Author(s): Louis D'Alecy, 2009

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O_2 and CO_2 Transport

M1 – Cardiovascular/
Respiratory Sequence

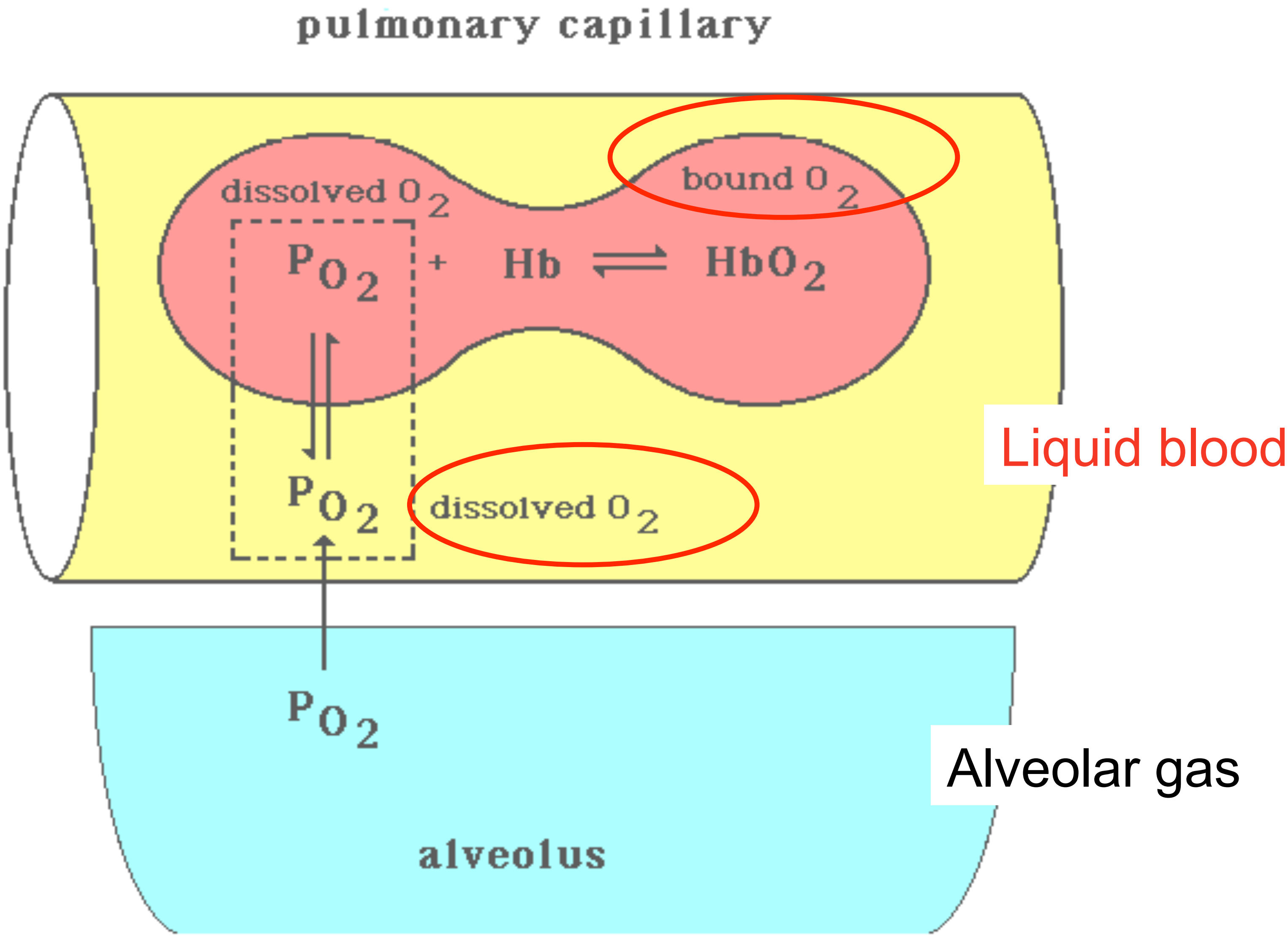
Louis D'Alecy, Ph.D.

Fall 2008

Tuesday 11/18/08, 9:00
O_2 and CO_2 Transport

35 slides, 50 minutes

1. Describe the amount of oxygen **dissolved** and **combined** **in blood**.
2. Define oxygen **delivery** to a tissue.
3. Describe the characteristics of the oxygen-Hb **saturation** curve.
4. Describe the **shifts** produced in the oxygen-Hb saturation curve.
5. Describe the effects of anemia on **oxygen content and PO_2.**
6. State the **three forms** in which **CO_2** is carried in the blood.
7. Describe the role of **carbonic anhydrase** in CO_2 transport.
8. Describe the chemical events associated with the uptake and release of CO_2.
9. Defines **chloride shift**.



O_2 content of blood = Dissolved + Hb bound O_2

How much gas is dissolved ?

A gas dissolves in a liquid in direct proportion to

its partial pressure and solubility.

"Henry's Law"

Henry's Law for O_2

The content of dissolved oxygen is equal to the product of the oxygen solubility coefficient and oxygen partial pressure.

$$C_{dO_2} = a_{O_2} \; P_{O_2}$$

Linear straight line Relationship like y = mx.

C_{dO_2} = content of dissolved O_2 mL/dL

a_{O_2} = solubility coefficient for O_2 in blood

$$a_{O_2} = 0.0031 \text{ mL/mm Hg/dL}$$

dL = 100 mL

Dissolved O_2

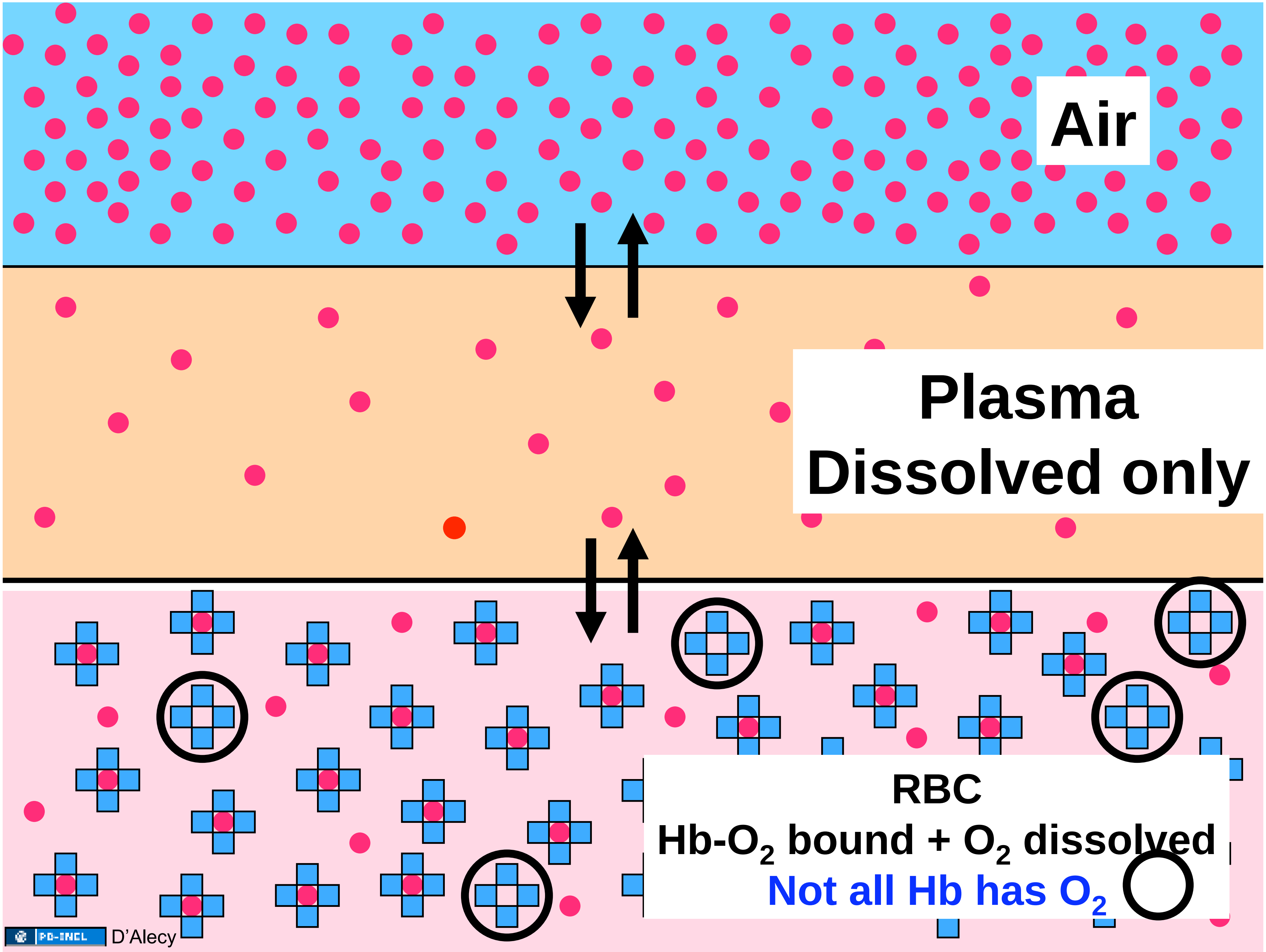
At PO_2 of 100 mmHg X 0.0031
you get 0.3 mL O_2/dL dissolved oxygen in blood.

With cardiac output of 5000 ml/min or 50 dL/min you would deliver (50 dL X 0.3 mL/dL) or 15 mL O_2/min.
BUT
We consume 20 X that or 250 mL O_2/min
so dissolved just will not do it!!

You need hemoglobin to bind and transport O_2.

dL = 100 mL

Hemoglobin


Air
Plasma
Dissolved only
RBC
Hb-O_2 bound + O_2 dissolved
Not all Hb has O_2
PD-INEL
D'Alecy

How much O_2 is in blood?
Concentration = Content

mL/dL = mL/100mL = Vol%

(mL of O_2 in 100 mL blood)

i.e. arterial blood has 20 Vol% O_2

Content $\neq$ %Hb Saturation

$$\% \text{ Hb Saturation} = \frac{O_2 \text{ bound to Hb}}{O_2 \text{ capacity of Hb}} \times 100\%$$

O_2 **content** (with flow) determines O_2 **delivery**.

Thus O_2 **content** is more important to O_2 **delivery** than is O_2 **saturation**.

