Gas Exchange (Diffusion)

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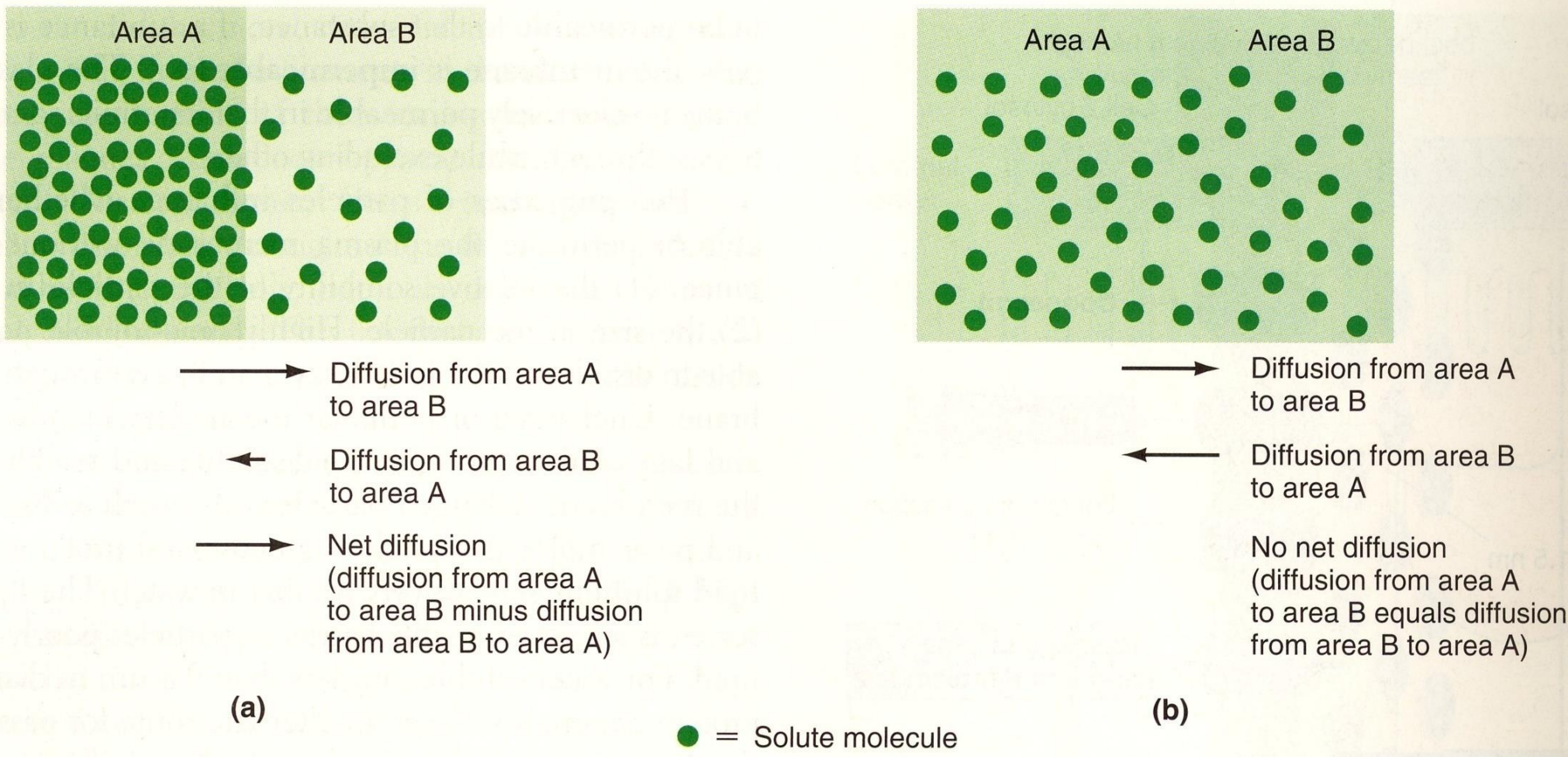
DIFUSI



Area A
Area B
Diffusion from area A to area B
Diffusion from area B to area A
Net diffusion (diffusion from area A to area B minus diffusion from area B to area A)
(a)
Area A
Area B
Diffusion from area A to area B
Diffusion from area B to area A
No net diffusion (diffusion from area A to area B equals diffusion from area B to area A)
(b)
= Solute molecule

Prinsip-Prinsip Fisis Pertukaran Gas; Difusi Oksigen dan Karbon dioksida Melalui Membran Pernafasan

- Difusi Gas Berdasarkan Molekul → sumber energi →
- Makin tinggi tekanan gas makin rapat molekul gas, makin besar energi untuk saling berbenturan.
- Difusi Netto Gas dalam Satu Arah - Efek Gradien Konsentarsi
- Difusi mengalir dari tempat dg konsentrasi tinggi ke konsentrasi rendah

Fick's law

$$\dot{V}_{gas} = \frac{A \times D \times (P_1 - P_2)}{T}$$

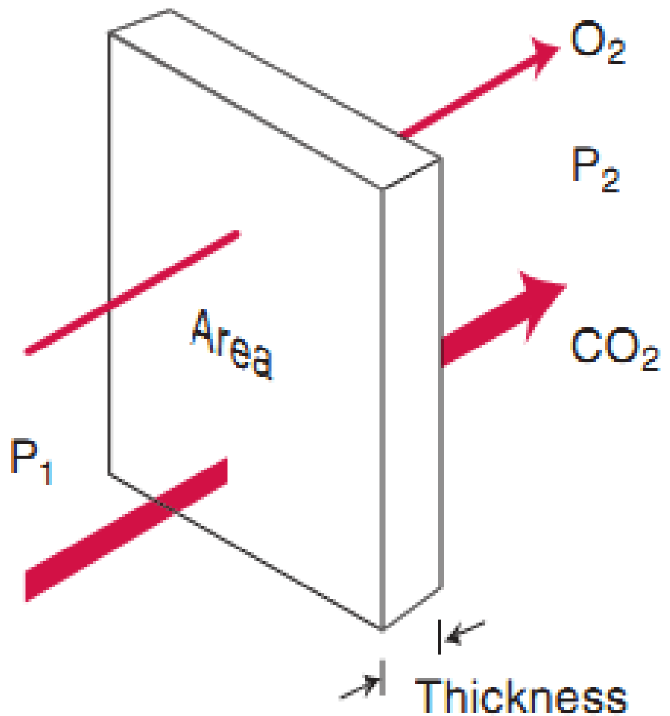
where $\dot{V}_{gas}$ = volume of gas diffusing through the tissue barrier per time, mL/min

A = surface area of the barrier available for diffusion

D = diffusion coefficient, or diffusivity, of the particular gas in the barrier

T = thickness of the barrier or the diffusion distance

$P_1 - P_2$ = partial pressure difference of the gas across the barrier



$$\dot{V}_{gas} \propto \frac{A}{T} \cdot D \cdot (P_1 - P_2)$$

$$D \propto \frac{Sol}{\sqrt{MW}}$$

Figure 3-1. Diffusion through a tissue sheet. The amount of gas transferred is proportional to the area (A), a diffusion constant (D), and the difference in partial pressure ($P_1 - P_2$), and is inversely proportional to the thickness (T). The constant is proportional to the gas solubility (Sol) but inversely proportional to the square root of its molecular weight (MW).

Tekanan Parsial

Adalah Kecepatan difusi masing-masing gas berbanding lurus dengan tekanan yang diakibatkan oleh gas itu sendiri

Tekanan Parsial Gas

Tekanan → gerakan kinetis/ pukulan konstan masing2 molekul melawan suatu permukaan

Tekanan Gas pada Permukaan saluran pernapasan dan alveoli adalah seimbang dengan jumlah kekuatan pukulan masing2 molekul

Tekanan Total berbanding lurus dengan konsentrasi molekul-molekul gas

Dalton's law

$$
\begin{aligned}
P_{N_2} &= 0.786 \times 760\ \text{mmHg} = 597.4\ \text{mmHg} \\
P_{O_2} &= 0.209 \times 760\ \text{mmHg} = 158.8\ \text{mmHg} \\
P_{Ar} &= 0.0009 \times 760\ \text{mmHg} = 0.7\ \text{mmHg} \\
P_{H_2O} &= 0.003 \times 760\ \text{mmHg} = 2.3\ \text{mmHg} \\
P_{CO_2} &= 0.0004 \times 760\ \text{mmHg} = 0.3\ \text{mmHg} \\
P_{\text{other gases}} &= 0.0006 \times 760\ \text{mmHg} = 0.5\ \text{mmHg} \\
\text{Total} &= 760.0\ \text{mmHg}
\end{aligned}
$$

