SISTEM PERNAFASAN

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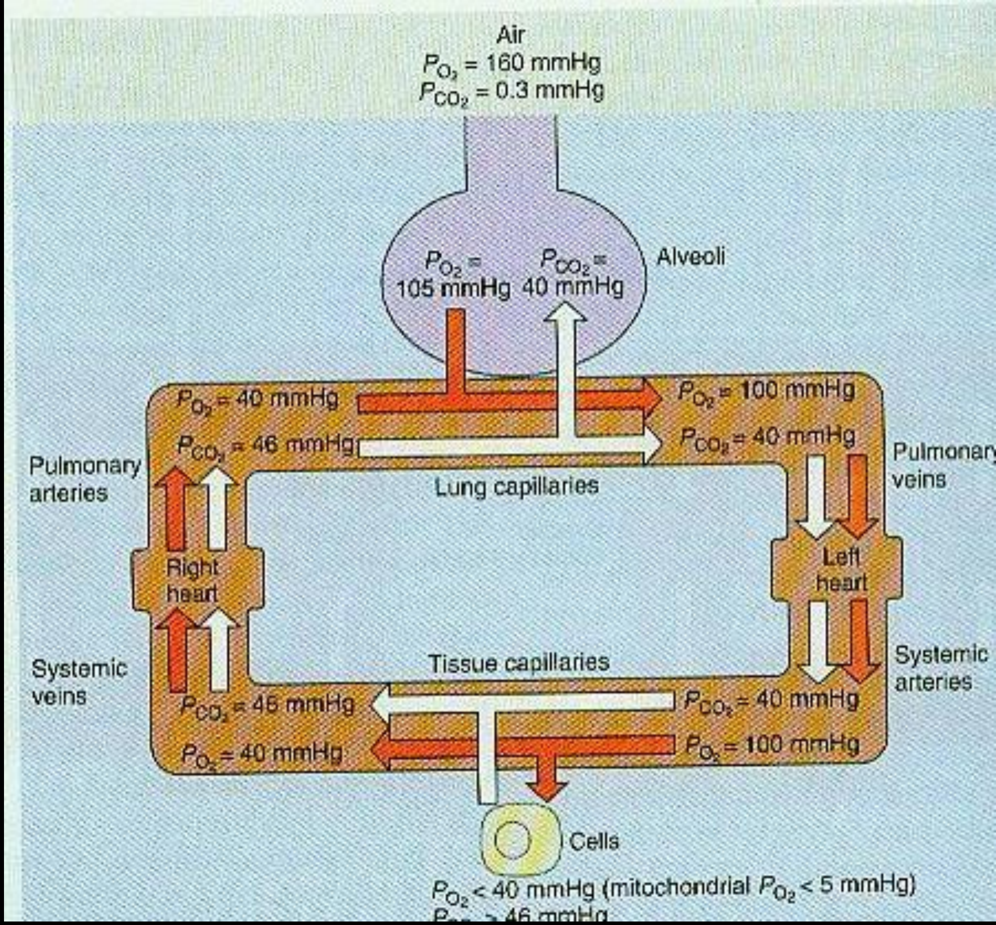
Semarang

Sistem Pernafasan

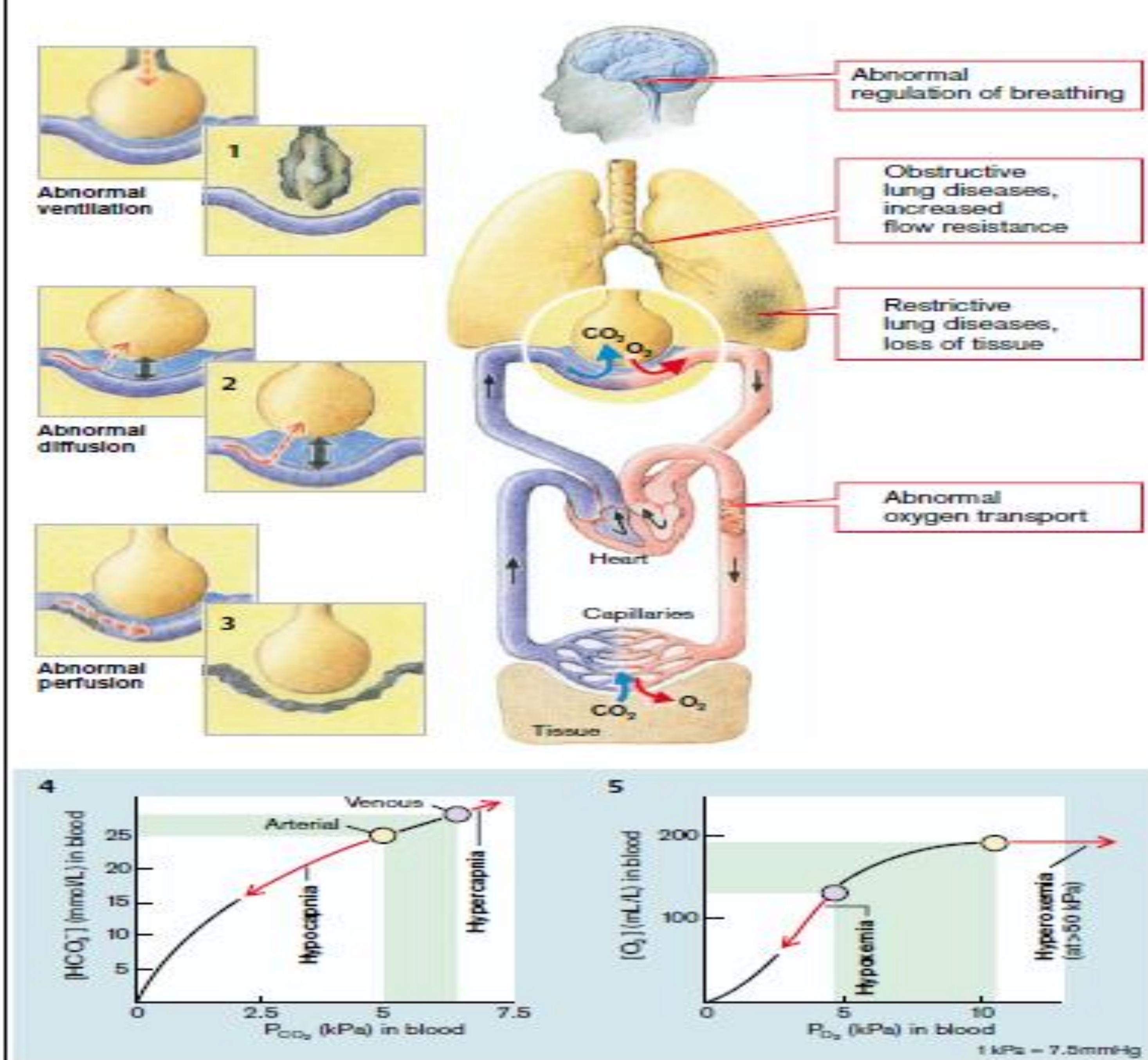
- Proses
  - Ventilasi
  - Difusi
  - Transportasi
  - Difusi
- Pengaturan pernafasan



Fungsi

- Pertukaran gas
- Pengaturan pH
- Perlindungan terhadap substansi patogen dan iritan yang terhirup
- Vokalisasi

A. Pathophysiology of Respiration (Overview)



VENTILASI

Inspirasi
Ekspirasi

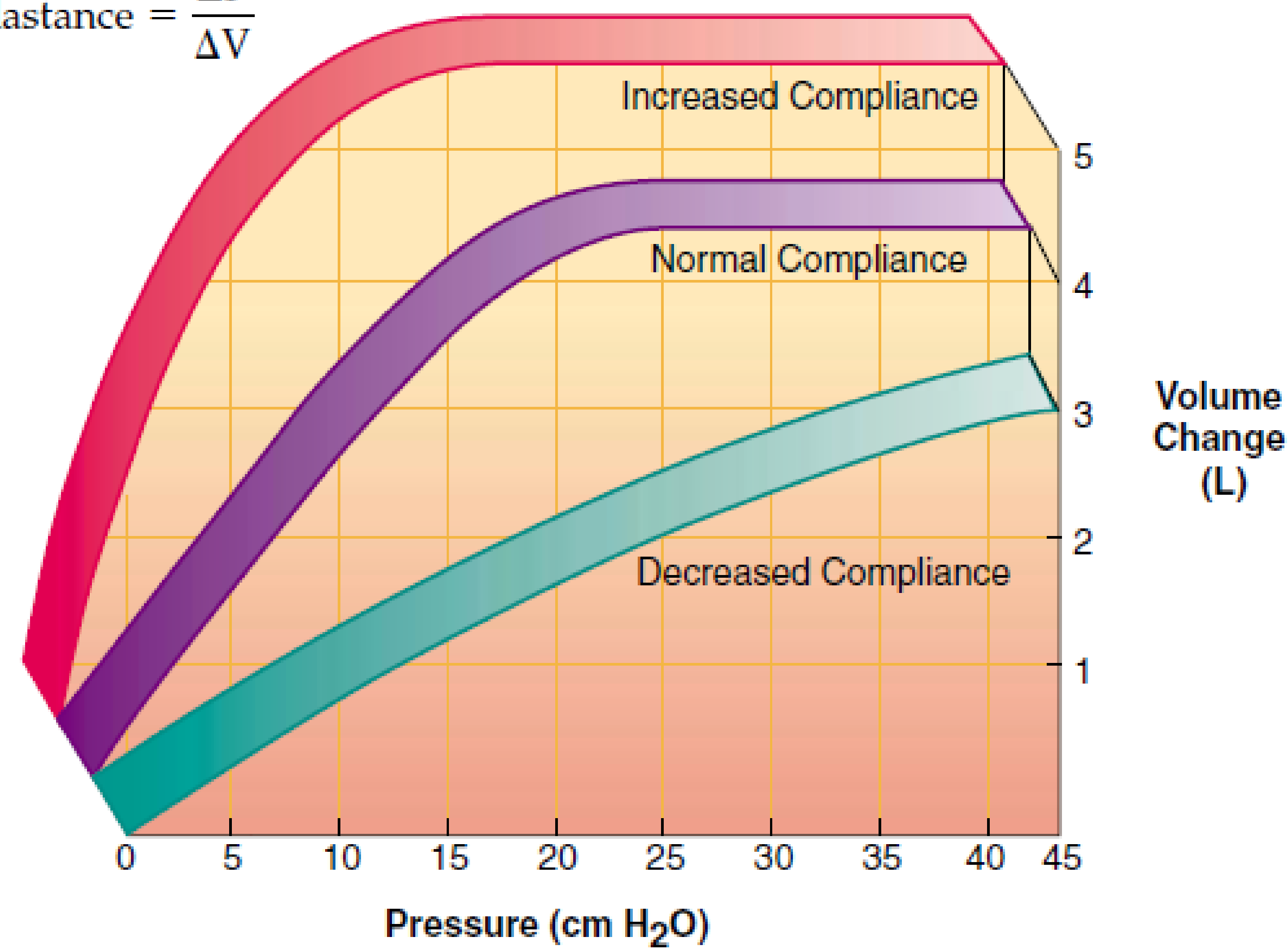
Compliance
Elastic Recoil

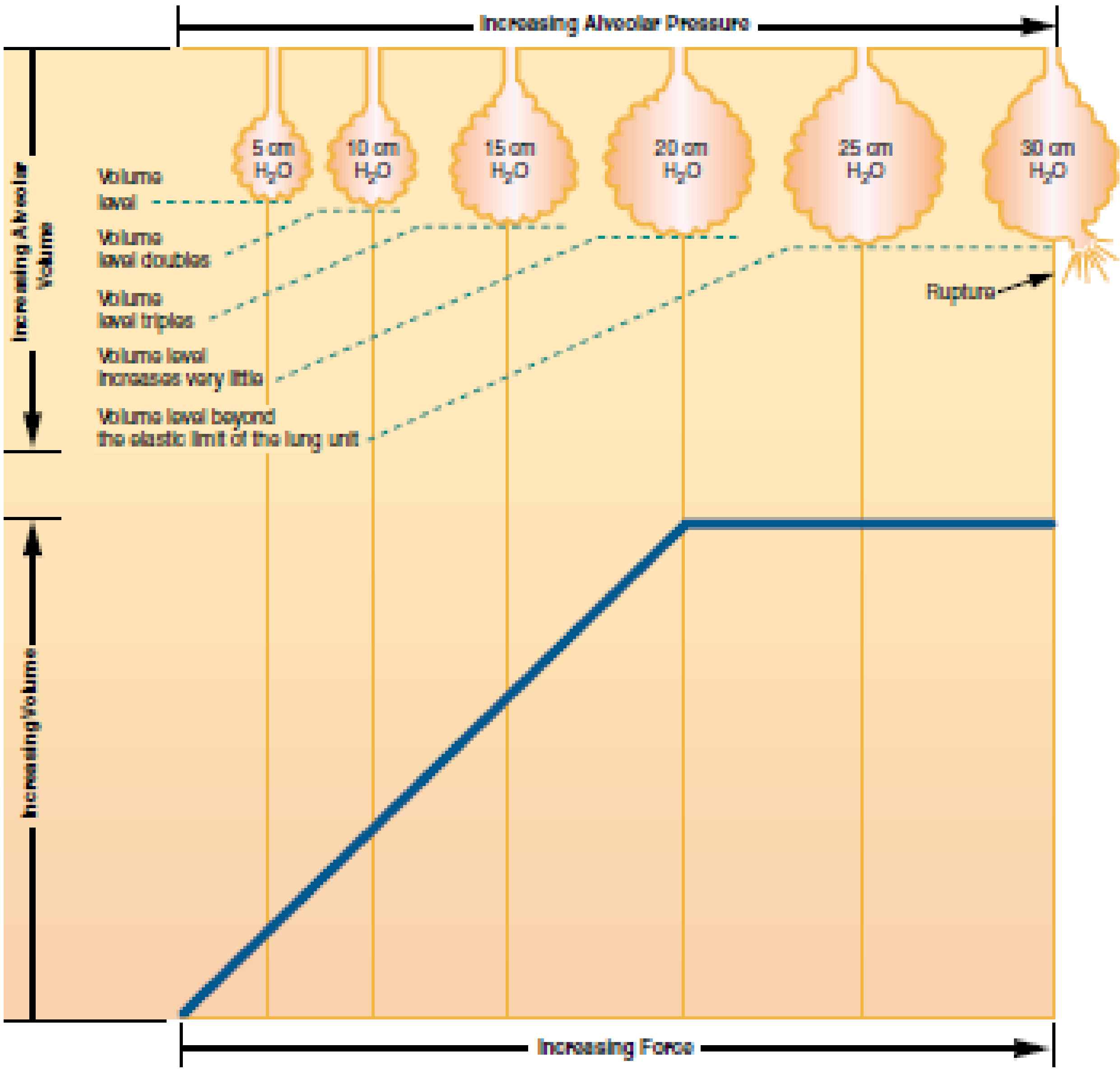
Ventilasi
Hukum HOOK

- Compliance
- (dV/dP)
  - Pengembangan Paru
  - Surfactan
    - Menurunkan tegangan permukaan
    - Menstabilkan ukuran alveoli
    - Interdependence alveoli
- Recoil Elastic
- (dP/dV)
  - Paru cenderung mengempis
    - Serabut elastik
    - Tegangan permukaan

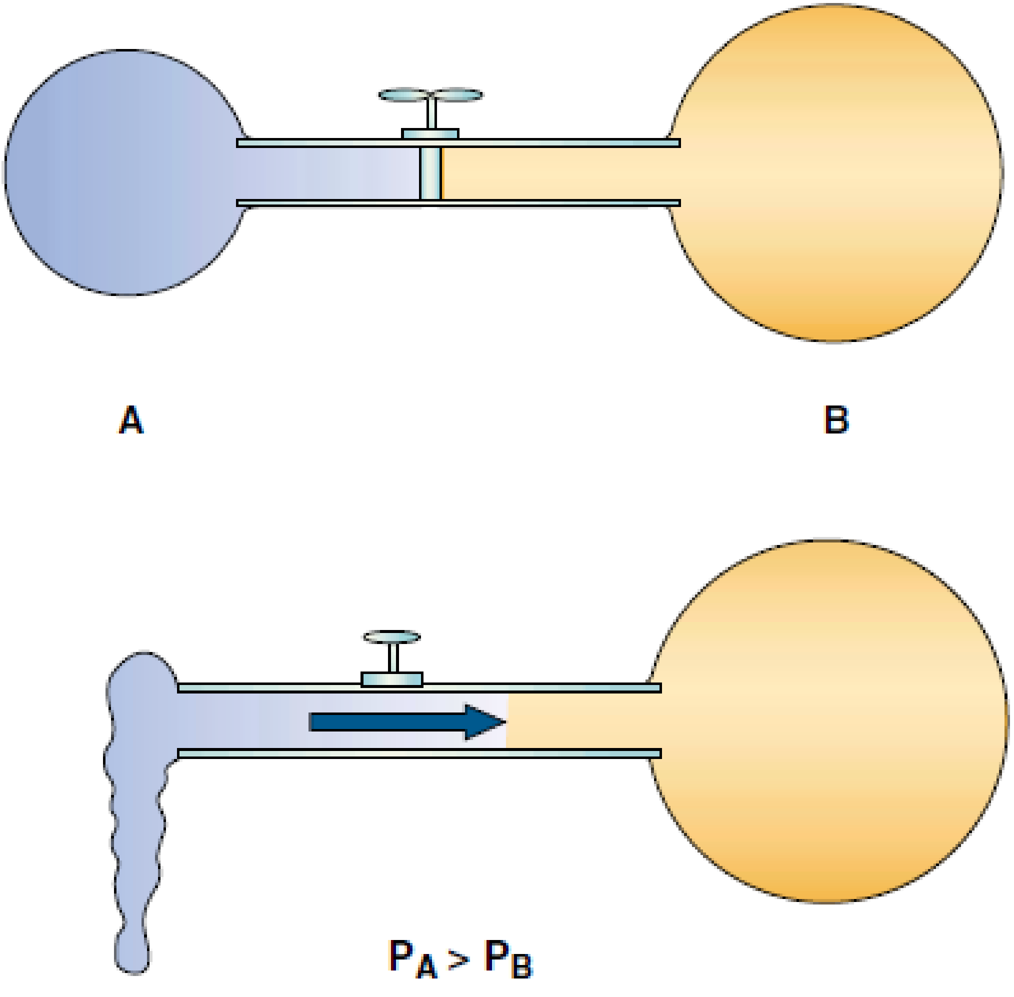
Hukum HOOKE

$$Elastance = \frac{\Delta P}{\Delta V}$$




Increasing Alveolar Pressure
5 cm H_2O
10 cm H_2O
15 cm H_2O
20 cm H_2O
25 cm H_2O
30 cm H_2O
Increasing Alveolar Volume
Volume level
Volume level doubles
Volume level triples
Volume level increases very little
Volume level beyond the elastic limit of the lung unit
Rupture
Increasing Volume
Increasing Force

Hukum LAPLACE



Hukum LAPLACE

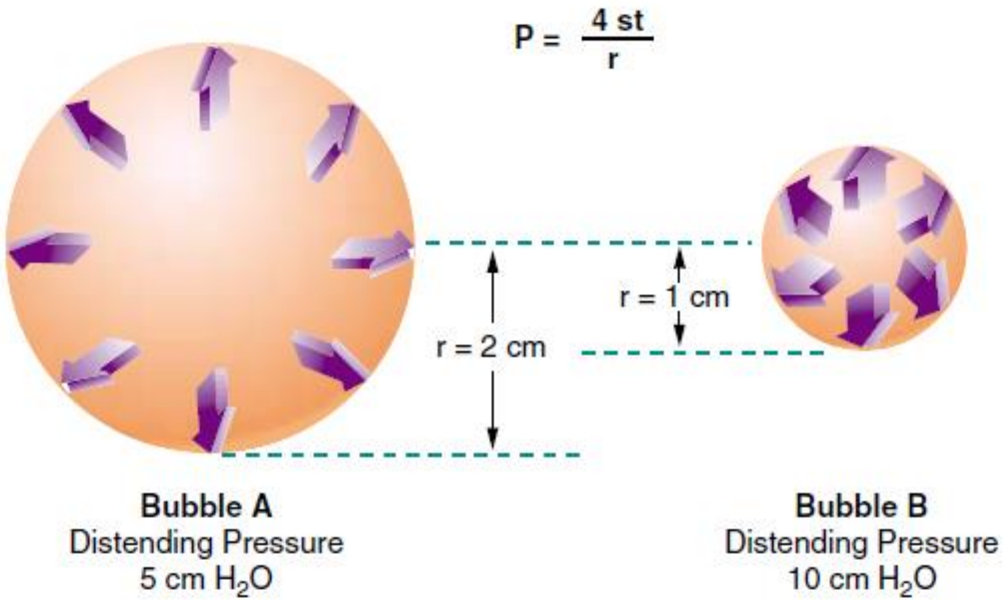


Figure 2–14. *The surface tension (ST) of bubbles A and B is identical. The radius (r) of bubble A is 2 cm, and it requires a distending pressure (P) of 5 cm H_2O to maintain its size. The radius of bubble B is 1 cm (one-half that of bubble A), and it requires a distending pressure of 10 cm H_2O (twice that of bubble A) to maintain its size.*