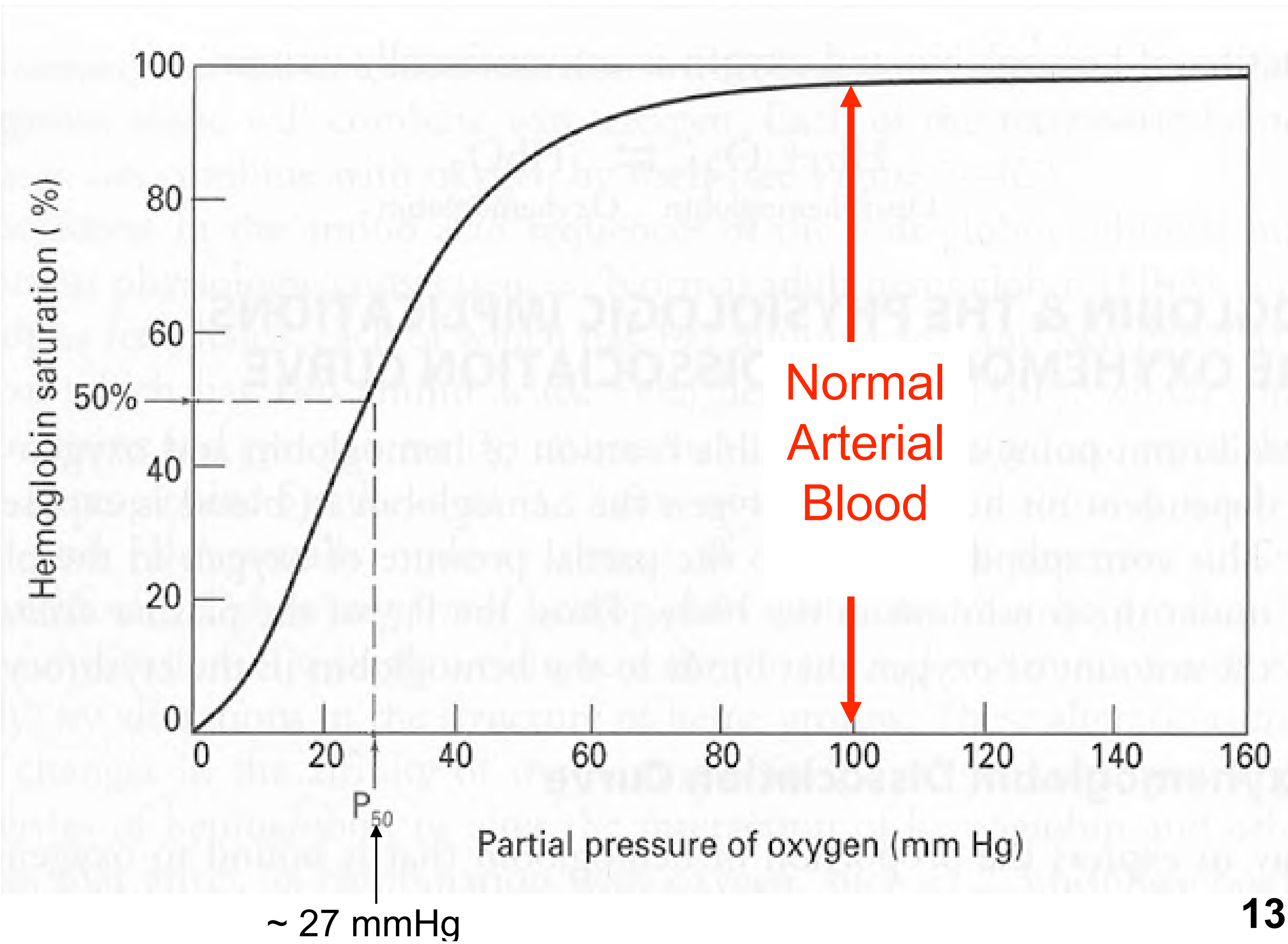
O_2 Content $\neq$ %Hb Saturation

So why do we talk about O_2 saturation?

<u>O_2 saturation is relatively easier to measure and O_2 content is much more difficult to measure.</u>

We need to understand the differences!!!!

Hb Saturation Curve



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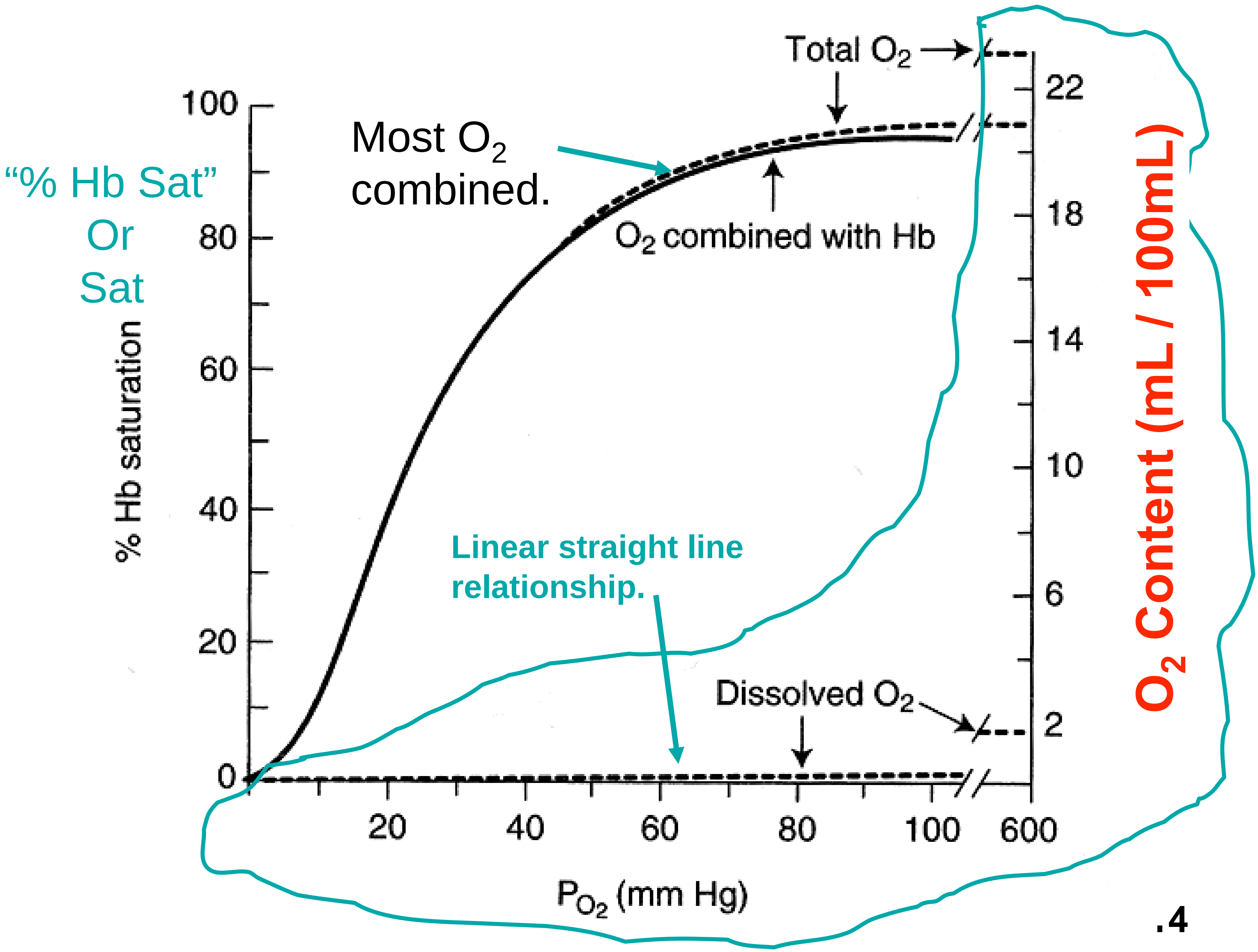
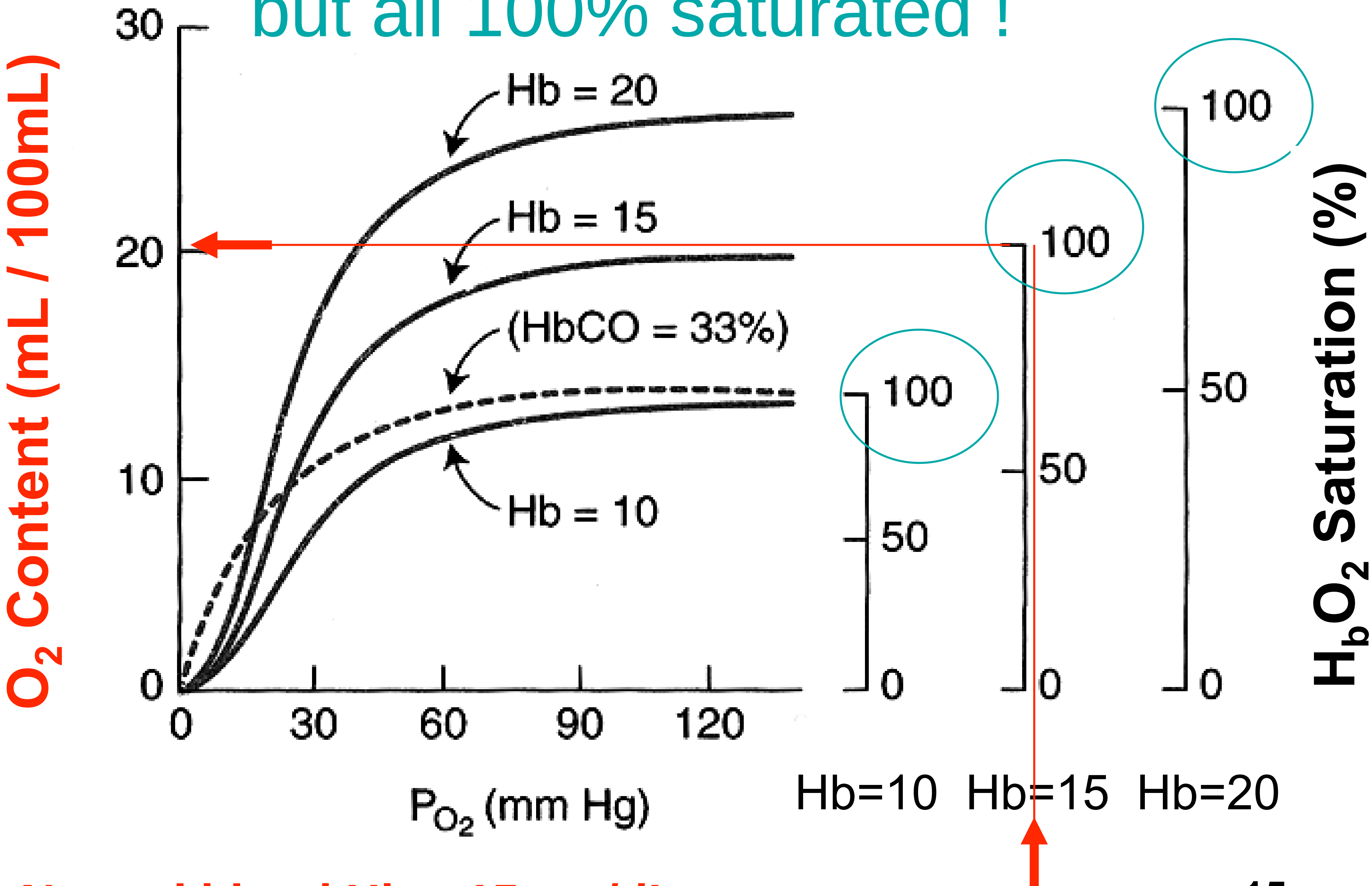


"% Hb Sat"
Or
Sat
% Hb saturation
Most O_2 combined.
Total O_2
O_2 combined with Hb
Linear straight line relationship.
Dissolved O_2
P_{O_2} (mm Hg)
O_2 Content (mL / 100mL)
100
80
60
40
20
0
20
40
60
80
100
600
22
18
14
10
6
2

.4

Different amounts of Hb but all 100% saturated !



