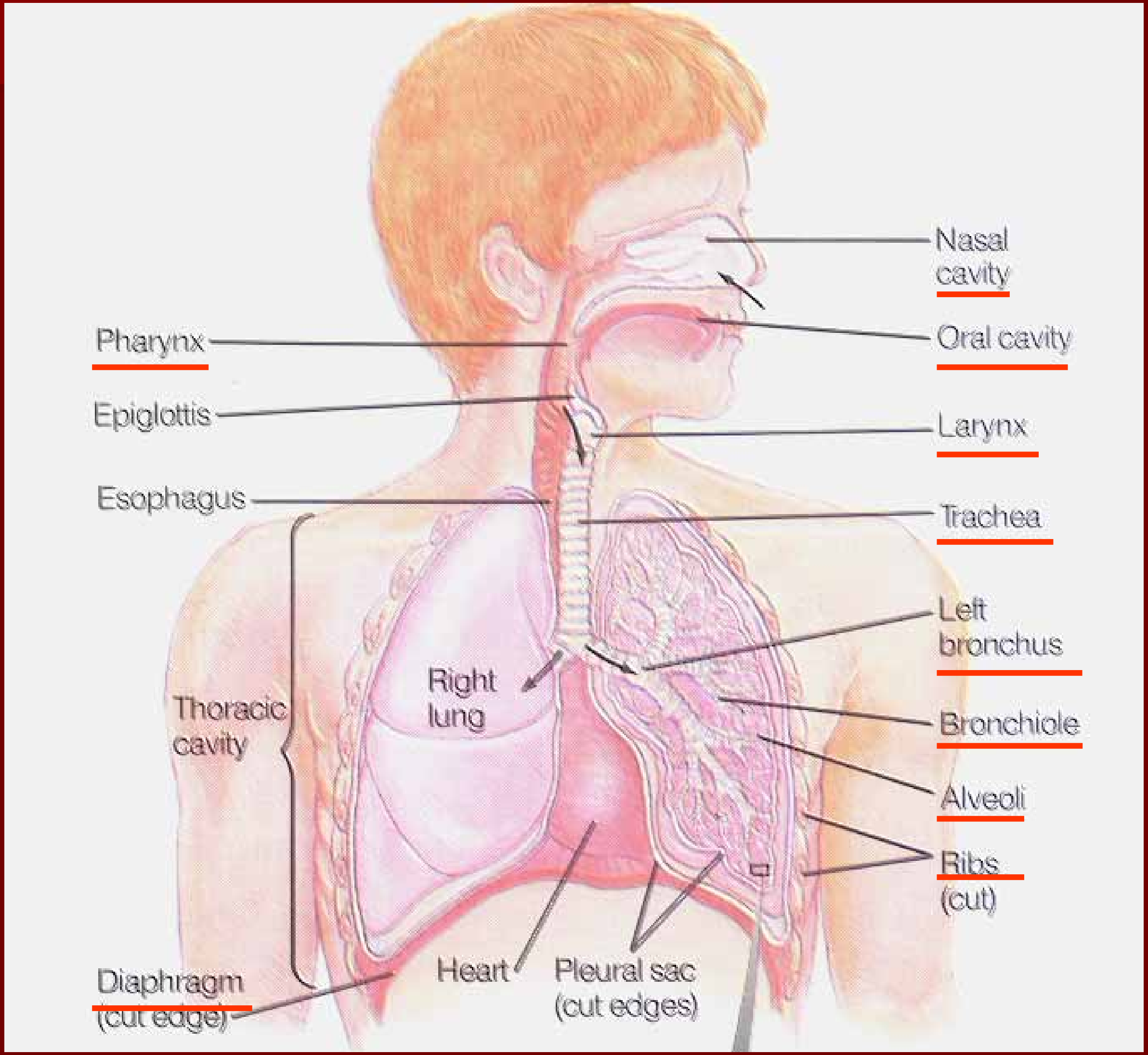
Respiration

Yu Yanqin, PhD
Dept. of Physiology
Zhejiang University, School of Medicine

Respiration

- Definition:
  - the bodily processes involved in exchange of oxygen (O_2) and carbon dioxide (CO_2) between an organism and the environment
- Consist of
  - Inspiration: the inhalation of air into the lung
  - Expiration: breathing out