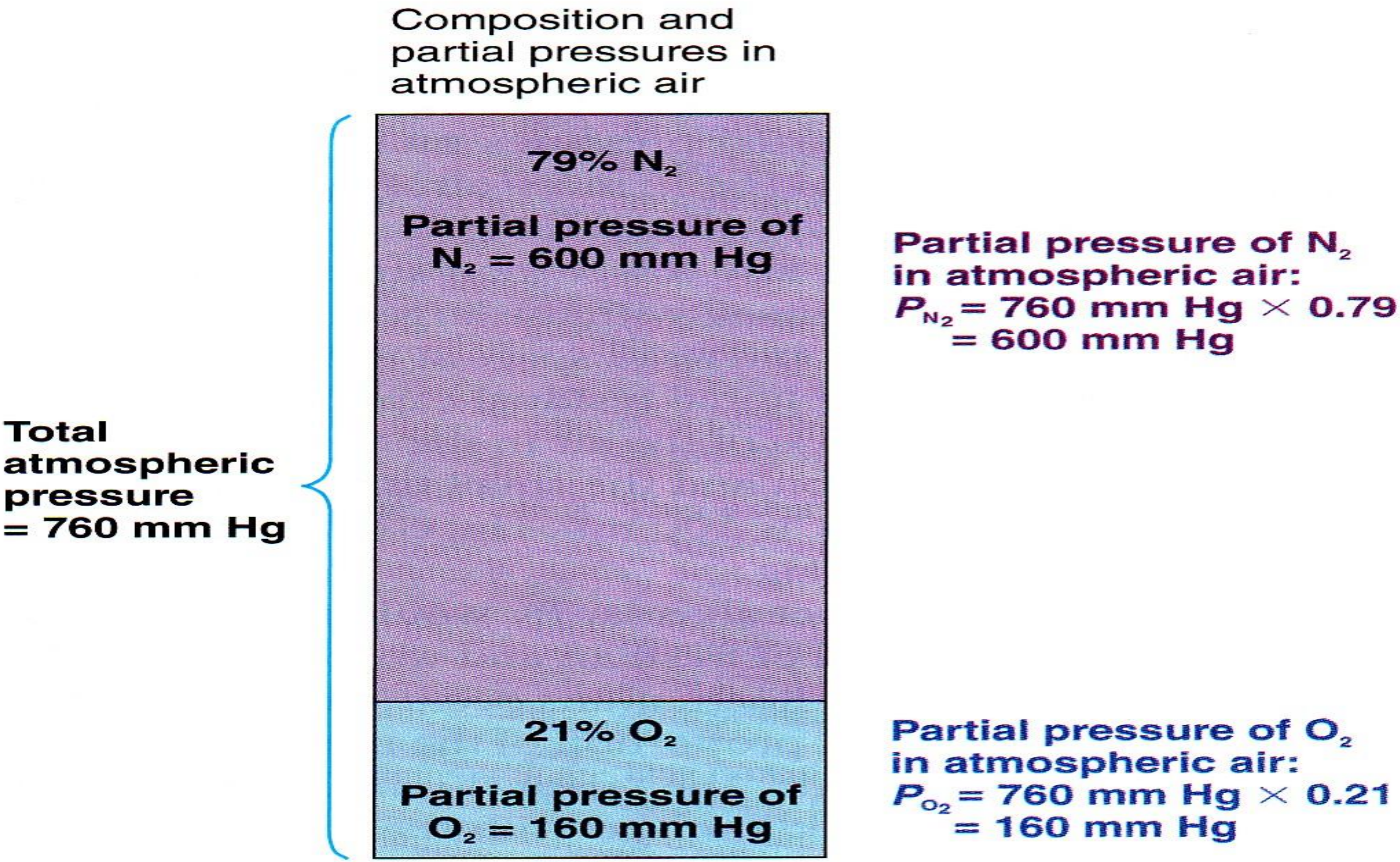


FIGURE 13-24

Concept of partial pressures. The partial pressure exerted by each gas in a mixture equals the total pressure times the fractional composition of the gas in the mixture.

- **Faktor-Faktor yang Menentukan Konsentrasi Gas Terlarut dalam Cairan.**

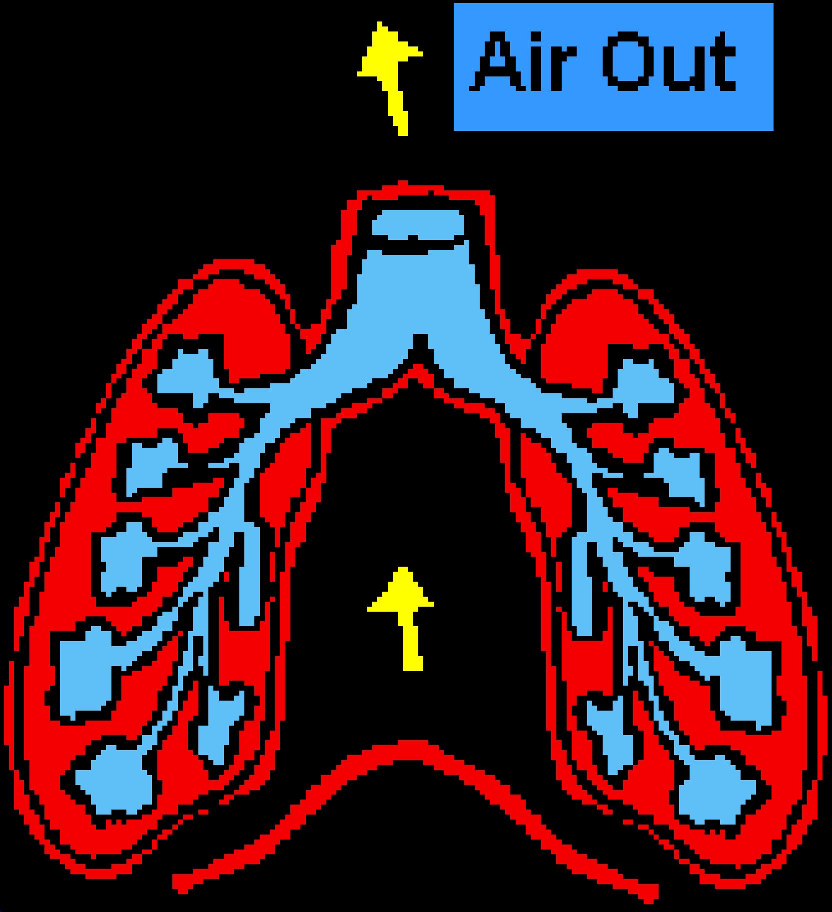
- Konsentrasinya
- *koefisien larutan* dari gas. Semakin tinggi maka tekanan yg ditimbulkannya semakin rendah (scr kimia dan fisik mudah ditarik oleh molekul air)