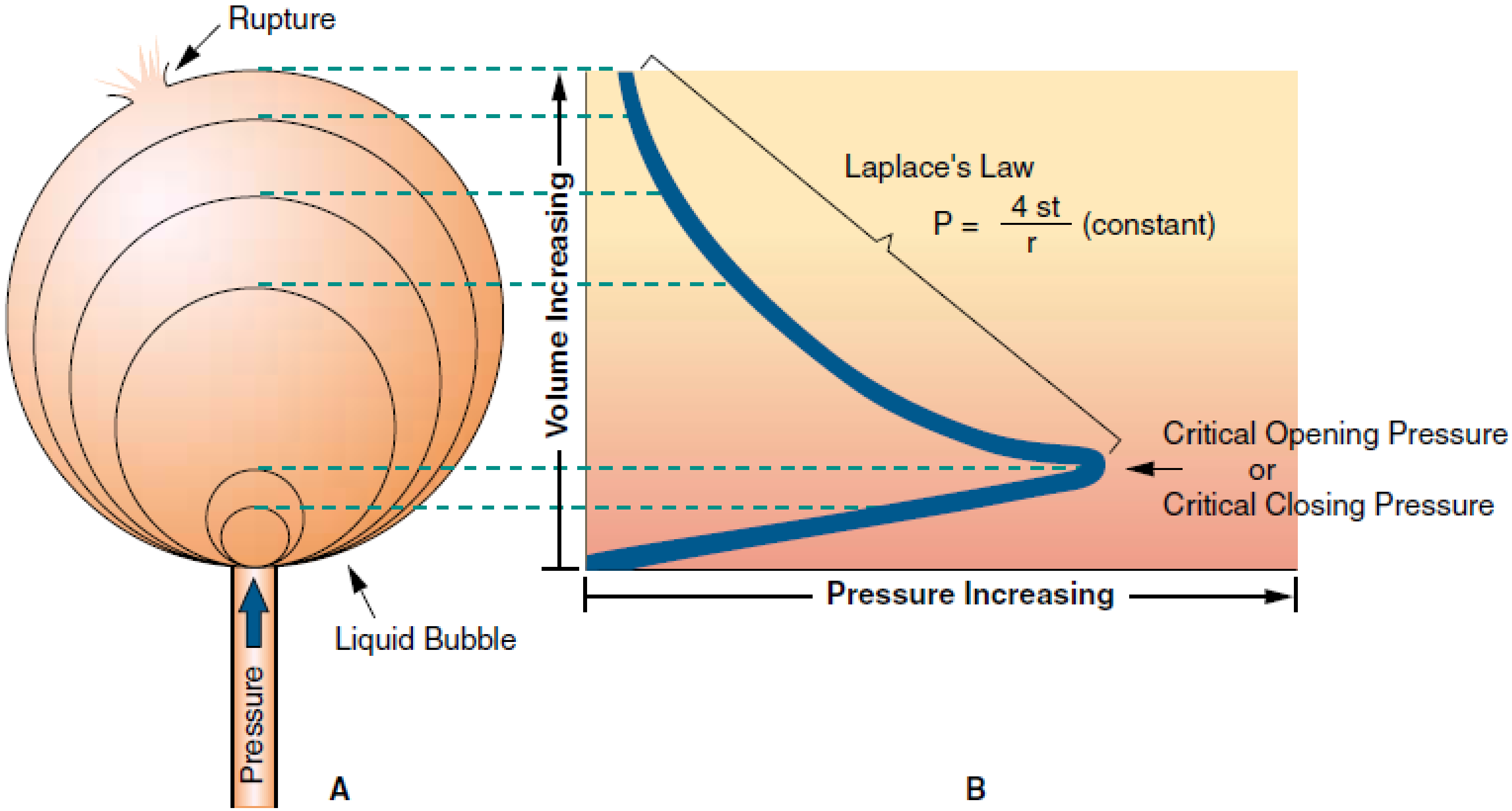
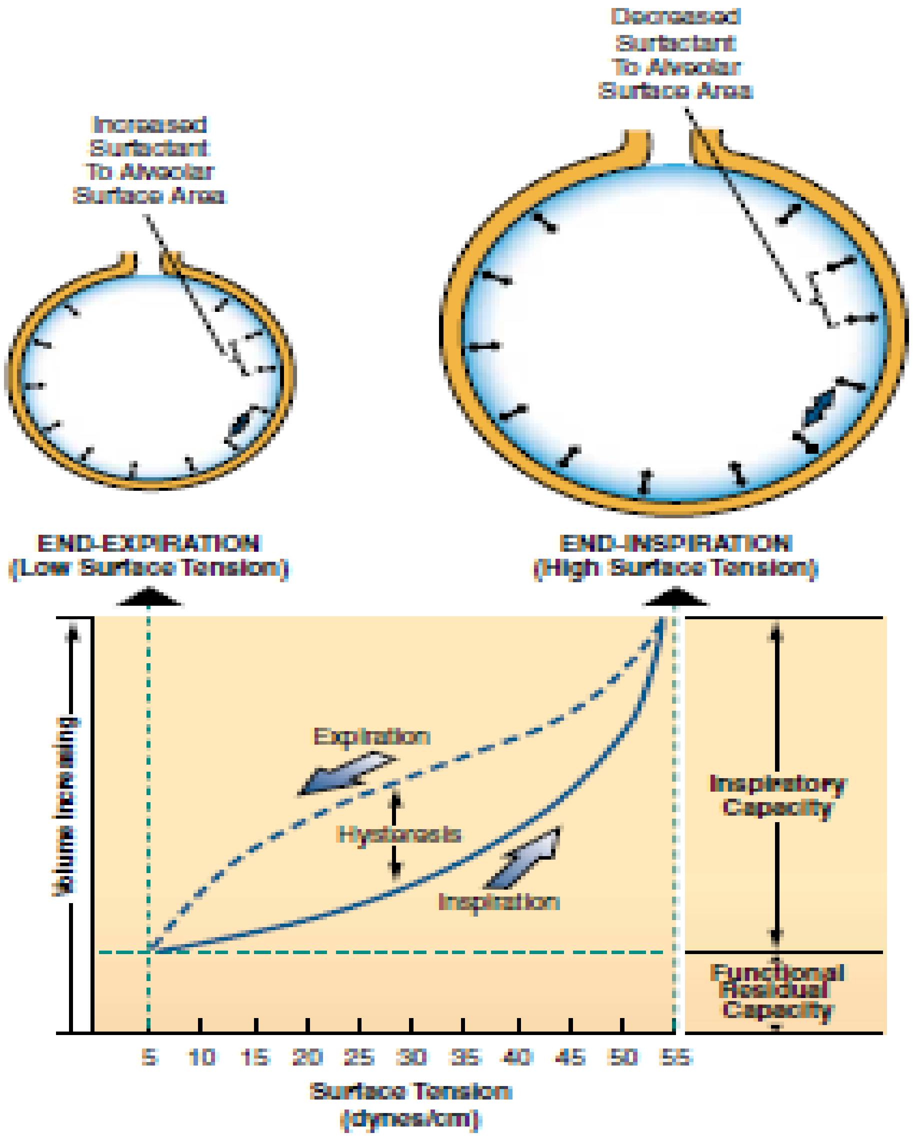


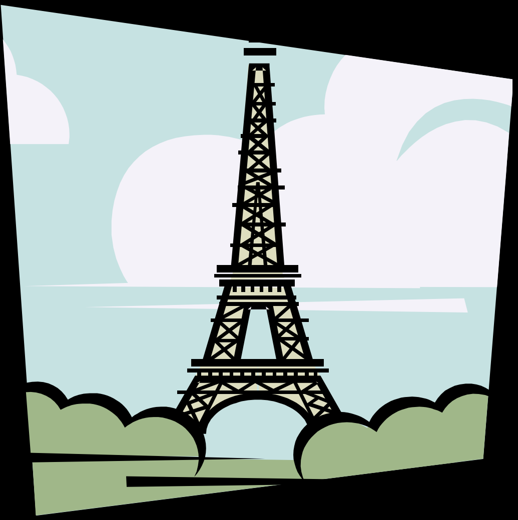
Figure 2–16. *(A) Model showing the formation of a new liquid bubble at the end of a tube. (B) Graph showing the distending pressure required to maintain the bubble's size (volume) at various stages. Initially, a very high pressure, providing little volume change, is required to inflate the bubble. Once the critical opening pressure (same as critical closing pressure) is reached, however, the distending pressure progressively decreases as the size of the bubble increases. Thus, between the critical opening pressure and the point at which the bubble ruptures, the bubble behaves according to Laplace's law. Laplace's law applies to the normal functional size range of the bubble.*

SURFACTANT

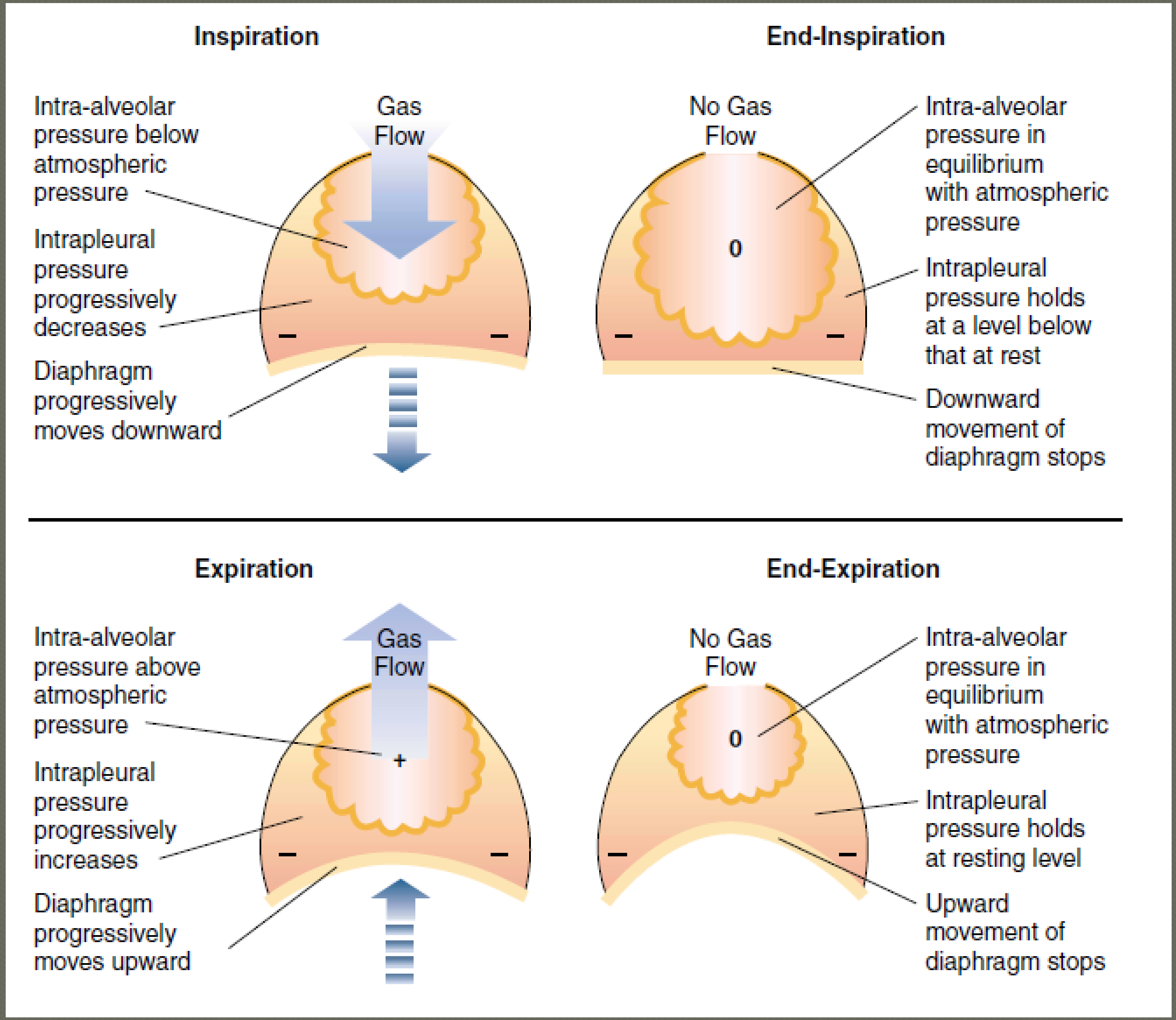


Decreased Surfactant To Alveolar Surface Area
Increased Surfactant To Alveolar Surface Area
END-EXPIRATION (Low Surface Tension)
END-INSPIRATION (High Surface Tension)
Volume Increasing
Expiration
Hysteresis
Inspiration
Inspiratory Capacity
Functional Residual Capacity
5 10 15 20 25 30 35 40 45 50 55
Surface Tension (dynes/cm)

Kerja Inspirasi



- Kerja Elastik
- Kerja Resistensi Jaringan
- Kerja Resistensi Saluran Nafas



Inspiration
Intra-alveolar pressure below atmospheric pressure
Gas Flow
Intrapleural pressure progressively decreases
Diaphragm progressively moves downward
End-Inspiration
No Gas Flow
0
Intra-alveolar pressure in equilibrium with atmospheric pressure
Intrapleural pressure holds at a level below that at rest
Downward movement of diaphragm stops
Expiration
Intra-alveolar pressure above atmospheric pressure
Gas Flow
+
Intrapleural pressure progressively increases
Diaphragm progressively moves upward
End-Expiration
No Gas Flow
0
Intra-alveolar pressure in equilibrium with atmospheric pressure
Intrapleural pressure holds at resting level
Upward movement of diaphragm stops

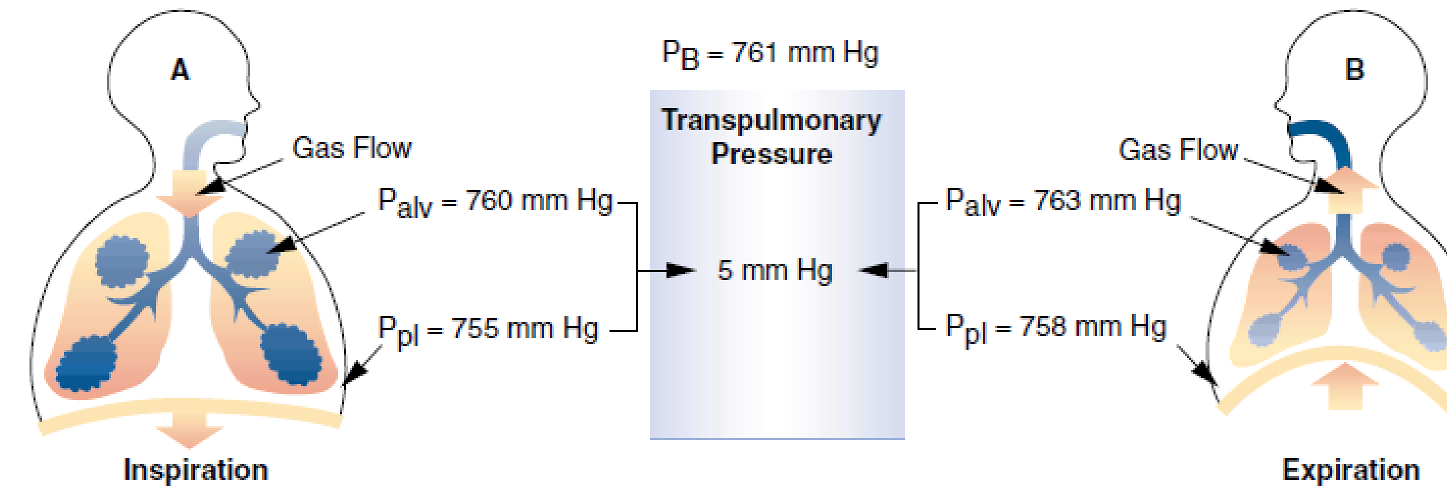


Figure 2–2. *Transpulmonary pressure: The difference between the alveolar pressure (P_{alv}) and the pleural pressure (P_{pl}). This illustration assumes a barometric pressure (P_B) of 761 mm Hg.*

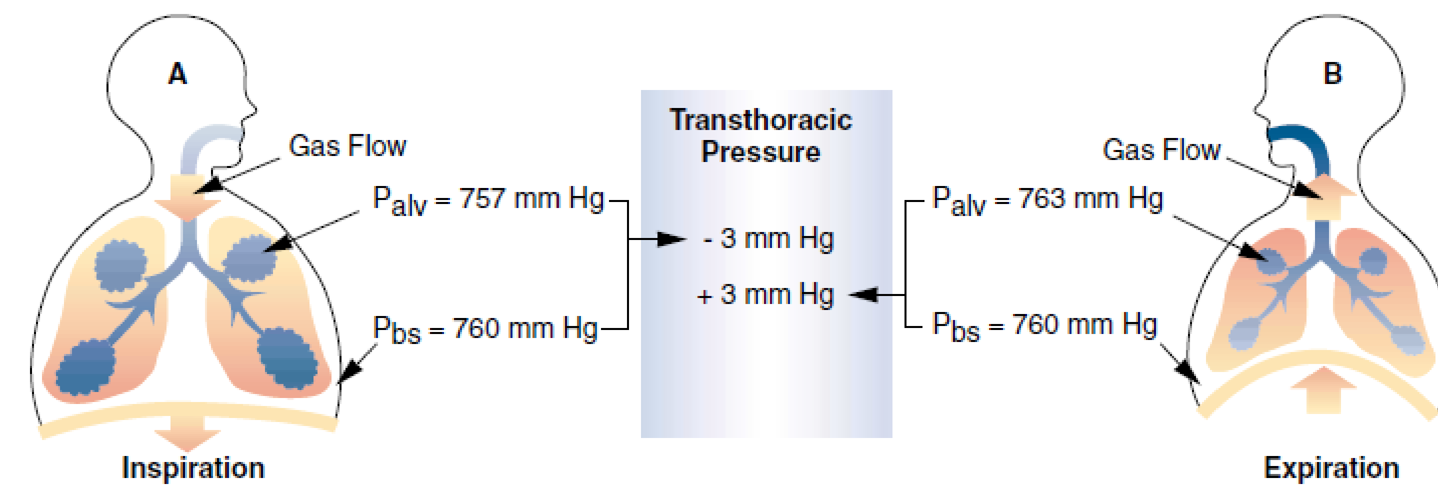


Figure 2–3. *Transthoracic pressure: The difference between the alveolar pressure (P_{alv}) and the body surface pressure (P_{bs}). Note: In this illustration, the body surface pressure (P_{bs}) is equal to the barometric pressure (P_B).*