Respiratory system

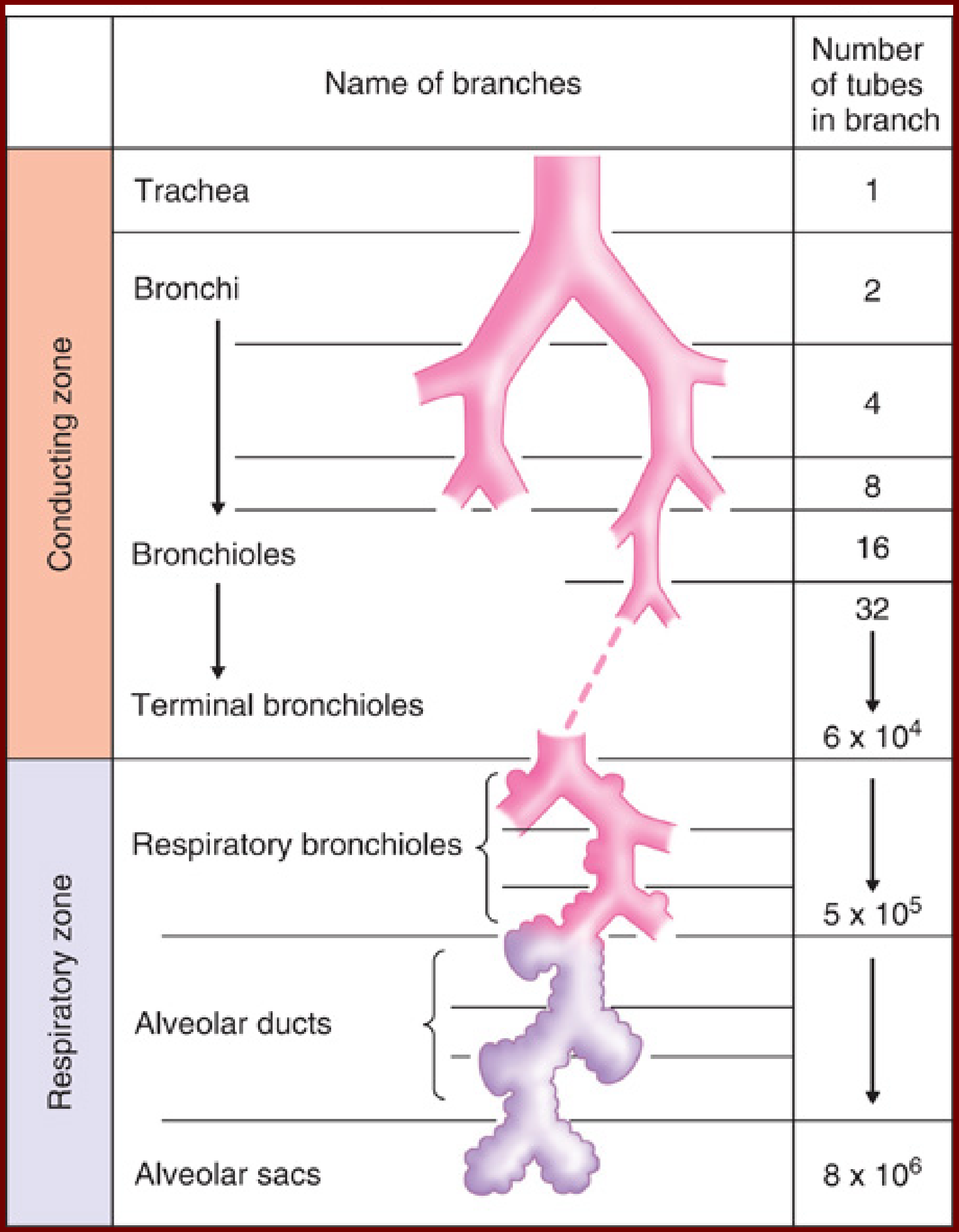


Upper airway

Lower airway

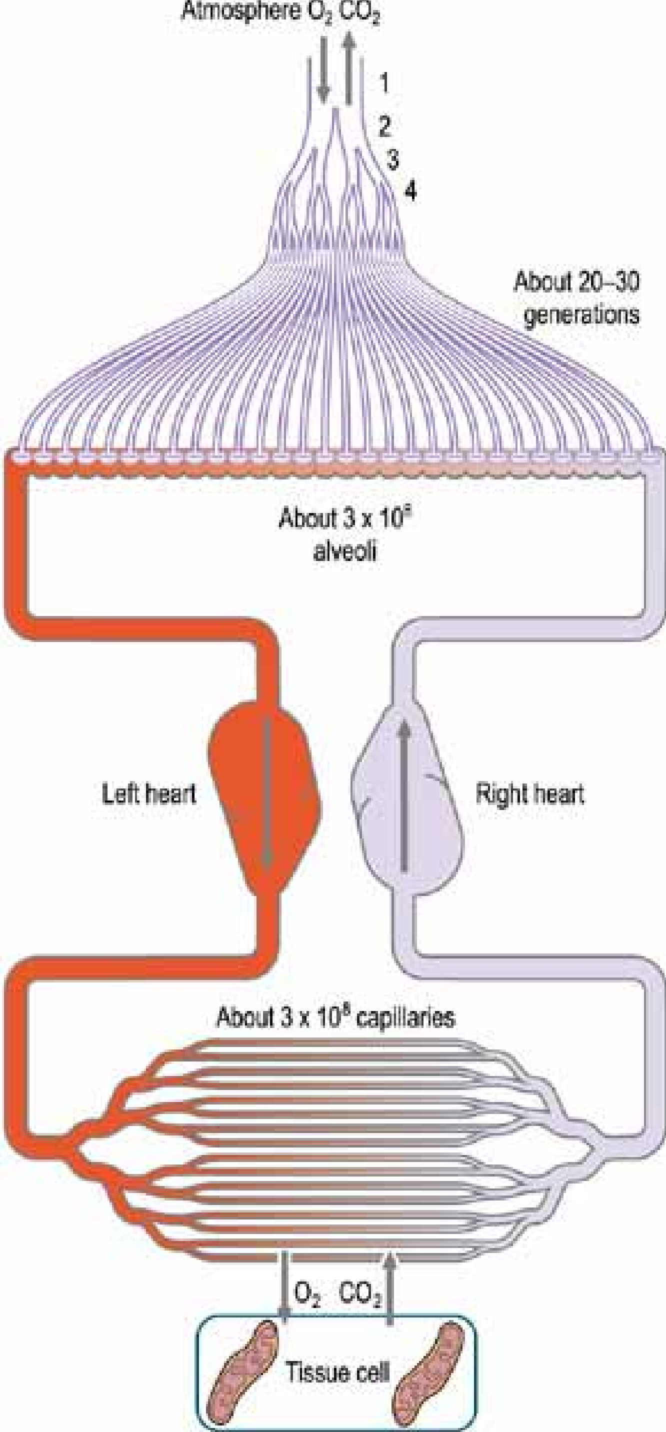
The relaxation/contraction of circular smooth muscle lining these "airways'" determines how easily airflow can occur.

Most gas exchange occurs in the alveolar sacs.



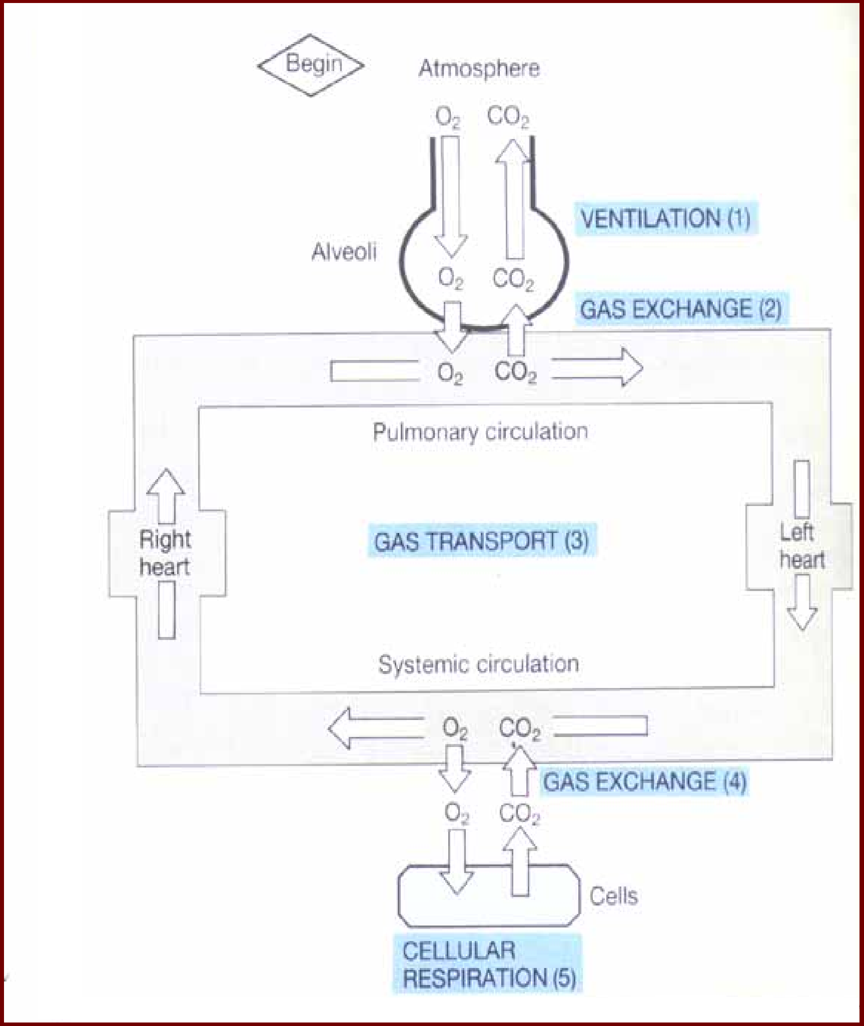
The goals of respiration

- to provide oxygen to the tissues
- to remove carbon dioxide.



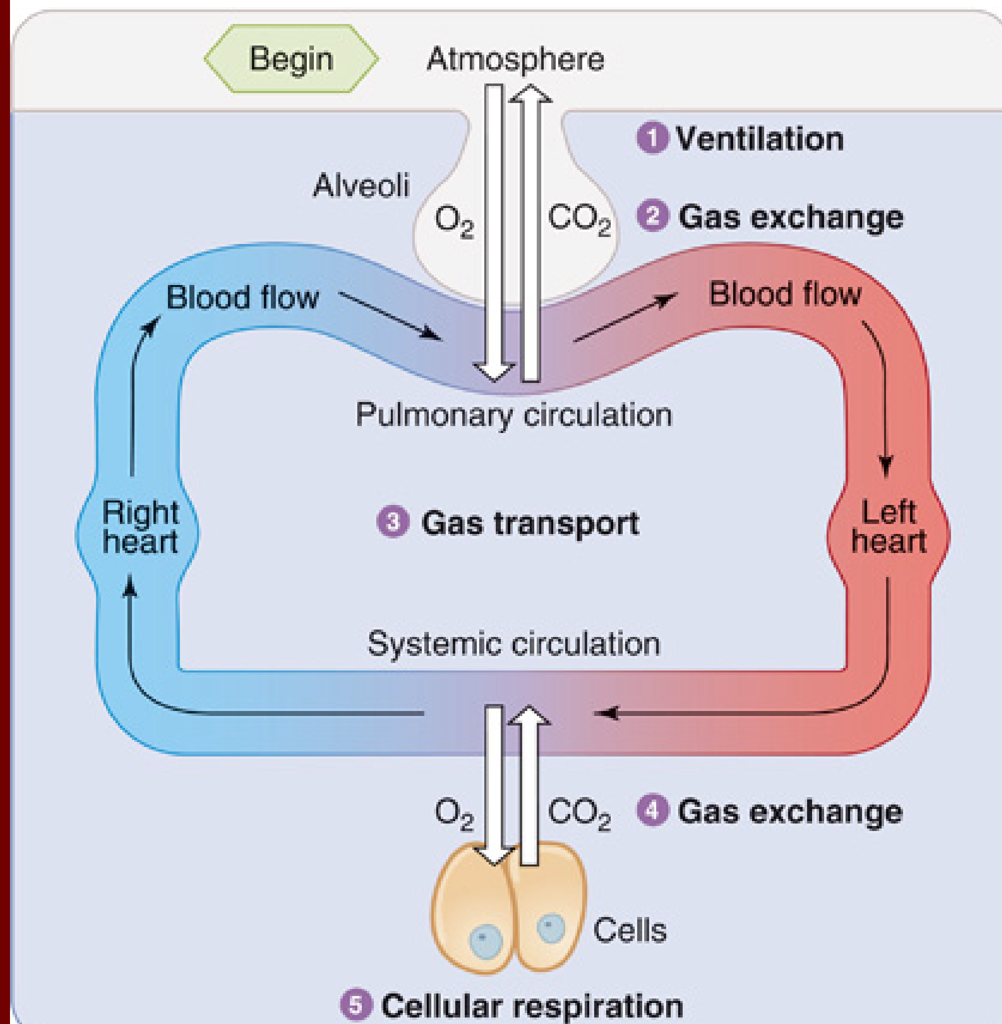
Four major functional events of respiration

- 1.Pulmonary ventilation
- 2.Gas exchange
  - Lung
  - Tissue
- 3.Gas transport in blood
- 4.Cellular respiration