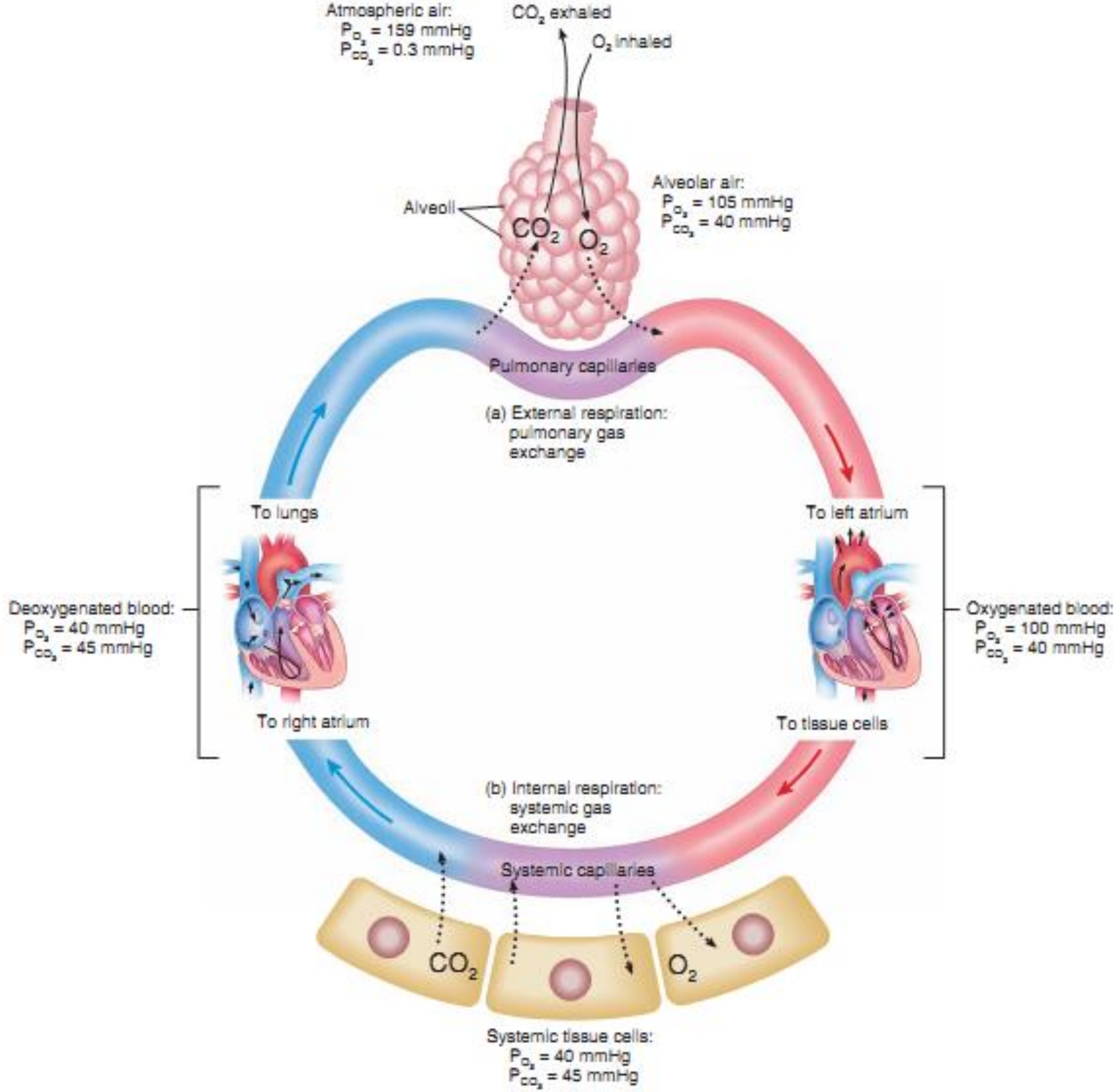
Hukum Henry

$$\text{Tekanan} = \frac{\text{Konsentrasi gas terlarut}}{\text{Koefisien kelarutan}}$$

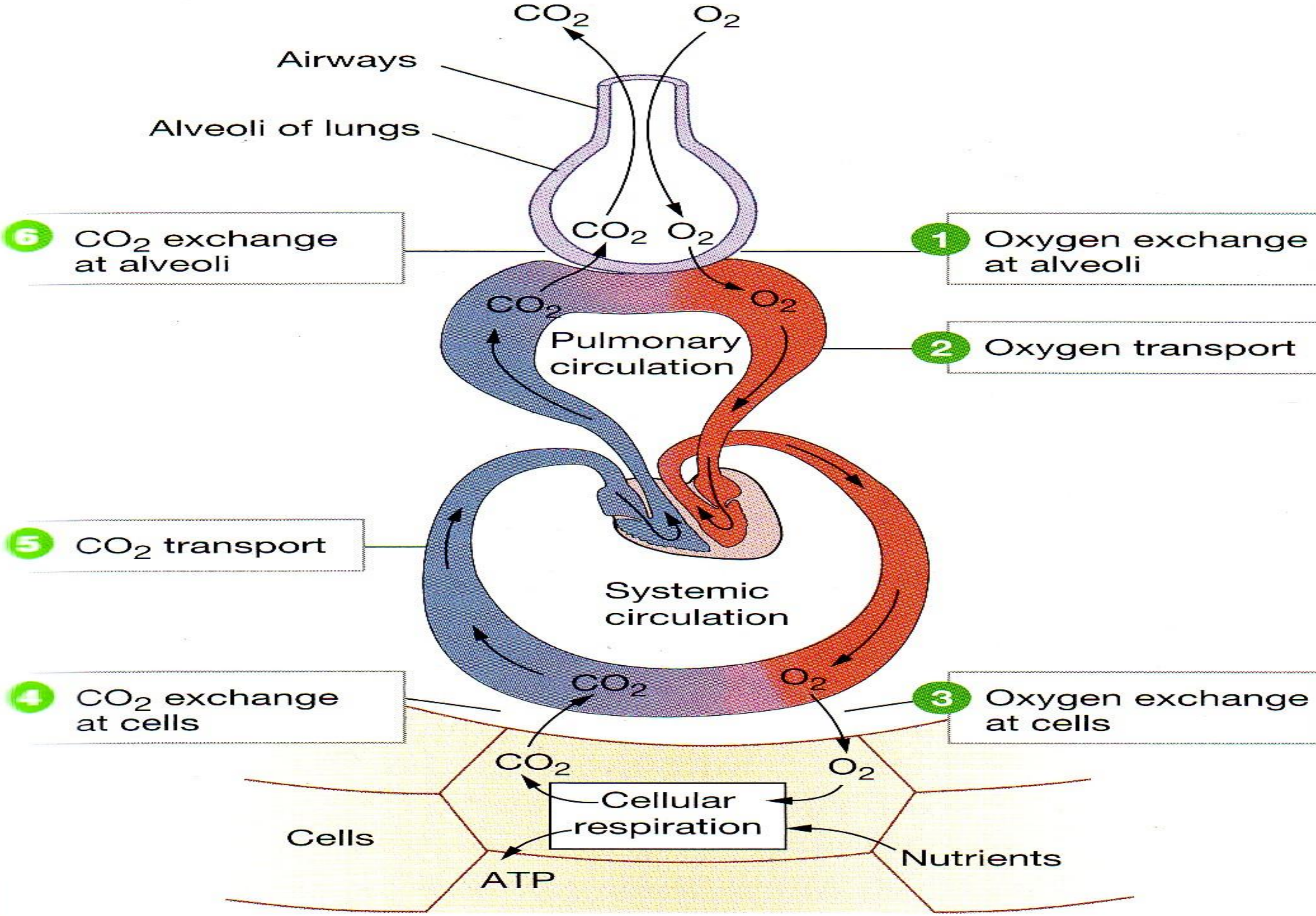
Oksigen 0,024
Karbon dioksida 0,57
Karbon monoksida 0,018
Nitrogen 0,012
Helium 0,008

Karbondioksida 20 X kelarutannya dibanding oksigen


Air Out



Atmospheric air:
P_{O_2} = 159 mmHg
P_{CO_2} = 0.3 mmHg
CO_2 exhaled
O_2 inhaled
Alveoli
CO_2
O_2
Alveolar air:
P_{O_2} = 105 mmHg
P_{CO_2} = 40 mmHg
Pulmonary capillaries
(a) External respiration:
pulmonary gas
exchange
To lungs
To left atrium
Deoxygenated blood:
P_{O_2} = 40 mmHg
P_{CO_2} = 45 mmHg
Oxygenated blood:
P_{O_2} = 100 mmHg
P_{CO_2} = 40 mmHg
To right atrium
To tissue cells
(b) Internal respiration:
systemic gas
exchange
Systemic capillaries
CO_2
O_2
Systemic tissue cells:
P_{O_2} = 40 mmHg
P_{CO_2} = 45 mmHg

