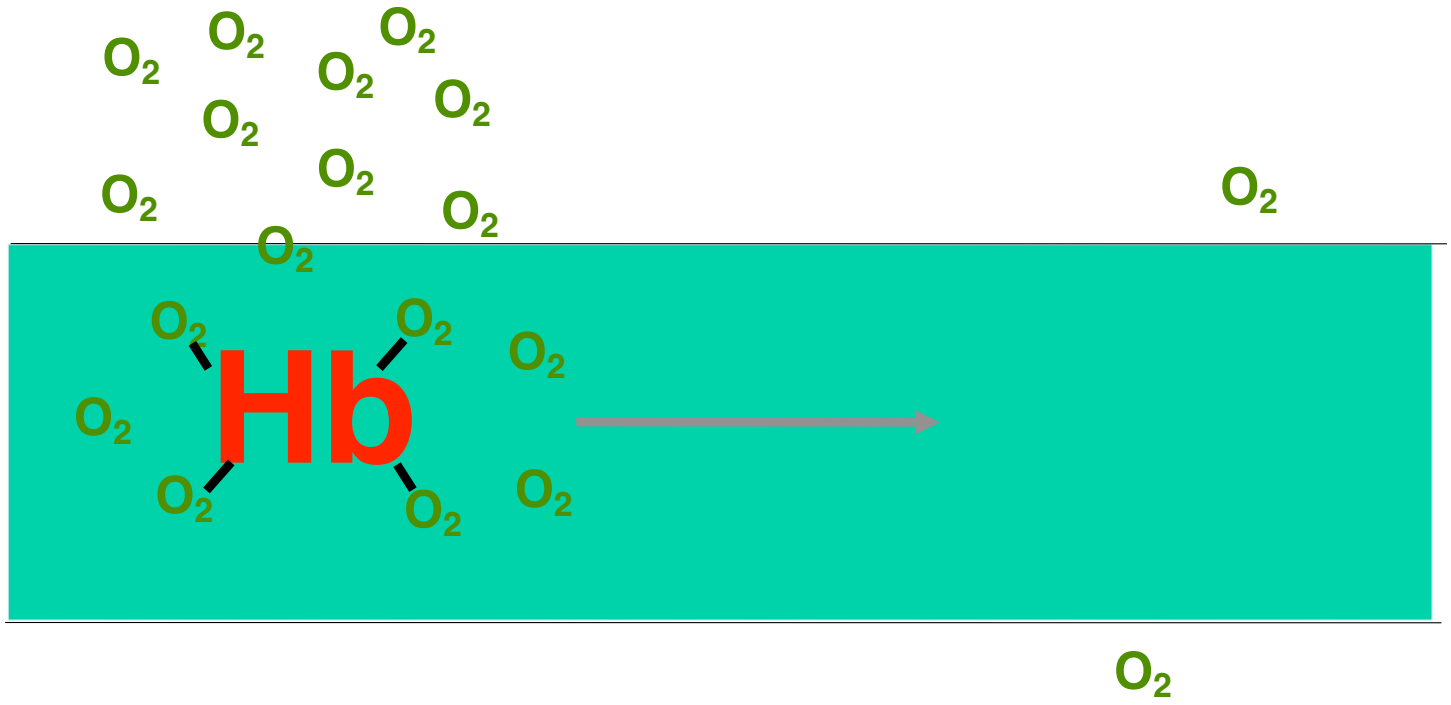
1.36 ml O_2 / g Hb x 150 g Hb / L x 5 L blood

= 1020 ml O_2

Total O_2 = 150 ml dissolved O_2 + 1020 ml O_2-Hb = 1170 ml

human uses 250 ml O_2 per minute;

so hemoglobin provides a large reserve of O_2


O2
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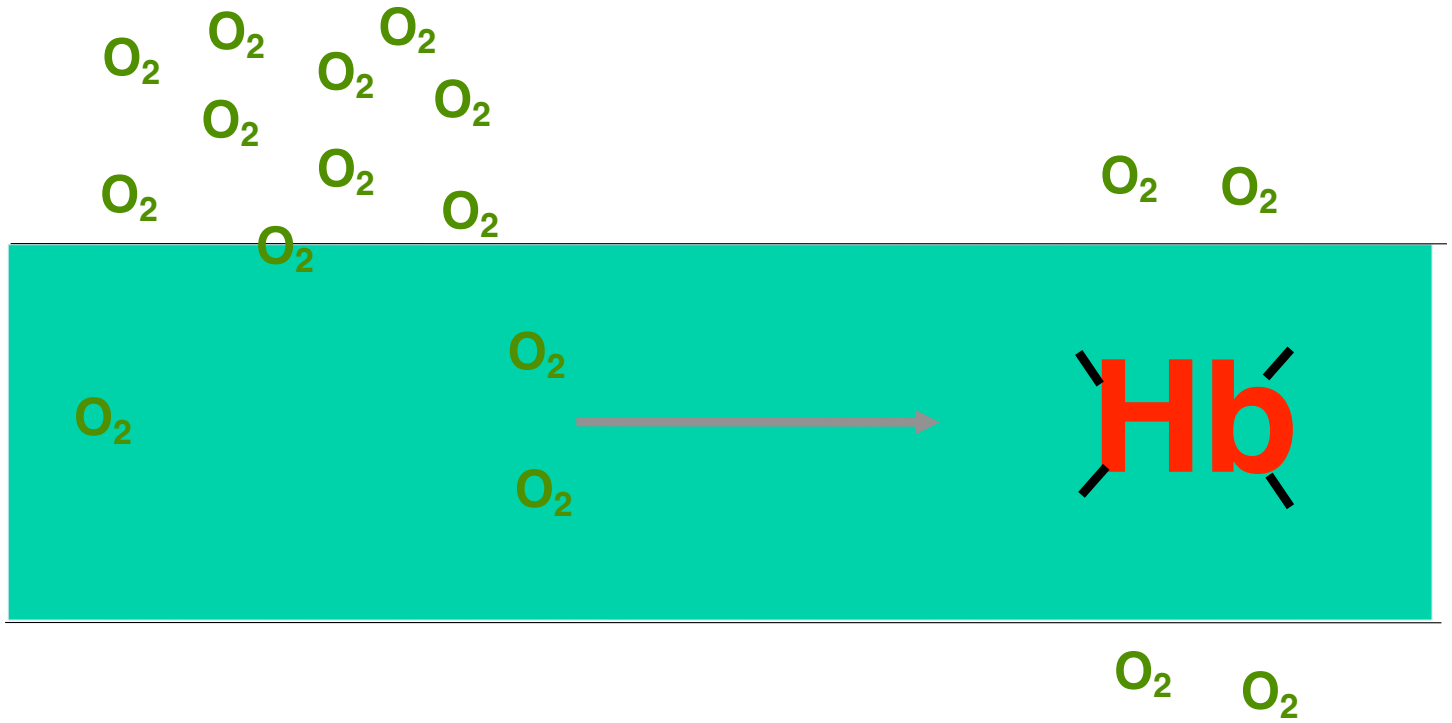
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Hemoglobin Dissociation curve