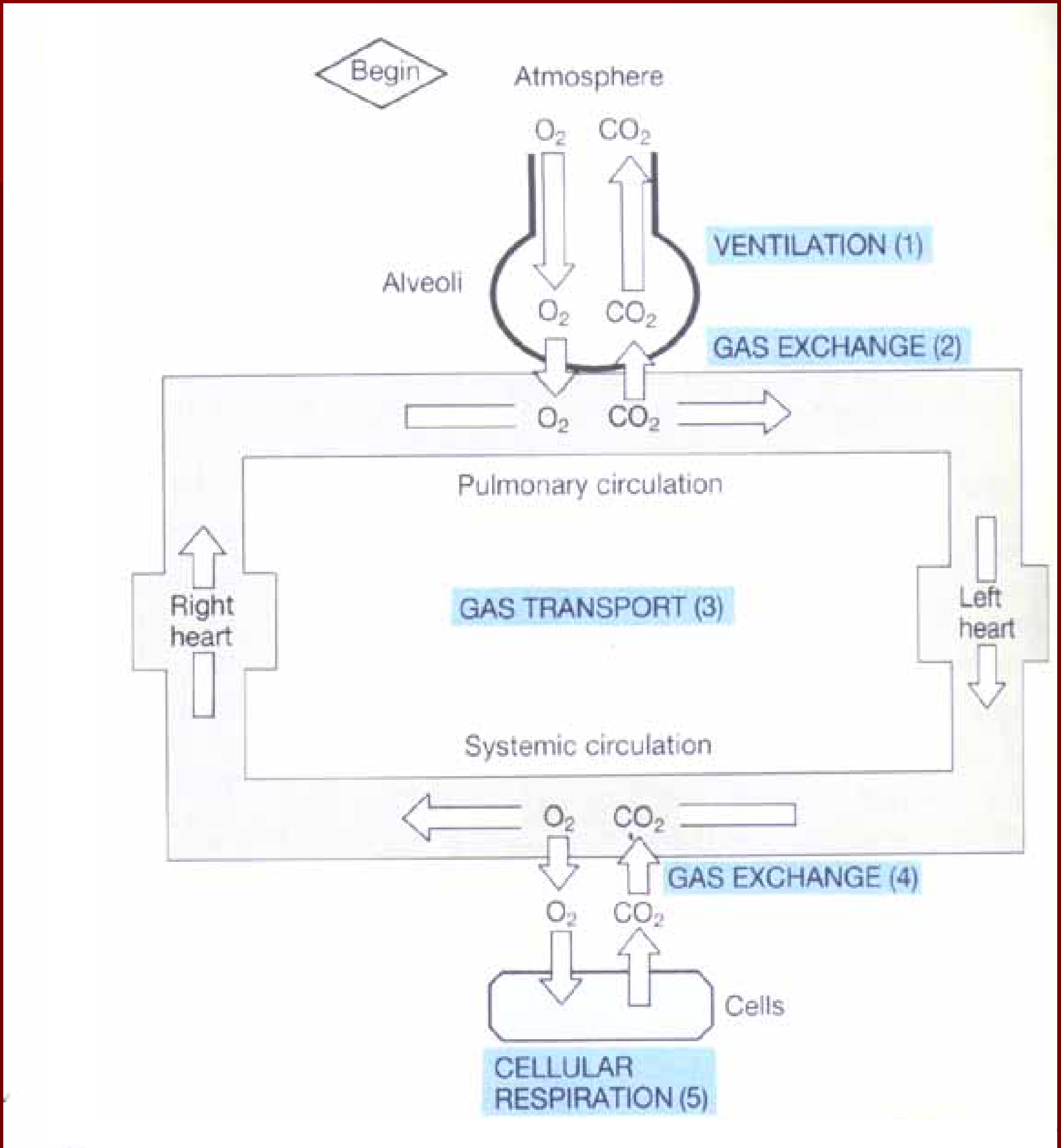


Process of respiration:

1. Ventilation: Exchange of air between atmosphere and alveoli by *bulk flow*
2. Exchange of O_2 and CO_2 between alveolar air and blood in lung capillaries by *diffusion*
3. Transport of O_2 and CO_2 through pulmonary and systemic circulation by *bulk flow*
4. Exchange of O_2 and CO_2 between blood in tissue capillaries and cells in tissues by *diffusion*
5. Cellular utilization of O_2 and production of CO_2



Respiratory process



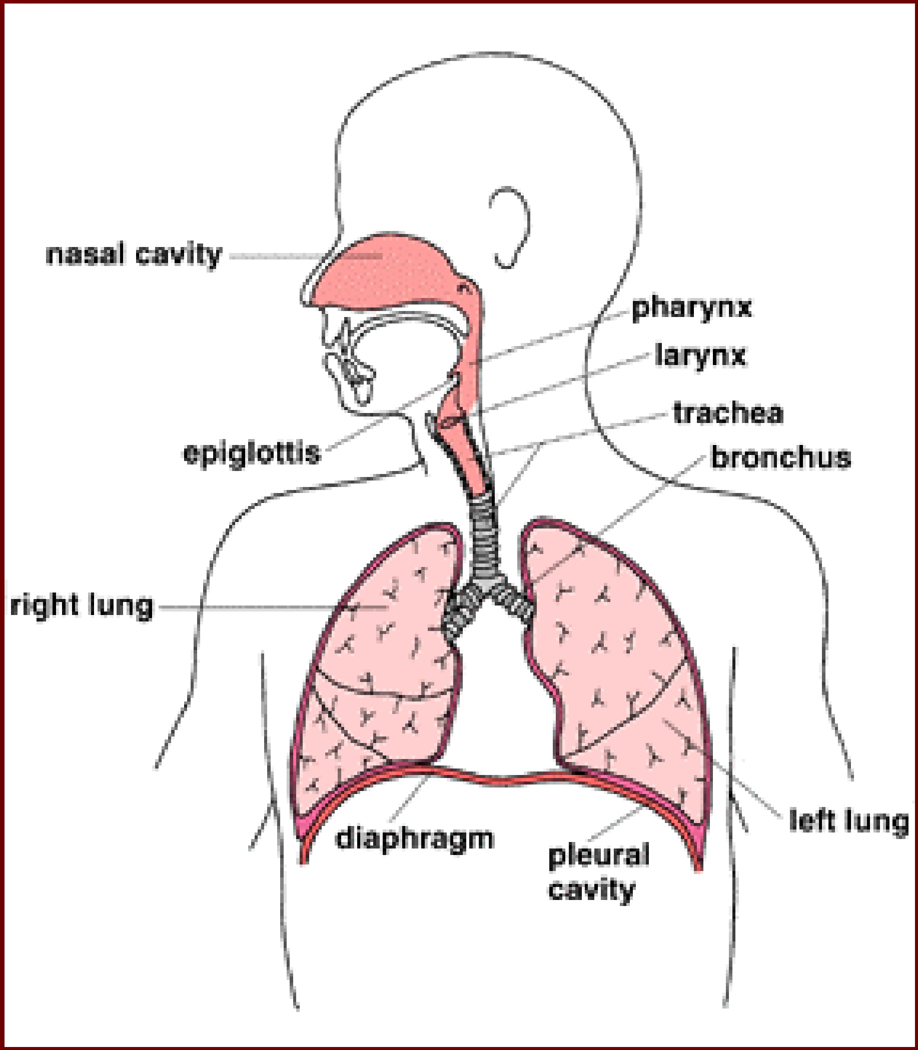
1. External respiration

2. Gas transport

3. Internal respiration

Pulmonary ventilation

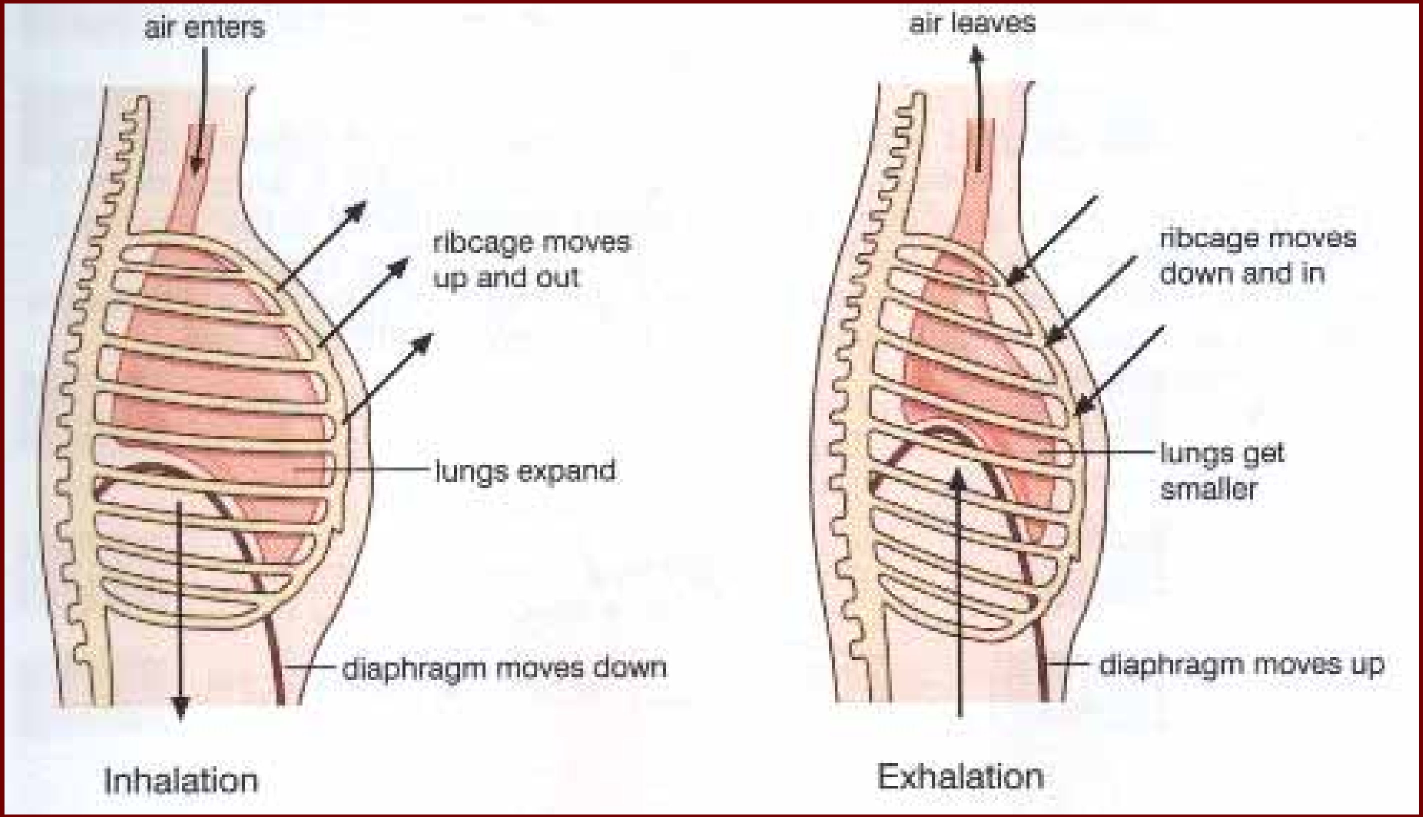
- Definition: The process of moving air into and out of the lungs