Normal blood Hb = 15 gm/dL

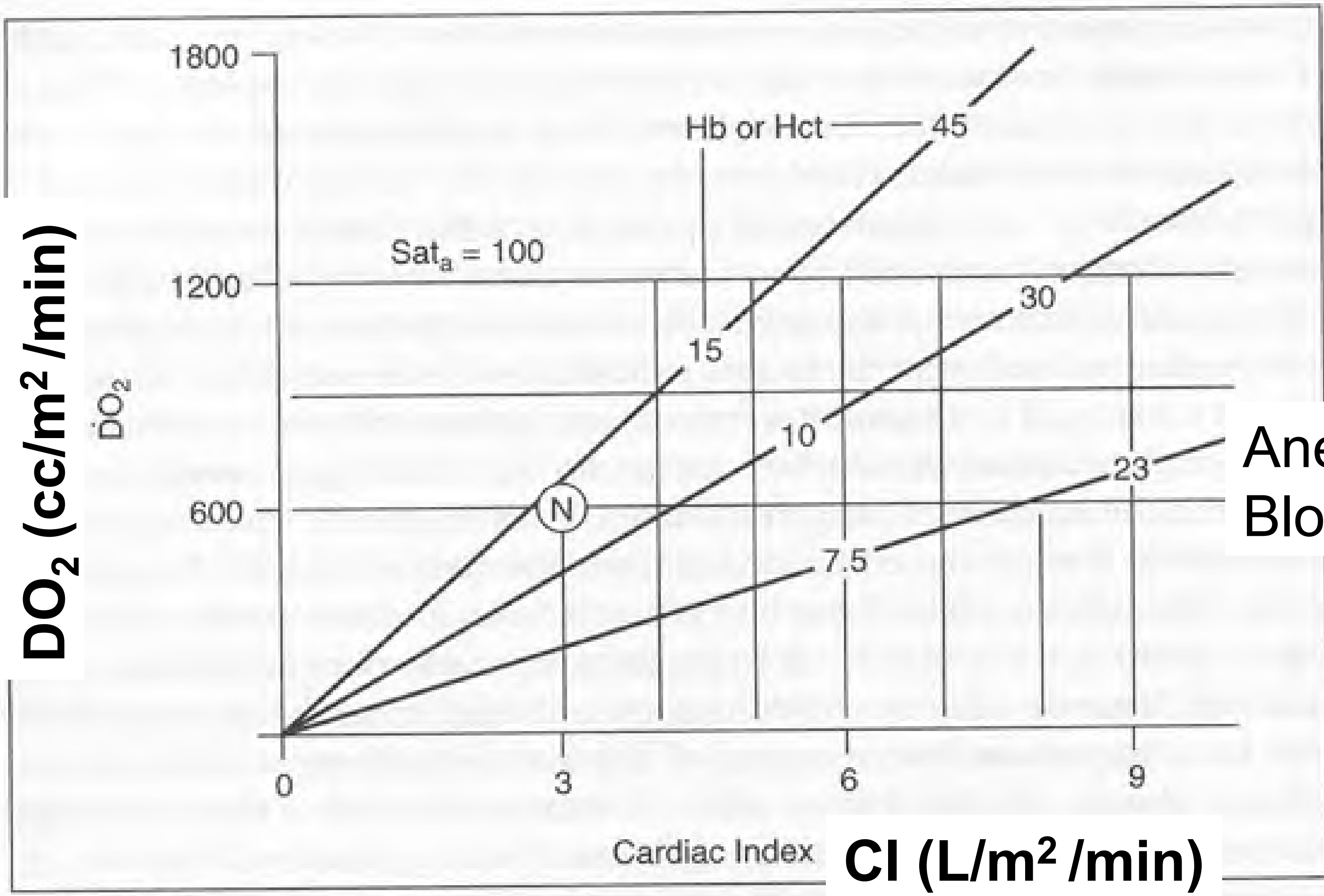


FIGURE 1-5. Estimating oxygen delivery. When the cardiac index and hemoglobin (*Hb*) level or hematocrit *Hct* is known, and if the arterial saturation (Sat_a) is close to 100%, the systemic oxygen delivery ($\dot{D}O_2$) can be quickly estimated using this graph.

Bartlett, Critical Care Physiology

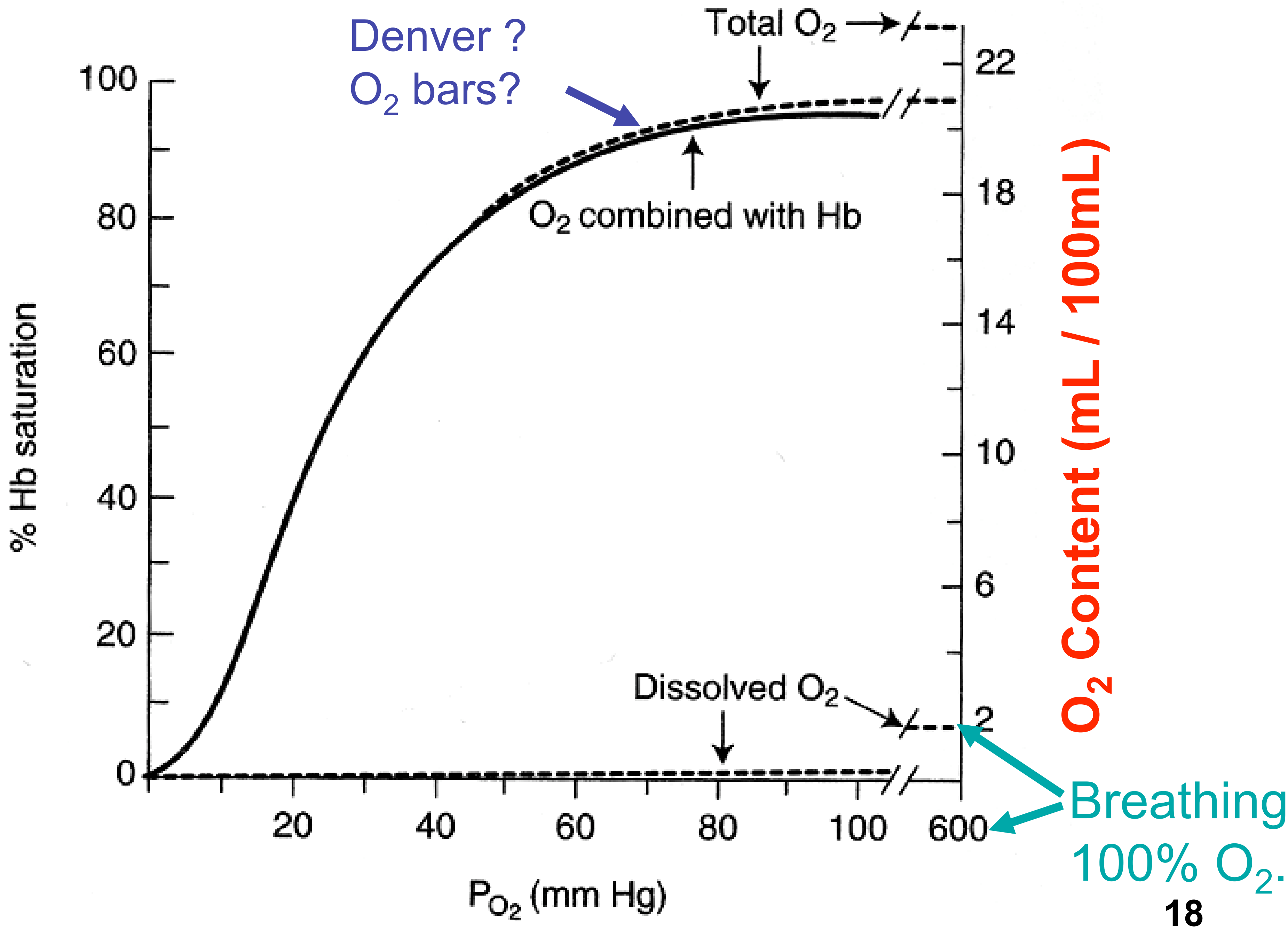
i.e. ANEMIA

Decreased Hb concentration so that % saturation can be normal (97-100%) but O_2 content is decreased.

1. Decreased number of RBC

2. Decreased Hb content per RBC

Normal blood Hb = 15 gm/dL



Denver ?
O_2 bars?
Total O_2
O_2 combined with Hb
Dissolved O_2
% Hb saturation
100
80
60
40
20
0
20
40
60
80
100
600
P_{O_2} (mm Hg)
22
18
14
10
6
2
O_2 Content (mL / 100mL)
Breathing 100% O_2.

Hemoglobin Bound Oxygen Content mL O_2 /dL

$$C_{bO_2} = S_{O_2} \, [\,Hb\,] \, Hb_s$$

S_{O_2} = % Hb saturation $= \dfrac{O_2 \text{ bound to Hb}}{O_2 \text{ capacity of Hb}} \times 100\%$

[Hb] = hemoglobin content gm/dL blood

Hb_s = saturated Hb O_2 content mL O_2 /gm Hb

Hb_s = 1.36 mL O_2 /gm Hb = O_2 capacity

Typical Arterial Blood Oxygen Content

P_{O_2} = 100 mm Hg $\quad$ S_{O_2} = 97% $\quad$ [Hb] = 15 gm/dL

Dissolved O_2

$$C_{dO_2} = a_{O_2} \; P_{O_2} = 0.0031 \times 100 = 0.31 \text{ mL / dL}$$

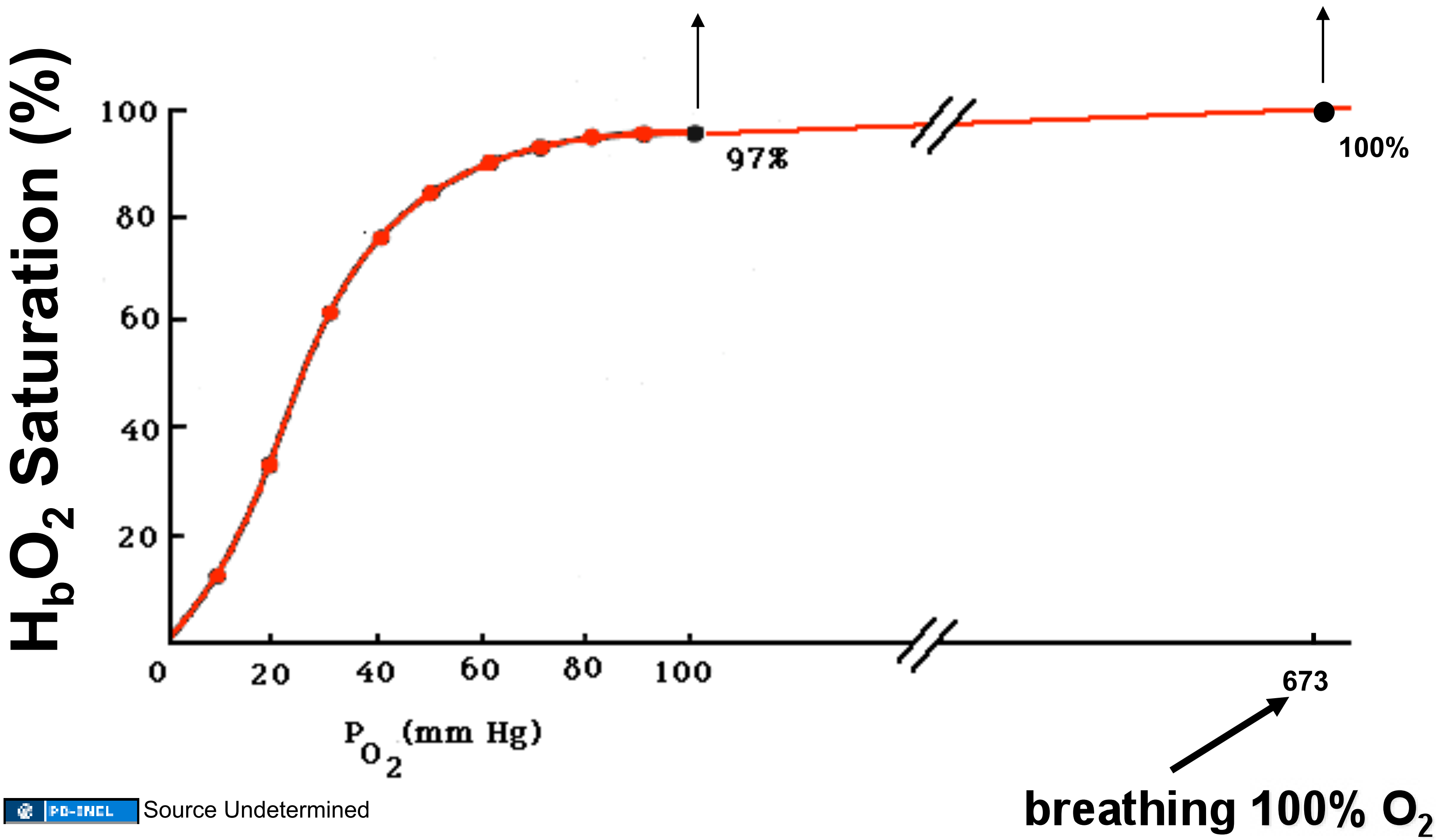
Bound O_2

$$C_{bO_2} = S_{O_2} \, [\text{ Hb }] \; Hb_s = 0.97 \times 15 \times 1.36 = 19.79 \text{ mL / dL}$$