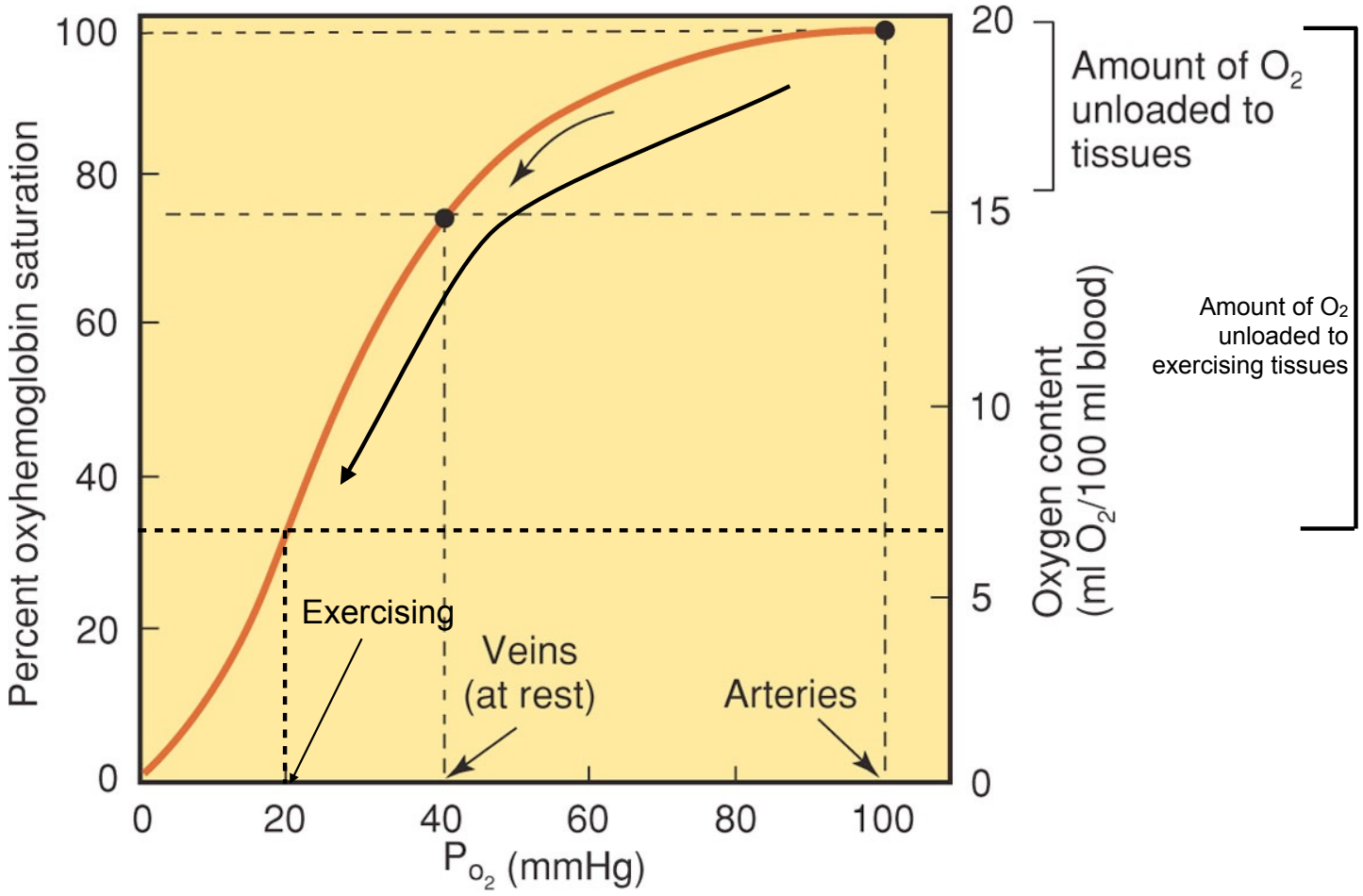


Figure 16.33

Bohr Shift: oxygen dissociates from hemoglobin at low pH (high CO_2 in tissues).