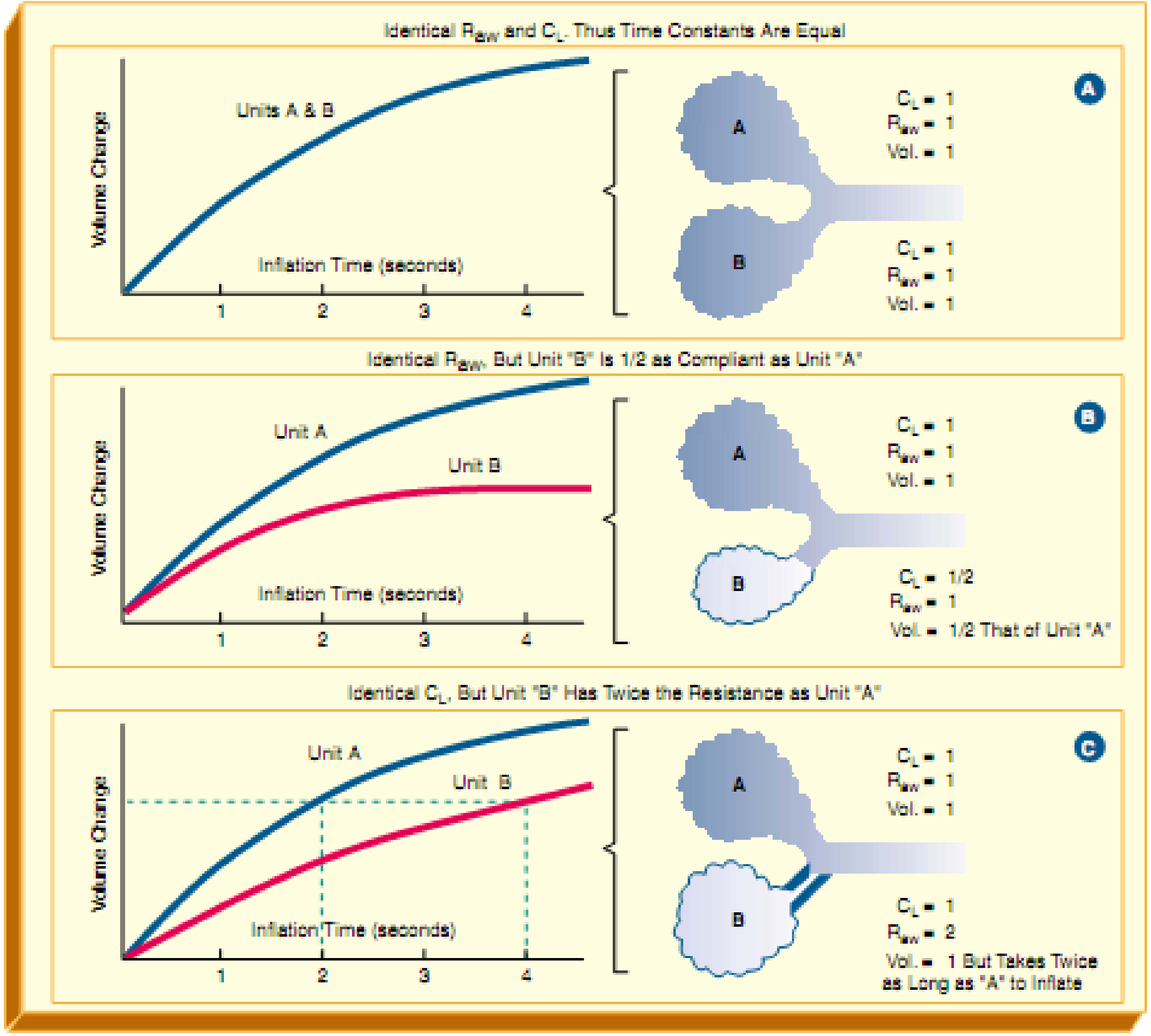
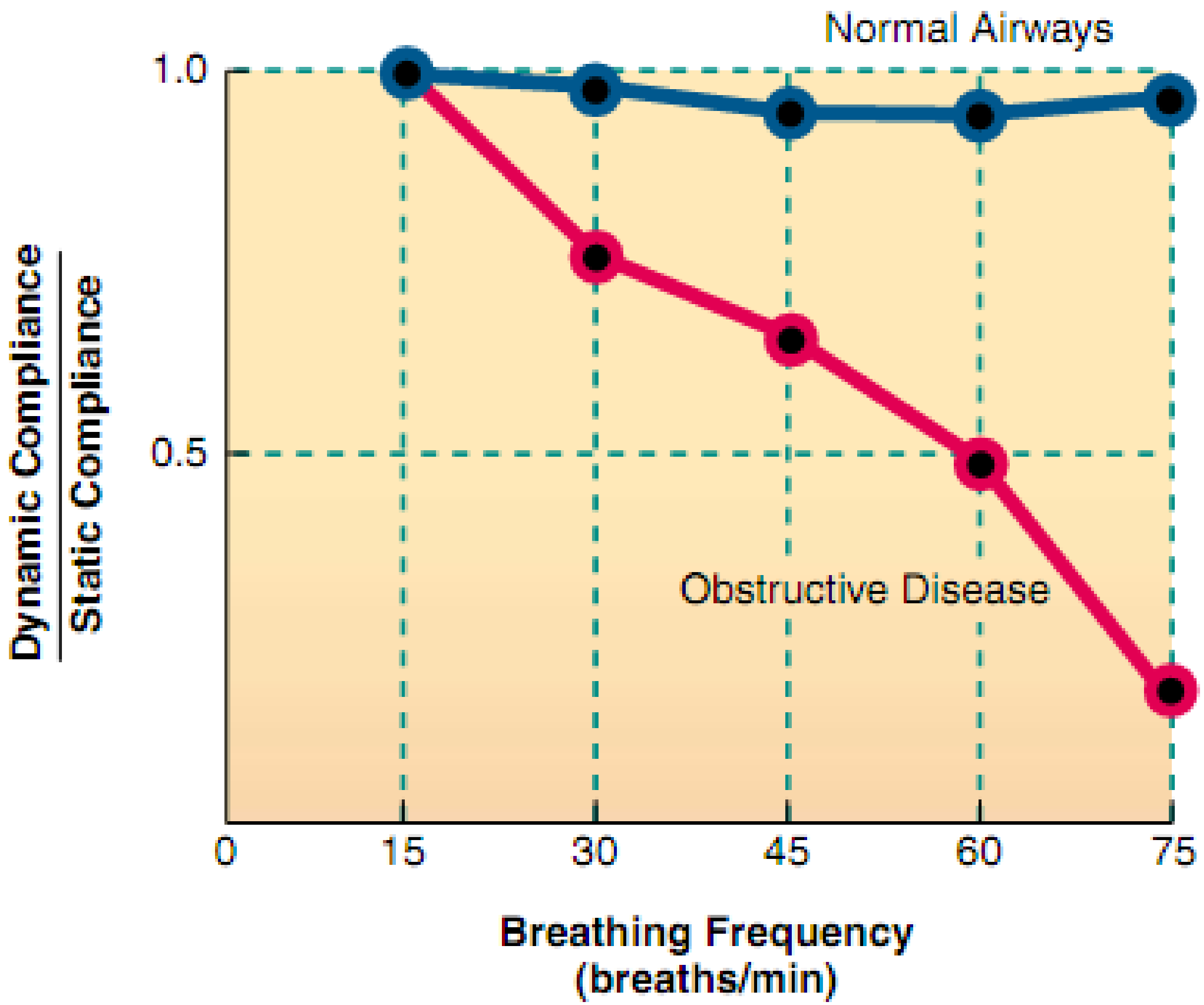


Figure 2–28. *Time constants for hypothetical alveoli with differing lung compliances (C_L), supplied by airways with differing resistances (R_{aw}).*

Dynamic Compliance : pengisian udara regio paru dalam satuan waktu



Normal Airways
1.0
0.5
Obstructive Disease
Dynamic Compliance
Static Compliance
0
15
30
45
60
75
Breathing Frequency
(breaths/min)

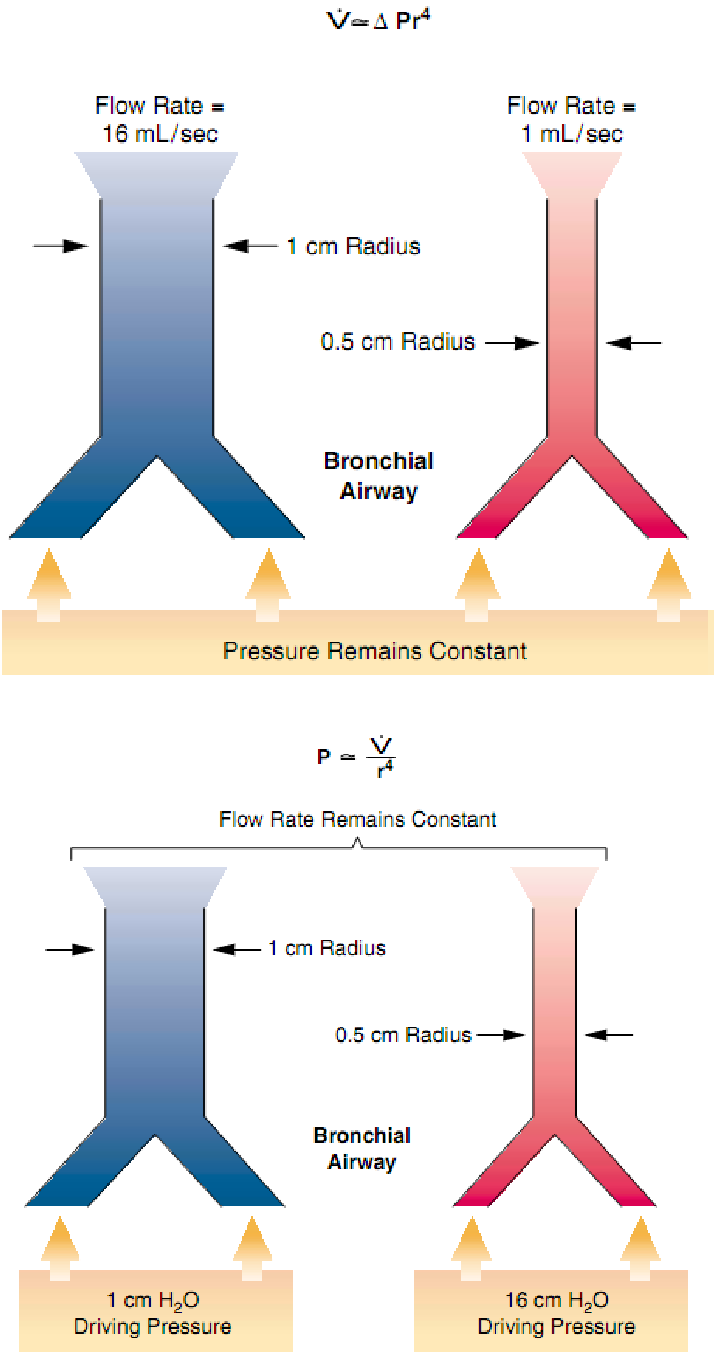
Kerja Resistensi Saluran Nafas

Hukum Poiseuille

$$\dot{V} = \frac{\Delta P r^4 \pi}{8 l \eta}$$

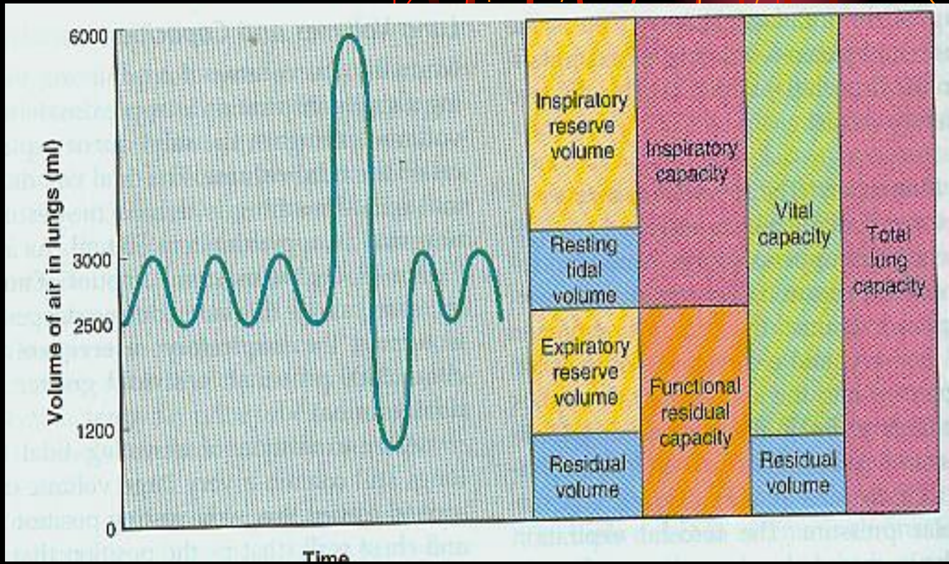
$$P = \frac{\dot{V} 8 l \eta}{r^4 \pi}$$

$$R_{aw} = \frac{\Delta P(\text{cm } H_2O)}{\dot{V}(\text{L/sec})}$$



Volume Paru

1. V. Tidal (500 cc)
2. V. Cadangan Inspirasi (3000 cc)
3. V. Cadangan Ekspirasi (1100 cc)
4. V. Residu (1200 cc)



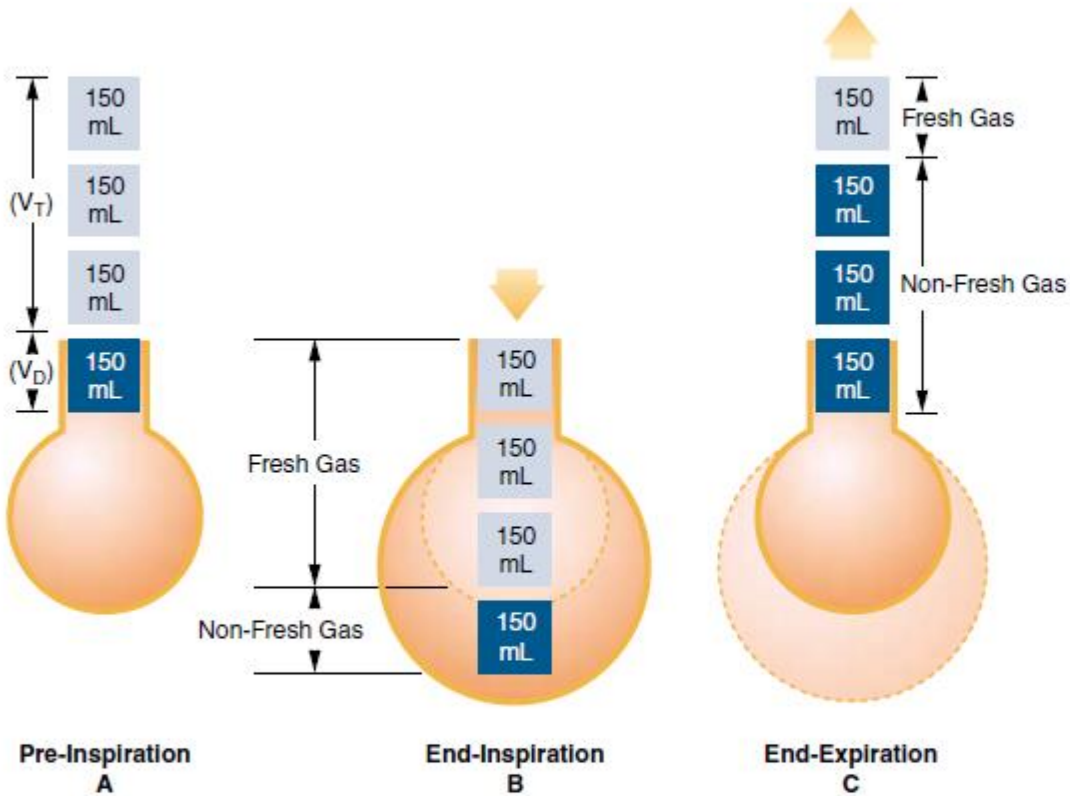
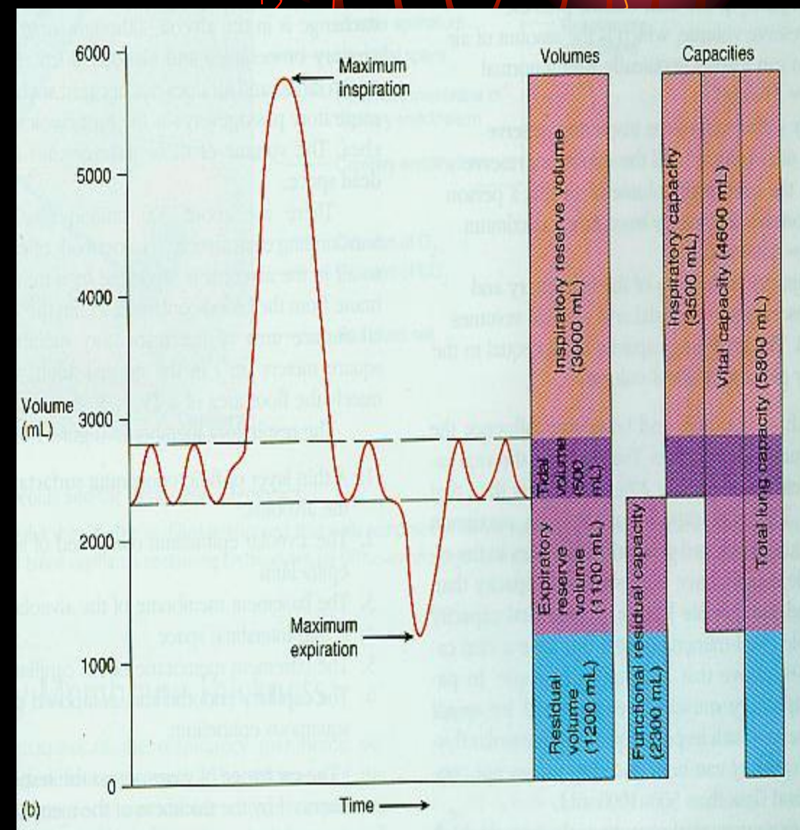


Figure 2–32. *Alveolar ventilation versus dead space ventilation during one ventilatory cycle.*

Kapasitas Paru

- **Kapasitas Inspirasi (3500 cc)**
  - **V. Tidal + V. Cadangan Inspirasi**
- **Kapasitas Vital (4600 cc)**
  - **V. Cadangan Inspirasi + V. Tidal + V. Cad Eksp**
- **Kapasitas Residu Fungsional (2300 cc)**
  - **V. Cadangan Eksp + V. Residu**
- **Kapasitas Paru total (5800 cc)**
  - **V. Cad Insp + V. Tidal + V. Cad Eksp + V. Residu**
  - **Metode Fick**



Maximal Voluntary Ventilation (maximal breathing capacity)

- Jumlah udara yang dapat keluar masuk paru dalam waktu 1 menit
→ 12 atau 15 detik
- Kekuatan otot respirasi, compliance paru dan thoraks, elastisitas, mekanisme kontrol saraf
- Umur 20-30 th
  - ♂ : 170 L/mnt, ♀ : 110 L/mnt
- Menurun : usia, penyakit paru obstruktif menahun

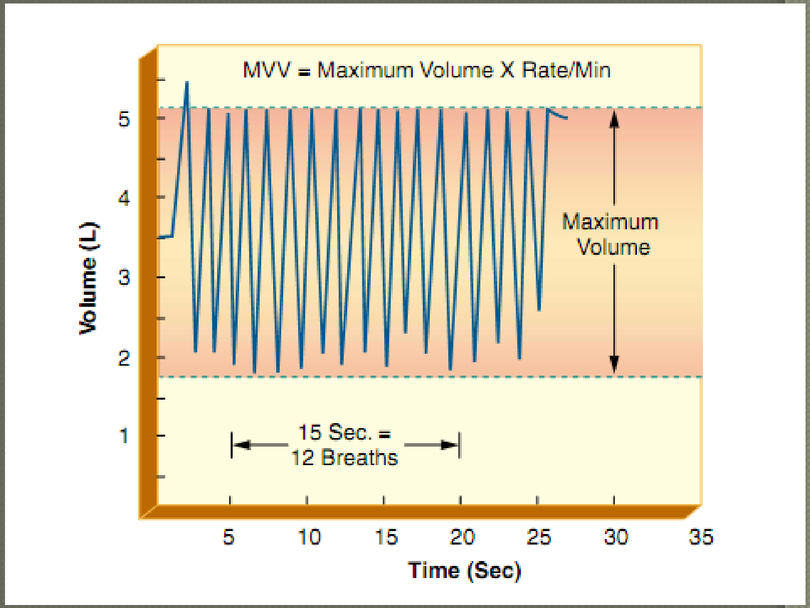


TABLE 234-1 Alterations in Ventilatory Function

	TLC	RV	VC	FEV_1/FVC	MIP	MEP
Obstructive	N to ↑	↑	↓	↓[a]	N	N
Restrictive						
Pulmonary parenchymal	↓	↓	↓	N to ↑	N	N
Extraparenchymal—inspiratory	↓	N to ↓	↓	N	↓/N[b]	N
Extraparenchymal—inspiratory + expiratory	↓	↑	↓	Variable	↓/N[b]	↓/N[b]

[a] Mild obstructive (small airways) disease may have decreased $FEF_{25-75\%}$ with normal (N) FEV_1/FVC.

[b] Reduced if due to respiratory muscle weakness; normal if due to chest wall stiffness.

Note: N, normal; for other abbreviations, see text.