Total Oxygen Content

$$C_{dO_2} + C_{bO_2} = 0.31 + 19.79 = \boxed{\mathbf{20.1 \text{ mL / dL}}}$$

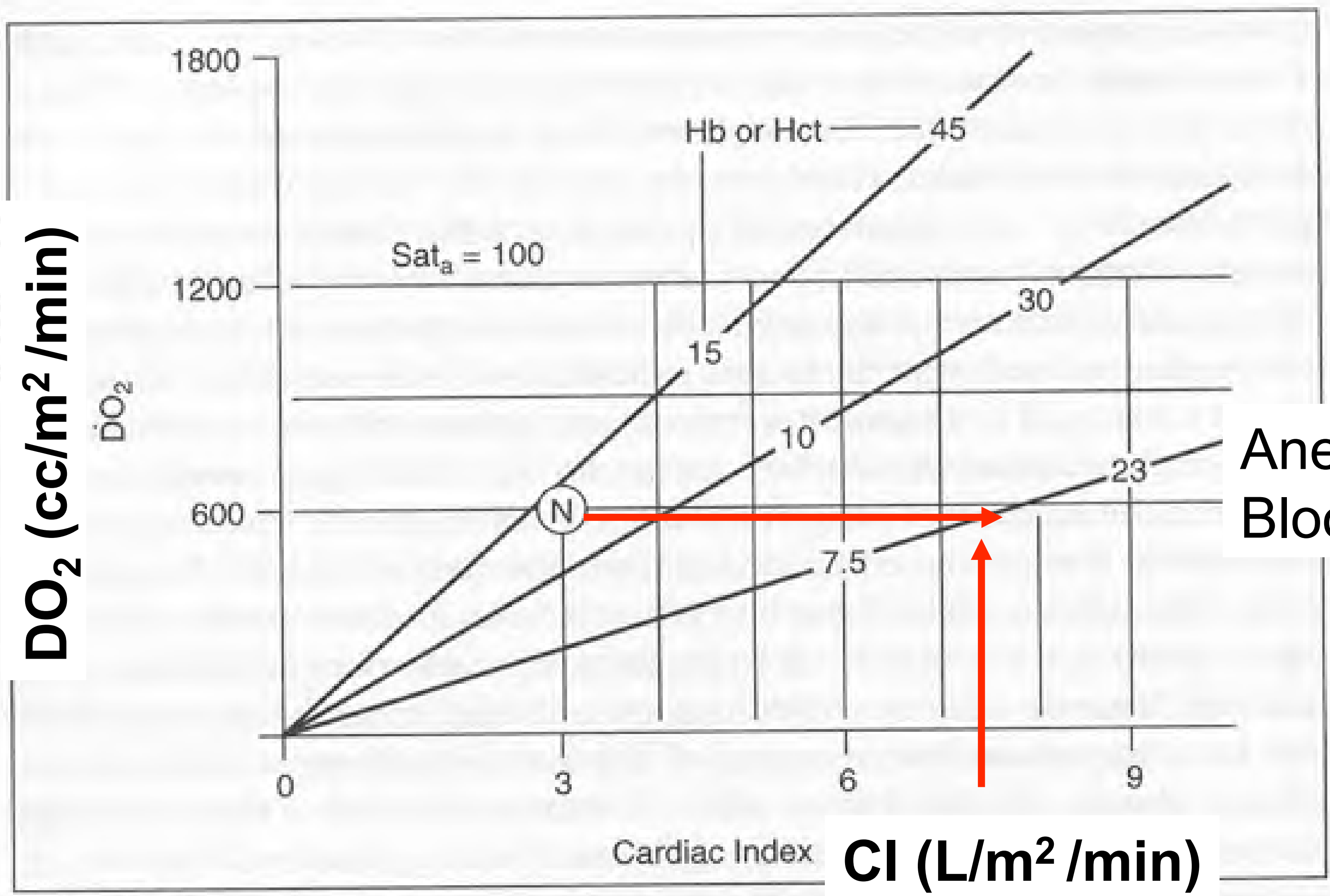
Bound	Cb_{O2}	19.97	mL / dL	20.1
Dissolved	Cd_{O2}	0.31		2.1
Total	C_{O2}	20.1		22.2



	P_aO_2	Content C_aO_2	SO_2
	mm Hg	mL / dL	%
	Breathing Room Air		
Normal Hb 15 g/dl	**100**	**20**	**97**
Anemia Hb 7.5 g/dl	**100**	**10**	**97**
	Breathing 100% O_2		
Normal Hb 15 g/dl	**673**	**22**	**100**
Anemia Hb 7.5 g/dl	**673**	**12**	**100**

Thus breathing 100% O_2 does not "fix" reduced oxygen transport capacity due to anemia.

2X or 3X CO could compensate



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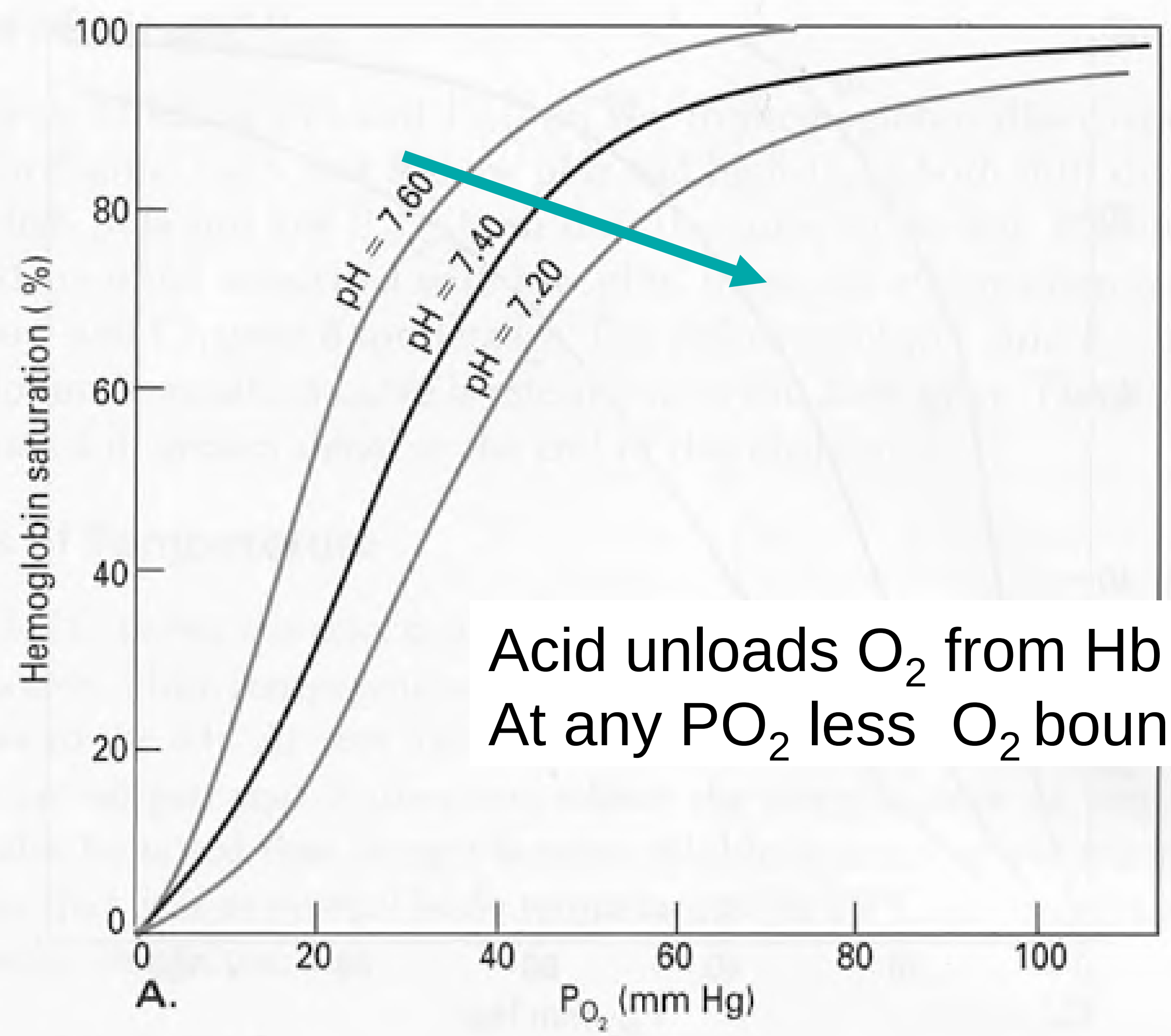
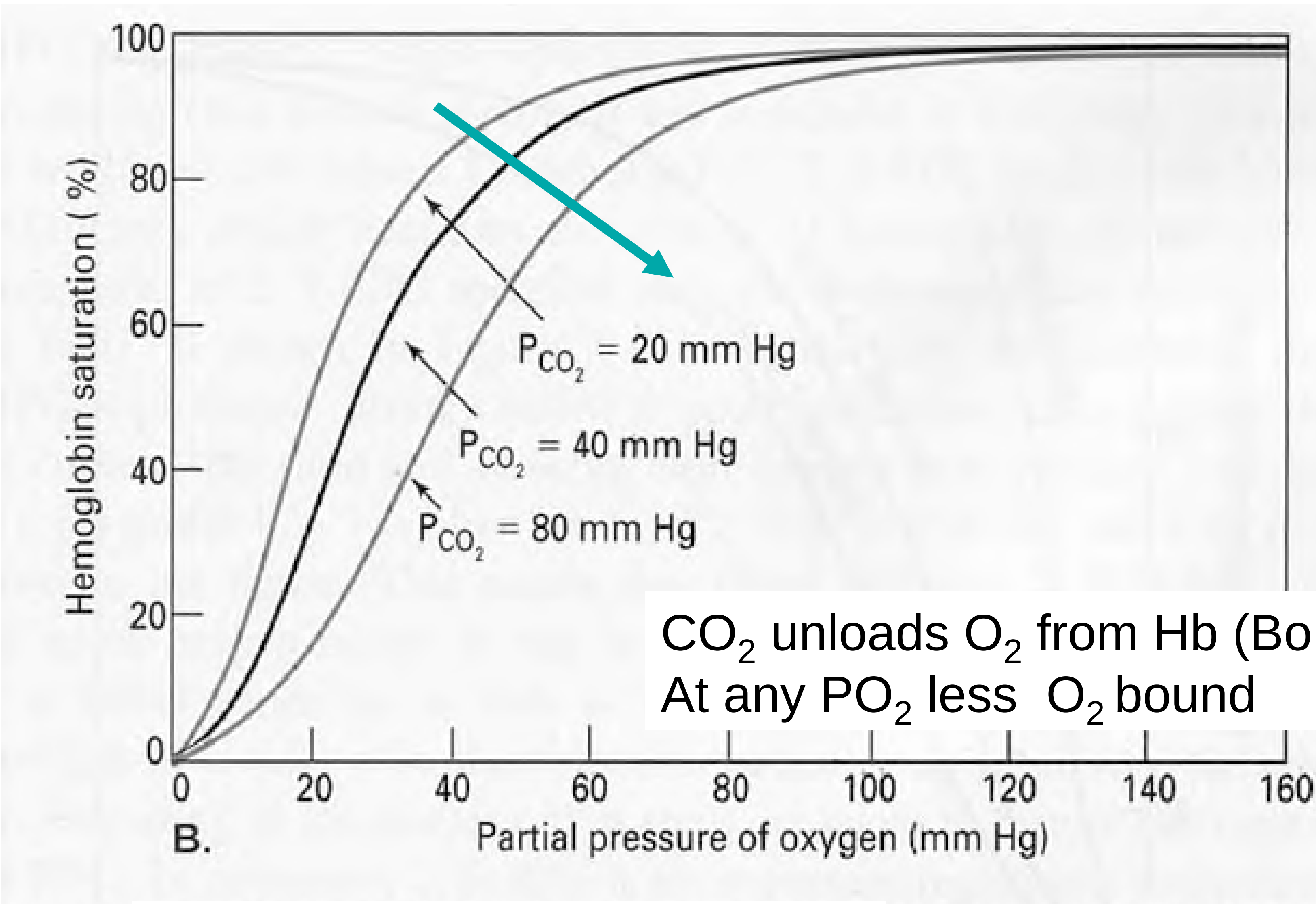
pH on O_2 Saturation of Hb