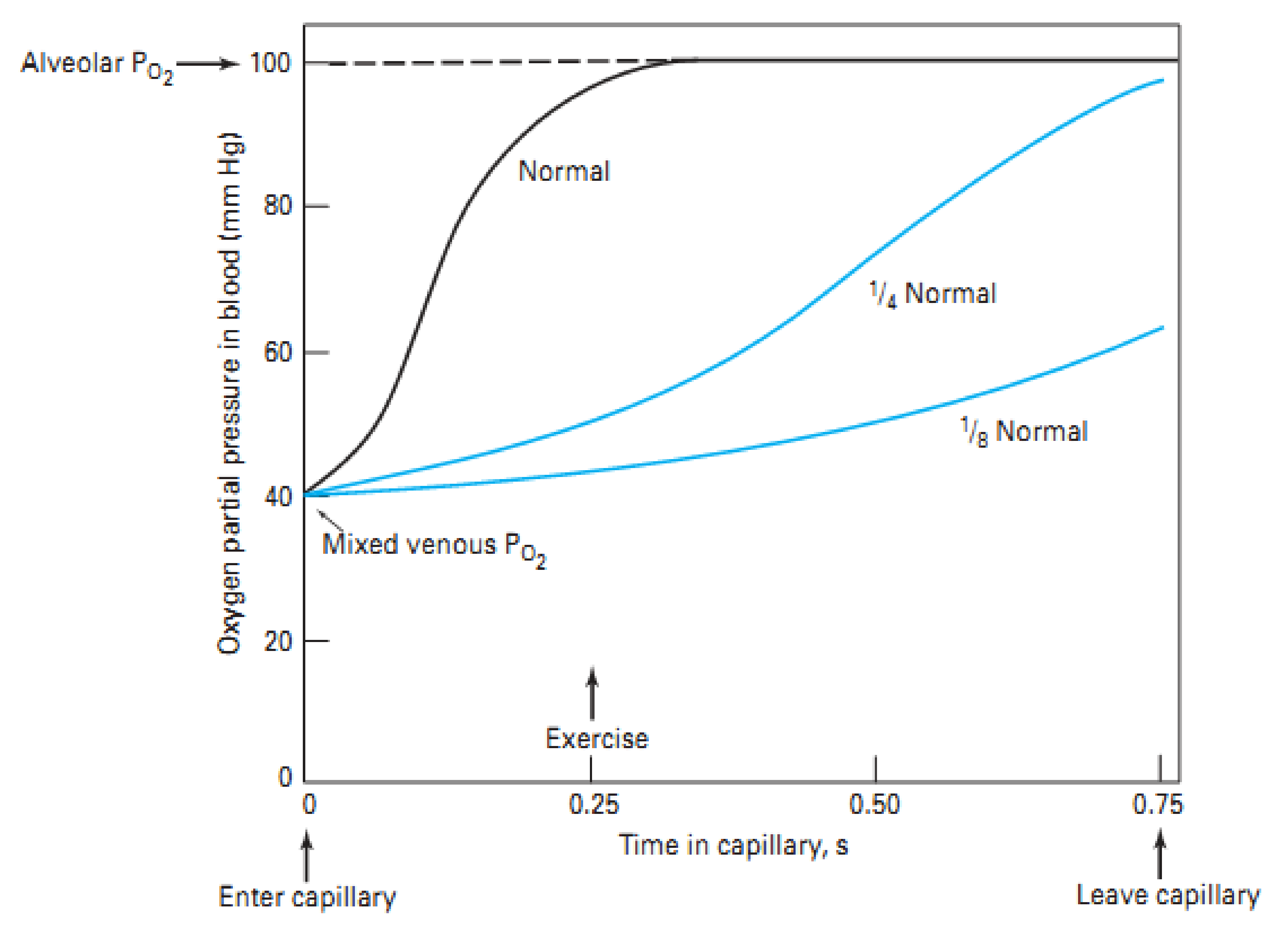


igure 18-1 *Overview of oxygen and CO_2 exchange and ransport*

Konsentrasi dan Tekanan Parsial Oksigen dalam Alveoli

Dipengaruhi :

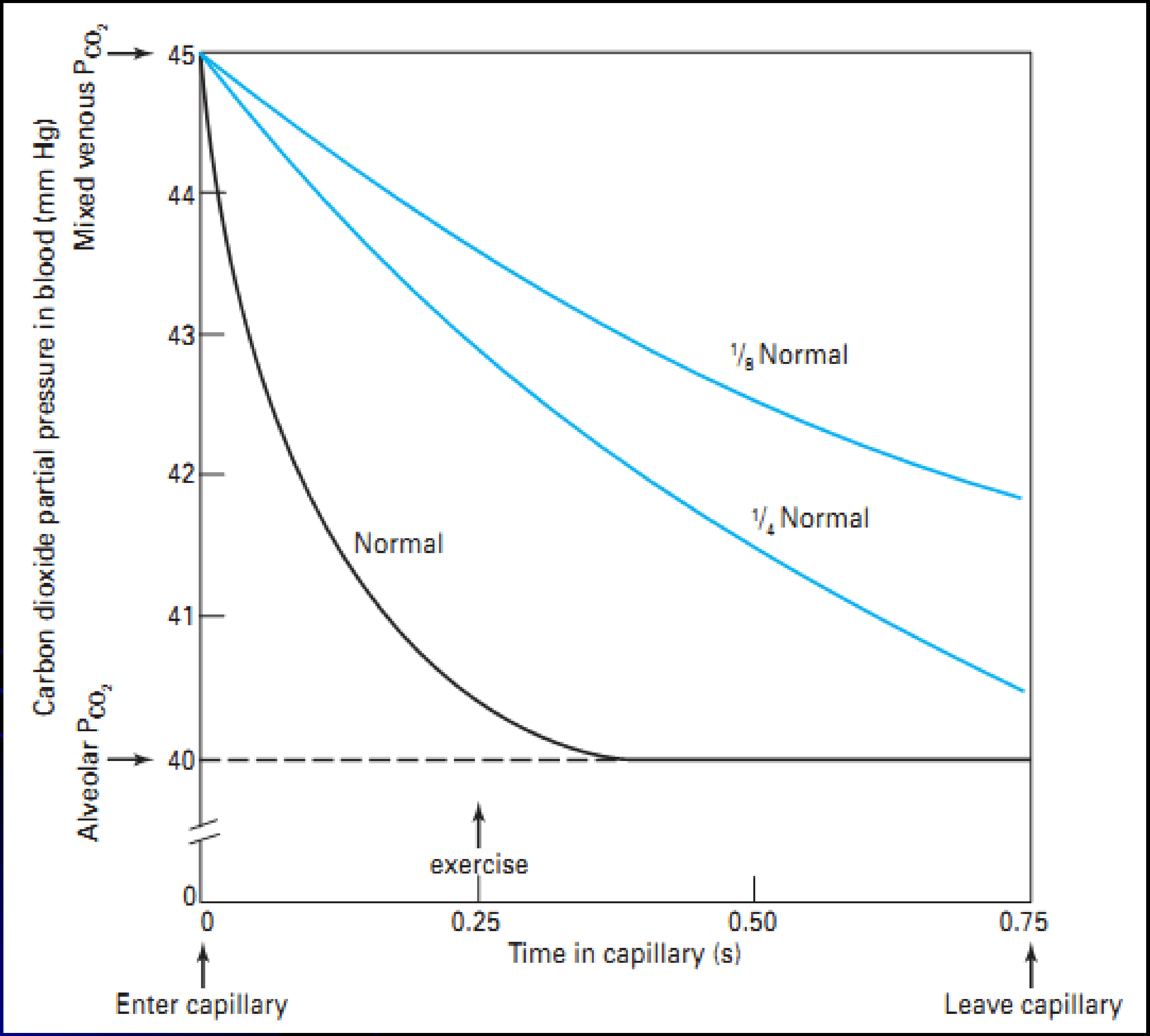
- kecepatan absorbsi oksigen ke dalam darah
- kecepatan masuknya oksigen baru ke dlm paru
- Saat aktivitas PO2 alveolus dipertahankan pd nilai normal (104mmHg)
- Nilai PO2 alveolus maksimal tercapai pd ventilasi di ketinggian permukaan laut (149 mmHg)



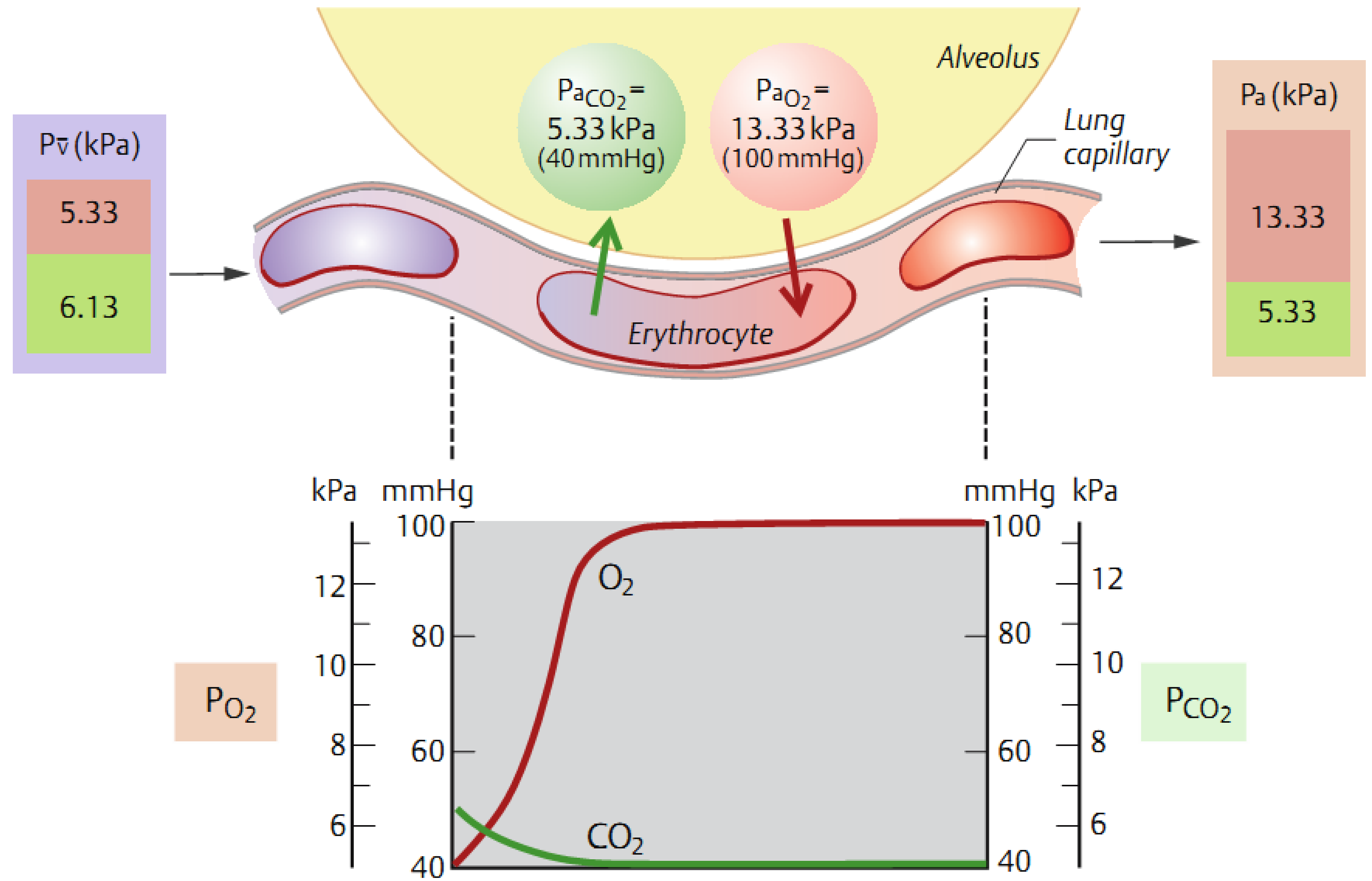
Alveolar P_{O_2}
100
80
60
40
20
0
Oxygen partial pressure in blood (mm Hg)
Normal
1/4 Normal
1/8 Normal
Mixed venous P_{O_2}
Exercise
0
0.25
0.50
0.75
Time in capillary, s
Enter capillary
Leave capillary