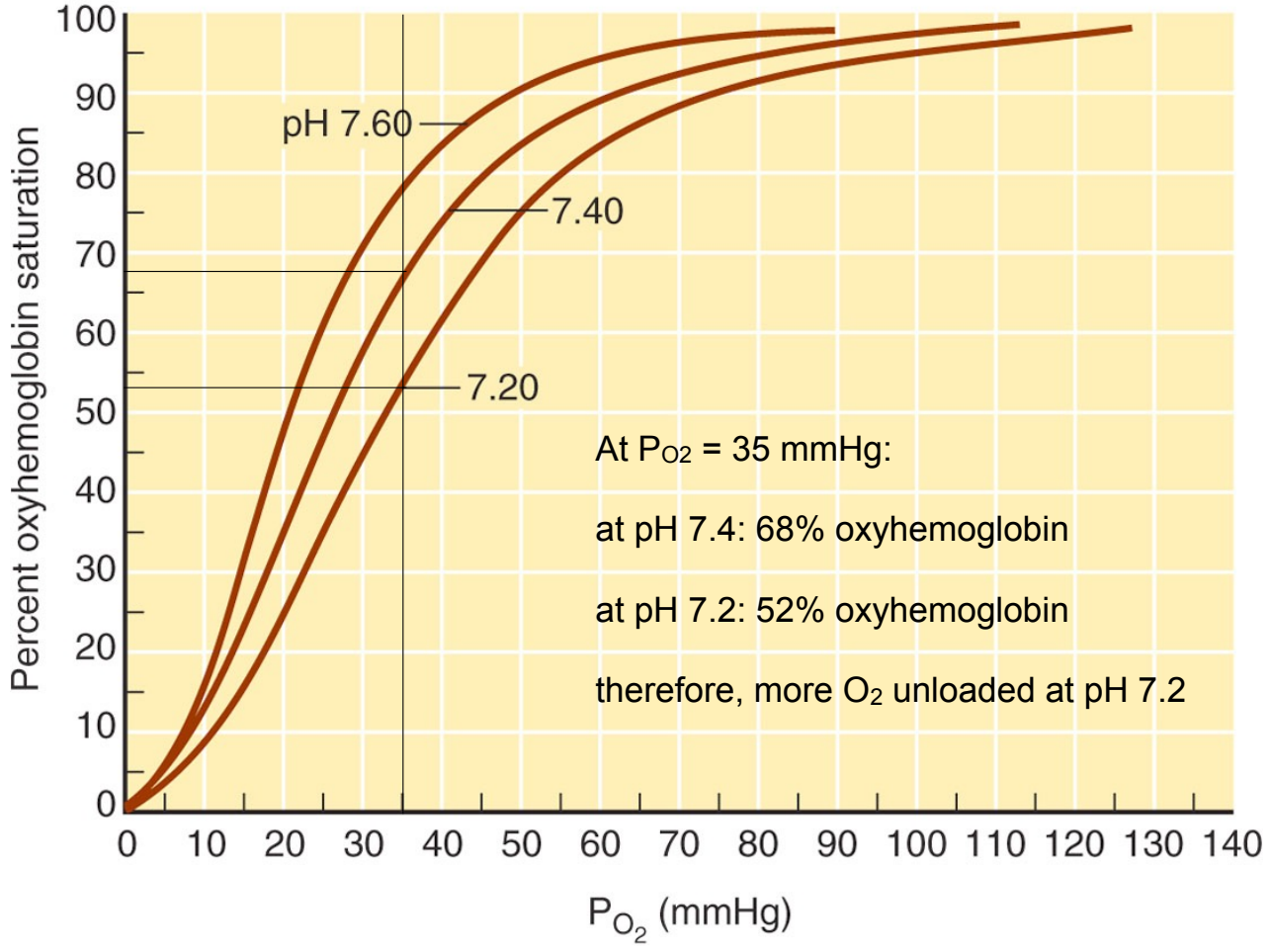


Figure 16.34

Myoglobin

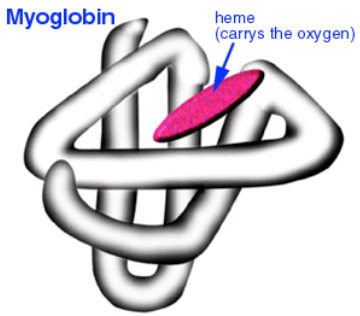
Respiratory pigment in skeletal and cardiac muscle cells. Similar to hemoglobin, but only 1 heme molecule. Stores oxygen in muscle cells, helps transfer oxygen from blood to muscle mitochondria.

Dissociation curve for myoglobin is shifted to the left: only unloads oxygen at very low oxygen levels (during exercise).

In heart muscle, myoglobin stores oxygen for use during systole, when coronary arteries are squeezed shut by contraction.

Myoglobin in the blood indicates damage to muscle tissue.

Myoglobin



Hemoglobin

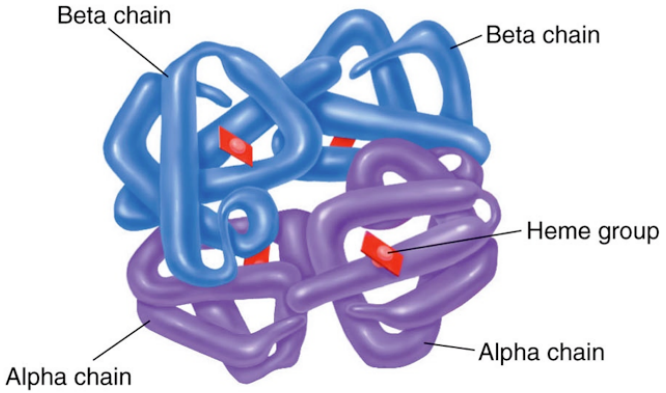
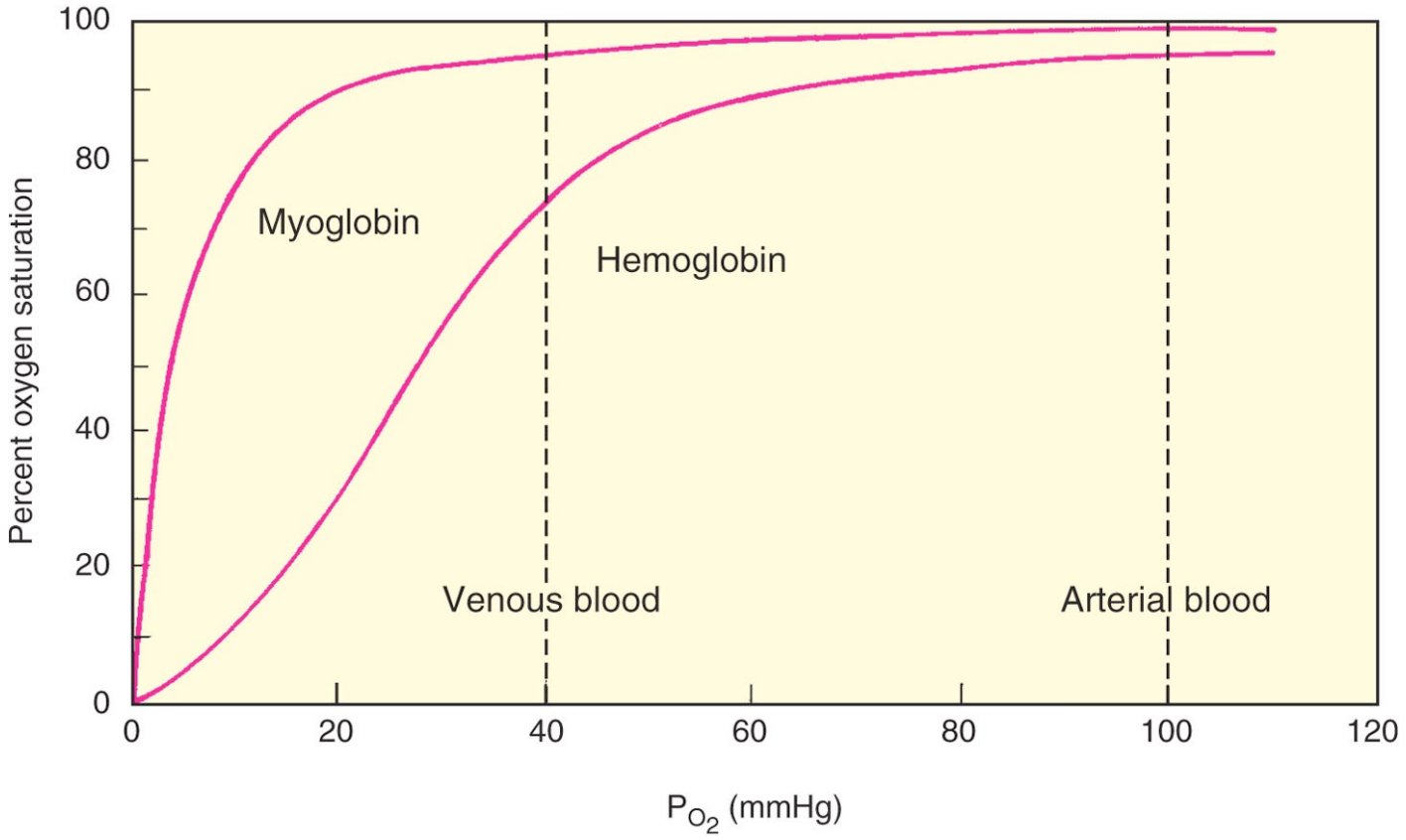


Figure 16.37

Myoglobin optimized for Low Oxygen Conditions



Carbon Dioxide transport

Carbon Dioxide is transported in the blood as:

dissolved CO_2 (7% of blood CO_2)
carbaminohemoglobin (20% of blood CO_2)
bicarbonate ion (HCO_3^-)

In Tissue Capillaries: Carbonic Anhydrase in red blood cells catalyzes H_2CO_3 formation. H+ binds to deoxyhemoglobin, HCO_3^- is exchanged for Cl- ion from plasma (chloride shift)

In Pulmonary Capillaries: Reverse chloride shift exchanges Cl- ion to bring HCO3- into red blood cell. Oxyhemoglobin releases H+, so H_2CO_3 -> CO_2 is formed and diffuses into lungs.