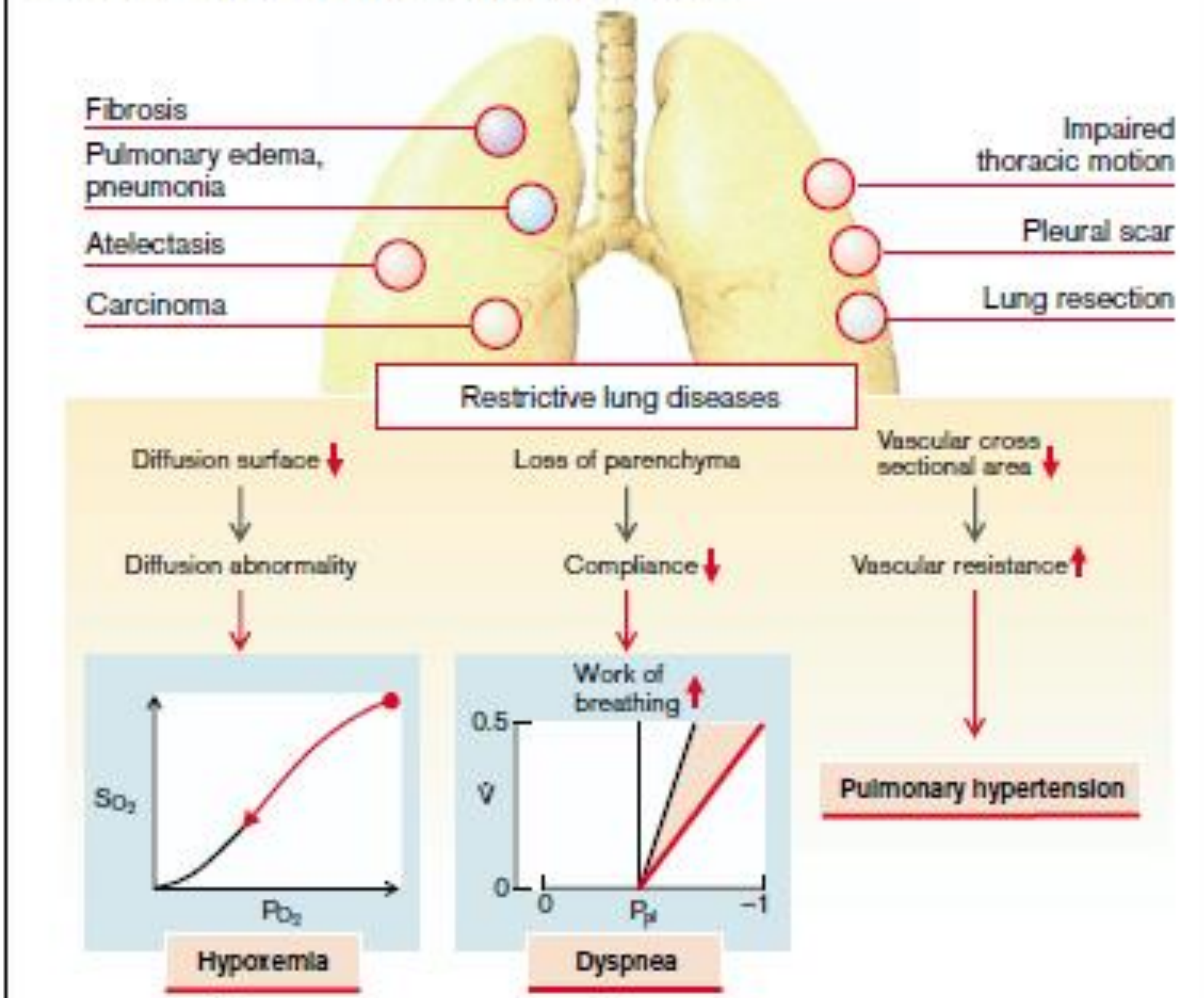
TABLE 234-2 Common Respiratory Diseases by Diagnostic Categories

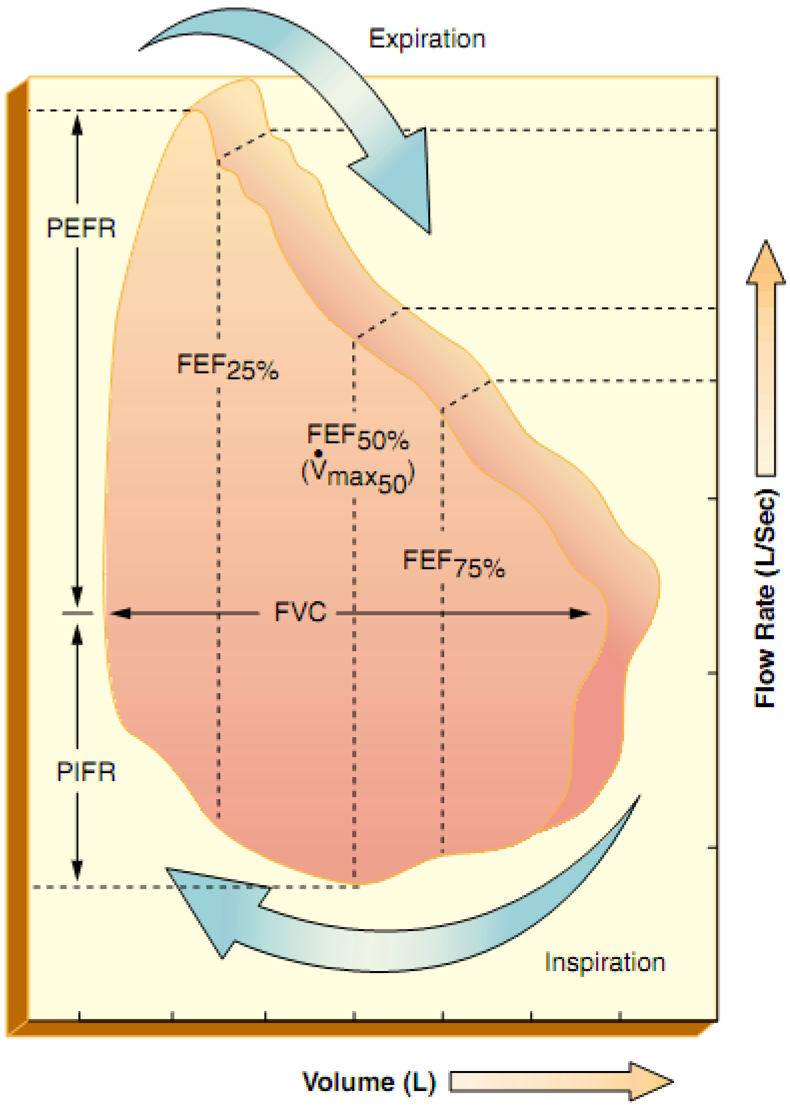
Obstructive
- Asthma
- Chronic obstructive lung disease (chronic bronchitis, emphysema)
- Bronchiectasis
- Cystic fibrosis
- Bronchiolitis

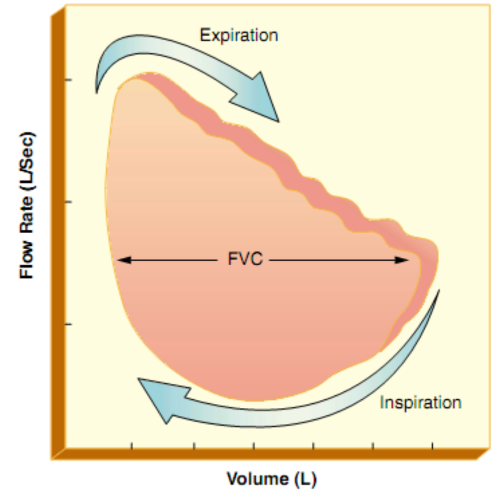
Restrictive—Parenchymal
- Sarcoidosis
- Idiopathic pulmonary fibrosis
- Pneumoconiosis
- Drug- or radiation-induced interstitial lung disease

Restrictive—Extraparenchymal
- Neuromuscular
  - Diaphragmatic weakness/paralysis
  - Myasthenia gravis[a]
  - Guillain-Barré syndrome[a]
  - Muscular dystrophies[a]
  - Cervical spine injury[a]
- Chest wall
  - Kyphoscoliosis
  - Obesity
  - Ankylosing spondylitis[a]

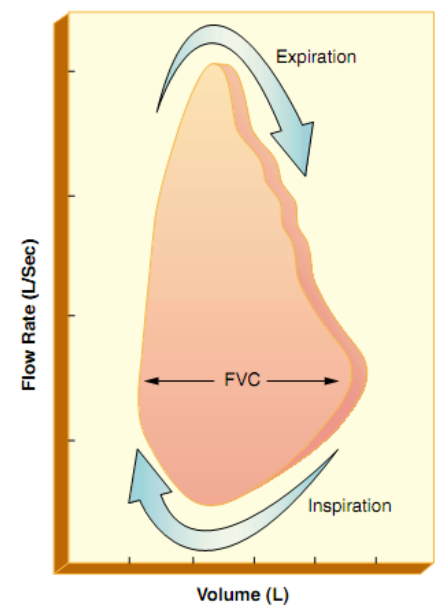
A. Causes and Effects of Restrictive Lung Diseases



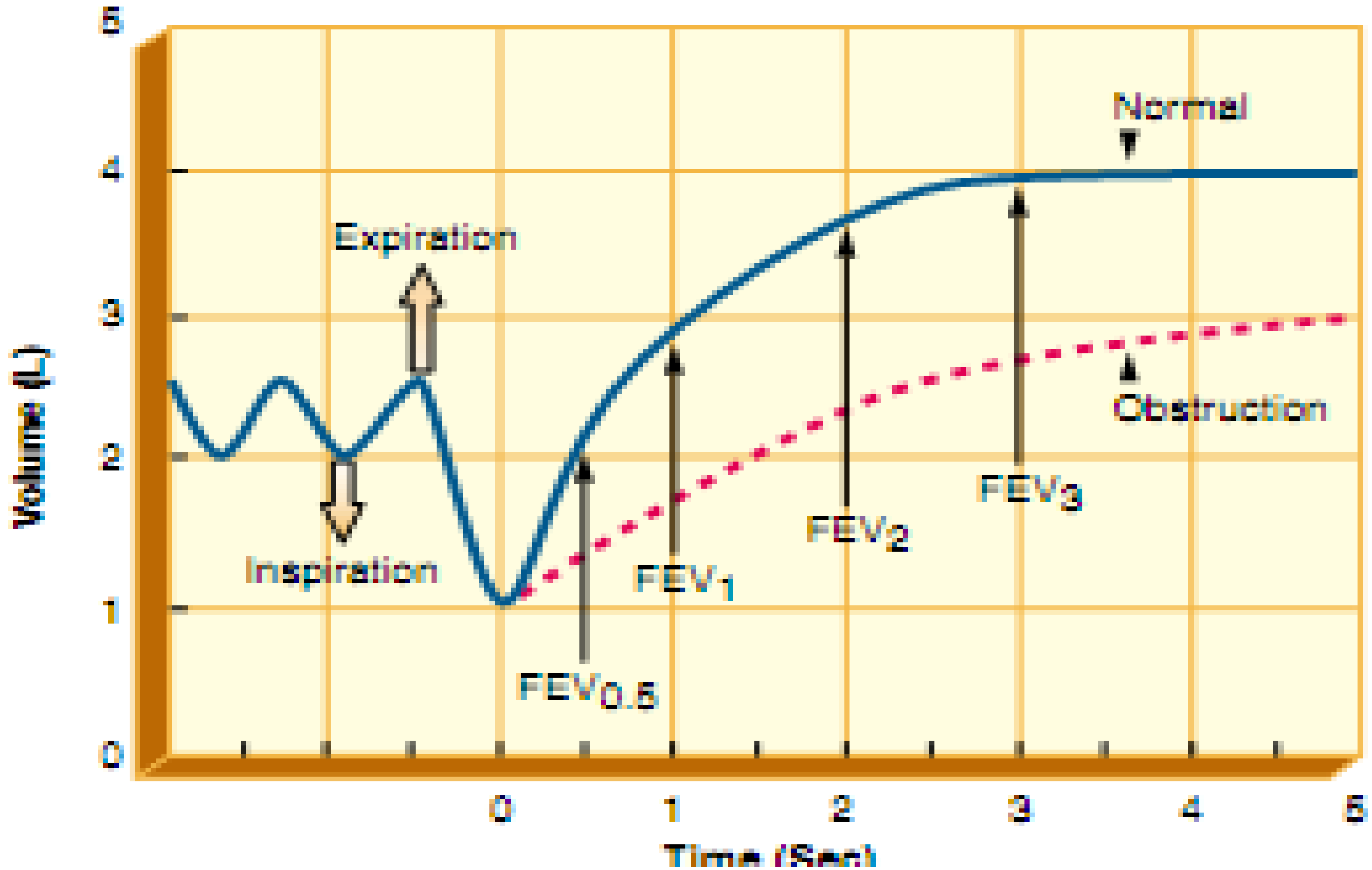




Flow-volume loop, obstructive pattern. FVC = forced vital capacity.



Flow-volume loop, restrictive pattern. FVC = forced vital capacity.



1. Obstruktif : FEV1, FEV1 % menurun
2. Restriktif : FEV1 menurun, FEV 1% : normal, meningkat

Difusi

- Perbedaan Tekanan Partial
- Membran difusi : tebal dan luas
- Koefisien difusi

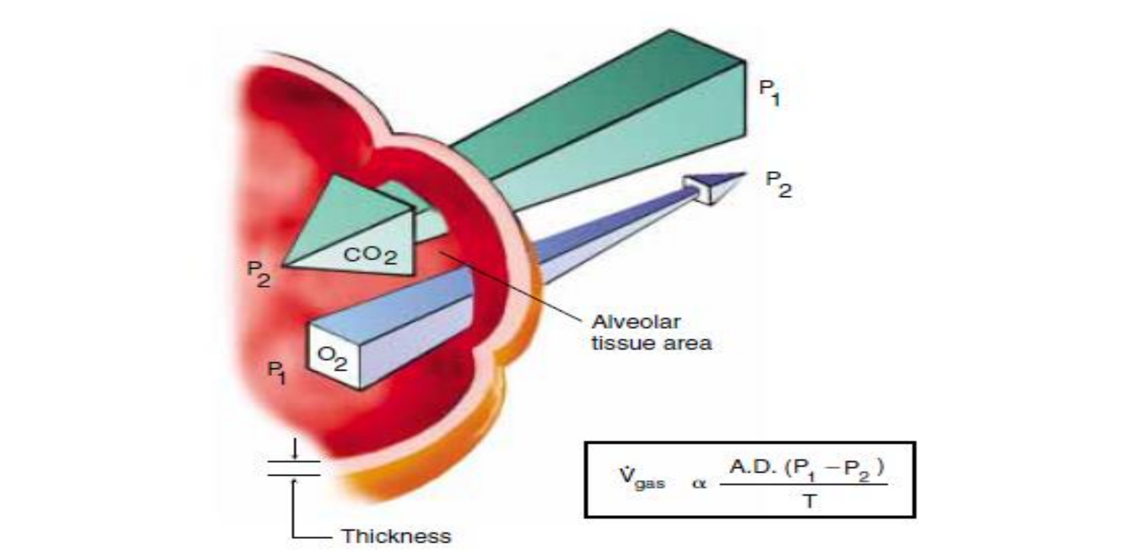
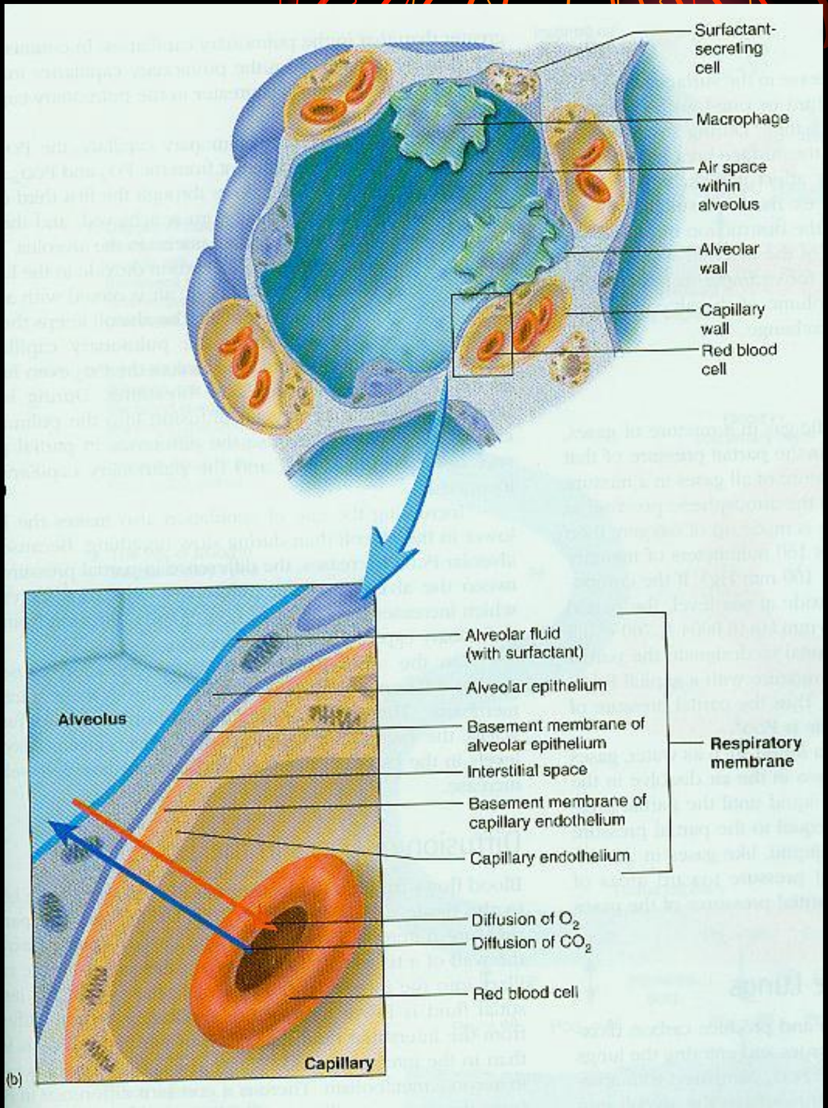
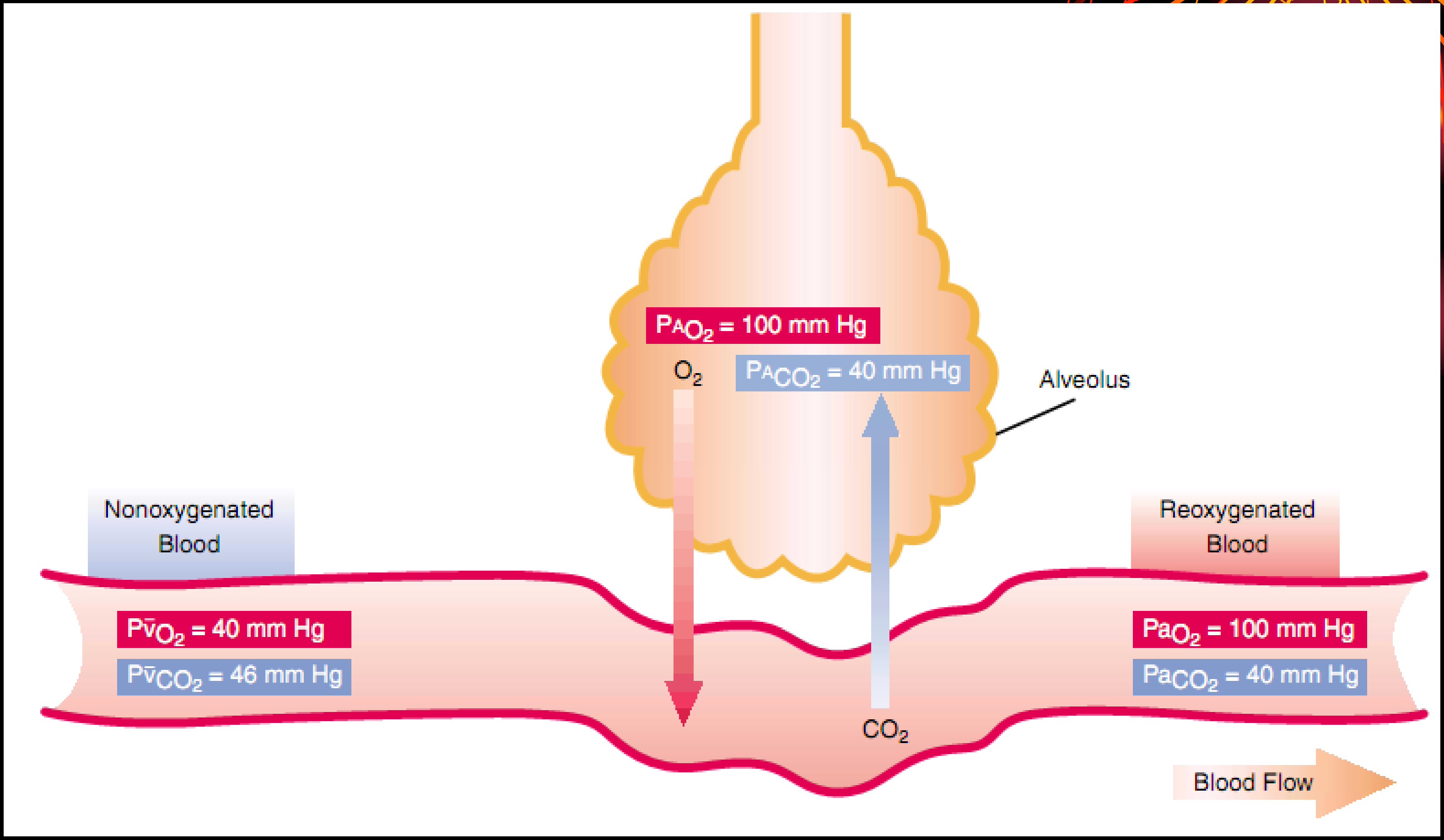