Konsentrasi dan Tekanan Parsial CO_2 dalam Alveoli

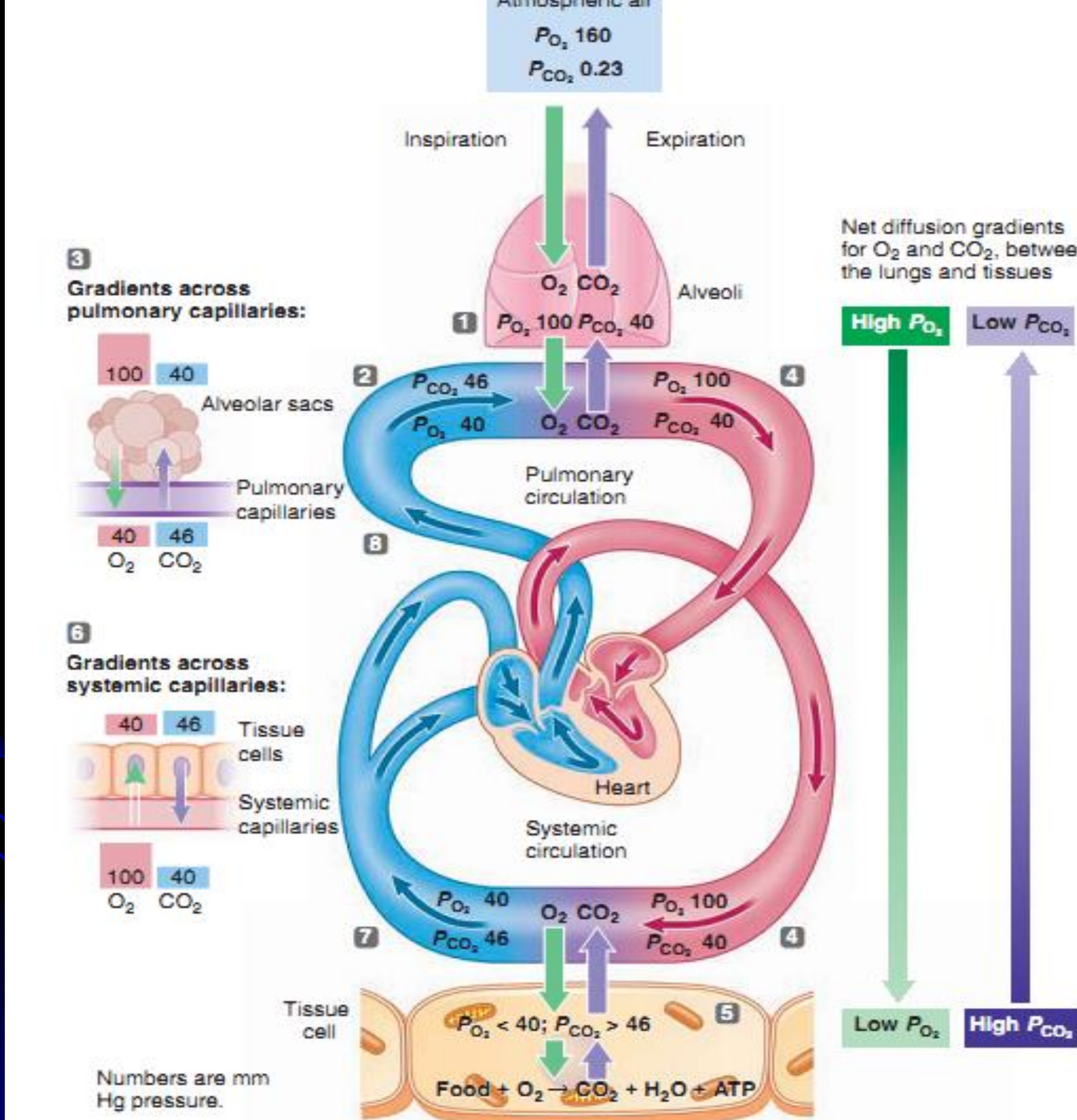
- peningkatan PCO_2 alveolus berbanding lurus dengan kecepatan ekskresi karbon dioksida.
- penurunan PCO_2 alveolus berbanding terbalik dengan ventilasi alveolus



Mixed venous P_{CO_2}
Carbon dioxide partial pressure in blood (mm Hg)
Alveolar P_{CO_2}
45
44
43
42
41
40
0
$^1/_8$ Normal
$^1/_4$ Normal
Normal
exercise
0
0.25
0.50
0.75
Time in capillary (s)
Enter capillary
Leave capillary



Alveolus
Pa_{CO_2} = 5.33 kPa (40 mmHg)
Pa_{O_2} = 13.33 kPa (100 mmHg)
Lung capillary
$P\bar{v}$ (kPa)
5.33
6.13
Pa (kPa)
13.33
5.33
Erythrocyte
kPa
mmHg
100
80
60
40
12
10
8
6
O_2
CO_2
P_{O_2}
P_{CO_2}



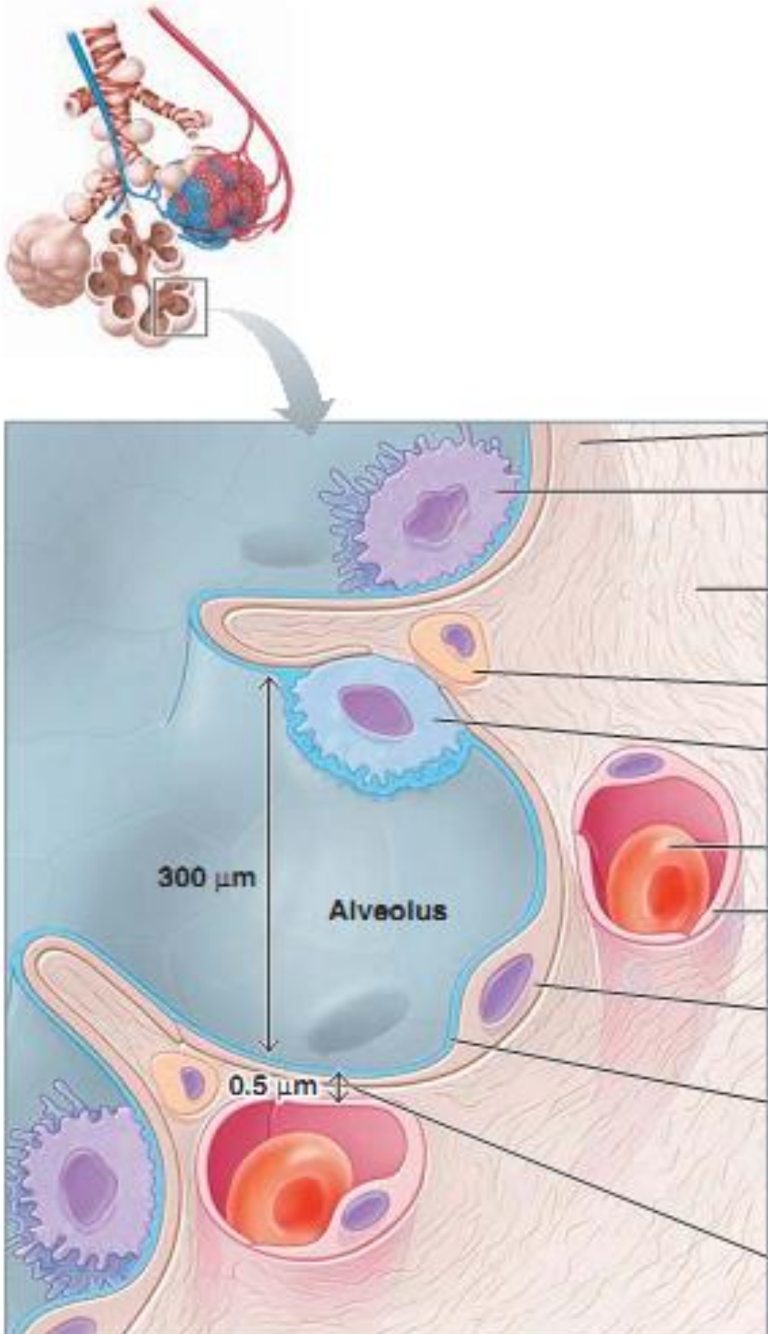
Atmospheric air
P_{O_2} 160
P_{CO_2} 0.23
Inspiration
Expiration
O_2 CO_2
Alveoli
1 P_{O_2} 100 P_{CO_2} 40
Net diffusion gradients for O_2 and CO_2 between the lungs and tissues
High P_{O_2}
Low P_{CO_2}
3
Gradients across pulmonary capillaries:
100 40
Alveolar sacs
Pulmonary capillaries
40 46
O_2 CO_2
2 P_{CO_2} 46
P_{O_2} 40
O_2 CO_2
4 P_{O_2} 100
P_{CO_2} 40
Pulmonary circulation
8
6
Gradients across systemic capillaries:
40 46
Tissue cells
Systemic capillaries
100 40
O_2 CO_2
Heart
Systemic circulation
P_{O_2} 40
P_{CO_2} 46
7
O_2 CO_2
P_{O_2} 100
P_{CO_2} 40
4
Tissue cell
P_{O_2} < 40; P_{CO_2} > 46
5
Food + O_2 → CO_2 + H_2O + ATP
Low P_{O_2}
High P_{CO_2}
Numbers are mm Hg pressure.