Carbon Monoxide poisoning
CO also binds hemoglobin, but binding is **irreversible** (210x higher than O_2). Binding of 50-80% of hemoglobin is fatal. Victims of CO poisoning are cherry red, because of carboxyhemoglobin color.

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Figure 16.38

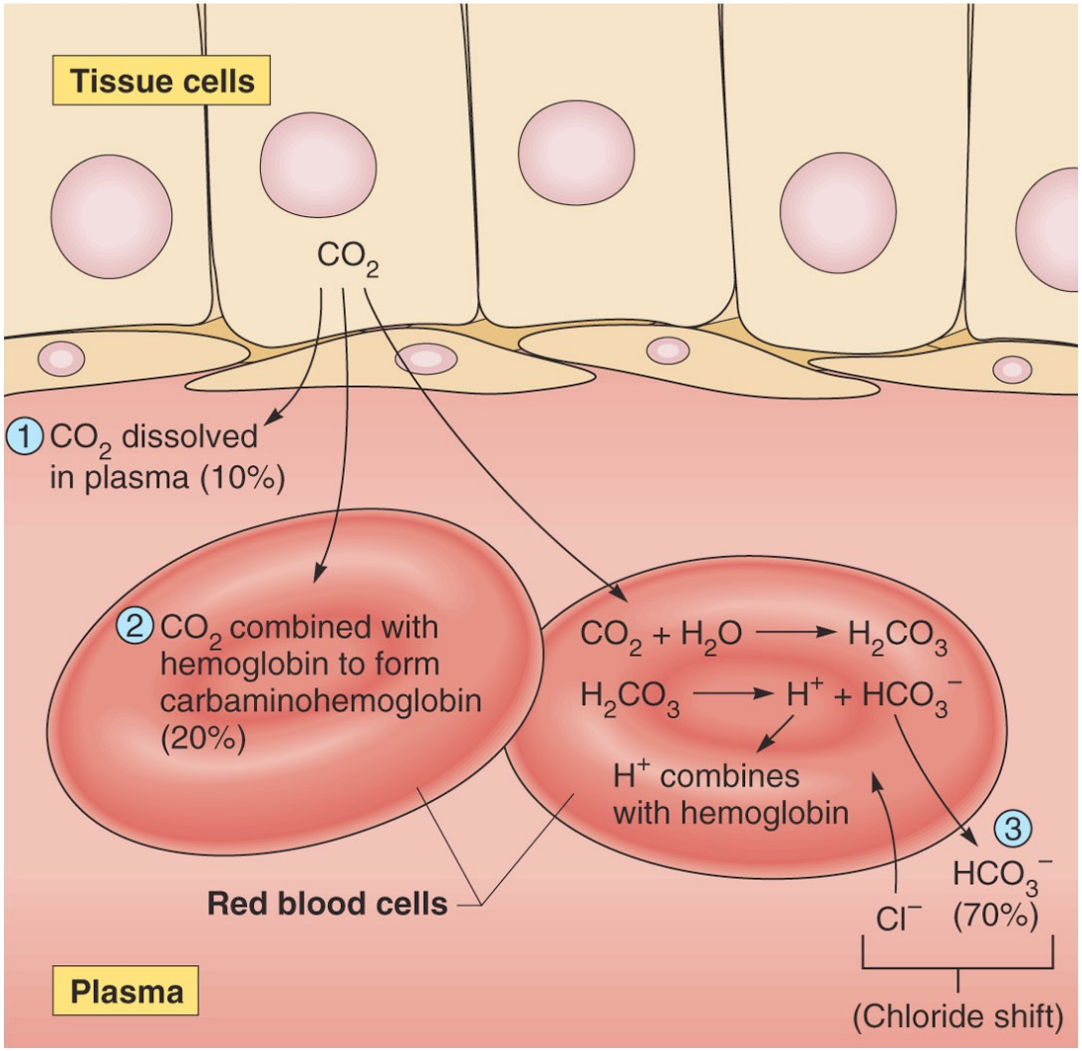
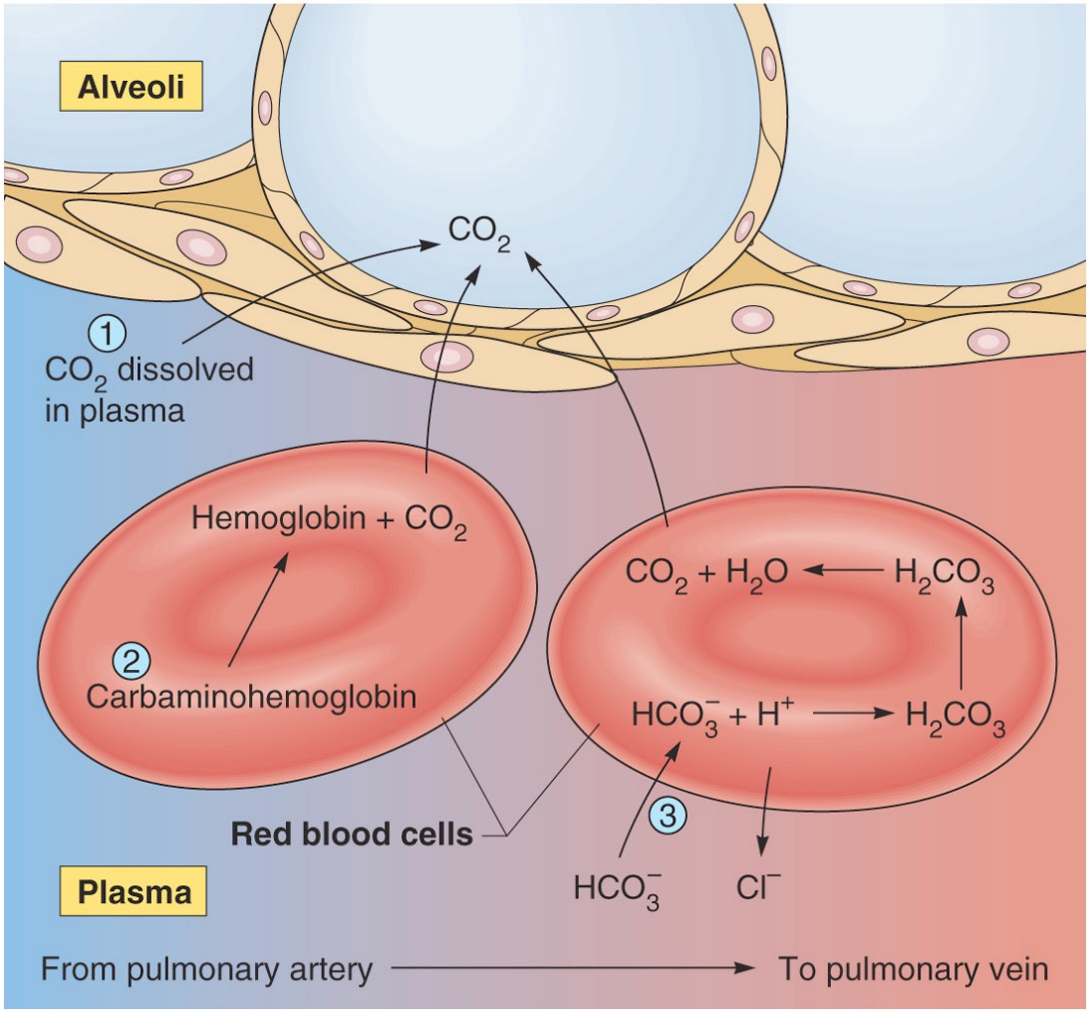