Acid unloads O_2 from Hb (Bohr Effect)
At any PO_2 less O_2 bound

Levitzky. Pulmonary Physiology. McGraw-Hill, 2003. 6th ed.

CO_2 on O_2 Saturation of Hb



CO_2 unloads O_2 from Hb (Bohr Effect)
At any PO_2 less O_2 bound

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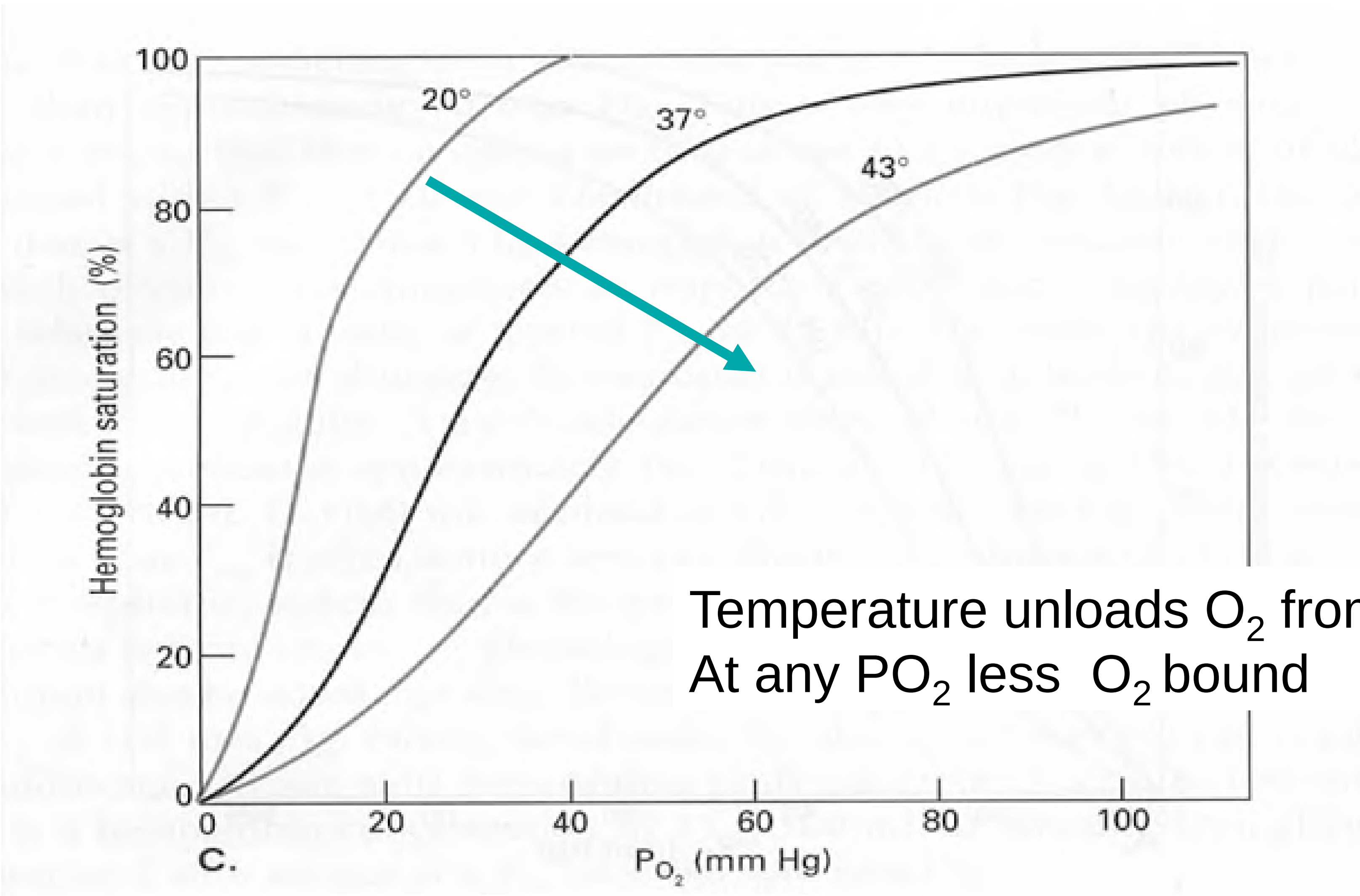
Temperature on O_2 Saturation of Hb



Temperature unloads O_2 from Hb
At any PO_2 less O_2 bound

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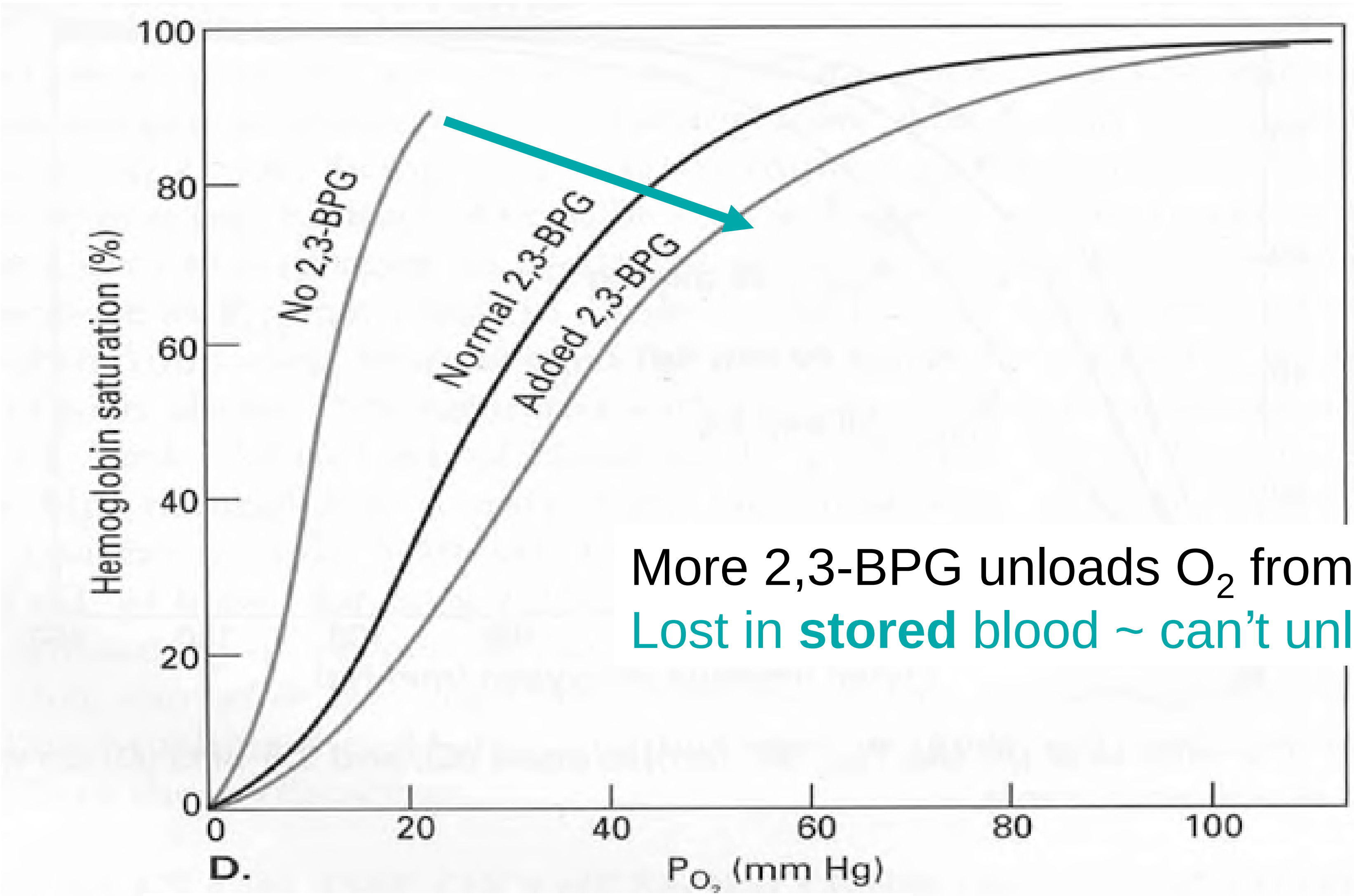
2,3-BPG on O_2 Saturation of Hb