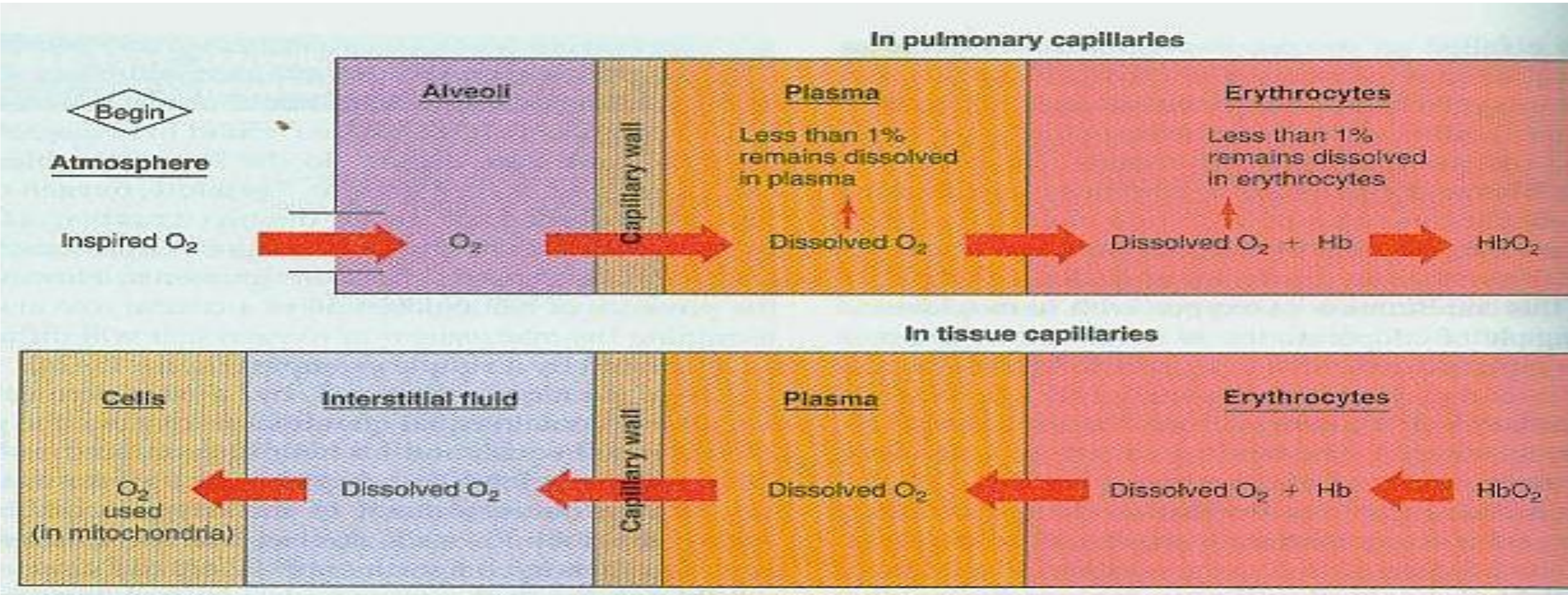
Figure 3–7. *Fick's law.*

Difusi

- **Membran difusi**
  - Surfactan
  - Epitel alveolus
  - Membran basalis epitel
  - Ruang intertitial
  - Membran basalis kapiler
  - Membran endotel
- **Koefisien difusi**
  - Oksigen 0,024
  - Karbon dioksida 0,59
  - Karbon monoksida 0,018
  - Nitrogen 0,012
  - helium 0,008

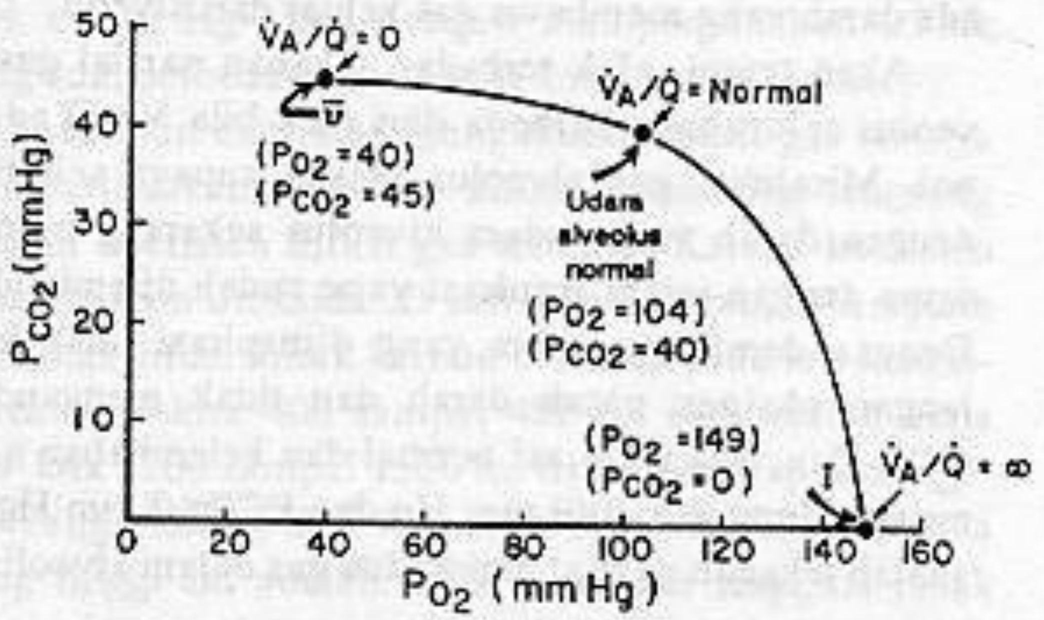



PAO2 = 100 mm Hg
O2
PACO2 = 40 mm Hg
Alveolus
Nonoxygenated Blood
Reoxygenated Blood
Pv̄O2 = 40 mm Hg
Pv̄CO2 = 46 mm Hg
PaO2 = 100 mm Hg
PaCO2 = 40 mm Hg
CO2
Blood Flow


In pulmonary capillaries
Begin
Atmosphere
Inspired O2
Alveoli
O2
Capillary wall
Plasma
Less than 1% remains dissolved in plasma
Dissolved O2
Erythrocytes
Less than 1% remains dissolved in erythrocytes
Dissolved O2 + Hb
HbO2
In tissue capillaries
Cells
O2 used (in mitochondria)
Interstitial fluid
Dissolved O2
Capillary wall
Plasma
Dissolved O2
Erythrocytes
Dissolved O2 + Hb
HbO2

Ventilasi - Perfusi

- **Ruang rugi Anatomi**
- **Ruang rugi fisiologi**



Gambar 40-11. Diagram PO_2-PCO_2 normal, dan V_A/Q.

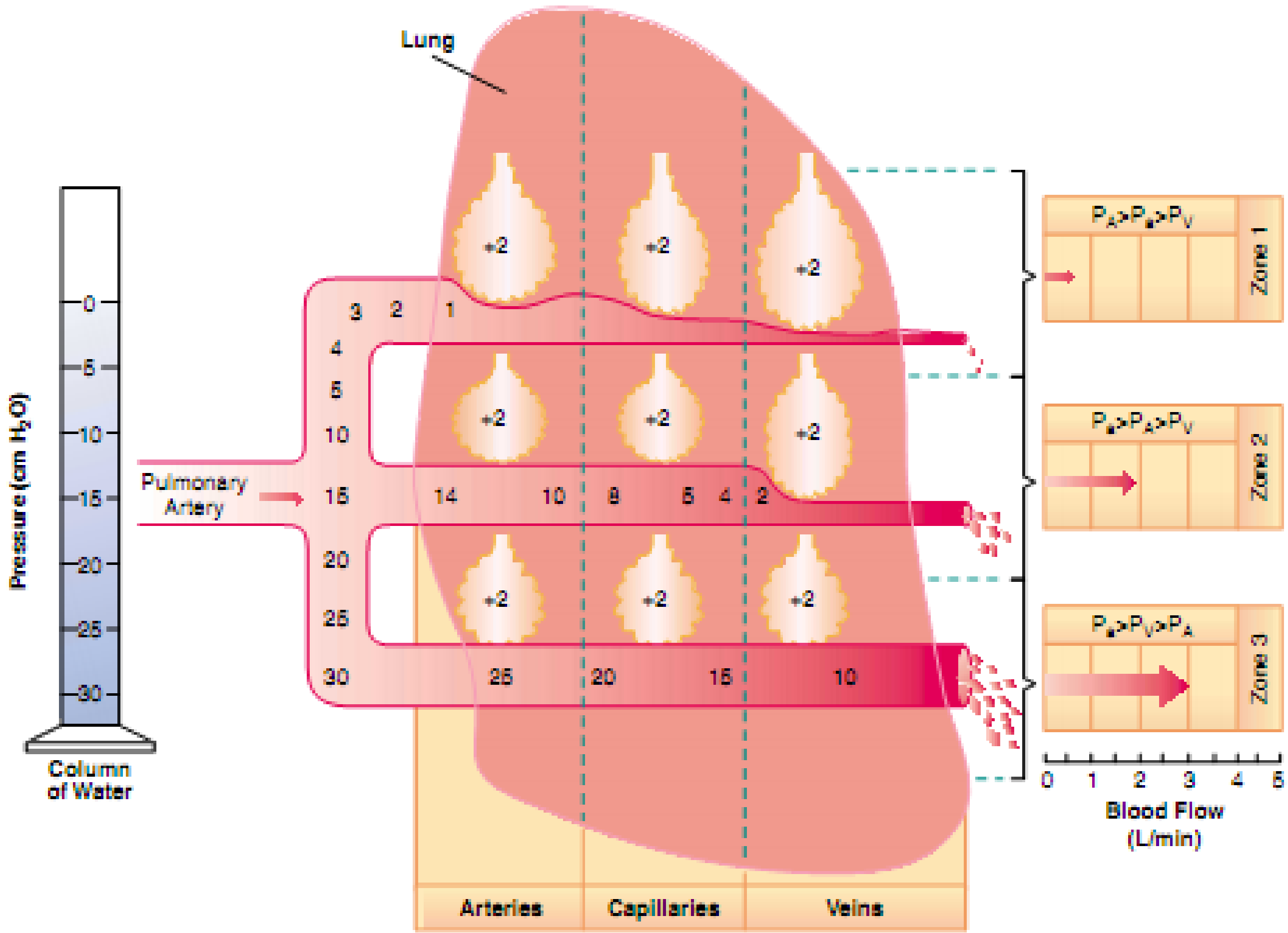
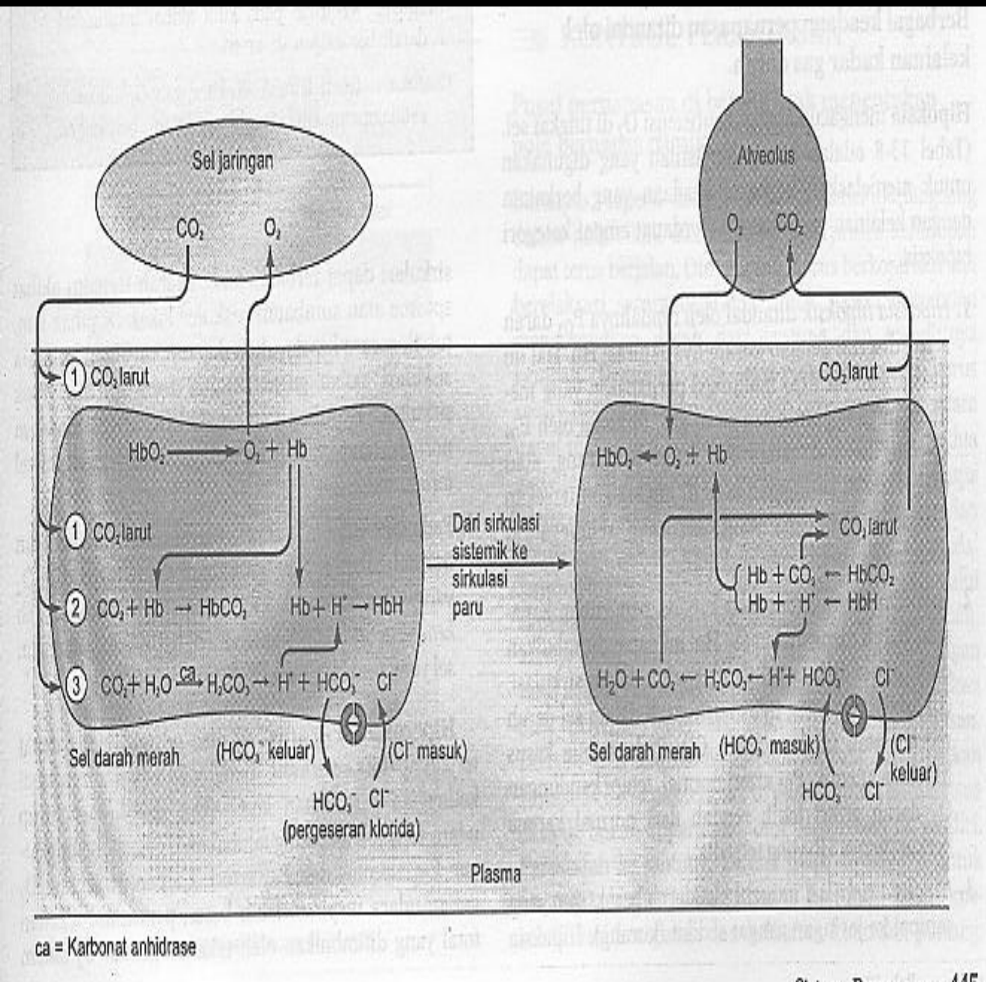
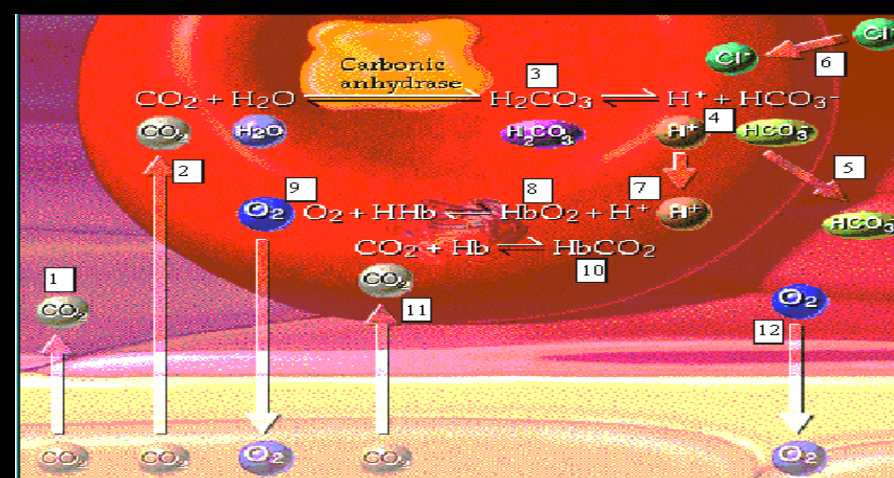


Figure 5–18. *Relationship between gravity, alveolar pressure (P_A), pulmonary arterial pressure (P_a), and pulmonary venous pressure (P_v) in different lung zones. Note: The +2 cm H_2O pressure in the alveoli (e.g., during expiration) was arbitrarily selected for this illustration.*

Transportasi





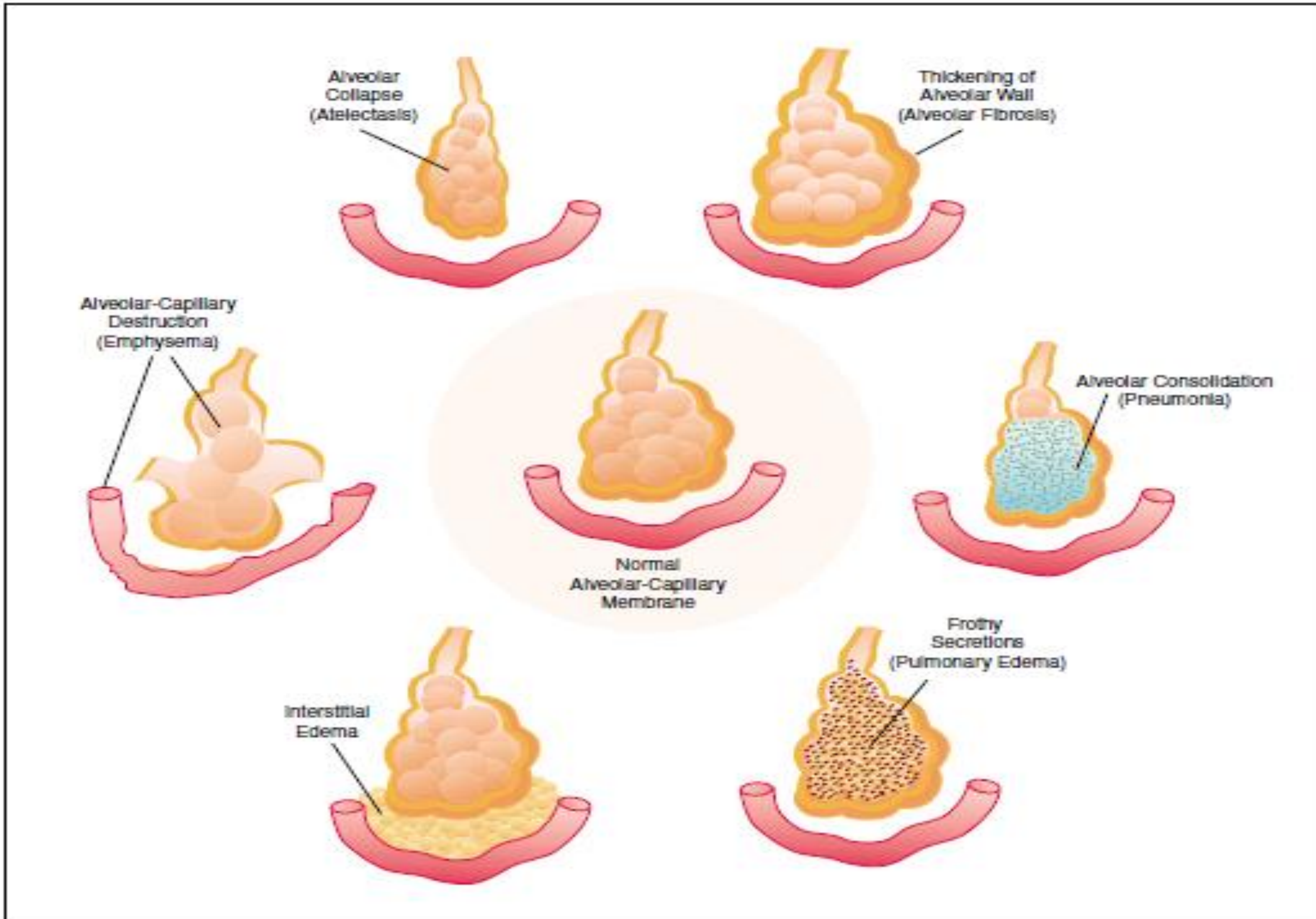
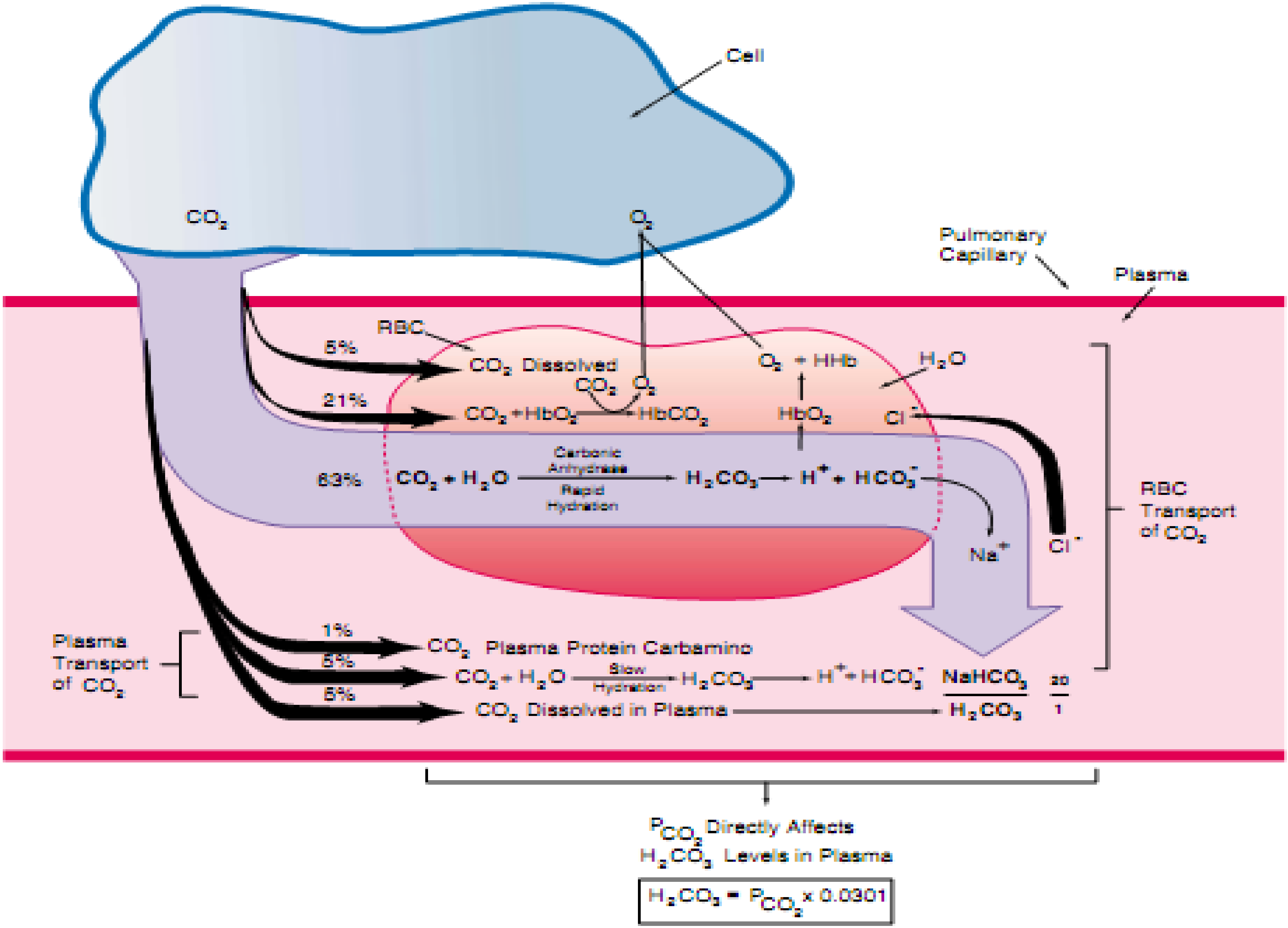
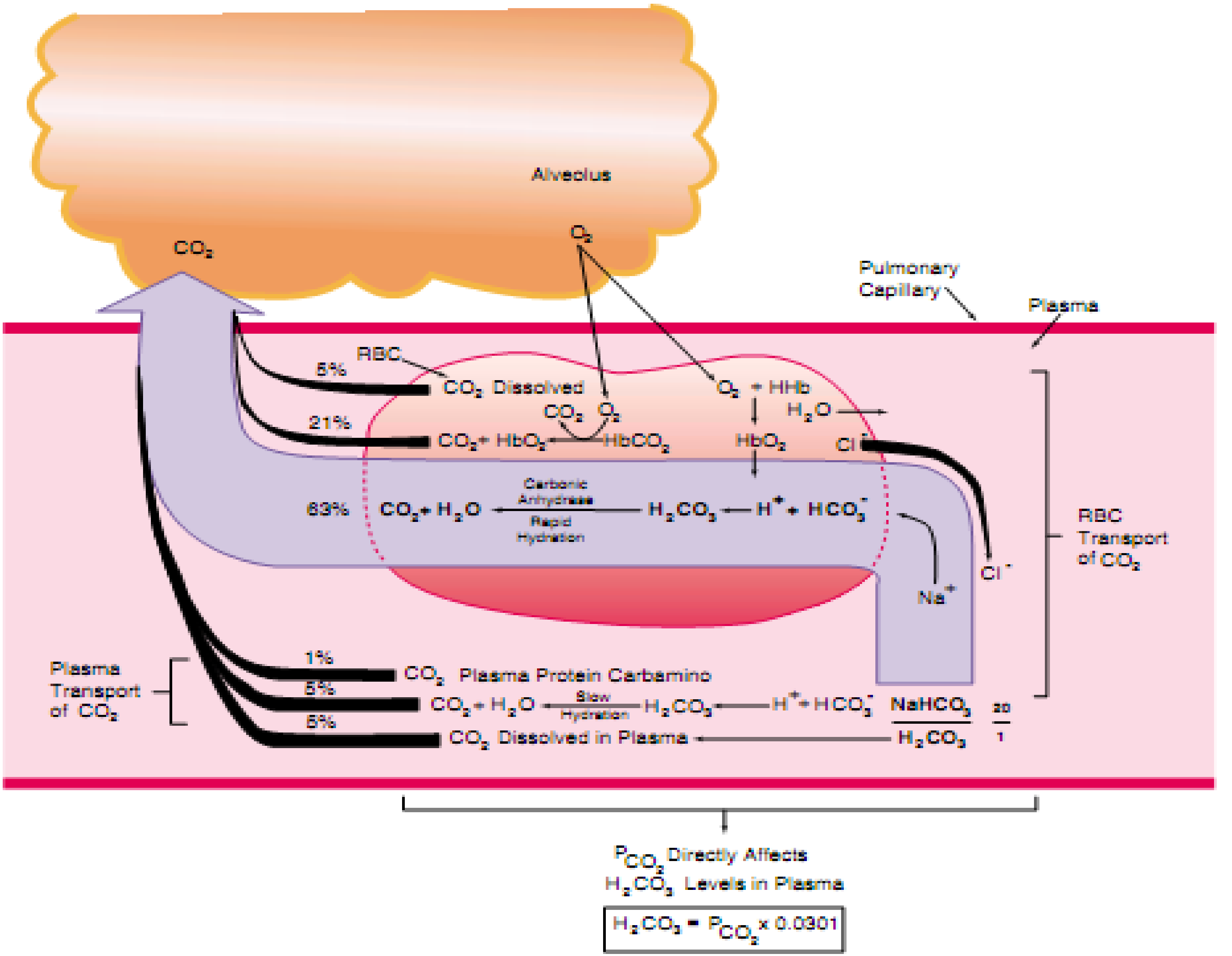