Tissue cells
CO_2
1 CO_2 dissolved in plasma (10%)
2 CO_2 combined with hemoglobin to form carbaminohemoglobin (20%)
$CO_2 + H_2O \rightarrow H_2CO_3$
$H_2CO_3 \rightarrow H^+ + HCO_3^-$
H^+ combines with hemoglobin
3
HCO_3^- (70%)
Cl^-
(Chloride shift)
Red blood cells
Plasma

Figure 16.39


Alveoli
CO_2
1
CO_2 dissolved in plasma
Hemoglobin + CO_2
2
Carbaminohemoglobin
$CO_2 + H_2O$
H_2CO_3
$HCO_3^- + H^+$
H_2CO_3
3
Red blood cells
Plasma
HCO_3^-
Cl^-
From pulmonary artery
To pulmonary vein

Fetal Circulation

- **Placenta**: Gas (and nutrient) exchange in high-surface area capillary bed between mom and fetus
- **Fetal Hemoglobin** binds more O_2 in low-O_2 environment of placenta
- Circulation of blood through **umbilical cord** to placenta to exchange gases.
- **Shunts** in fetal heart to send O_2 rich blood directly from vena cava to left atrium (**oval foramen**) and to aorta (**ductus arteriosus**) so that **lungs are bypassed**