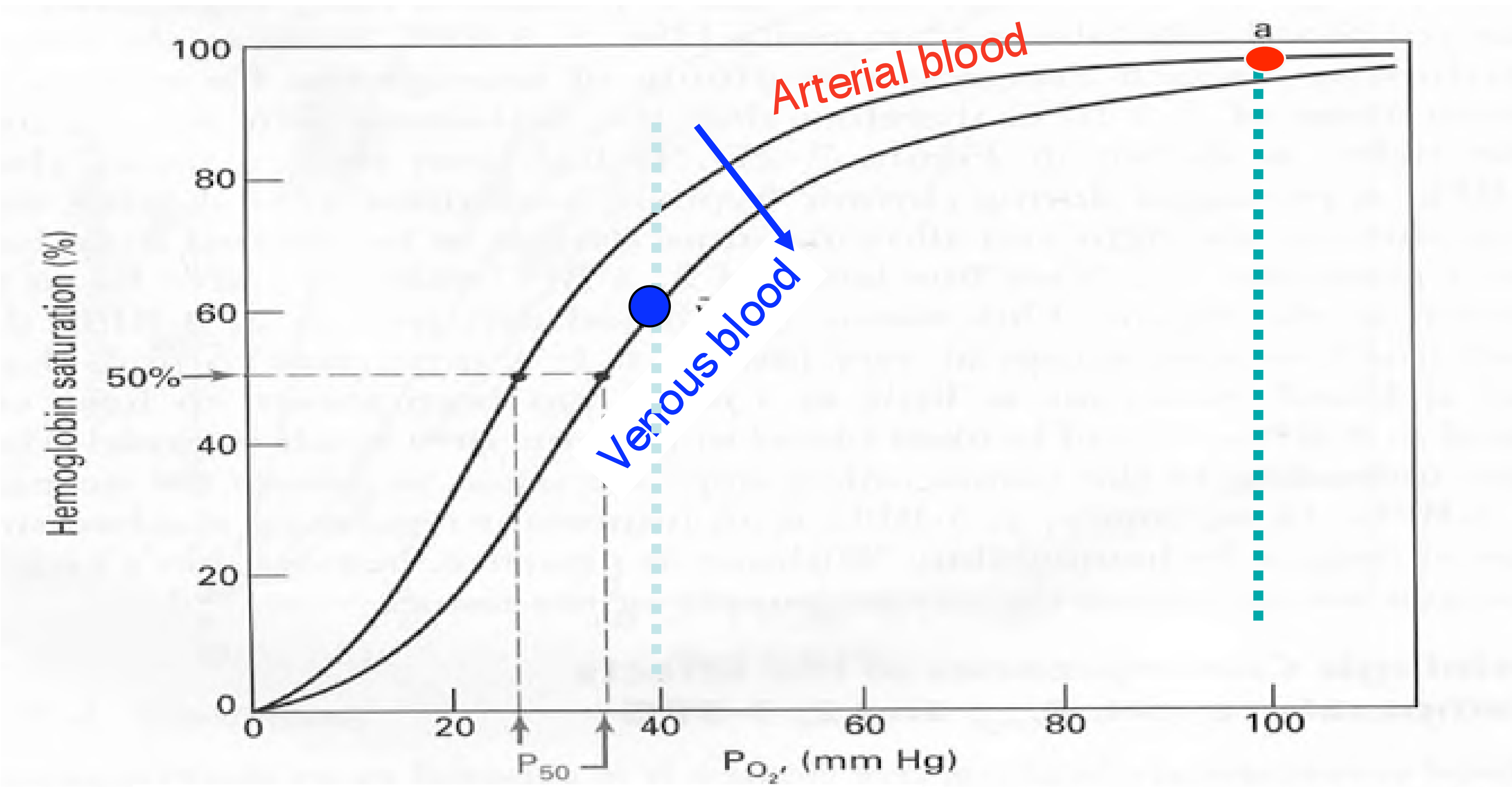


More 2,3-BPG unloads O_2 from Hb

Lost in **stored** blood ~ can't unload O_2

Levitzky. Pulmonary Physiology. McGraw-Hill, 2003. 6th ed.

Venous blood on O_2 Saturation of Hb



PD-INEL Levitzky. Pulmonary Physiology. McGraw-Hill, 2003. 6th ed.

Venous blood unloads O_2 from Hb

P_{50} is PO_2 at 50% O2 saturation.

Summary

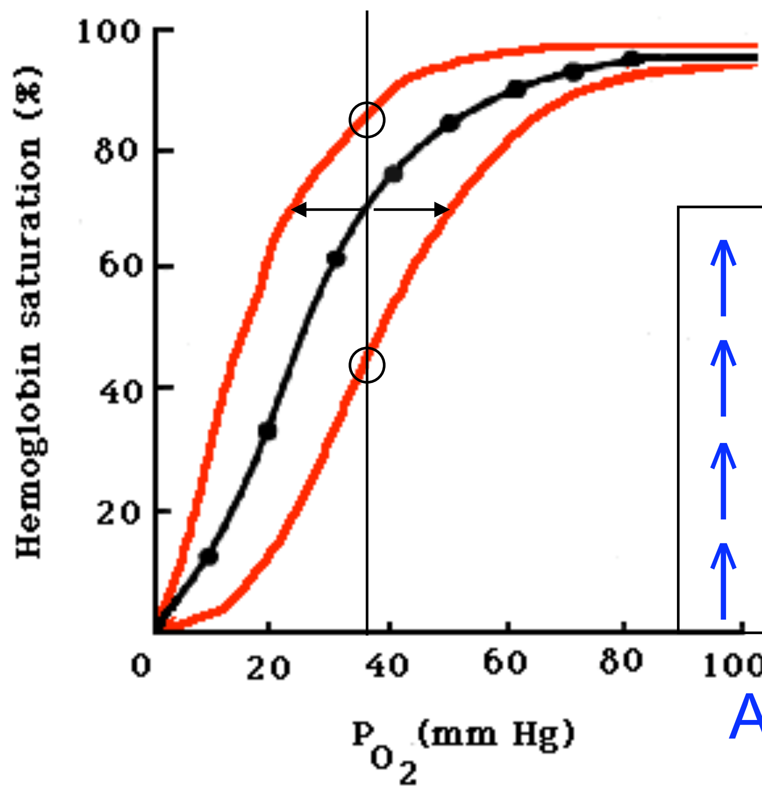
left shift (lungs)

↓ H^+
↓ CO_2
↓ temperature
↓ 2,3 BPG

At any PO_2 more O_2 bound.

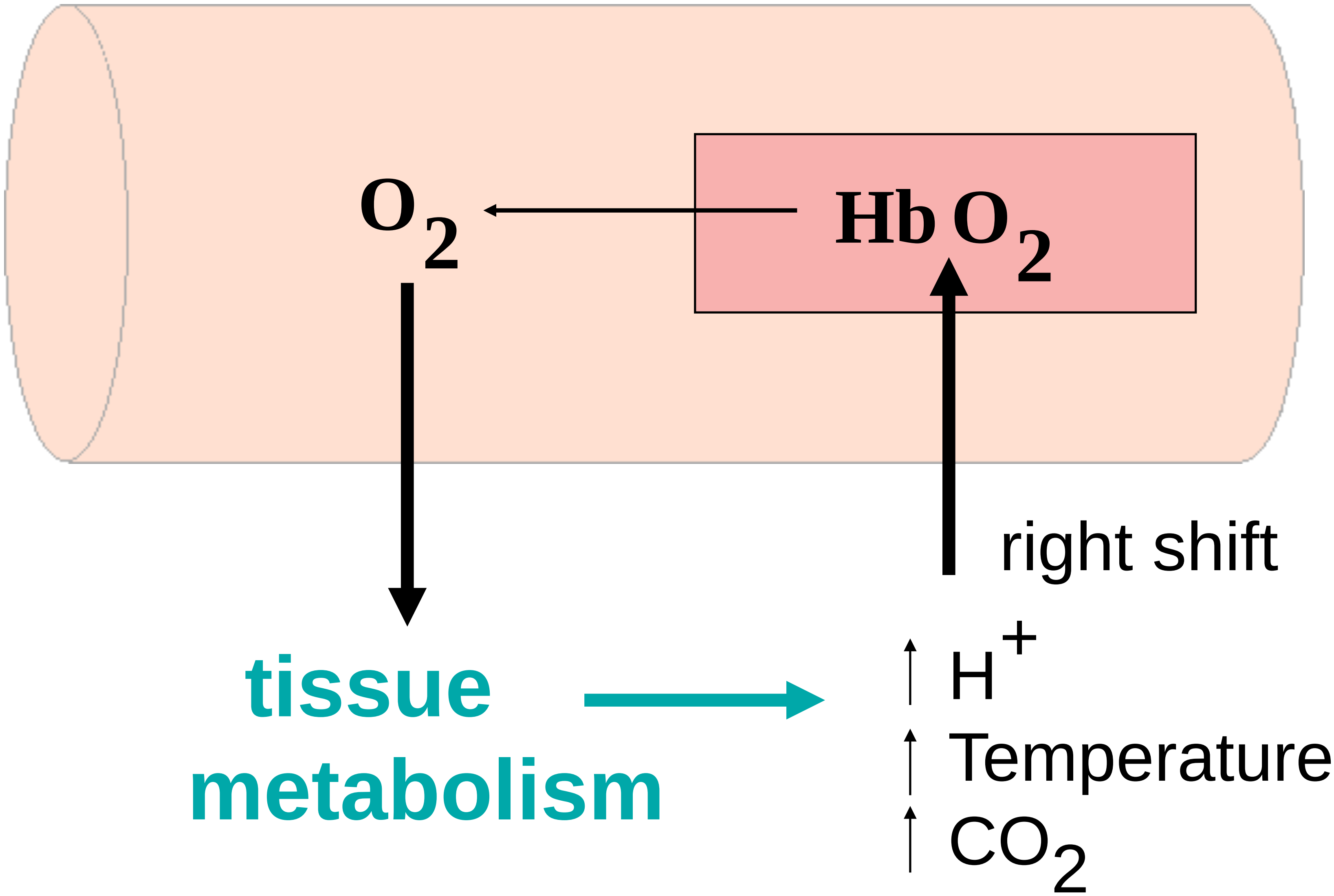
right shift (tissues)

↑ H^+ (Bohr shift)
↑ CO_2
↑ temperature
↑ 2,3 BPG

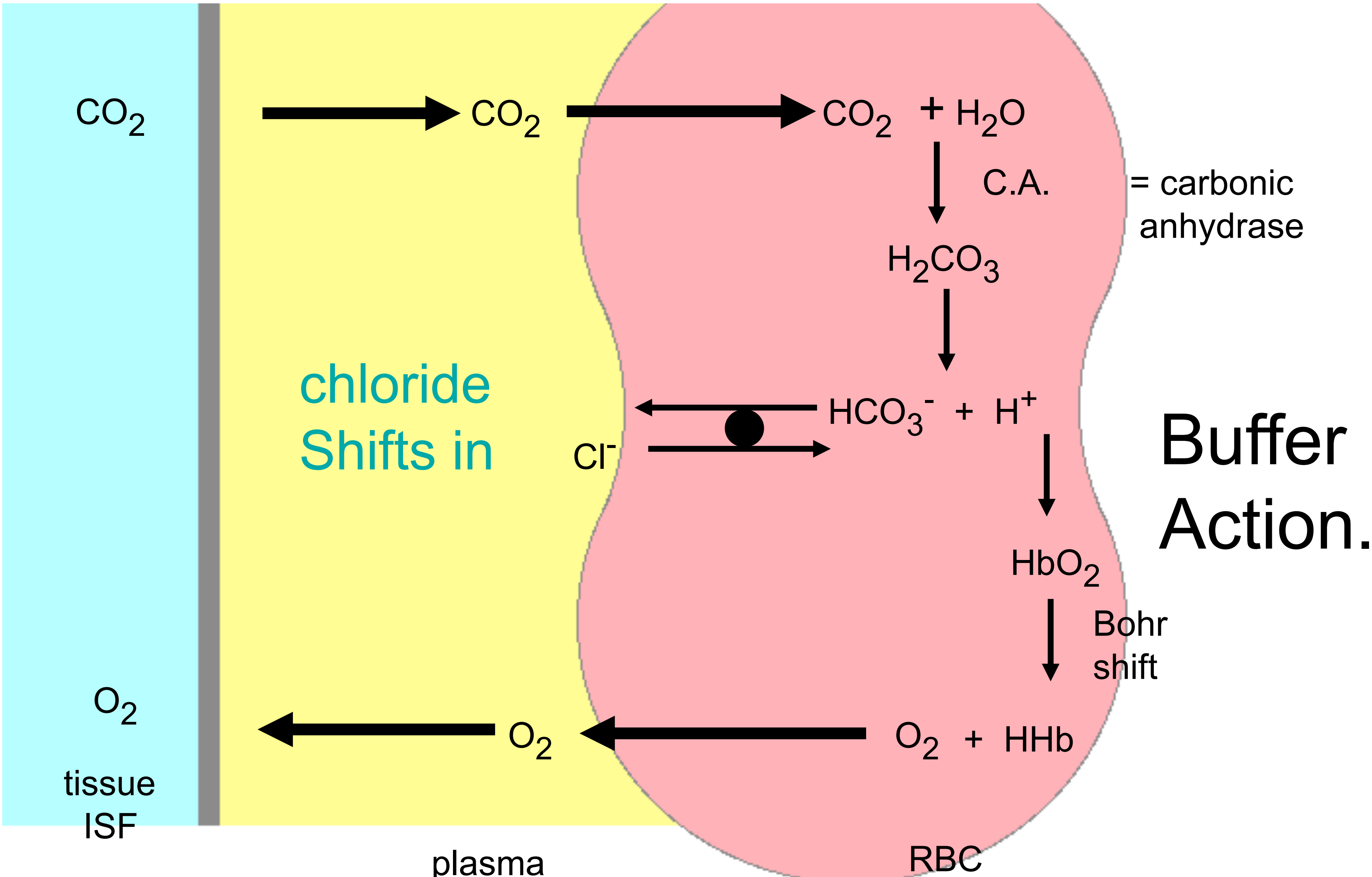


At any PO_2 less O_2 bound.