Difusi Gas

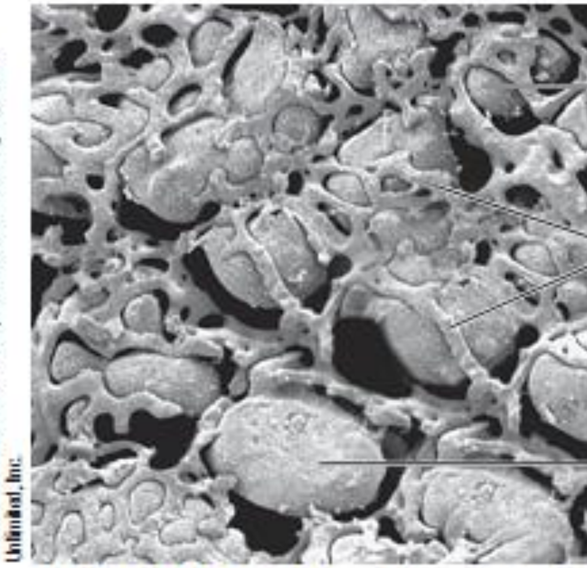
Adanya perbedaan tekanan gas → 0_2 berdifusi dari alveoli paru ke darah dalam kapiler paru karena tekanan (P) O_2 > besar dari darah kapiler paru

Difusi Gas Melalui Membran Pernafasan

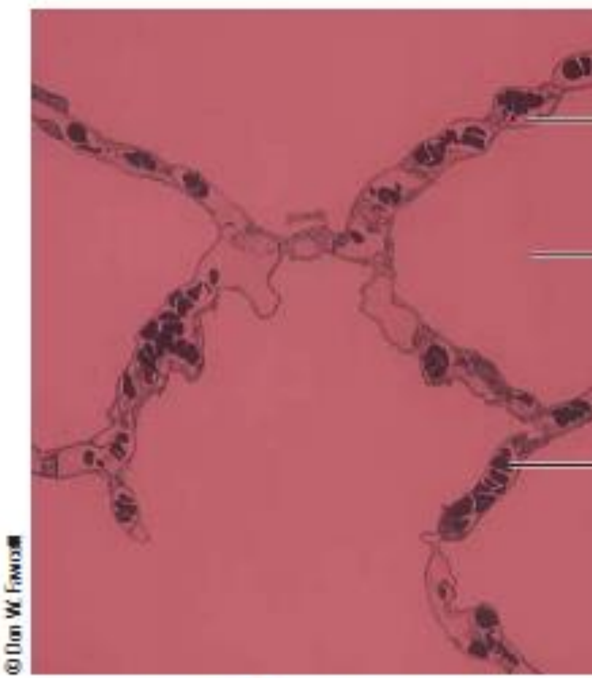
- Alveolus sangat tipis di dalamnya terdapat jaringan kapiler yang hampir padat dan saling berhubungan sebagai suatu lembaran aliran darah. Gas alveolus berada amat sangat dekat dengan darah kapiler. Akibatnya pertukaran gas antara udara alveous dan darah paru terjadi melalui membran pernapasan (paru).



(a) Alveolus and surrounding pulmonary capillaries



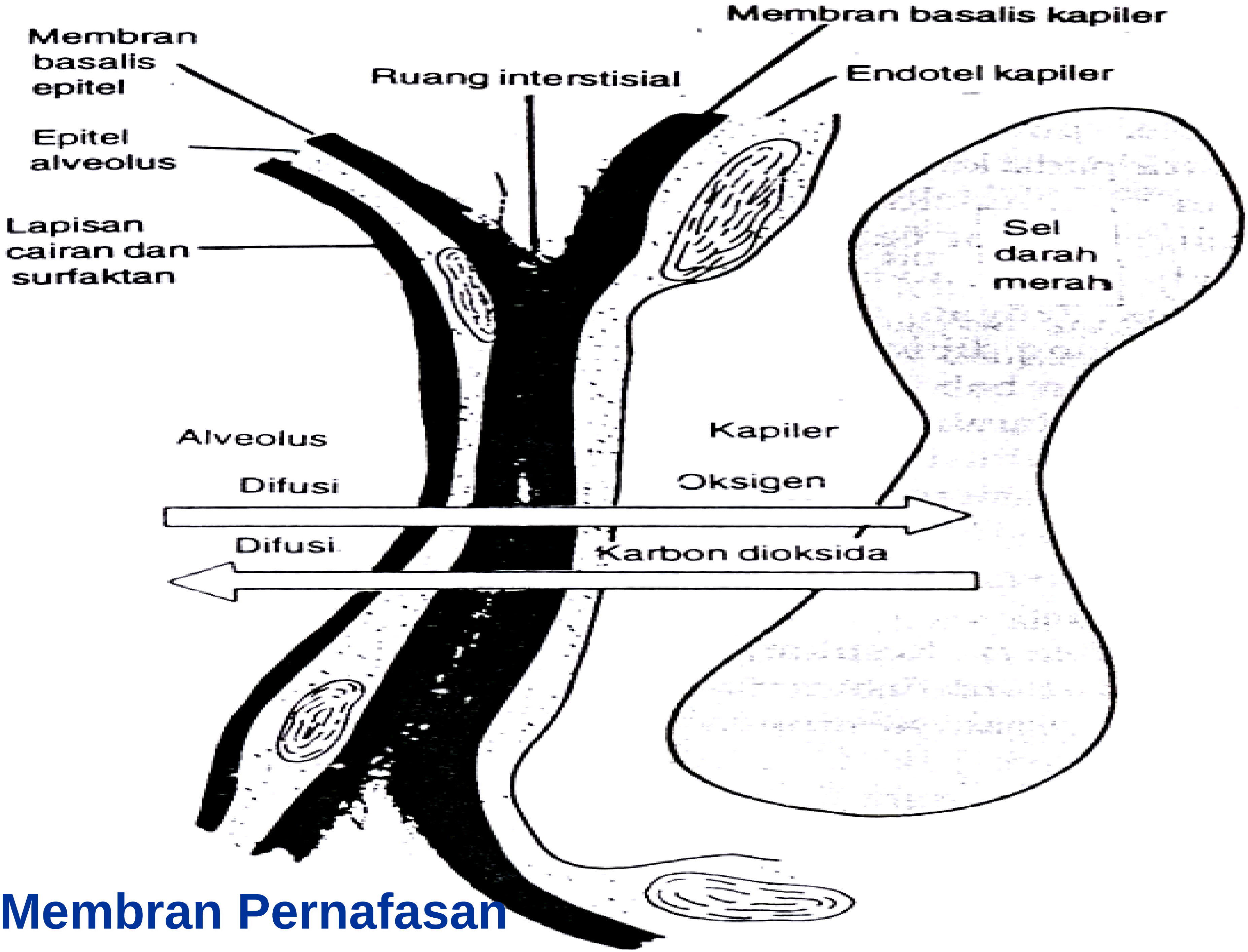
(b) Scanning electron micrograph of alveoli and surrounding pulmonary capillaries