Structures of pulmonary ventilation

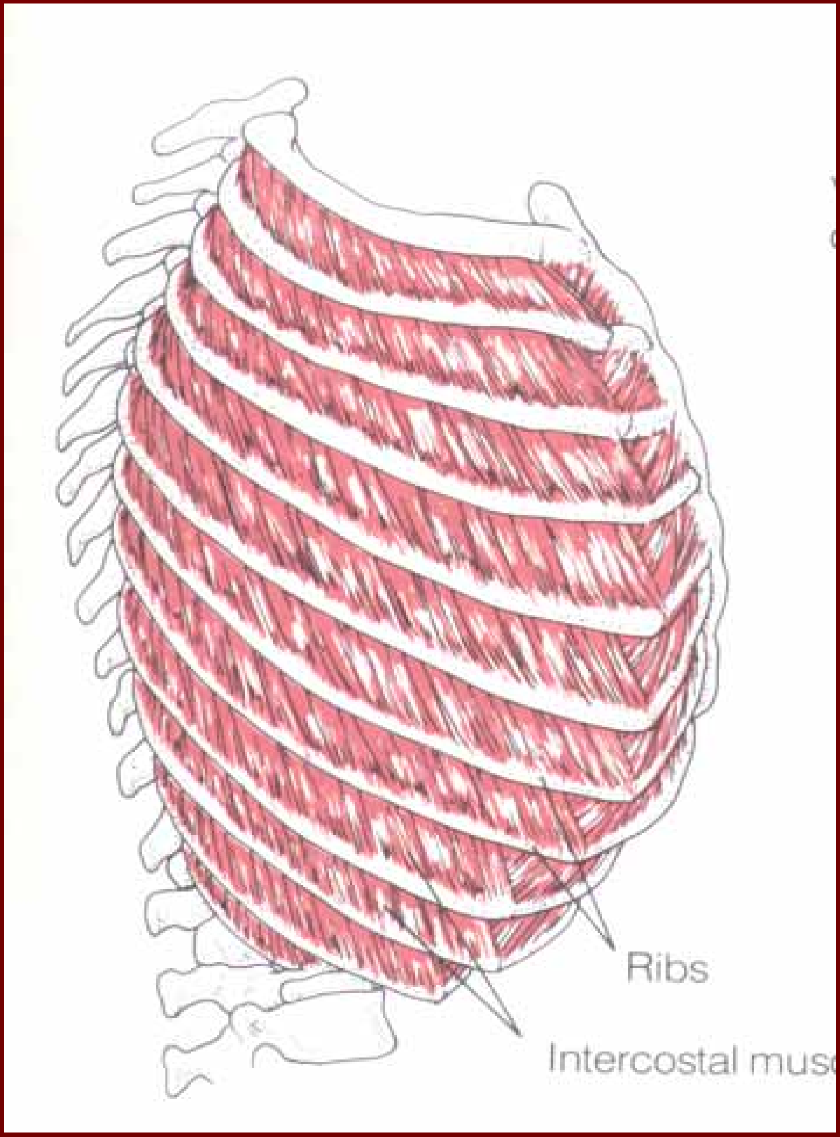
1. Respiratory muscle

Primary muscles of respiration: external intercostals & diaphragm

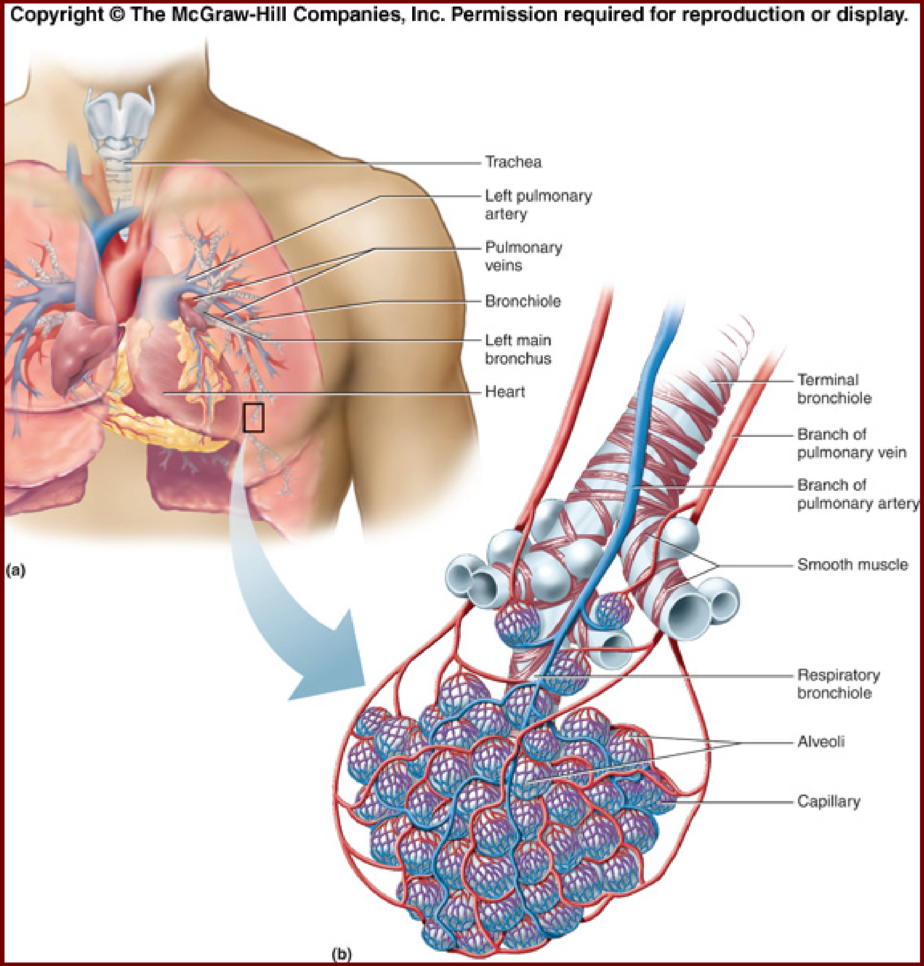


2. Thorax

- The thorax is a closed compartment that is bounded at the neck by muscles and connective tissue and completely separated from the abdomen by the diaphragm.