Figure 3–10. *Clinical conditions that decrease the rate of gas diffusion. These conditions are known as* diffusion-limited problems.



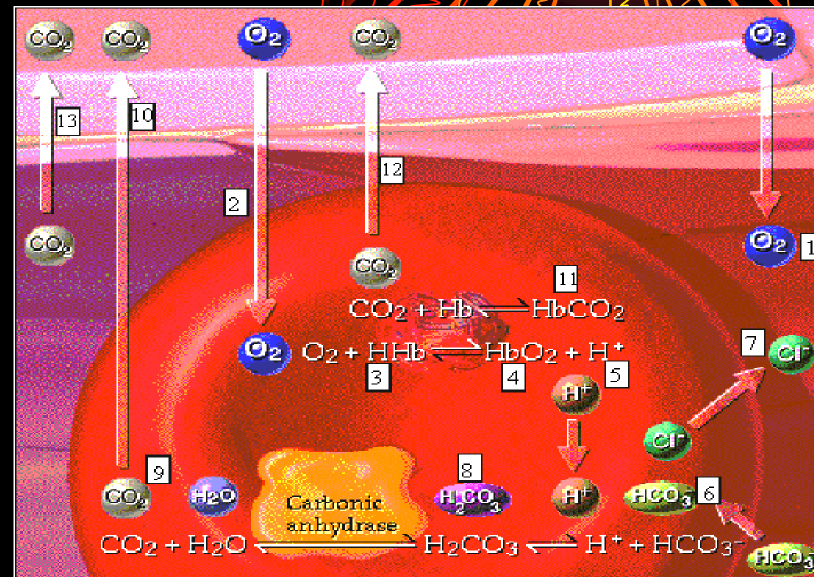
Cell
CO_2
O_2
Pulmonary Capillary
Plasma
RBC
5%
CO_2 Dissolved
CO_2 O_2
O_2 + HHb
H_2O
21%
CO_2 + HbO_2 → $HbCO_2$
HbO_2
Cl^-
63%
$CO_2 + H_2O$ Carbonic Anhydrase / Rapid Hydration → H_2CO_3 → $H^+ + HCO_3^-$
Na^+
Cl^-
RBC Transport of CO_2
Plasma Transport of CO_2
1%
CO_2 Plasma Protein Carbamino
5%
$CO_2 + H_2O$ Slow Hydration → H_2CO_3 → $H^+ + HCO_3^-$
5%
CO_2 Dissolved in Plasma
$NaHCO_3$ / H_2CO_3 20 / 1
P_{CO_2} Directly Affects H_2CO_3 Levels in Plasma
$H_2CO_3 = P_{CO_2} \times 0.0301$

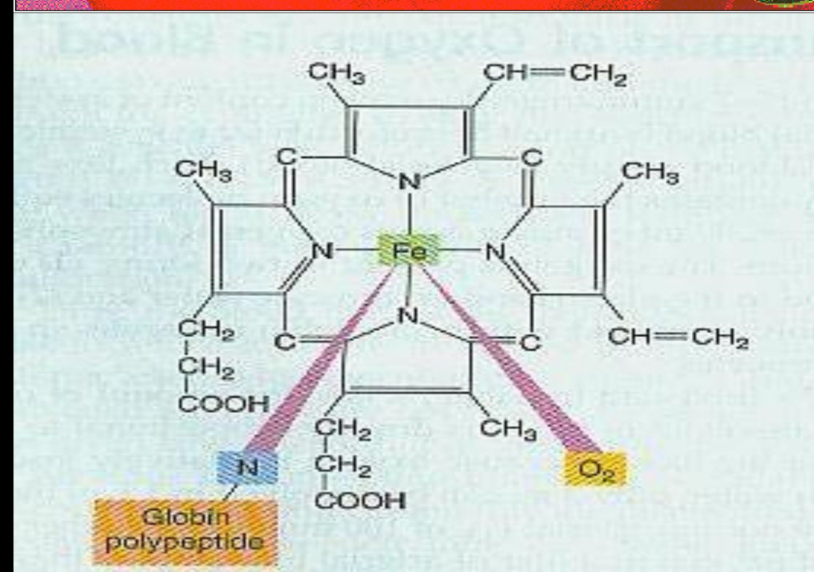


Alveolus
CO_2
O_2
Pulmonary Capillary
Plasma
RBC
5%
CO_2 Dissolved
21%
CO_2 O_2
$CO_2 + HbO_2$ ← $HbCO_2$
O_2 + HHb
H_2O →
HbO_2
Cl^-
63%
$CO_2 + H_2O$ ← H_2CO_3 ← $H^+ + HCO_3^-$
Carbonic Anhydrase
Rapid Hydration
Na^+
Cl^-
RBC Transport of CO_2
Plasma Transport of CO_2
1%
CO_2 Plasma Protein Carbamino
5%
$CO_2 + H_2O$ ← H_2CO_3 ← $H^+ + HCO_3^-$
Slow Hydration
5%
CO_2 Dissolved in Plasma
$\frac{NaHCO_3}{H_2CO_3}$ $\frac{20}{1}$
P_{CO_2} Directly Affects H_2CO_3 Levels in Plasma
$H_2CO_3 = P_{CO_2} \times 0.0301$

Transpor Oksigen

- **97 % dengan Hb**
  - **1 gram Hb berikatan 1,34 ml O_2**
- **3 % terlarut dalam cairan plasma dan sel**



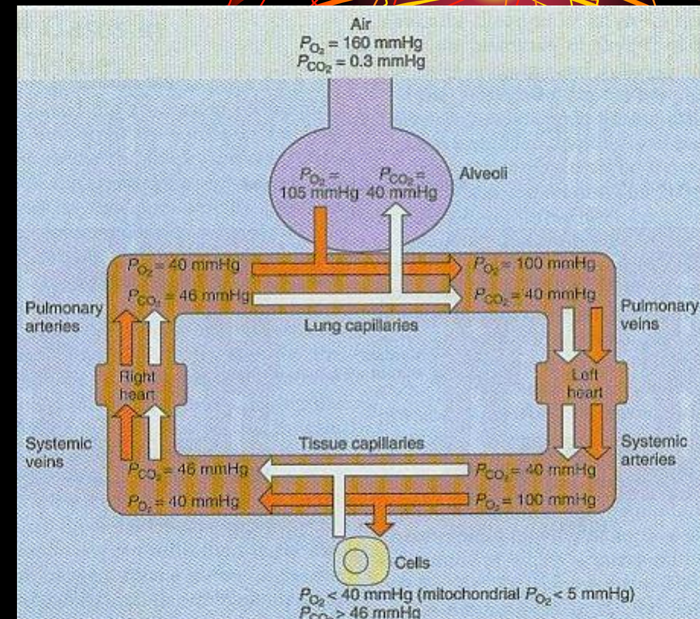


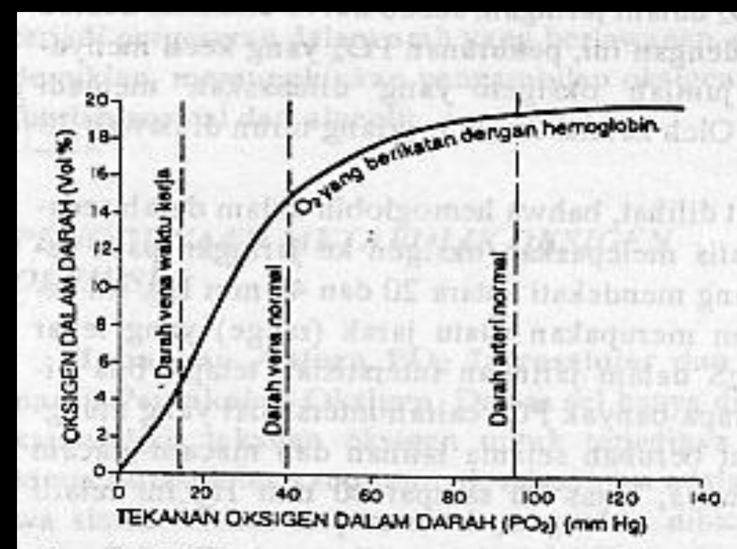
Transpor Oksigen

- **Efek Bohr**
- **100 cc ⟶ 15 gr%**

  (19,4 ml O_2/100 cc)
- **Di Jaringan : 40 mmHg**

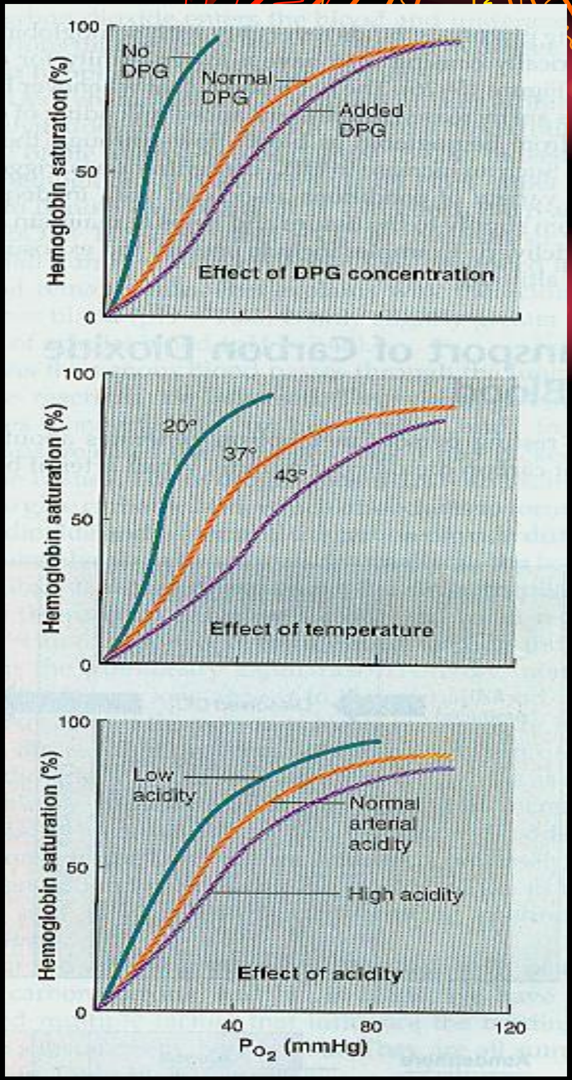
  (75 % saturasi, 14,4 cc : 5 cc/100cc darah)

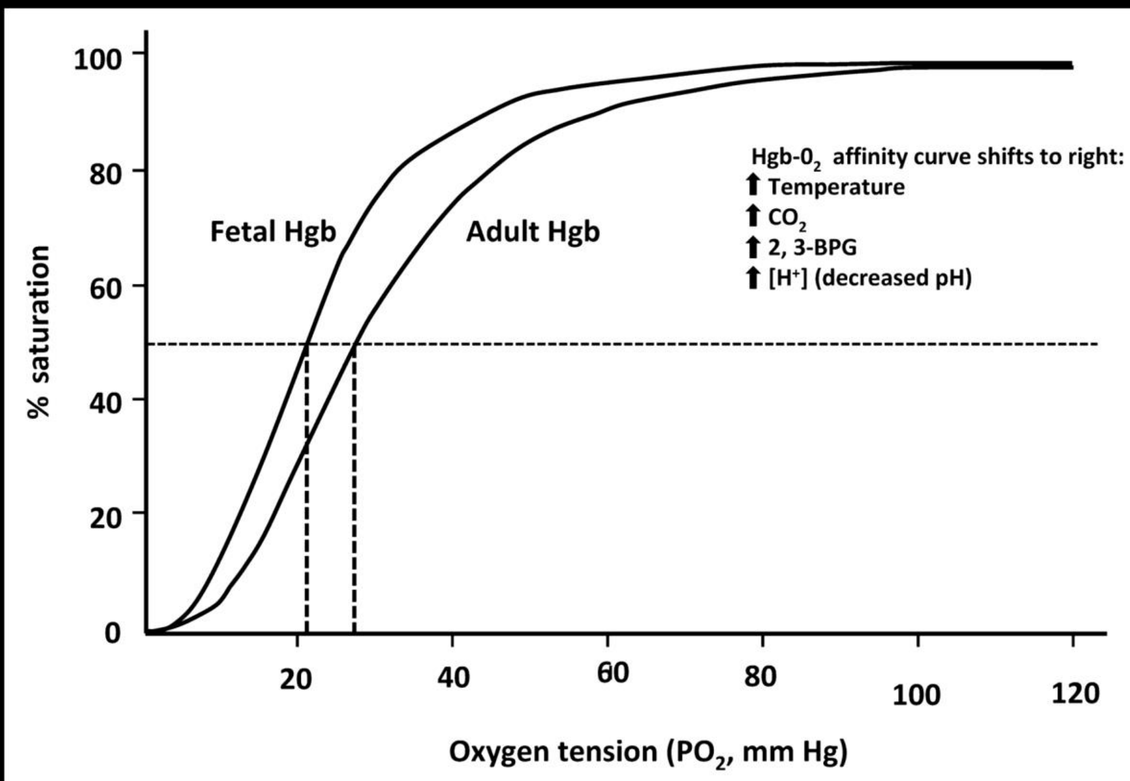


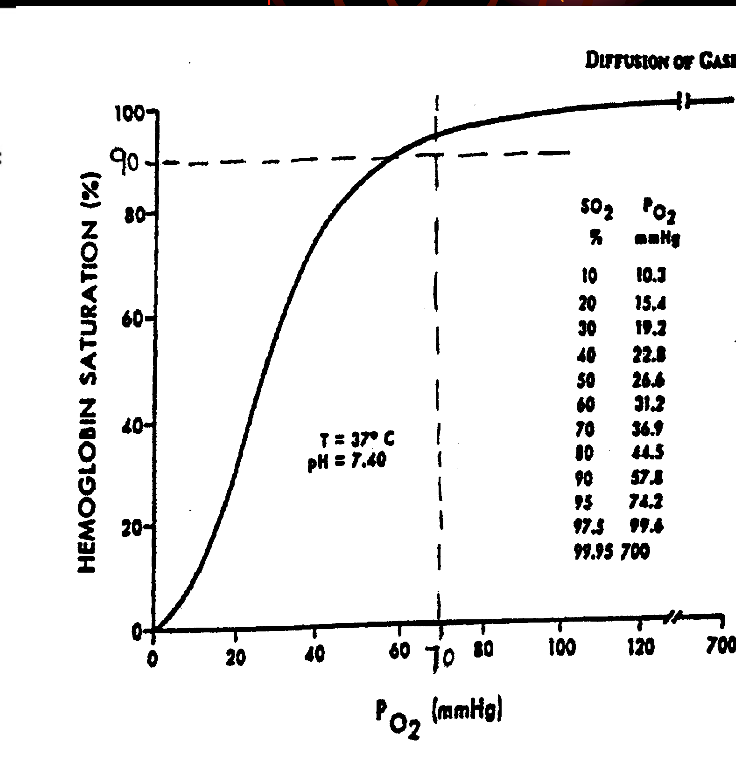


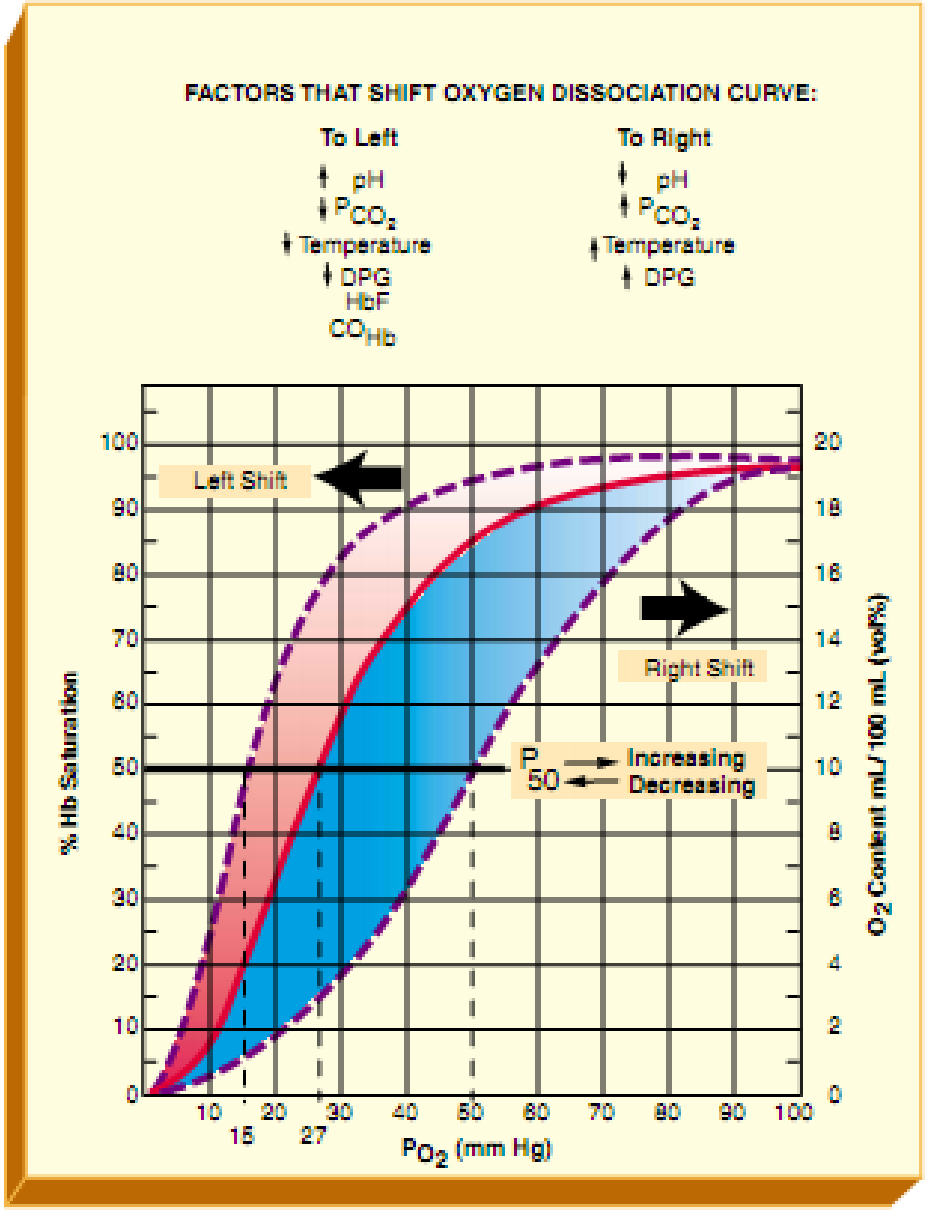
Pergeseran Kurve disosiasi

- Geser Ke kanan
  - Peningkatan ion hidrogen
  - Peningkatan CO2
  - Peningkatan temperatur
  - Peningkatan DPG