(c) Transmission electron micrograph of several alveoli and surrounding pulmonary capillaries

Lapisan Membran Respirasi Terdiri dari :

1. Lapisan Cairan berisi surfaktan yang melapisi alveoli
2. Epitel alveolus yang tipis
3. Membran basalis epitel
4. Ruang intersisiel antara epitel alveolus dan membran kapiler
5. Membran basalis kapiler
6. Membran endotel kapiler



Membran Pernafasan

Faktor-Faktor yang Mempengaruhi Kecepatan Difusi Gas Melalui Membran Pernafasan

- Ketebalan membran (edem,fibrosis: ketebalan>>)
- luas permukaan membran(lobektomi, emfisema)
- koefisien difusi gas dalam subtansi membran (berbanding lurus dg kelarutan gas dan berbanding terbalik terbail dg akar pangkat 2 molekulnya)
- perbedaan tekanan antara ke2 sisi membran

  (perbedaan tekanan parsial gas dalam alveoli dg tekanan dlm darah)

TABLE 13-5

Factors That Influence the Rate of Gas Transfer across the Alveolar Membrane

FACTOR	INFLUENCE ON THE RATE OF GAS TRANSFER ACROSS THE ALVEOLAR MEMBRANE	COMMENTS
Partial Pressure Gradients of O_2 and CO_2	Rate of transfer ↑ as partial pressure gradient ↑	Major determinant of the rate of transfer
Surface Area of the Alveolar Membrane	Rate of transfer ↑ as surface area ↑	Surface area remains constant under resting conditions Surface area ↑ during exercise as more pulmonary capillaries open up when the cardiac output increases and the alveoli expand as breathing becomes deeper Surface area ↓ with pathological conditions such as emphysema and lung collapse
Thickness of the Barrier Separating the Air and Blood across the Alveolar Membrane	Rate of transfer ↓ as thickness ↑	Thickness normally remains constant Thickness ↑ with pathological conditions such as pulmonary edema, pulmonary fibrosis, and pneumonia
Diffusion Coefficient (Solubility of the Gas in the Membrane)	Rate of transfer ↑ as diffusion coefficient ↑	Diffusion coefficient for CO_2 is 20 times that of O_2, offsetting the smaller partial pressure gradient for CO_2; therefore, approximately equal amounts of CO_2 and O_2 are transferred across the membrane

Kapasitas Difusi Membran Pernafasan

Kemampuan membran pernafasan dalam pertukaran gas antara alveoli dan darah paru dapat dinyatakan secara kuantitatif dengan *kapasitas difusi membran yang didefinisikan sebagai volume gas yang berdifusi melalui membran tiap menit pada setiap pebedaan tekanan 1 mm Hg*.

Difusi Gas Melalui Jaringan

- daya larutnya yang tinggi dalam lipid
- pembatas utama kecepatan difusi gas adalah melalui air jaringan (*tissue water*), misalnya melalui membran sel. Difusi gas melalui jaringan membran pernafasan, hampir sama dengan difusi gas melalui air.
- Udara alveolus mempunyai komposisi konsentrasi gas yang tidak sama dengan udara atmosfer

Kapasitas Difusi Oksigen

Rata-rata laki-laki dewasa muda kapasitas difusi oksigen pada keadaan istirahat rata-rata 21 ml/menit/mm Hg. Perbedaan tekanan oksigen rata-rata diantara membran pernafasan selama pernafasan tenang dan normal adalah kira-kira 11 mm Hg. Perkalian tekanan ini dengan kapasitas difusi (11x21) memberi hasil total kira-kira 230 milimeter difusi oksigen melalui membran pernafasan tiap menit, ini sebanding dengan kecepatan pemakaian oksigen tubuh.

PO2 dalam alveoli = 104mmHg , PO2 darah vena dalam kapiler paru 40 mmHg → difusi → PO2 darah meninggalkan paru = 104 mmHg

Bila darah arteri sampai jaringan → PO2 = 95 mmHg ; PO2 cairan intersisiel 40mmHg dan PO2 intrasel = 23 mmHg

Perbedaan tekanan hebat → difusi O2 dari darah ke seluler

Pada akhir vena dari kapiler → PO2 = 40 mmHg

Table 18-1: Normal Blood Values in Pulmonary Medicine

	ARTERIAL	VENOUS
P_{O_2}	95 mm Hg (85–100)	40 mm Hg
P_{CO_2}	40 mm Hg (35–45)	46 mm Hg
pH	7.4 (7.38–7.42)	7.37

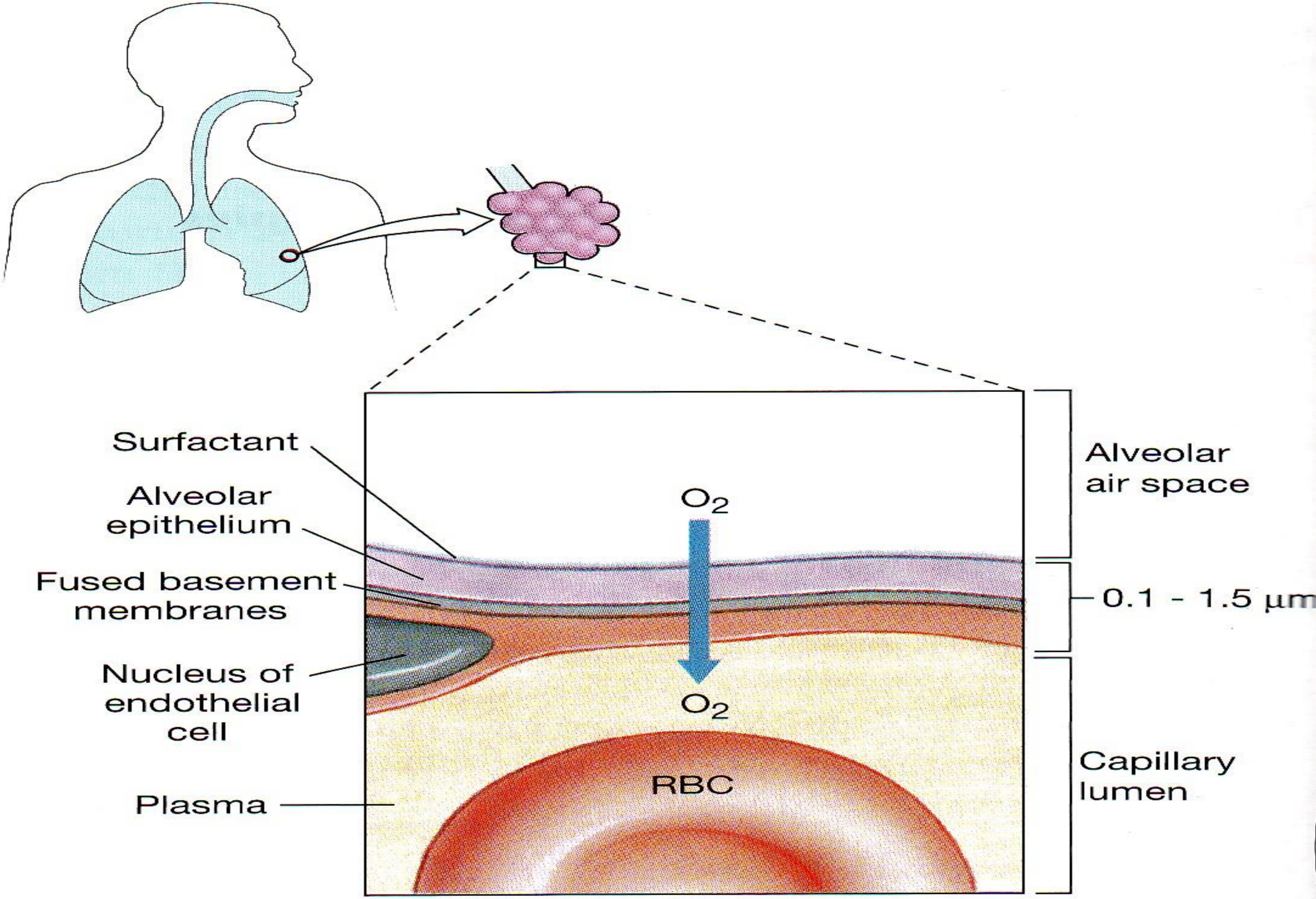


Figure 18-5 *Oxygen diffuses across the alveolar and endothelial cells to enter the plasma*