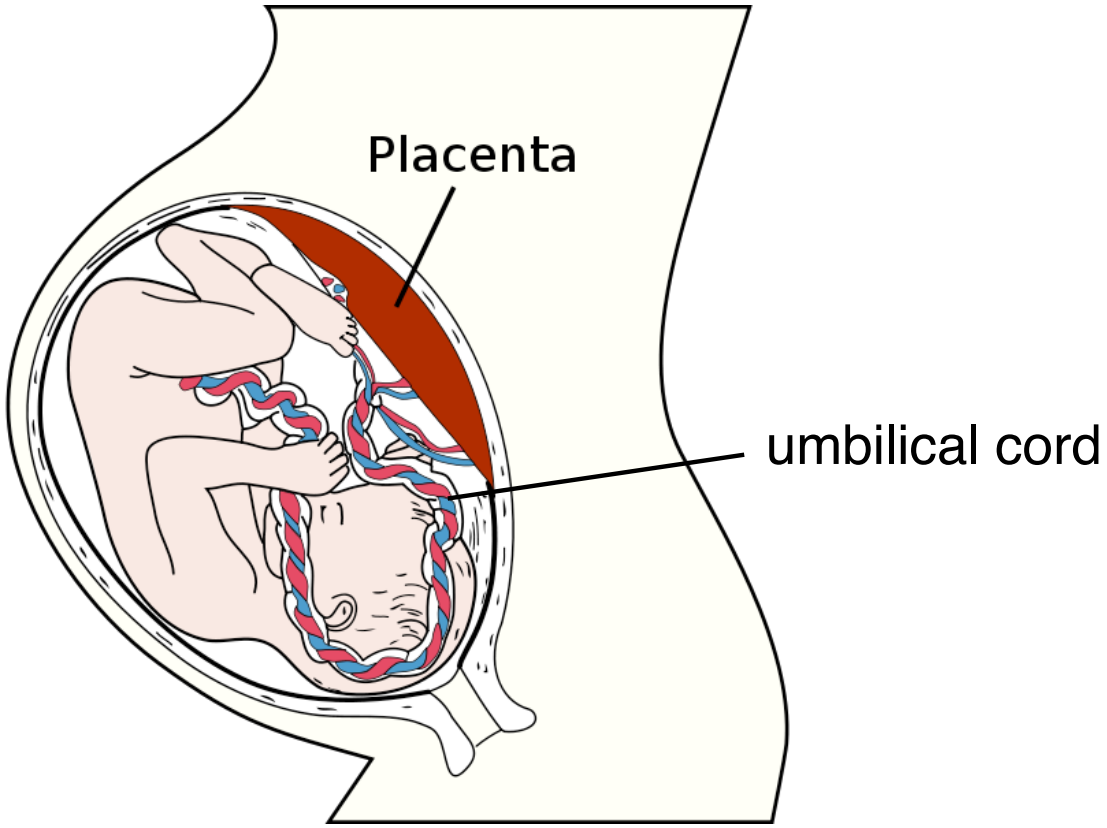
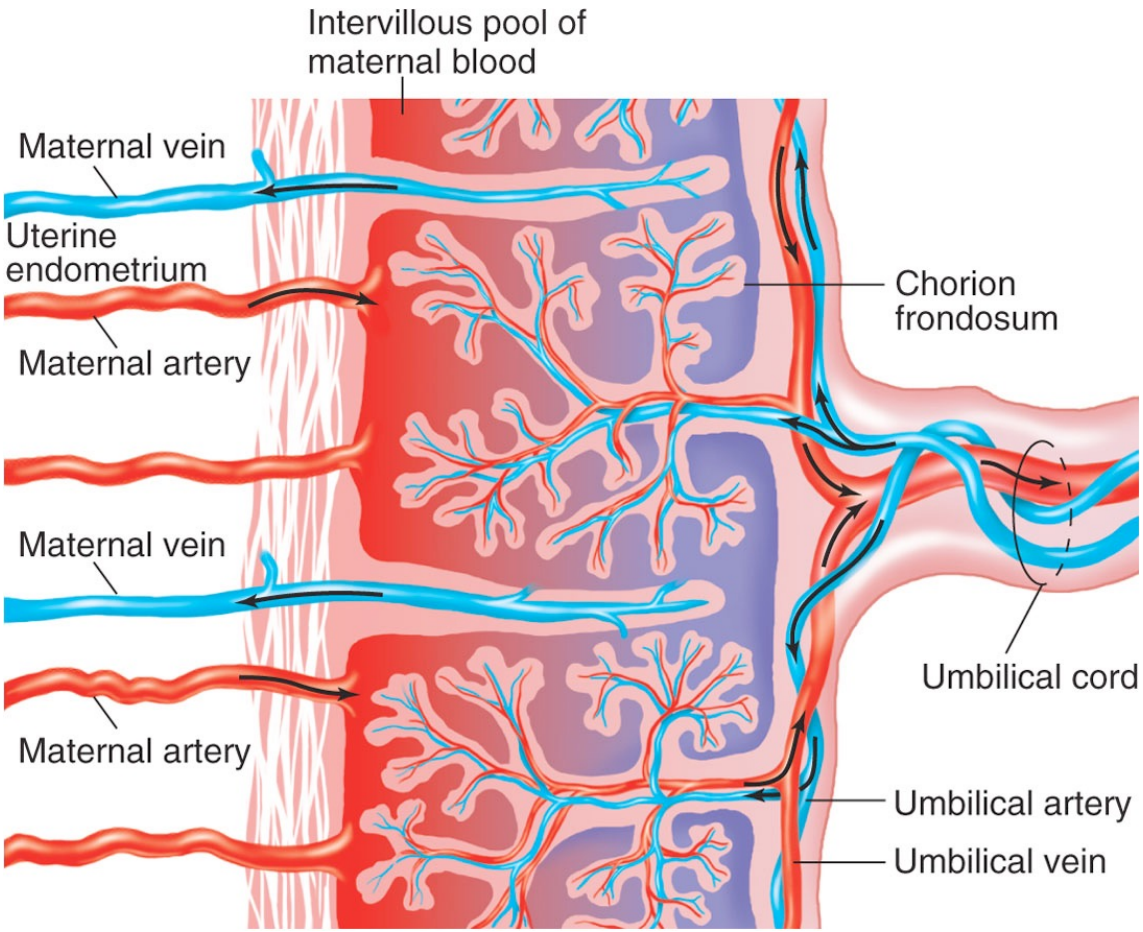
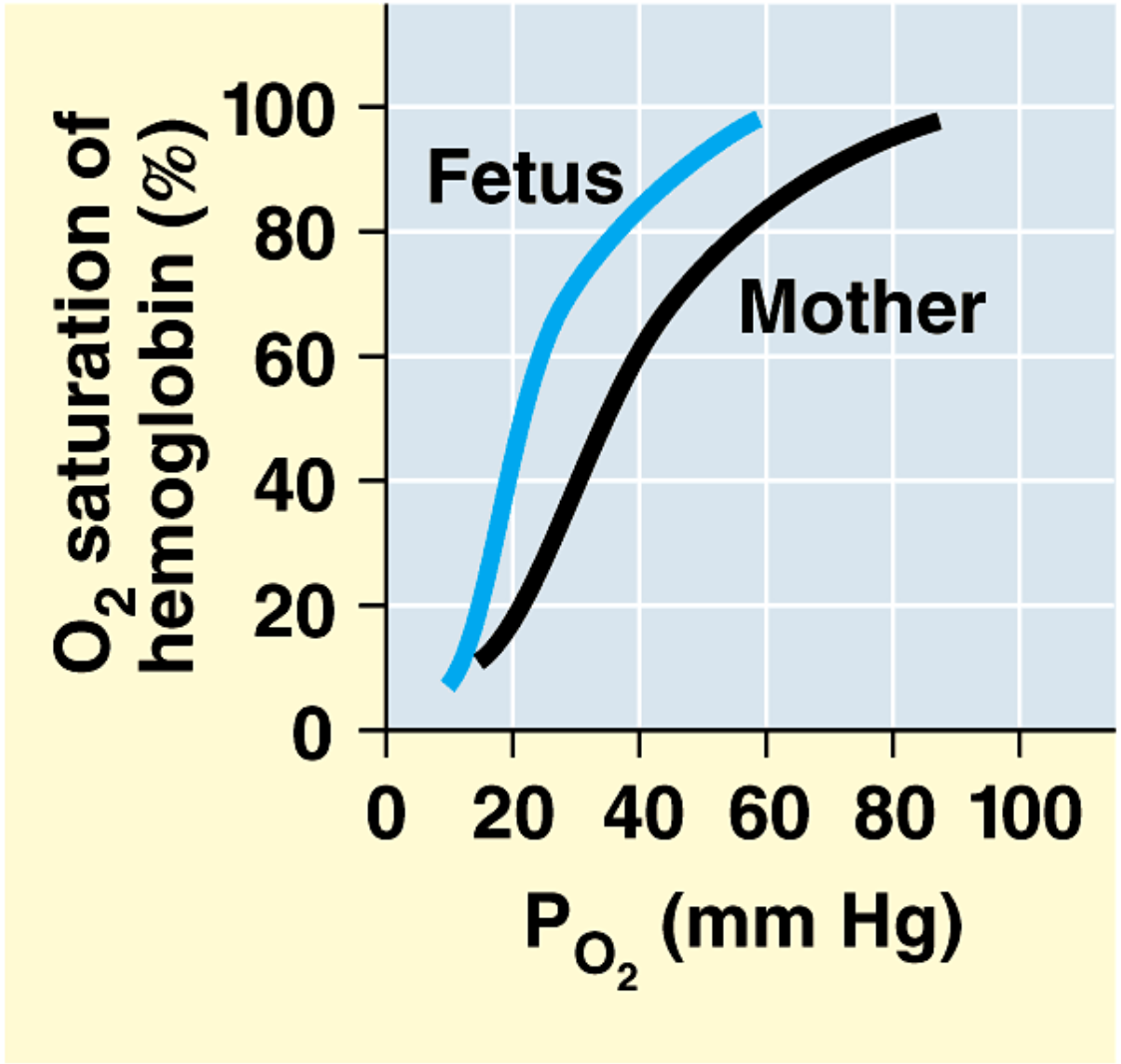