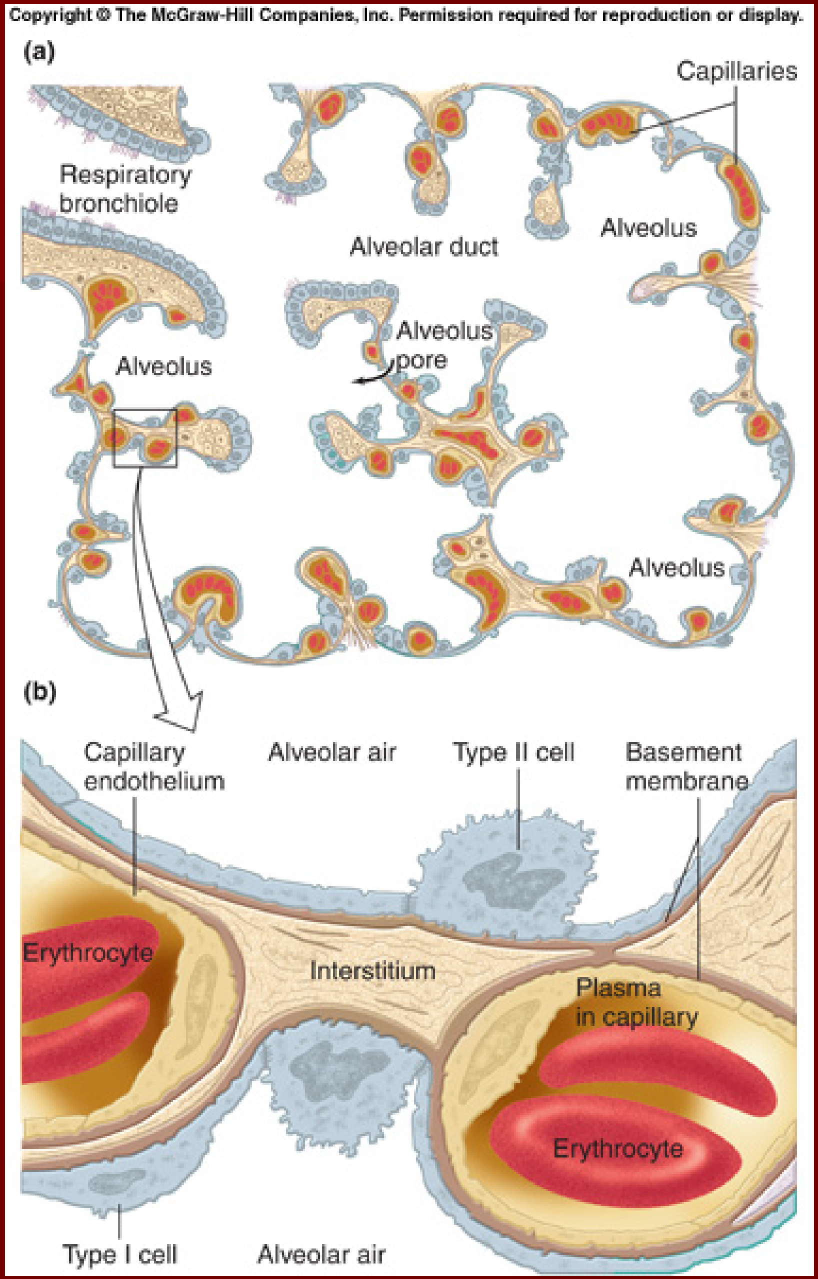
3. Alveoli



Each of the clustered alveoli includes an abundance of pulmonary capillaries, thereby assuring that the ventilated air is brought into close proximity to the “pulmonary” blood, allowing efficient and thorough gas exchange between the air and the blood.

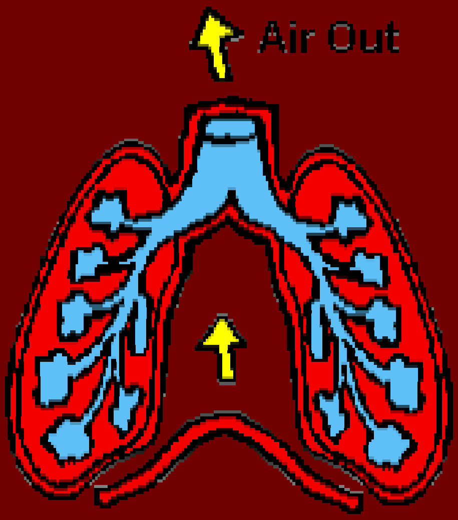
Extensive branching of alveoli produces lots of **surface area** for exchange between air and blood.

Alveolar and capillary **walls are thin**, permitting rapid diffusion of gases.



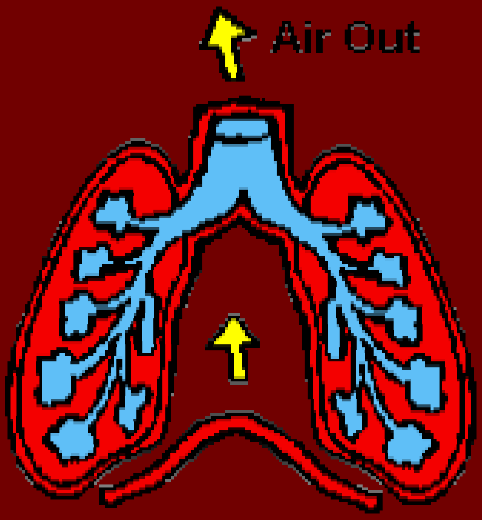
Breathing is an active process

- To inhale
  - Contraction of external intercostal muscles → elevation of ribs & sternum → increased front- to-back dimension of thoracic cavity → lowers air pressure in lungs → air moves into lungs
  - Contraction of diaphragm → diaphragm moves downward → increases vertical dimension of thoracic cavity → lowers air pressure in lungs → air moves into lungs

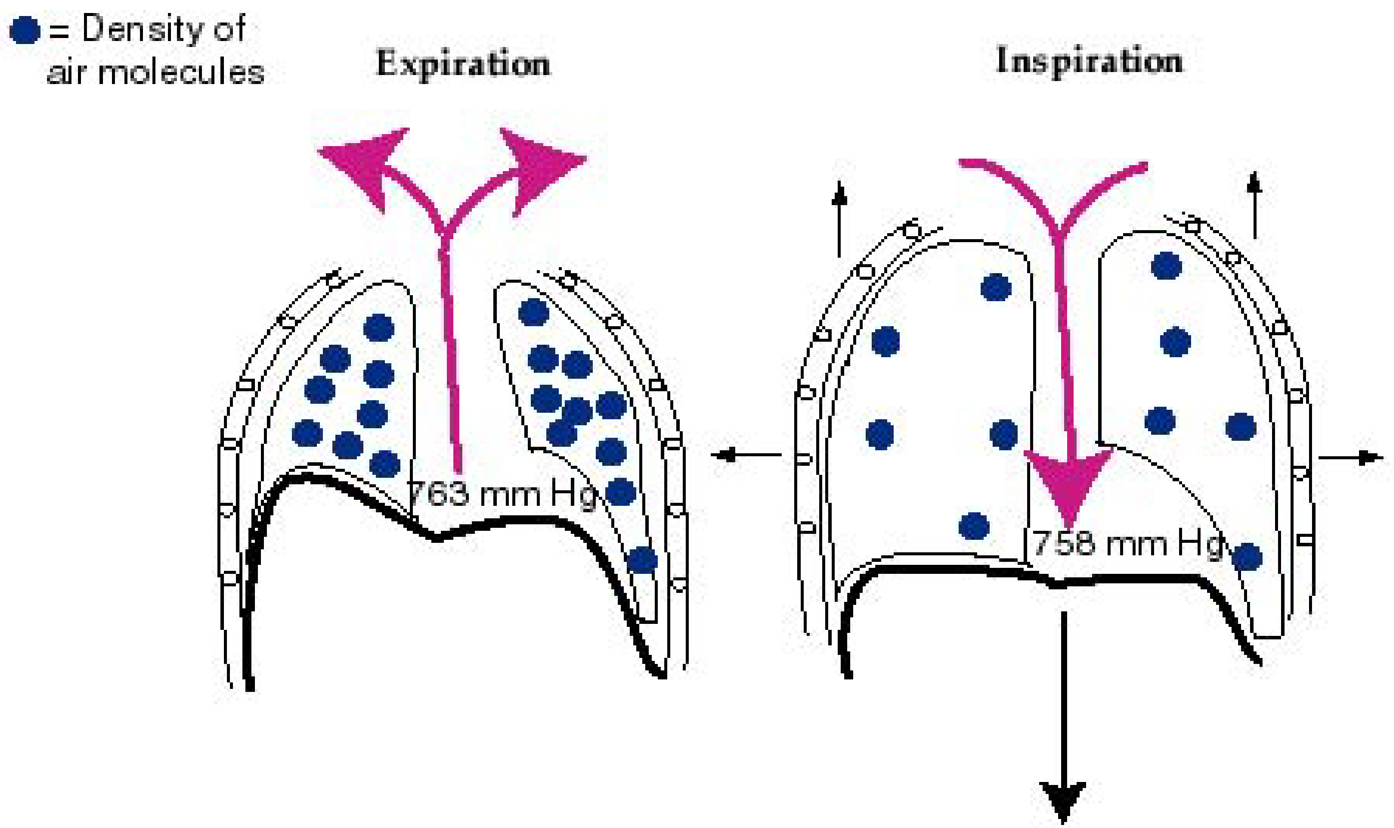


Breathing is an active process

- To exhale
  - Relaxation of external intercostal muscles & diaphragm → return of diaphragm, ribs, & sternum to resting position → restores thoracic cavity to preinspiratory volume → increases pressure in lungs → air is exhaled