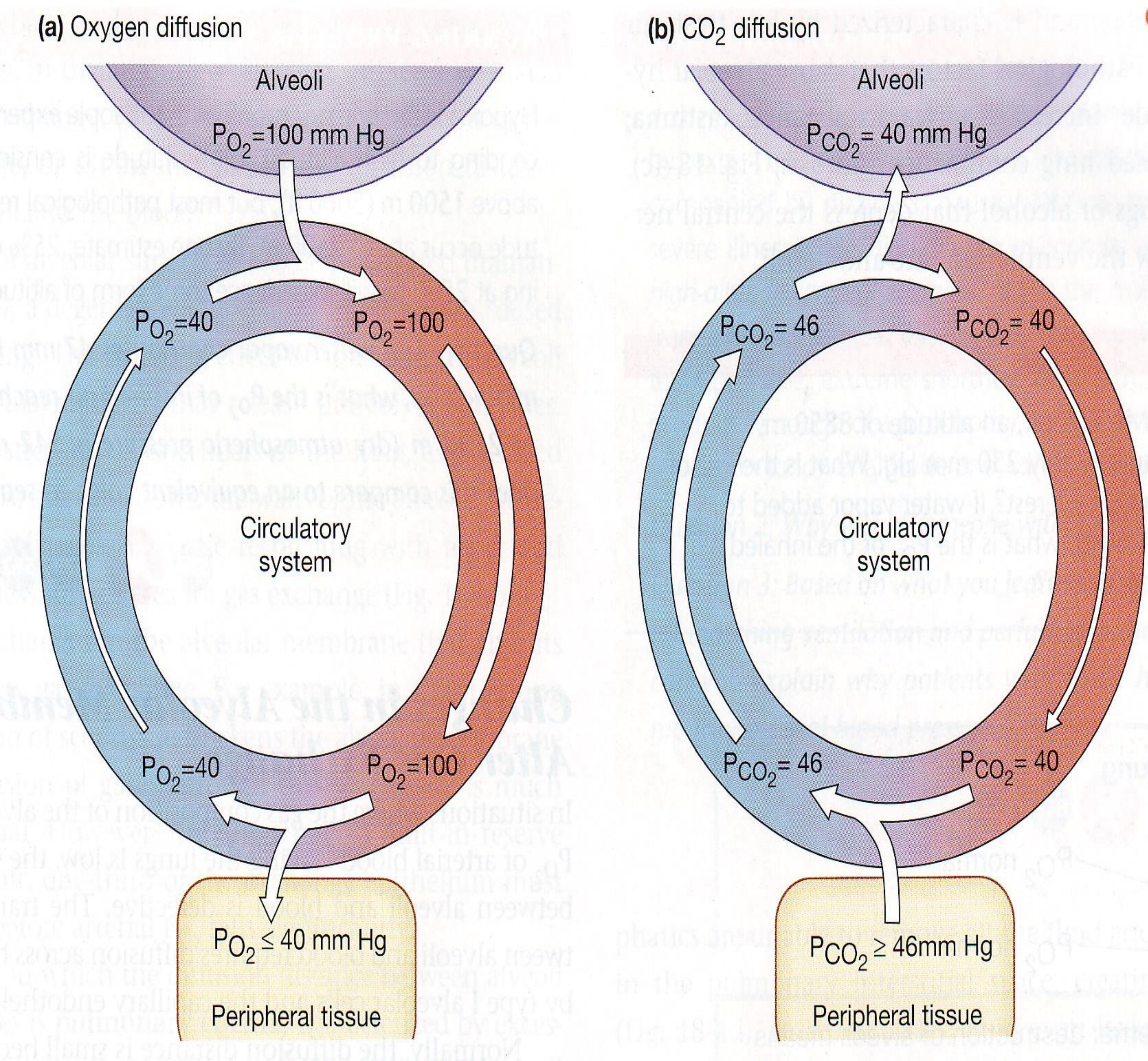


Figure 18-3 *Gas exchange at the alveoli and cells*

Perubahan Kapasitas Difusi Oksigen Selama Kerja

- *Selama kerja berat aliran darah paru* dan *ventilasi alveolus* : *kapasitas difusi oksigen meningkat pada pria dewasa muda sampai maksimum kira-kira 65 ml/menit mm Hg*, *3x kapasitas difusi pada keadaan istirahat*. *Peningkatan disebabkan* (1) *pembukaan sejumlah kapiler paru* (2) pertukaran yang lebih baik antara ventilasi alveoli dan perfusi kapiler alveolus dengan darah disebut *ratio ventilasi perfusi*. Oksigen darah meningkat → peningkatan ventilasi alveolus dan dgn memperbesar kapasitas membran untuk memindahkan oksigen ke dlm darah.

Kapasitas Difusi Karbon dioksida

- Kapasitas difusi karbon dioksida *belum pernah diukur* → *kesukaran* teknik : *karbon dioksida berdifusi melalui mebran pernafasan sedemikian cepatnya hingga PCO2 dalam darah paru tidak berbeda banyak dengan PCO2 dalam alveoli, perbedaannya rata-rata kurang dari 1 mm Hg* -→ perbedaan ini sangat kecil untuk diukur.

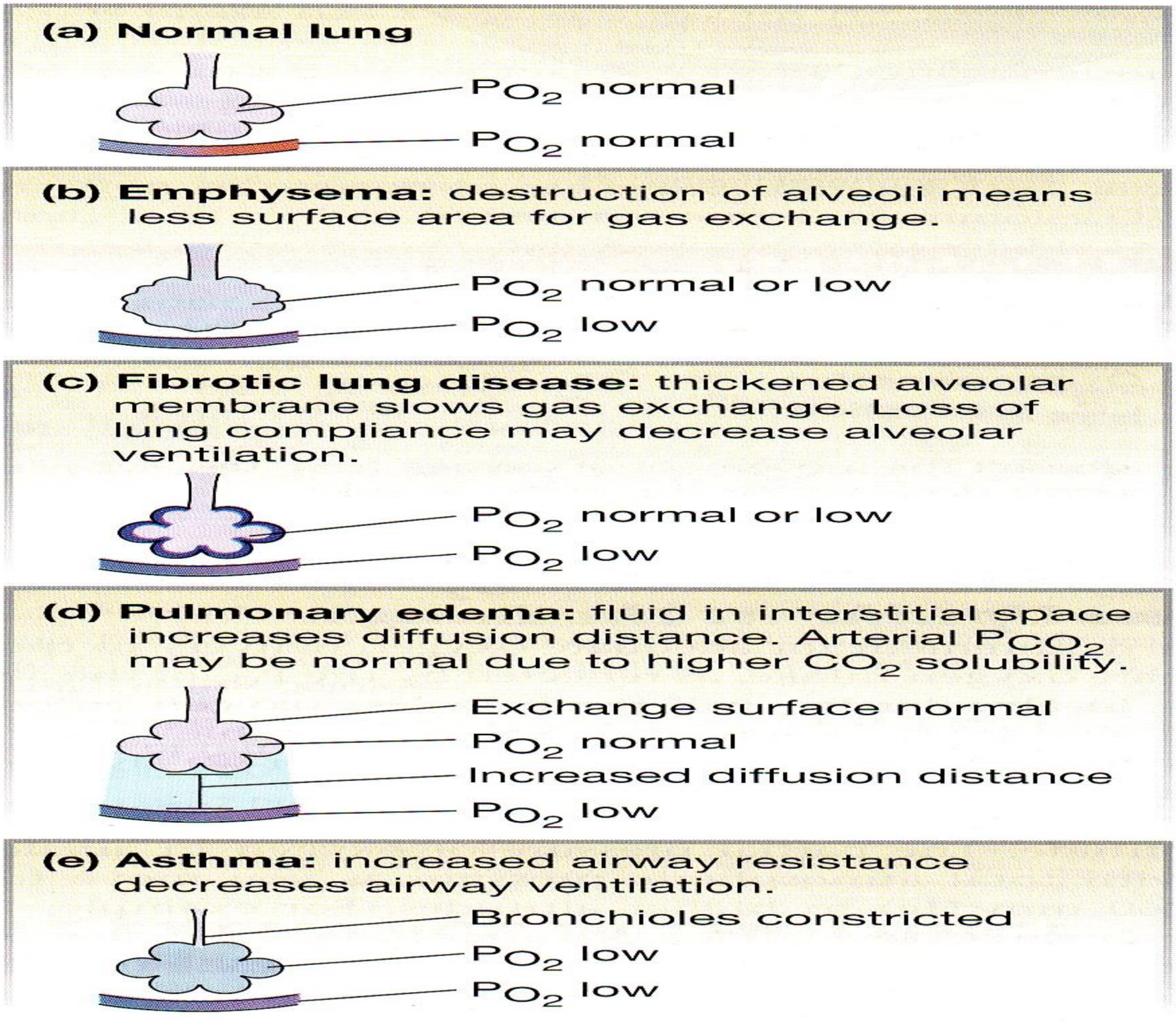


Figure 18-4 *Pulmonary pathologies that affect alveolar ventilation and gas exchange*


Thank You