Placenta
umbilical cord

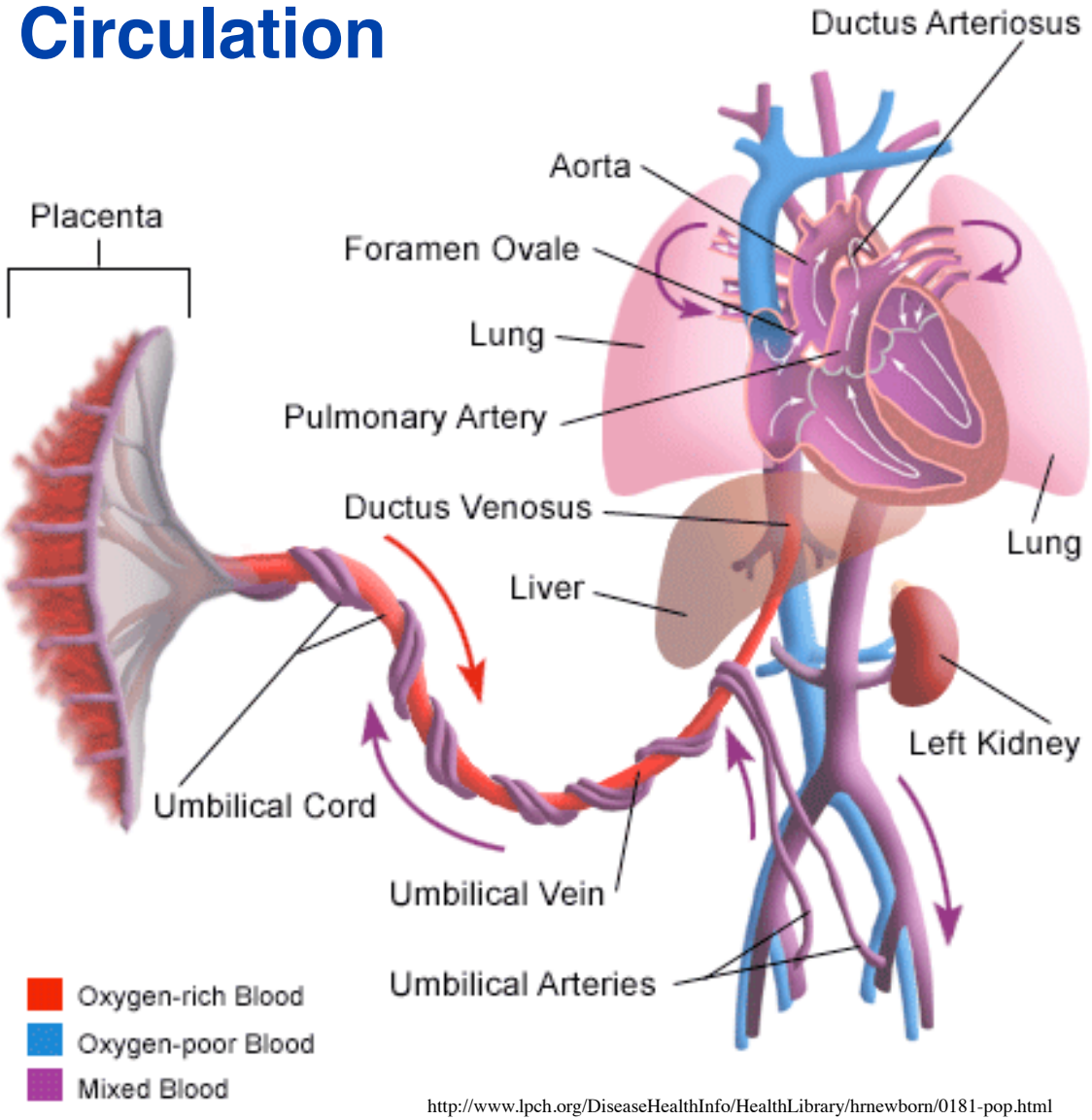
Figure 20.48


Intervillous pool of maternal blood
Maternal vein
Uterine endometrium
Maternal artery
Maternal vein
Maternal artery
Chorion frondosum
Umbilical cord
Umbilical artery
Umbilical vein

Fetal Hemoglobin : binds oxygen better in lower oxygen condition of placenta



Fetal Circulation



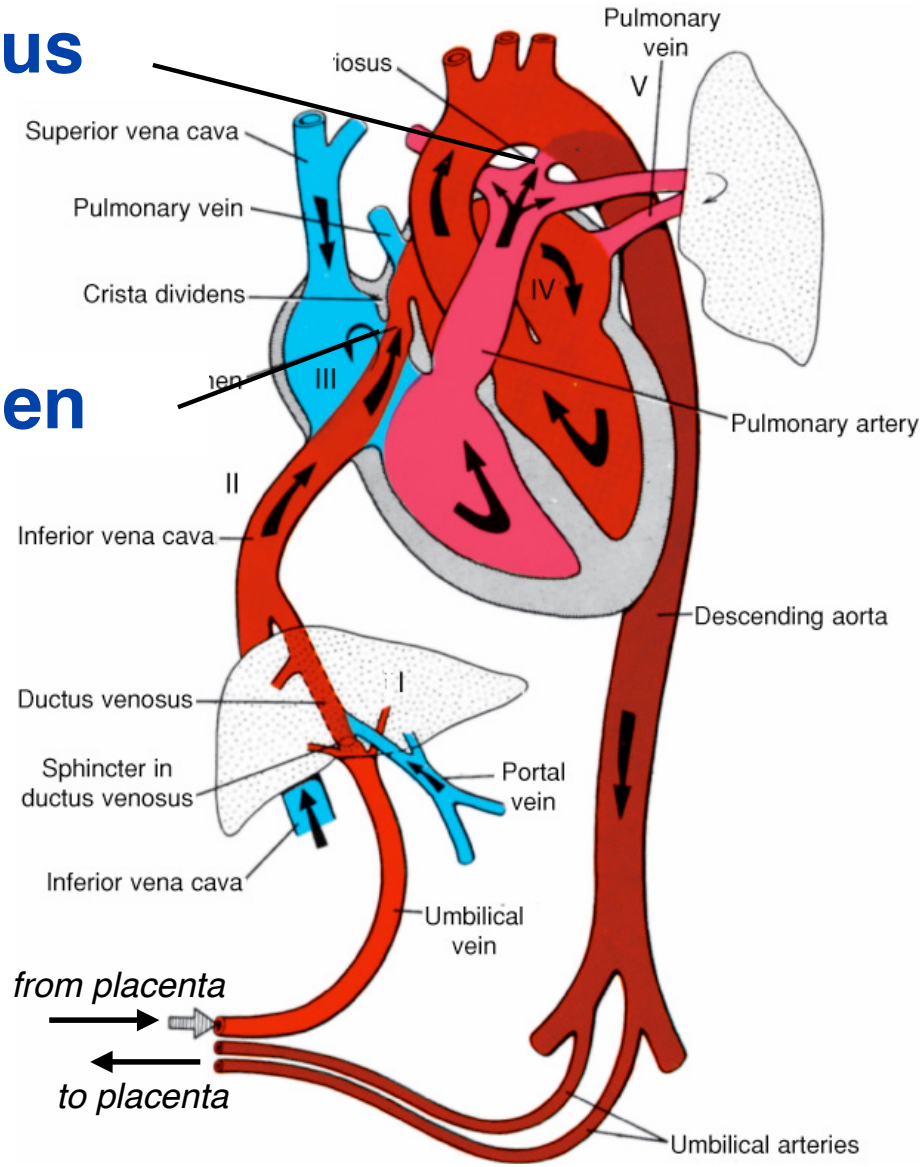
http://www.lpch.org/DiseaseHealthInfo/HealthLibrary/hrnewborn/0181-pop.html