100
80
60
40
20
0
% saturation
Fetal Hgb
Adult Hgb
Hgb-0_2 affinity curve shifts to right:
⬆ Temperature
⬆ CO_2
⬆ 2, 3-BPG
⬆ [H^+] (decreased pH)
20
40
60
80
100
120
Oxygen tension (PO_2, mm Hg)


DIFFUSION OF GASES
100
90
80
60
40
20
0
HEMOGLOBIN SATURATION (%)
T = 37° C
pH = 7.40
SO_2 %
P_{O_2} mmHg
10 10.3
20 15.4
30 19.2
40 22.8
50 26.6
60 31.2
70 36.9
80 44.5
90 57.8
95 74.2
97.5 99.6
99.95 700
0
20
40
60
70
80
100
120
700
P_{O_2} (mmHg)


FACTORS THAT SHIFT OXYGEN DISSOCIATION CURVE:
To Left
↑ pH
↓ PCO2
↓ Temperature
↓ DPG
HbF
COHb
To Right
↓ pH
↑ PCO2
↑ Temperature
↑ DPG
Left Shift
Right Shift
P50 → Increasing
← Decreasing
% Hb Saturation
O2 Content mL/ 100 mL (vol%)
PO2 (mm Hg)
0
10
20
30
40
50
60
70
80
90
100
15
27
2
4
6
8
12
14
16
18

Aklimatisasi Pa O_2 rendah

- Ventilasi paru meningkat
- Hb meningkat
- Kemampuan difusi meningkat
- Vaskularisasi jaringan meningkat
- Aklimatisasi selular

Keracunan Oksigen

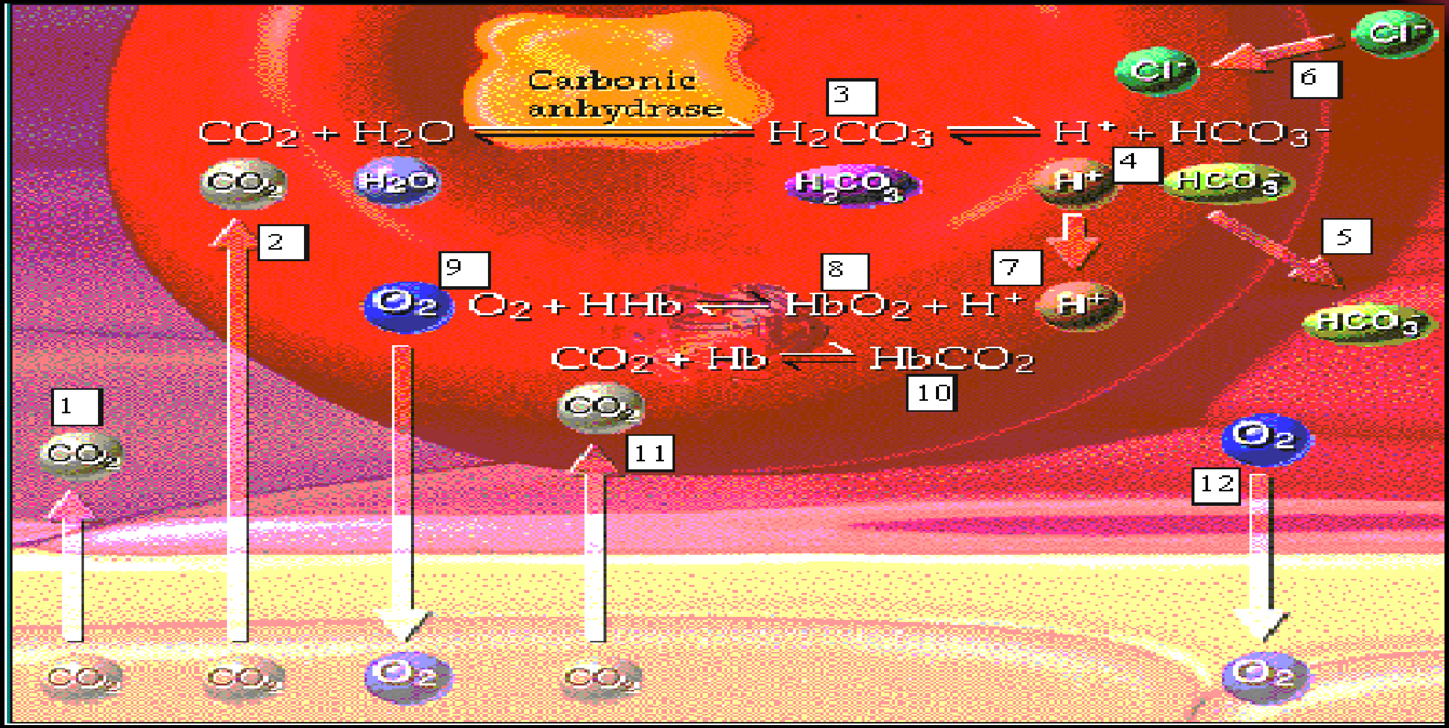
- **O2 → radikal bebas pengoksidasi (radikal bebas superoksid)**
  - Ensim yang dengan cepat menghilangkan radikal bebas : peroksidase, katalase, superoksid dismutase
  - Mengoksidasi asam lemak tidak jenuh
  - Vasokontriksi hebat → aliran menurun
- **Kronis → destruksi oksidatif**
  - pembengkaan saluran nafas, edema paru dan atelektasis

Terapi O_2

- **Kapan diberikan ?**
  - Hipoksia atmosfir
  - Hipoksia hipoventilasi
  - Hipoksia gangguan difusi
  - Hipoksia anemia
  - Hipoksia iskemia
  - Hipoksia oleh karena shunt fisiologis
  - Hipoksia oleh karena pemakaian O2 jaringan yang tidak adekuat

Transpor CO_2

- CO2 dalam bentuk terlarut (7 %)
- Ion Bikarbonat (70 %)
- Karbamino hemoglobin (23 %)

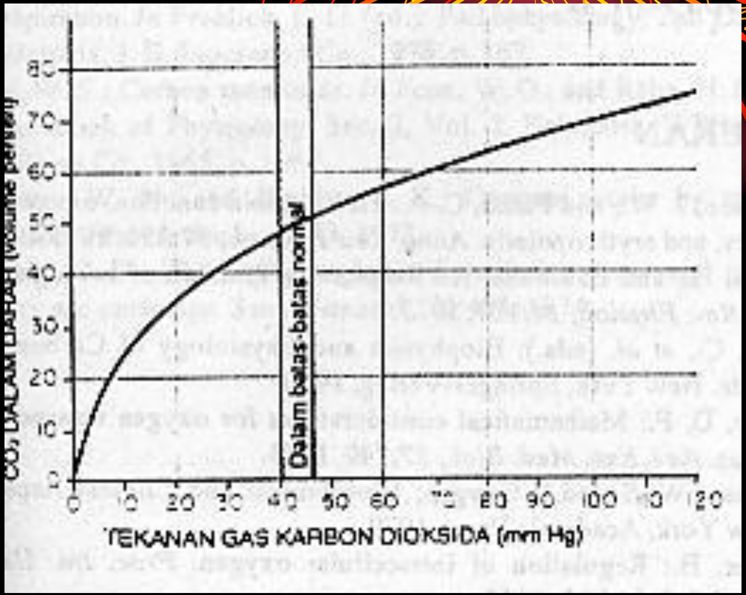


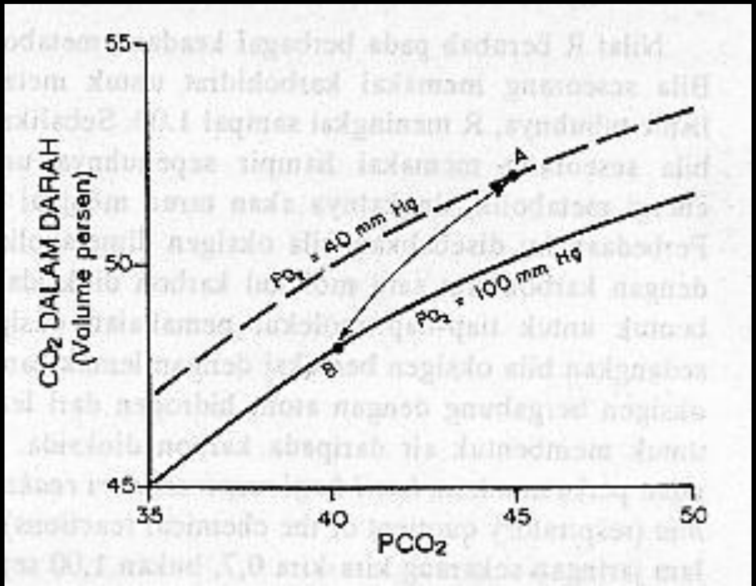
Transpor CO_2

- **Efek Haldene**

  Semakin tinggi Hb berikatan dengan O_2 semakin cenderung untuk melepaskan CO_2 .

Hb menjadi asam lebih kuat





Keracunan CO_2

- Diatas 80 mmHg
  - Depresi pusat pernafasan
  - Asidosis respiratori

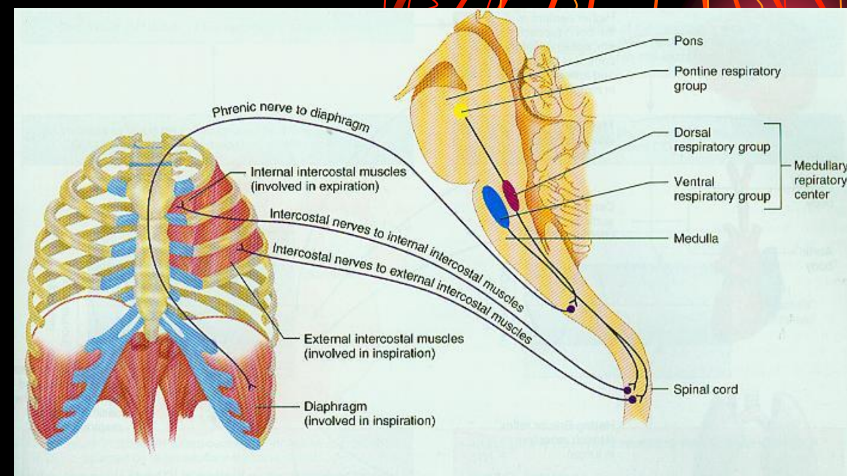
Penyelaman

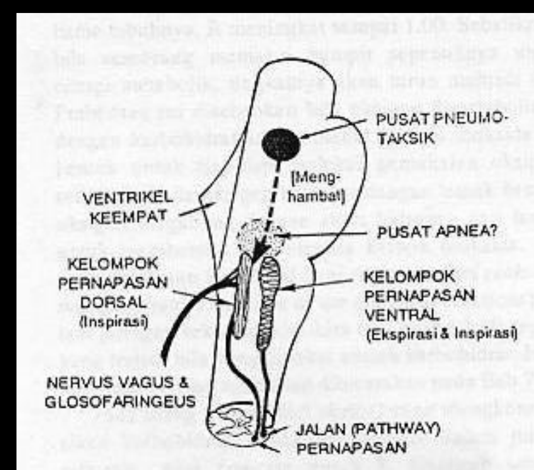
- **Hukum Boyle**
  - **Tekanan meningkat → volume paru mengecil**
- **Keracunan Nitrogen**
- **Keracunan oksigen**

Pengaturan Penafasan

- Pusat pernafasan
  - tersebar bilateral di Medula oblongata dan pons

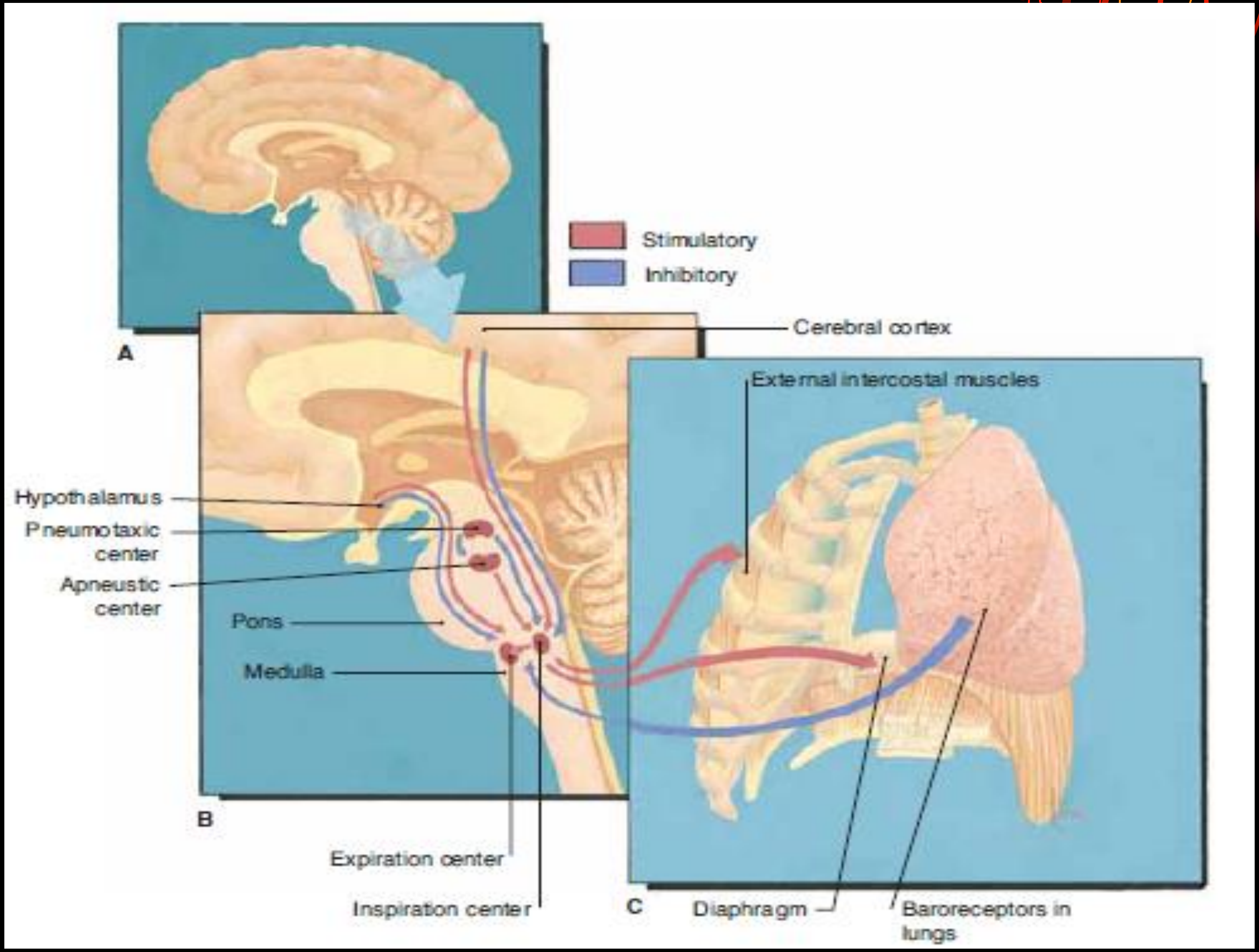
1. Kel. pernafasan dorsal
2. Kel. pernafasan ventral
3. Pusat pneumotaksik





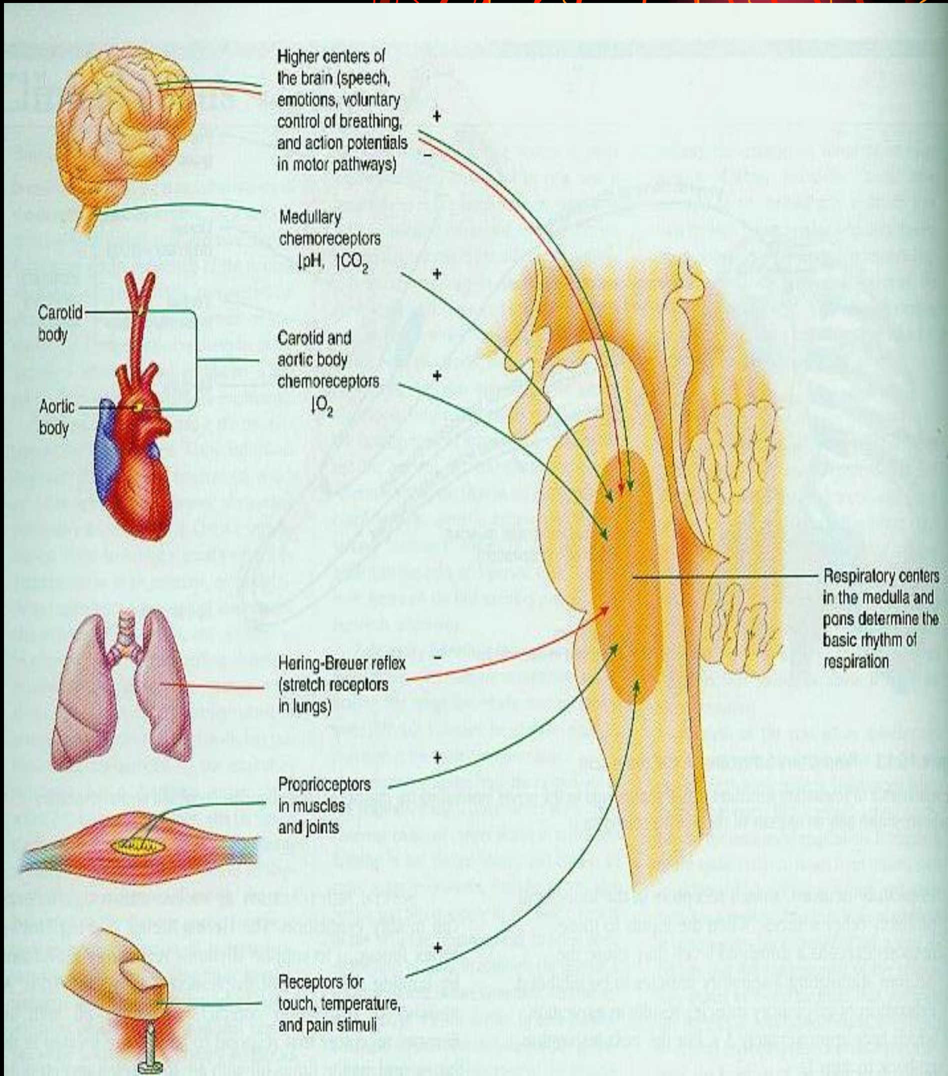
Gambar 42-1. Organisasi pusat pernapasan.