Ambient air pressure
=760 mm Hg



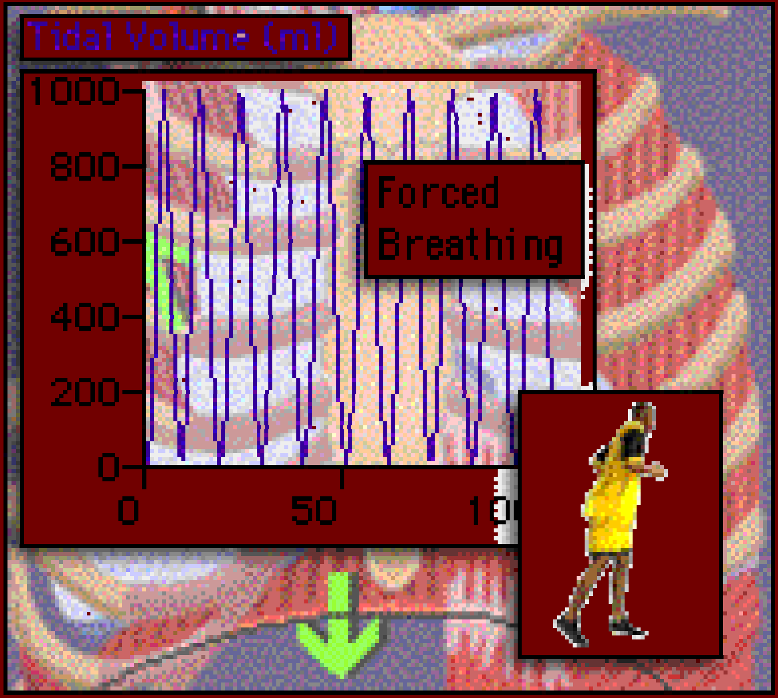
1. Contraction of ribs (internal intercostals)
2. Intrathoracic volume decreased
3. Intrathoracic pressure rises
4. Therefore, air flows out of airway down its pressure gradient

1. Elevation of ribs (external intercostals)
2. Intrathoracic volume increased
3. Intrathoracic pressure falls
4. Therefore, air flows into airway down its pressure gradient

Patterns of respiration

- Eupnea: inspiration is active, expiration is passive.
  - Abdominal breathing
  - Thoracic breathing

- Forced breathing: respiratory movement is greatly enhanced during physical exercise

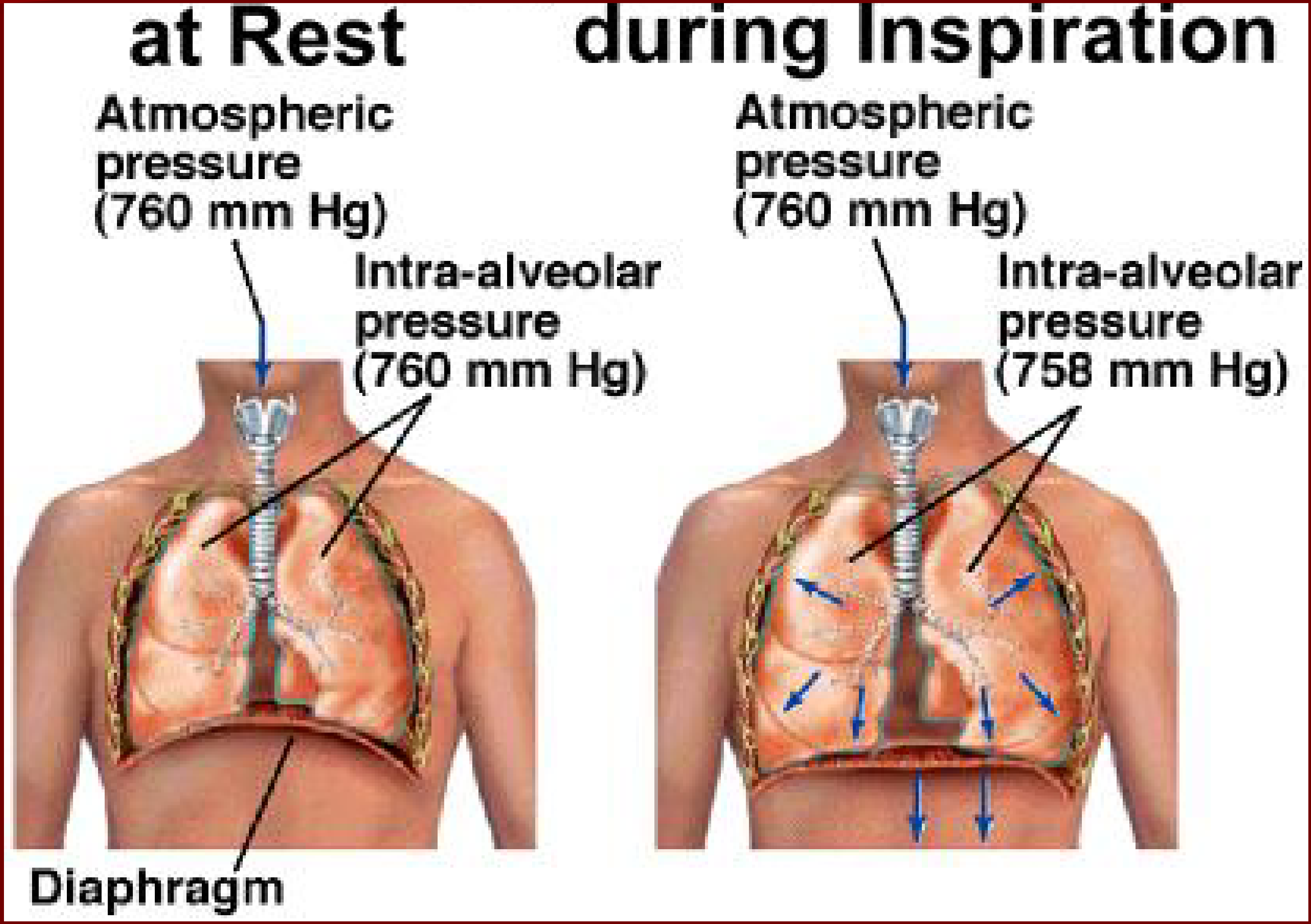


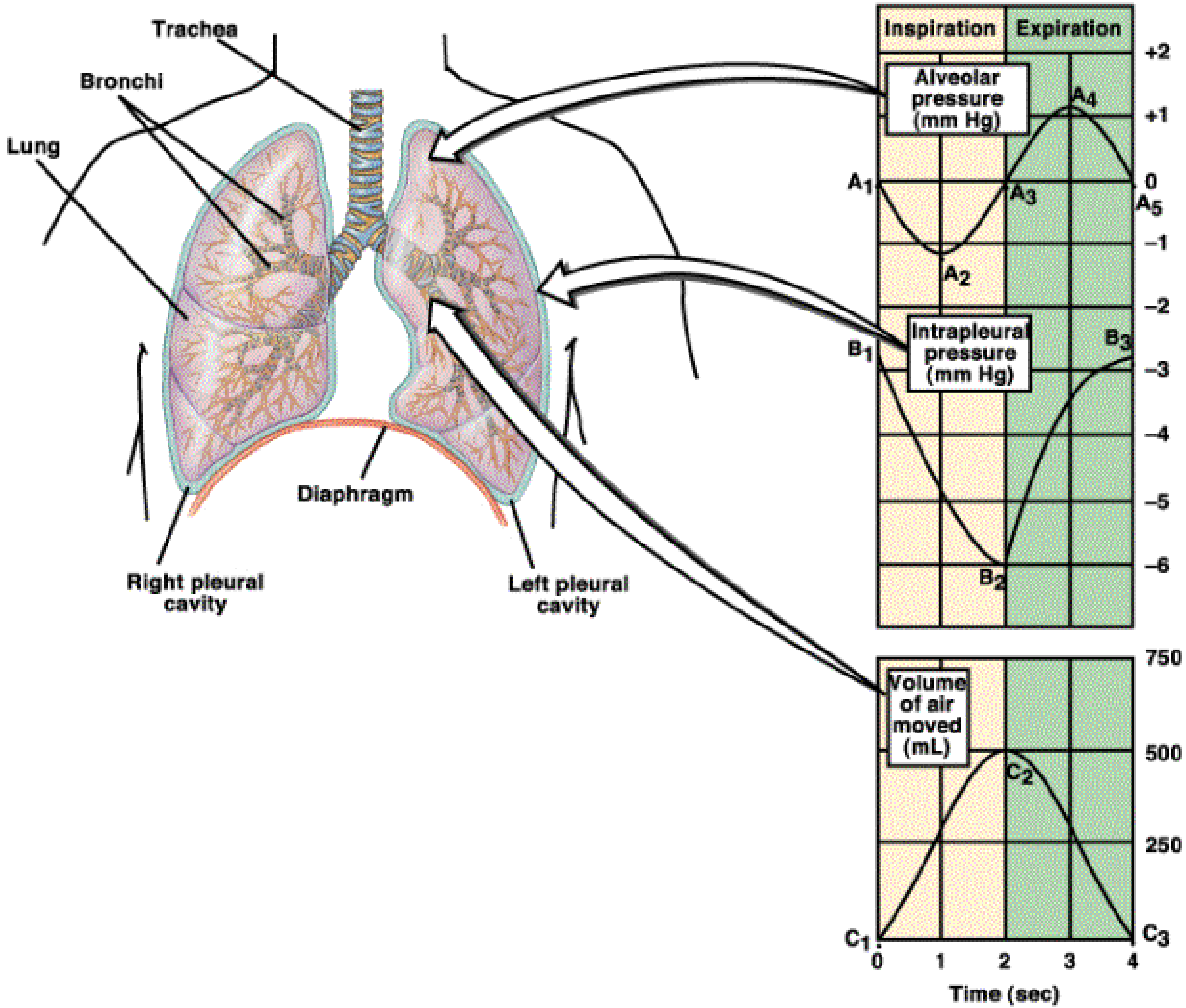
Principles of pulmonary ventilation

- Direct force of breathing
  - Pressure gradient between atmosphere and lung
- Original force of breathing
  - Repiatory movement