Ductus Arteriosus

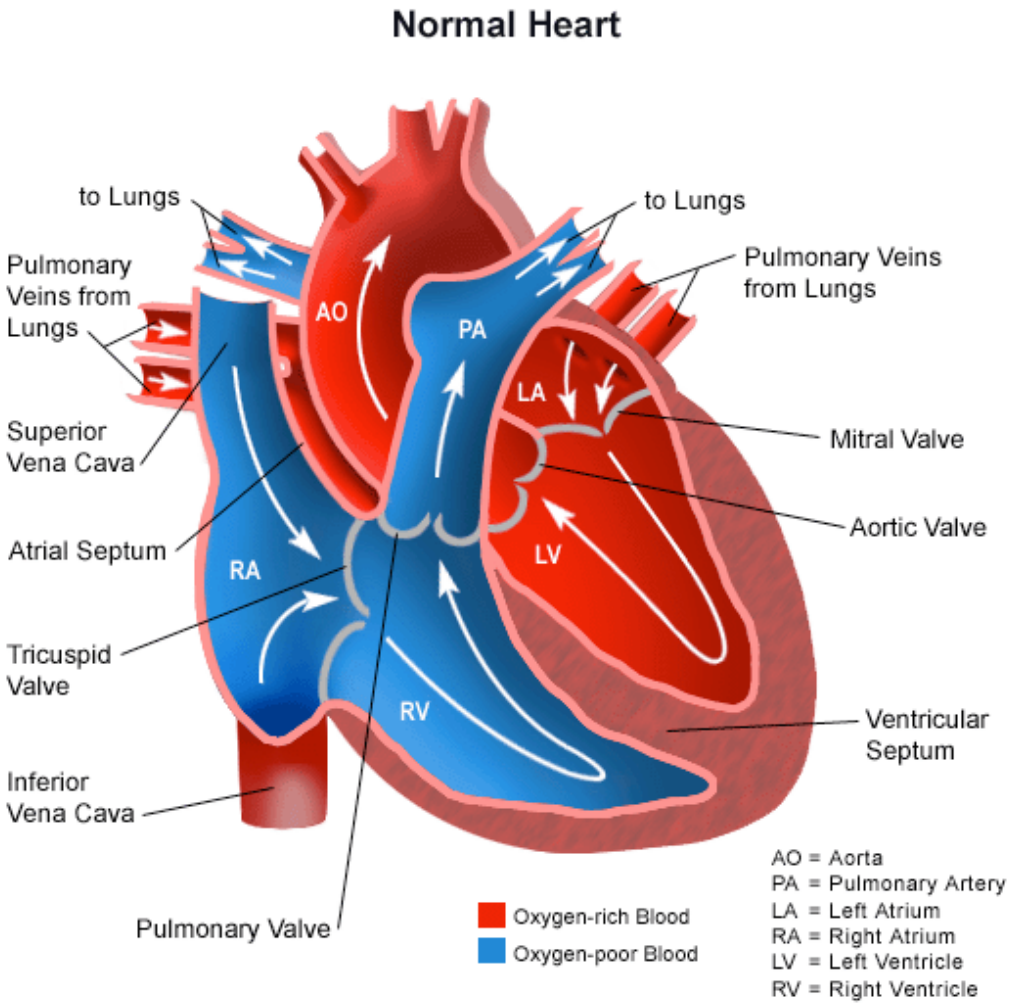
Shunt connects pulmonary artery to aorta (bypassing lungs)

Oval Foramen

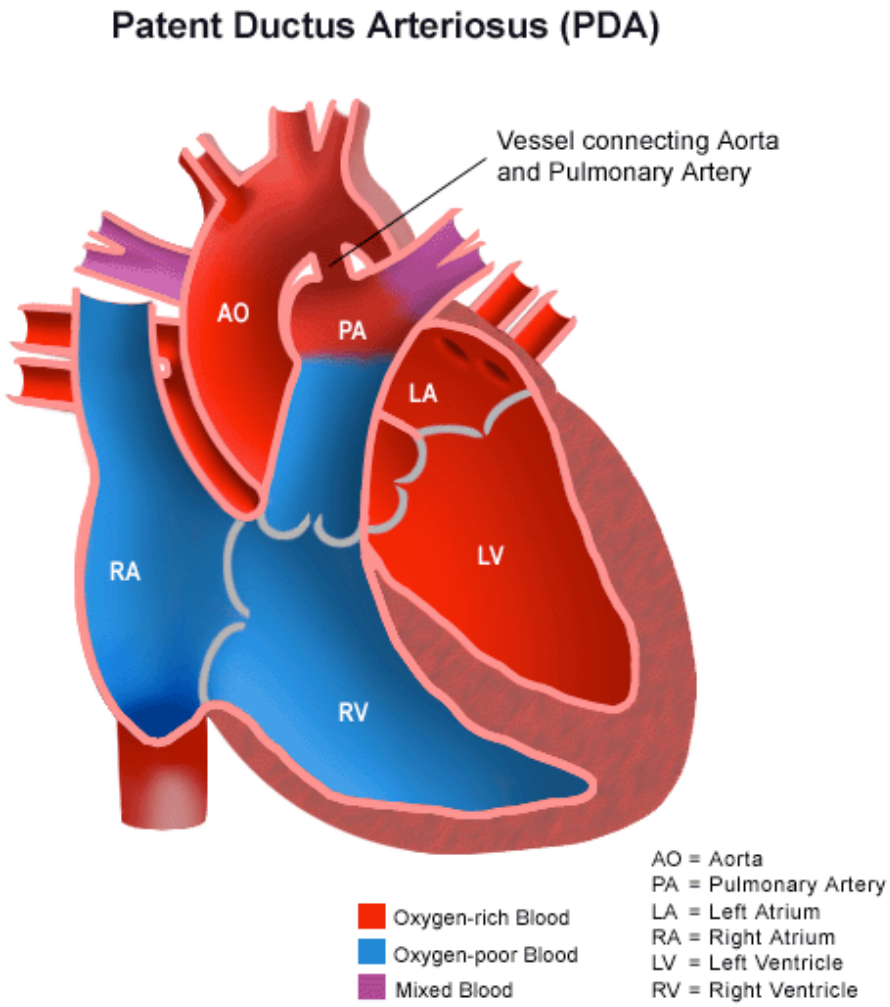
Shunt connects right atrium to left atrium (bypassing lungs)



http://macomb-rspt.com/FILES/RSPT1210/MODULE%20A/Fetal%20Circulation.jpg



http://www.chop.edu/healthinfo/patent-ductus-arteriosus-pda.html



see Figure 13.14

http://www.chop.edu/healthinfo/patent-ductus-arteriosus-pda.html