O_2 is “unloaded” in tissues

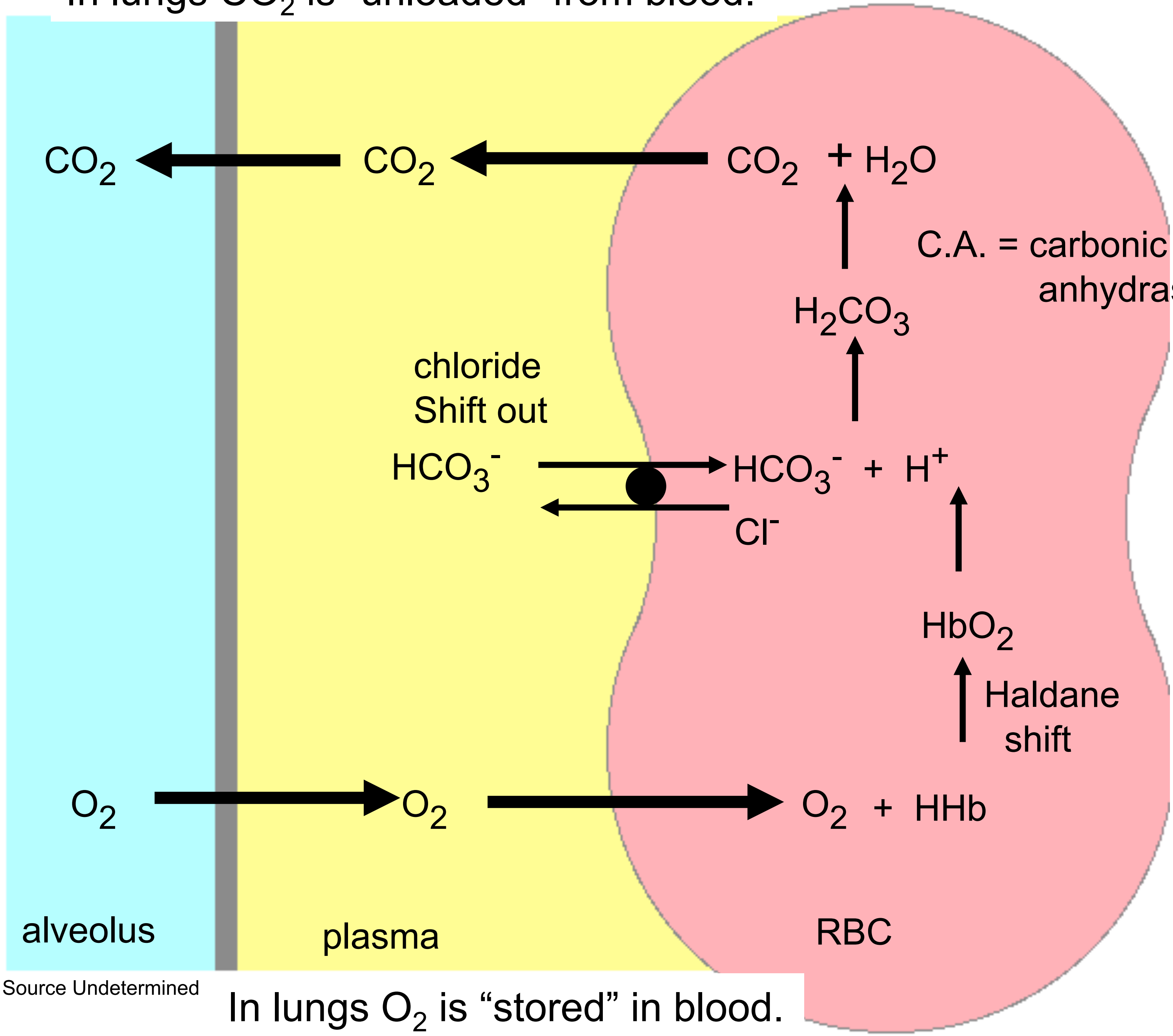


In tissues CO_2 is "stored" in blood (for transport).



In tissues O_2 is "unloaded" from blood.

In lungs CO_2 is “unloaded” from blood.



In lungs O_2 is “stored” in blood.

How is CO_2 Transported?

CO_2 is about 20 x more soluble than O_2

But still only 5% (art.) to 10% (ven.) of transport is dissolved!!

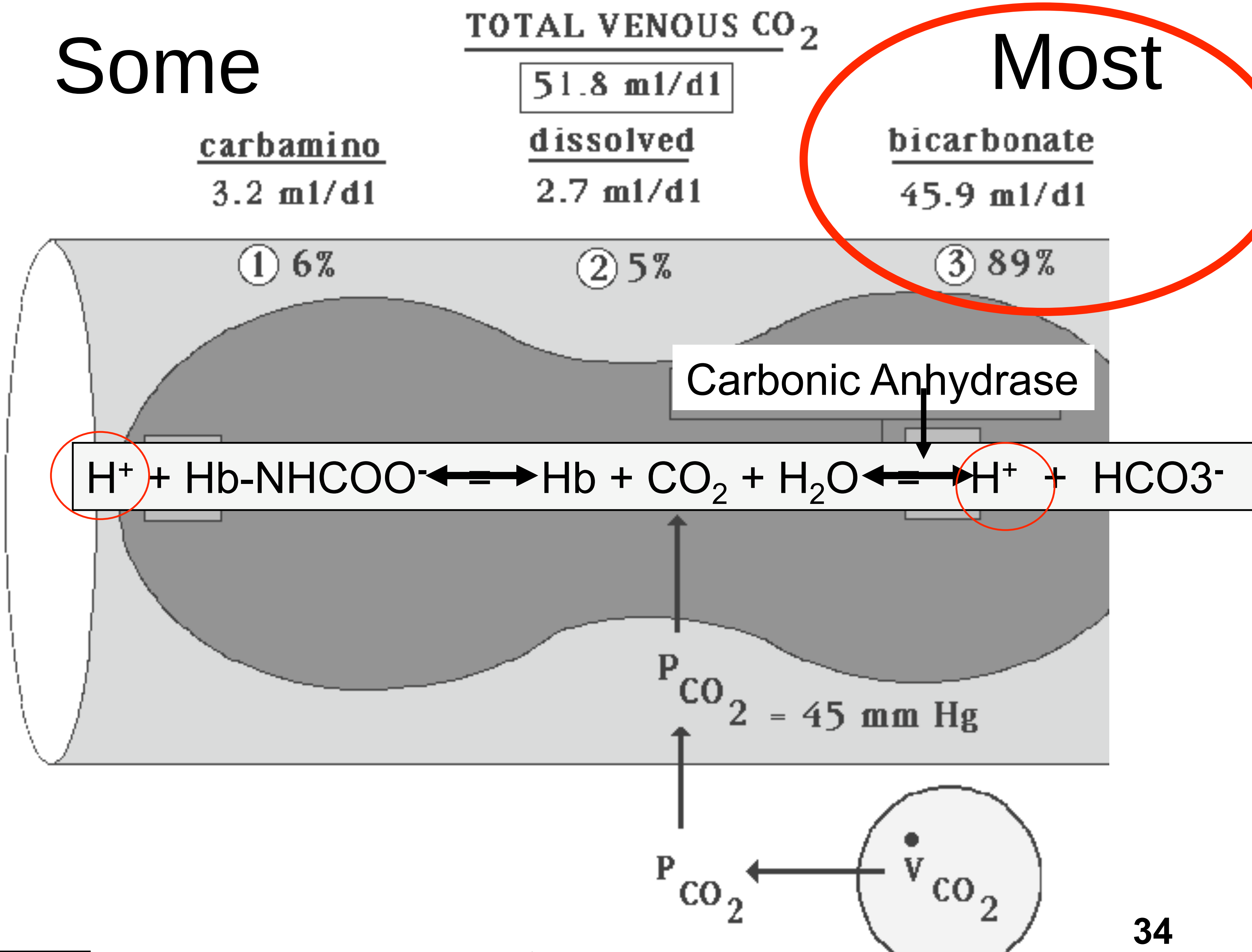
The content of dissolved gas (C_{dx}) is the product of the solubility coefficient (a_x) and the partial pressure of the gas (P_x).