Pengaturan Penafasan



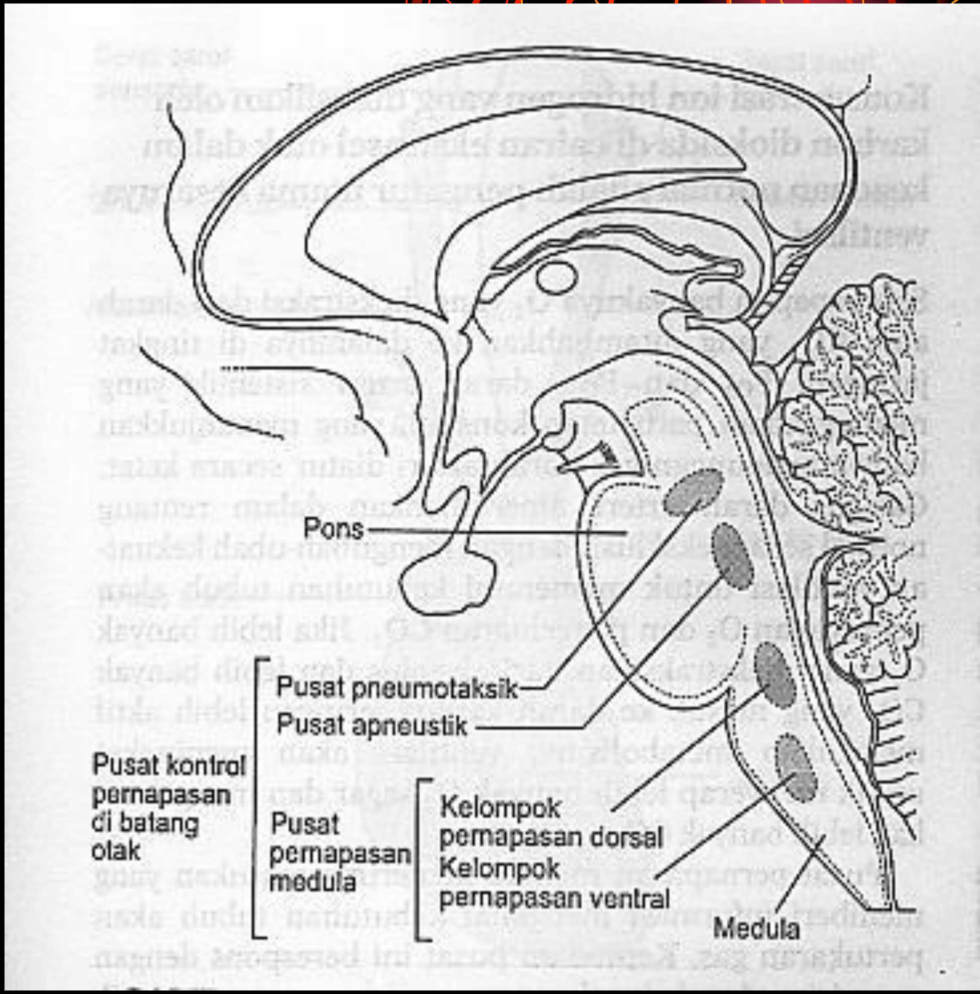
Pengaturan Pernafasan

- **Kel. Pernafasan Dorsal**
  - **Nukl. Tract Solitarius : N X & IX**
  - **Inspirasi : ramp sinyal**



Pengaturan Pernafasan

- **Pusat Pneumotaksik**
  - **Membatasi masa inspirasi dan meningkatkan kecepatan pernafasan**



Refleks Inflasi Hering-Breuer

Inflasi paru

↓

N X

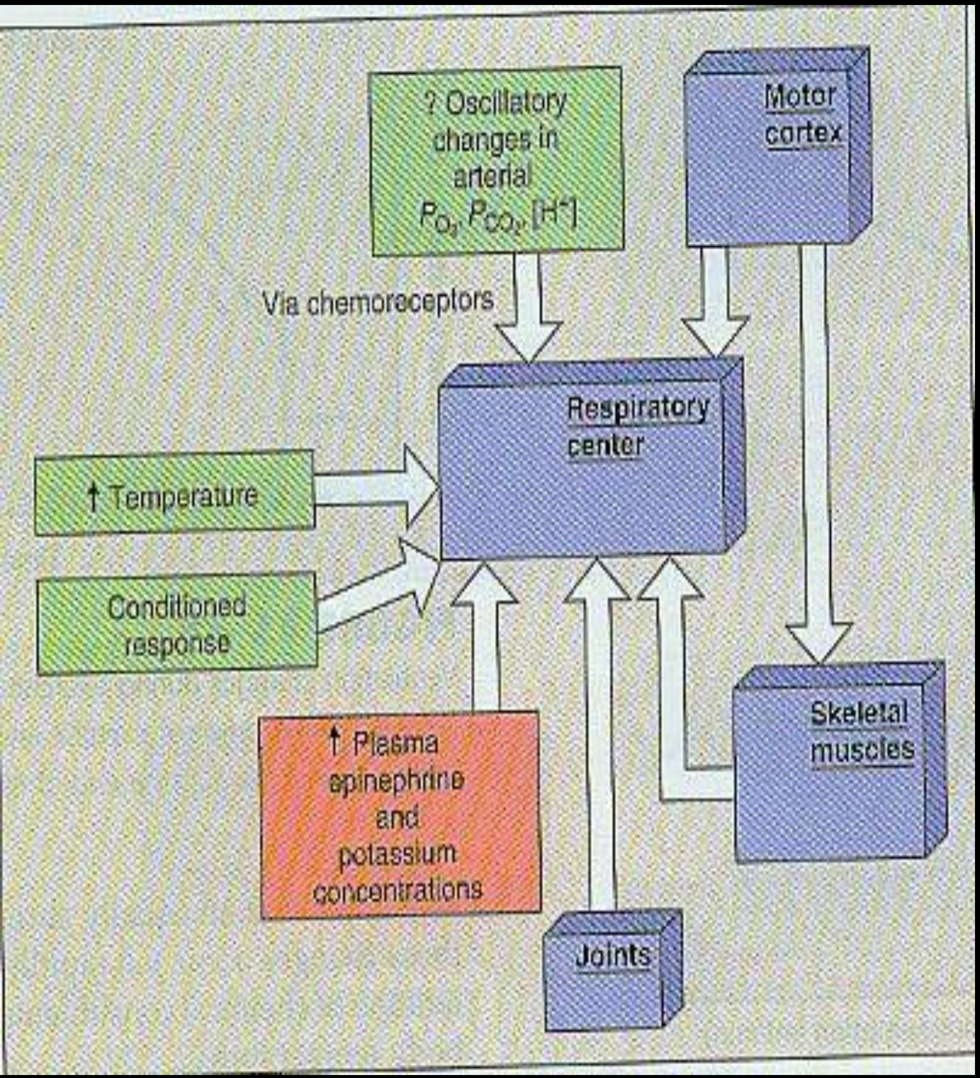
↓

Ramp Inspirasi (-)

Pengaturan Pernafasan

- Kel. Pernafasan Ventral
  - Inaktif pada saat pernafasan normal
  - Untuk meningkatkan ventilasi
  - Menyokong inspirasi dan ekspirasi

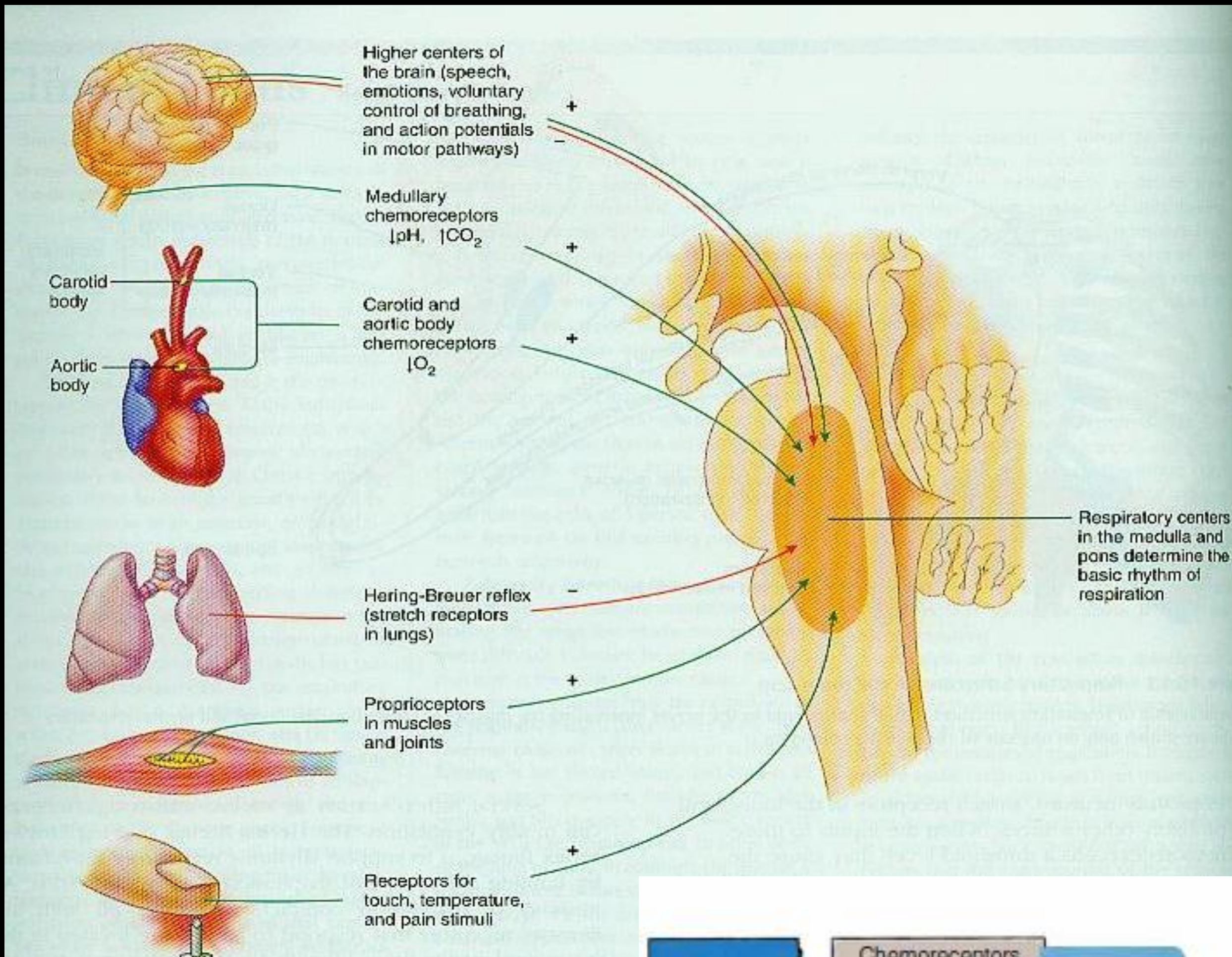
Pengaturan Pernafasan

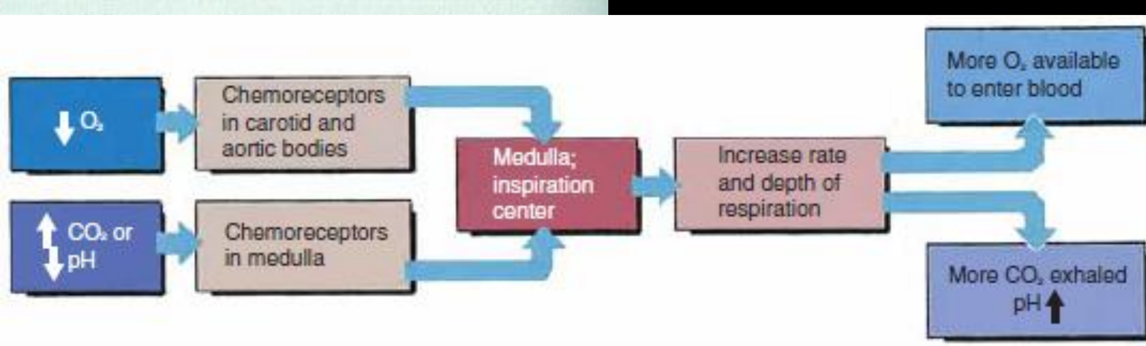


Pengaturan Aktivitas pusat pernafasan

1. Perubahan komposisi kimia darah : CO_2, Ion H, O_2
2. Rangsangan dari bagian lain

Pengaturan Pusat Pernafasan





Pengaturan Pusat Pernafasan

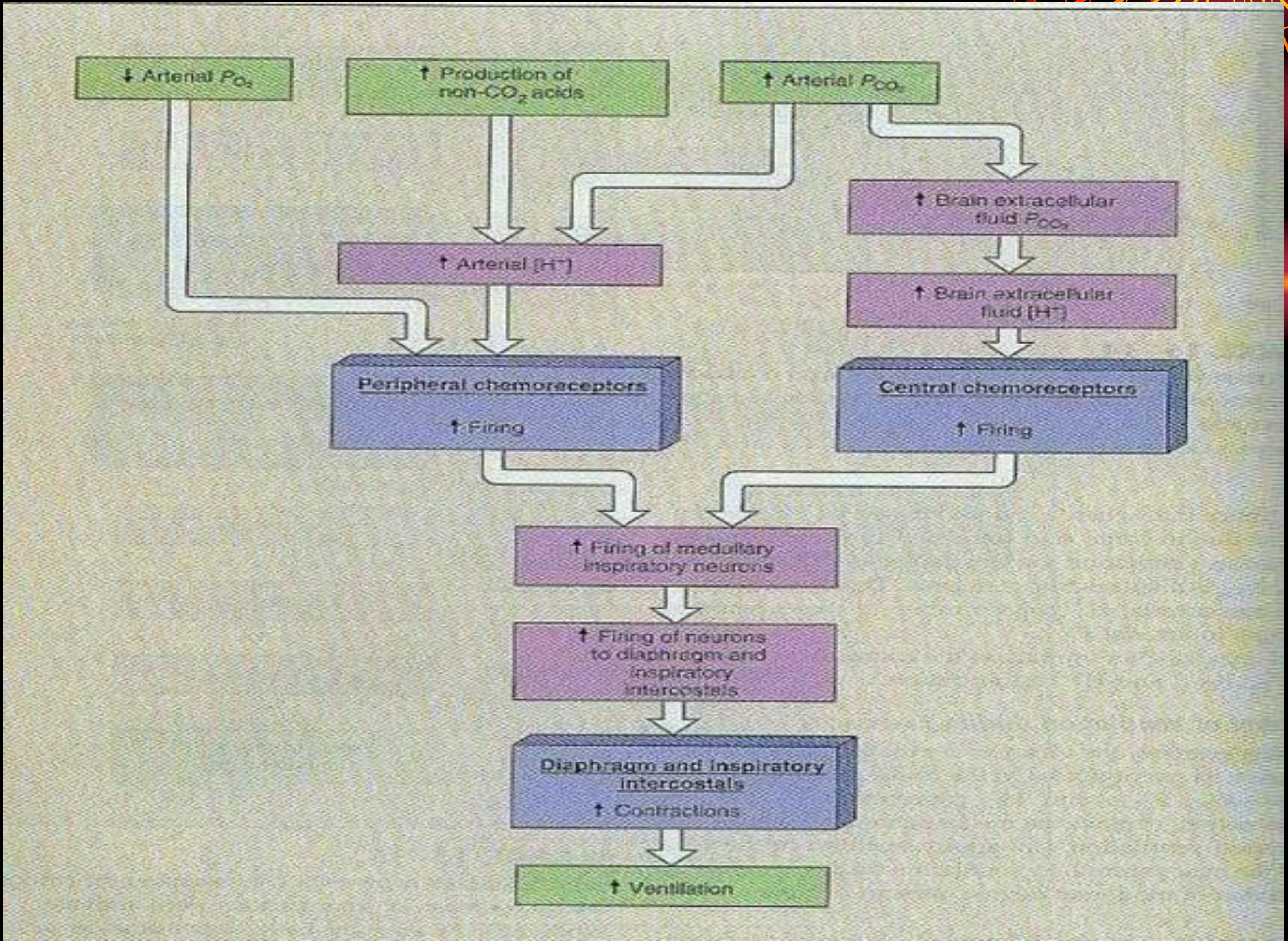


TABLE 1–2. Some Effects of Autonomic Nervous System Activity

EFFECTOR SITE	SYMPATHETIC NERVOUS SYSTEM	PARASYMPATHETIC NERVOUS SYSTEM
Heart	Increases rate Increases strength of contraction	Decreases rate Decreases strength of contraction
Bronchial smooth muscle	Relaxation	Constriction
Bronchial glands	Decreases secretions	Increases secretions
Salivary glands	Decreases secretions	Increases secretions
Stomach	Decreases motility	Increases motility
Intestines	Decreases motility	Increases motility
Eyes	Widens pupils	Constricts pupils

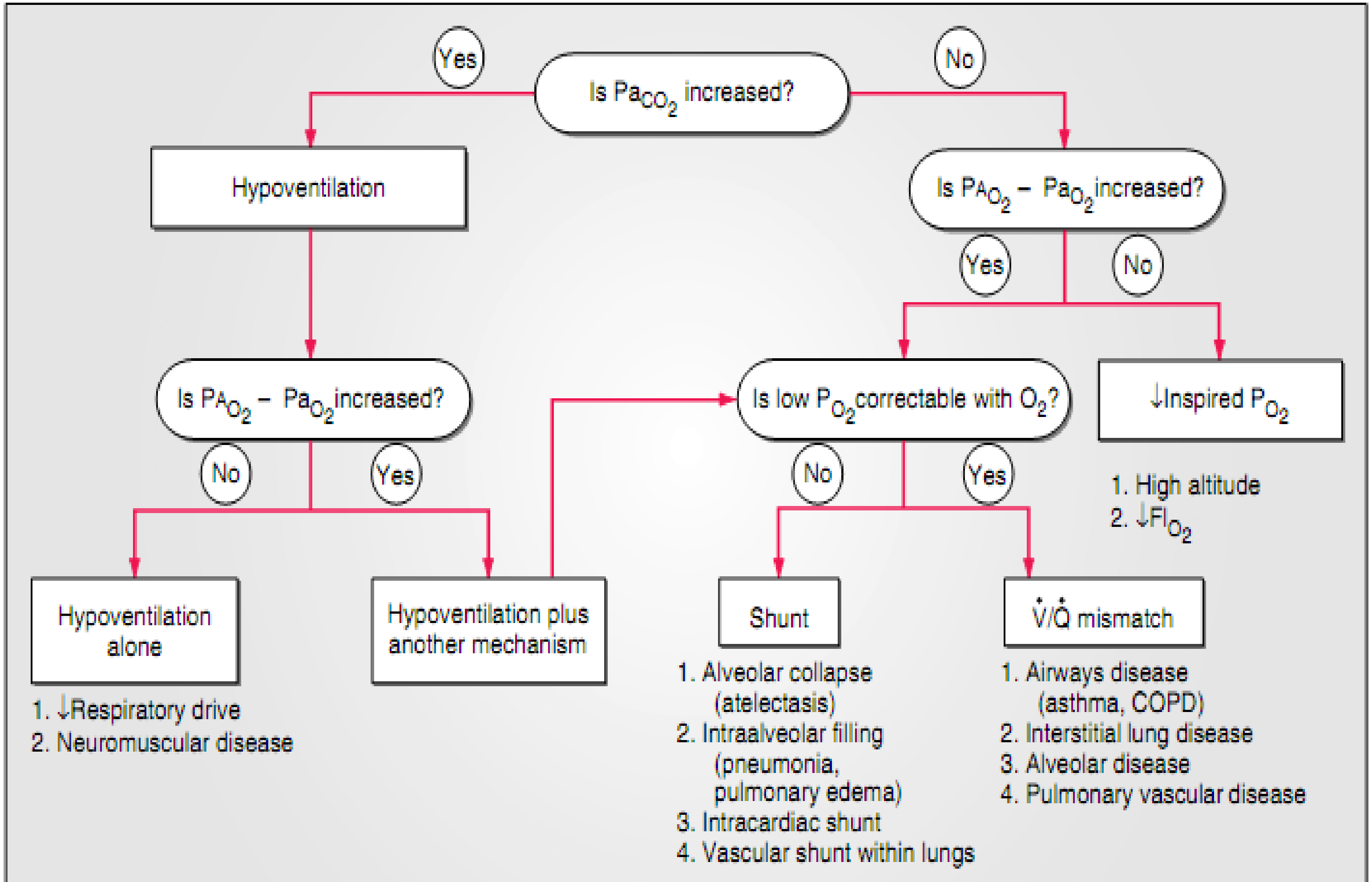


FIGURE 234-5 Flow diagram outlining the diagnostic approach to the patient with hypoxemia ($Pa_{O_2} < 80$ mmHg). $PA_{O_2} - Pa_{O_2}$ is usually < 15 mmHg for subjects ≤30 years old and increases by ~3 mmHg per decade after age 30. COPD, chronic obstructive pulmonary disease.