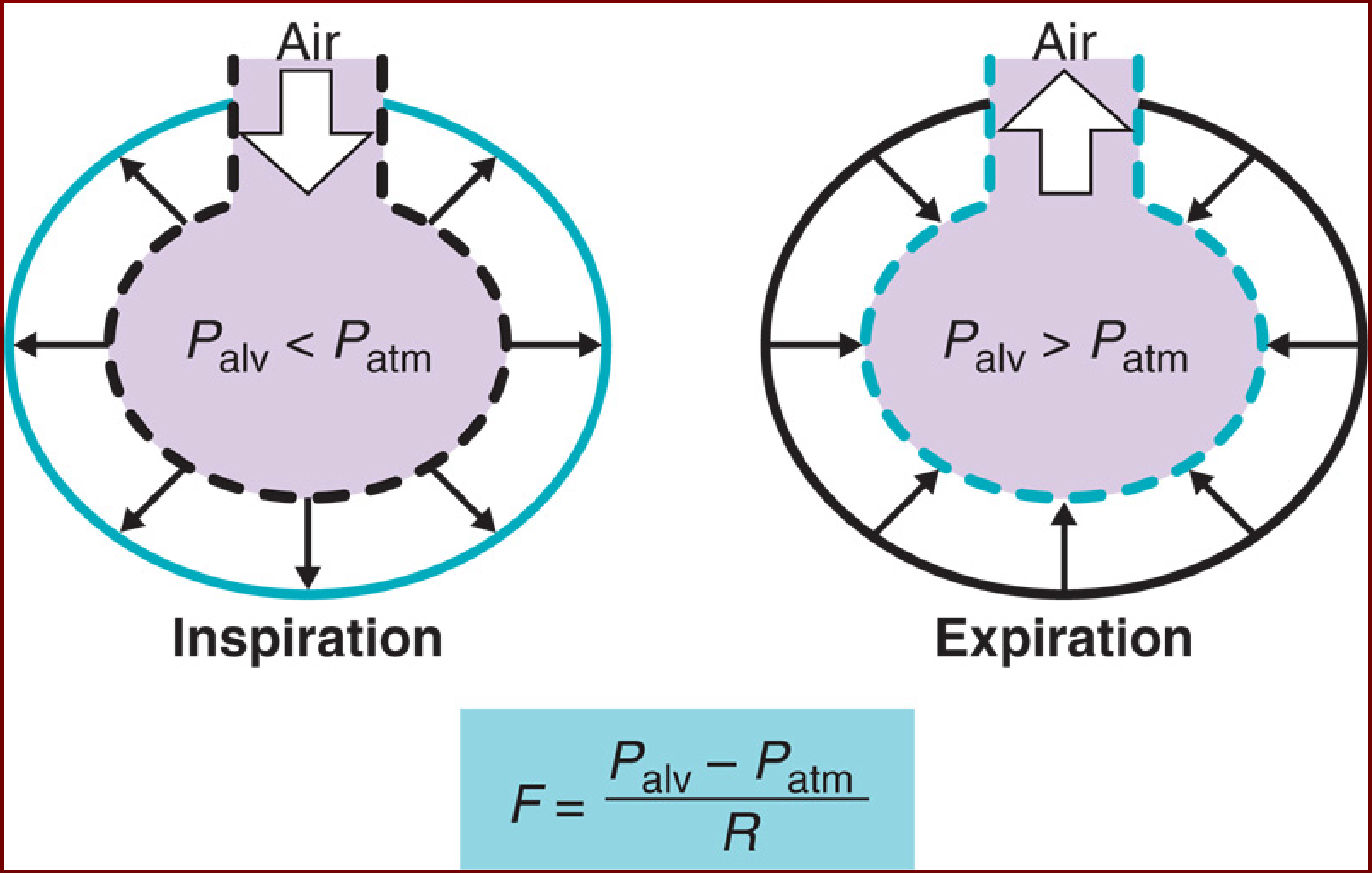
Intrapulmonary pressure

= Alveolar pressure =The pressure of air inside the lung alveoli





Trachea
Bronchi
Lung
Diaphragm
Right pleural cavity
Left pleural cavity
Inspiration
Expiration
Alveolar pressure (mm Hg)
Intrapleural pressure (mm Hg)
Volume of air moved (mL)
A1
A2
A3
A4
A5
B1
B2
B3
C1
C2
C3
+2
+1
0
−1
−2
−3
−4
−5
−6
750
500
250
0
1
2
3
4
Time (sec)



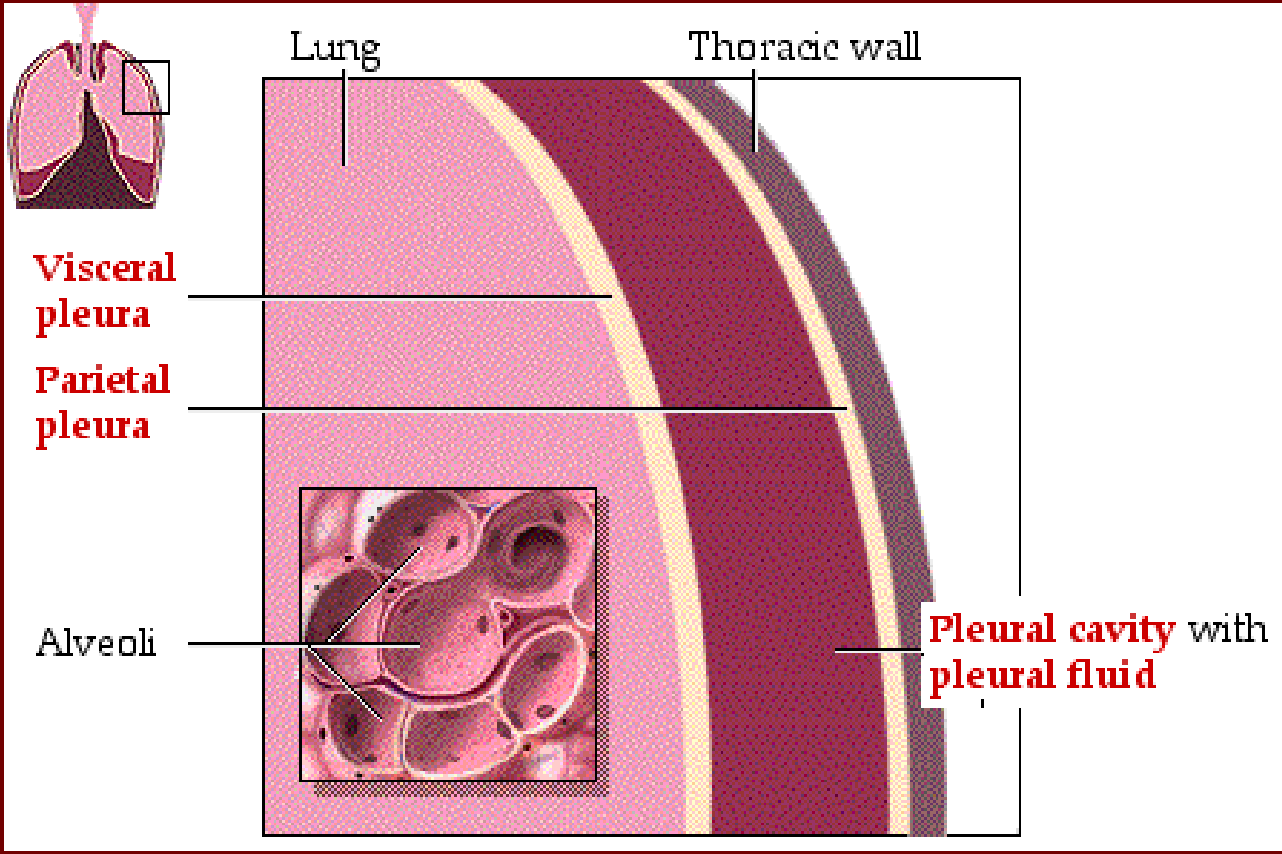
Airflow (F) is a function of the pressure differences between the alveoli (P_{alv}) and the atmosphere (P_{atm}) divided by airflow resistance (R).