$$C_{dx} = a_x P_x$$

C_{dx} **= dissolved gas content mL/dL**

a_{O_2} = 0.003 mL / mm Hg /dL

a_{CO_2} = 0.06 mL / mm Hg /dL



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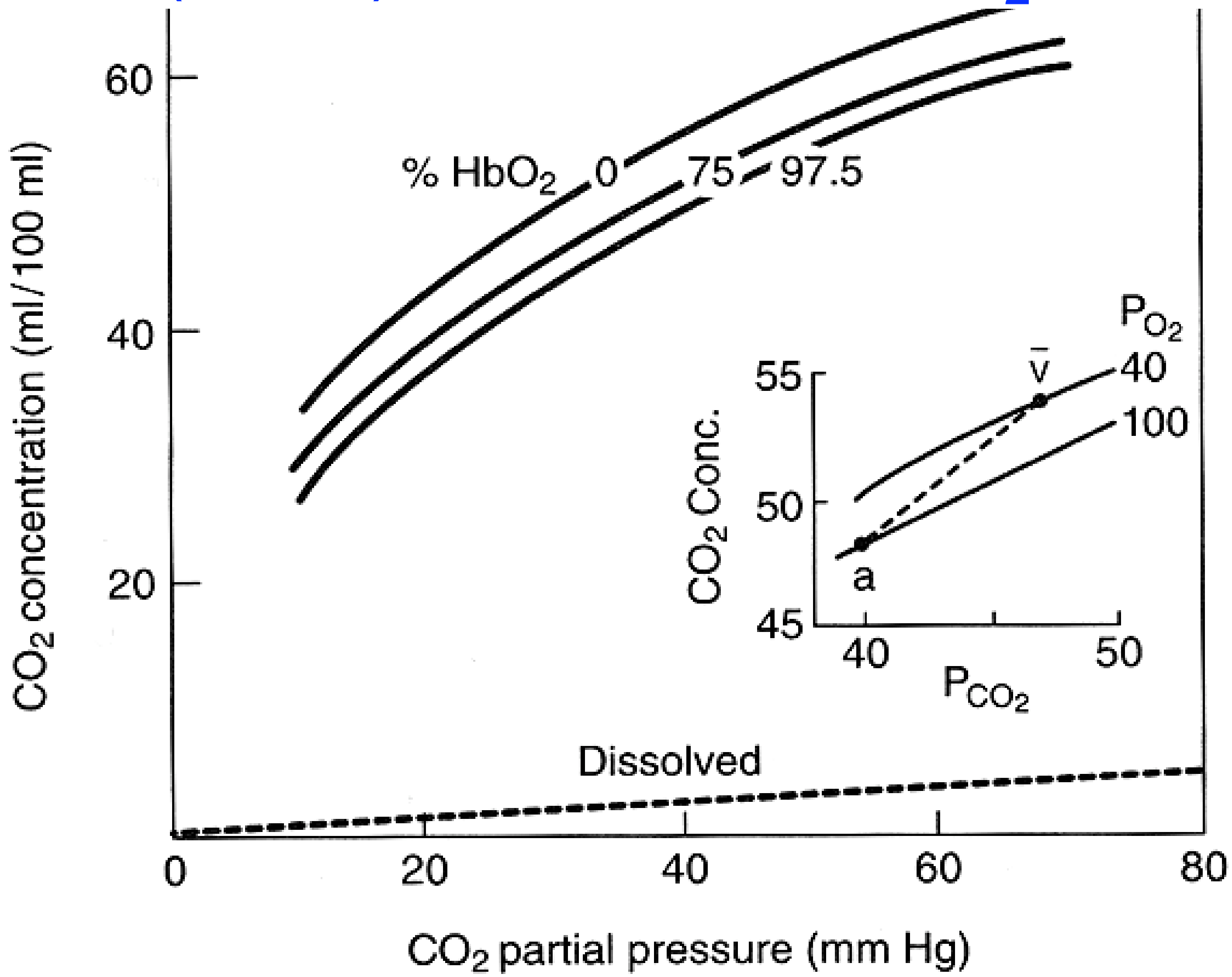
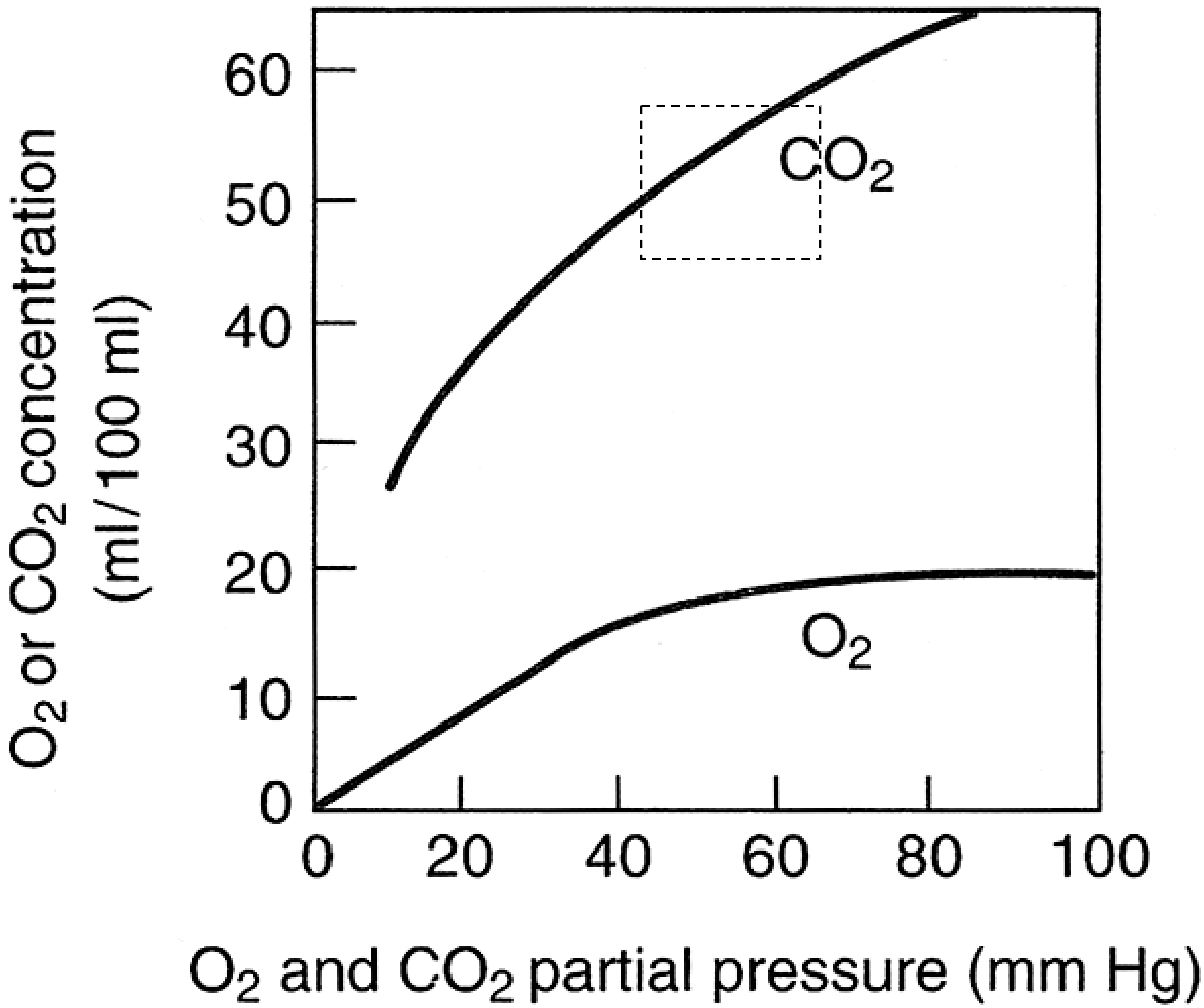
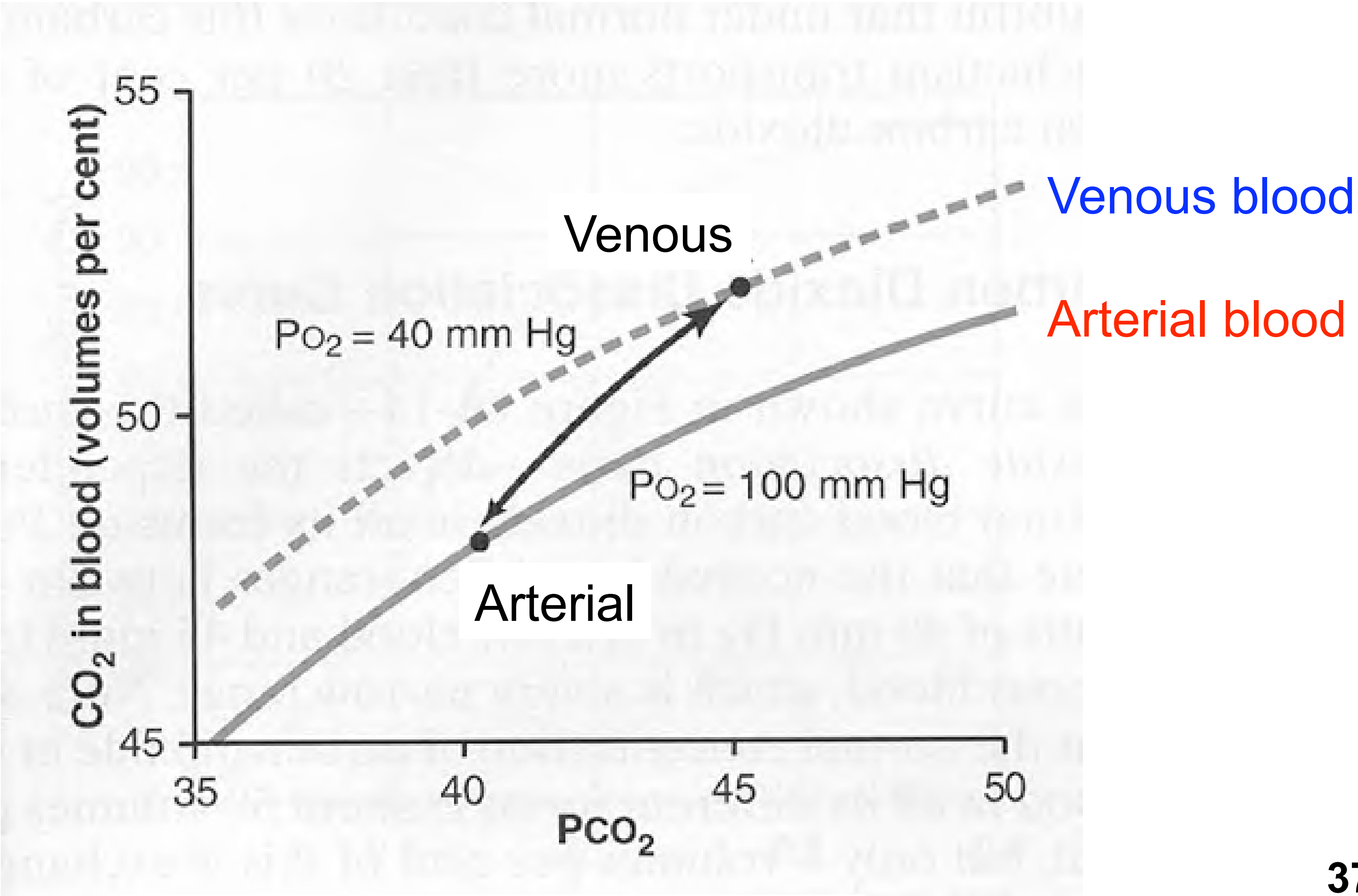
Reduced (de-ox)Hb binds more CO_2 than HbO_2




60
50
40
30
20
10
0
0
20
40
60
80
100
CO2
O2
O2 or CO2 concentration (ml/100 ml)
O2 and CO2 partial pressure (mm Hg)

Reduced (de-ox)Hb binds more CO_2 than HbO_2, venous blood can carry more CO_2 then arterial blood.



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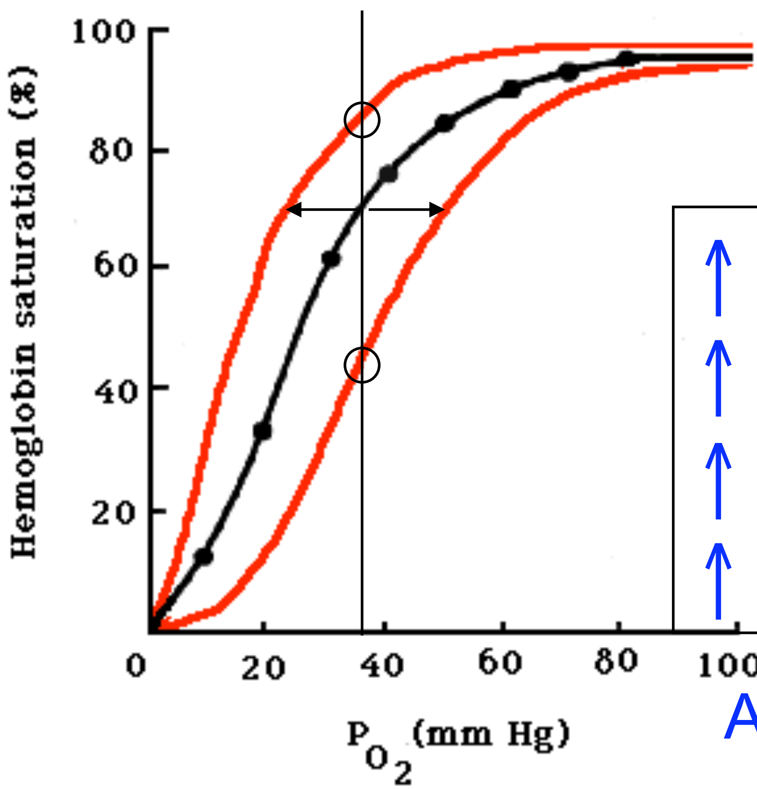
Summary

left shift (lungs)

- ↓ H^+
- ↓ CO_2
- ↓ temperature
- ↓ 2,3 BPG

At any PO_2 more O_2 bound.



right shift (tissues)

- ↑ H^+ (Bohr shift)
- ↑ CO_2
- ↑ temperature
- ↑ 2,3 BPG

At any PO_2 less O_2 bound.

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