Air enters the lungs when $P_{alv} < P_{atm}$

Air exits the lungs when $P_{alv} > P_{atm}$

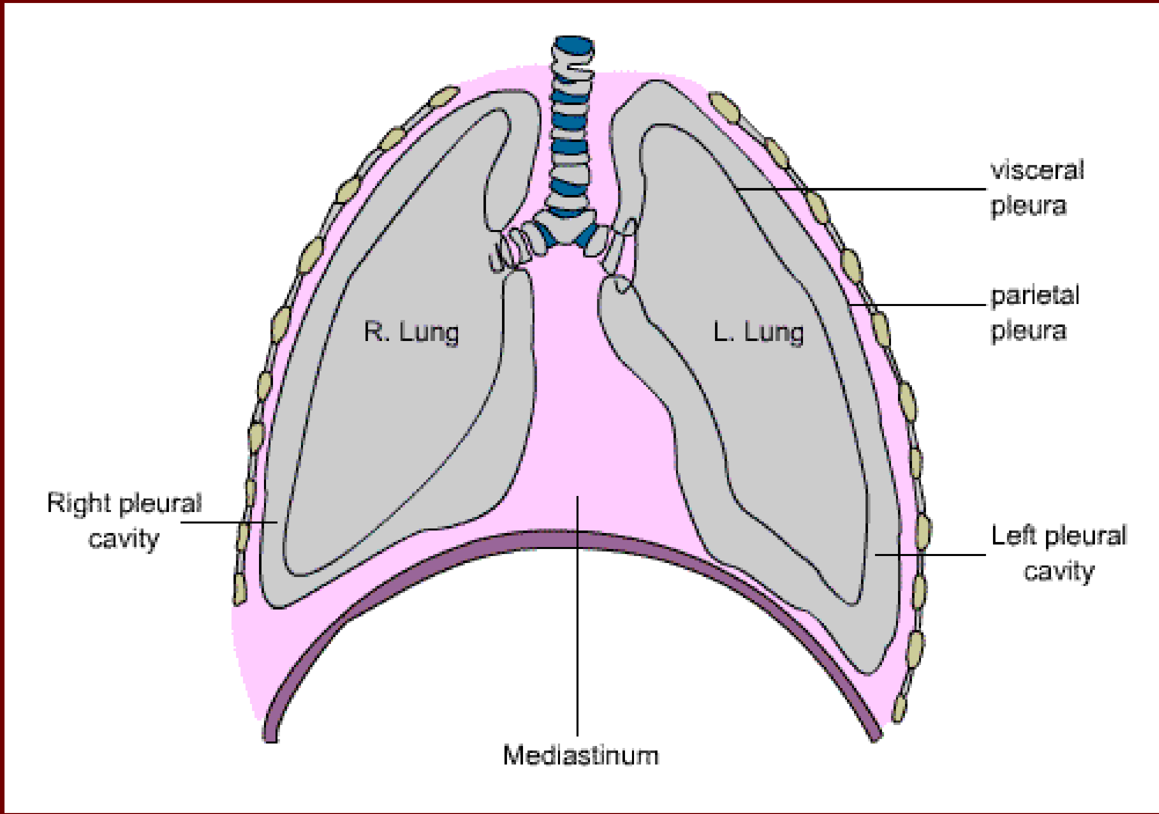
Intrapleural pressure

- Intrapleural pressure is the pressure within <u>pleural cavity</u>.



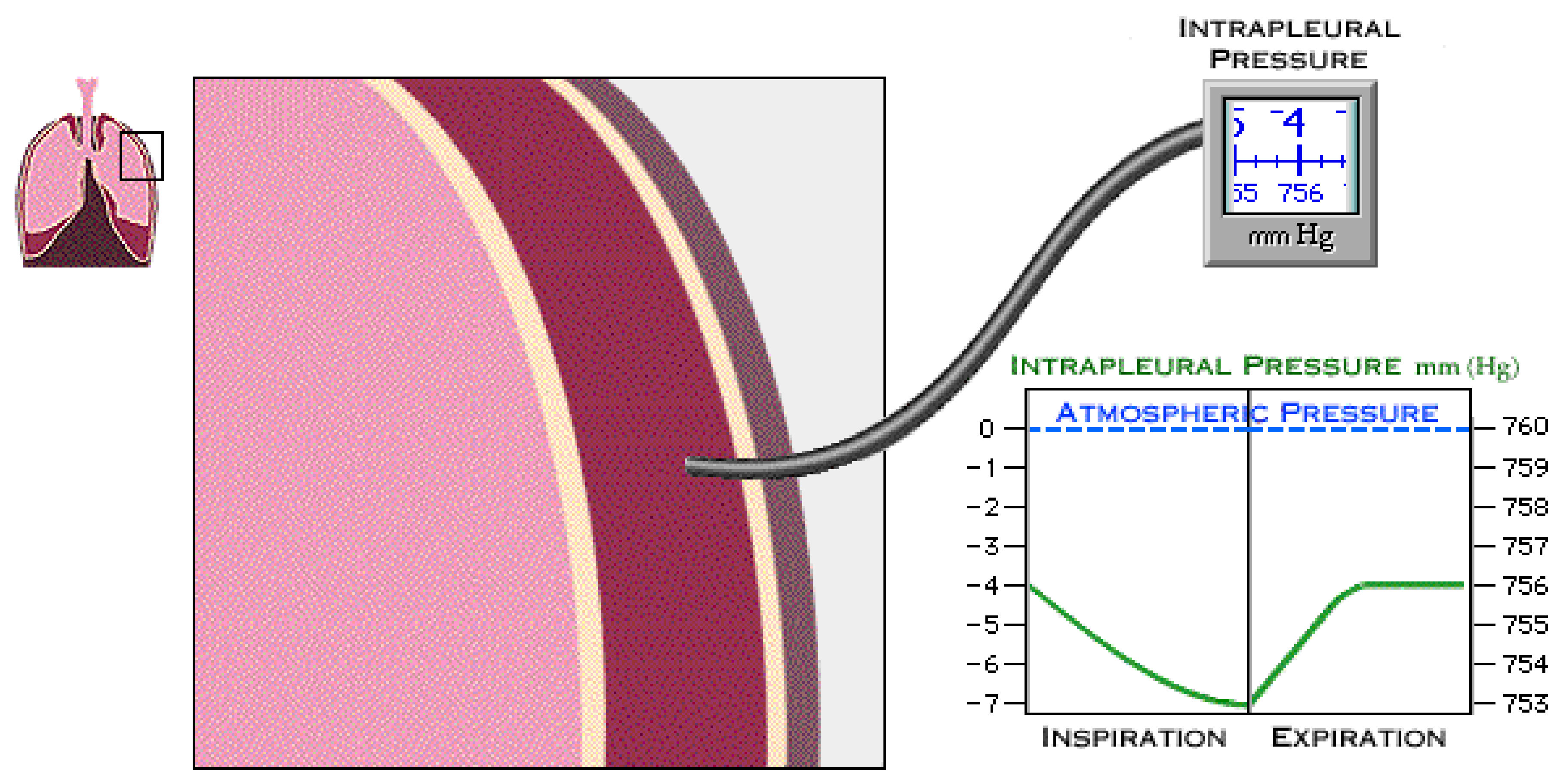
Intrapleural pressure

- Pleural cavity
  - Pleural cavity is the closed space between parietal pleura & lungs covered with visceral pleura



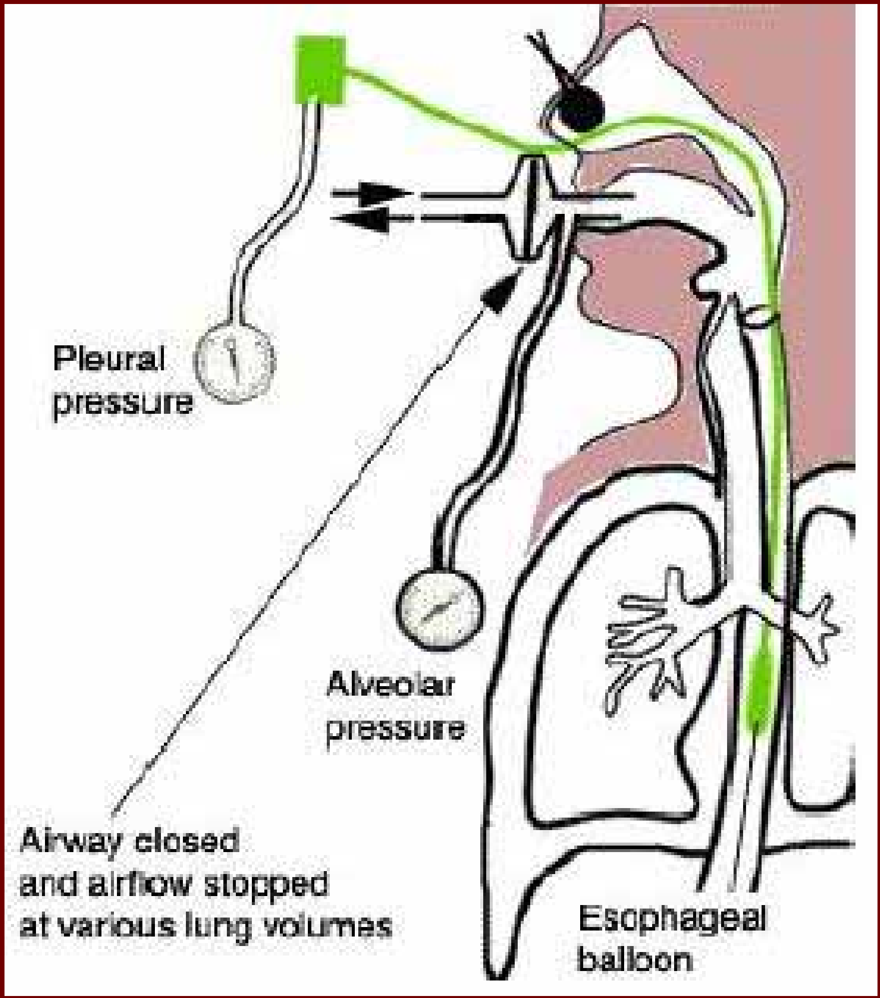
Measurement of intrapleural pressure

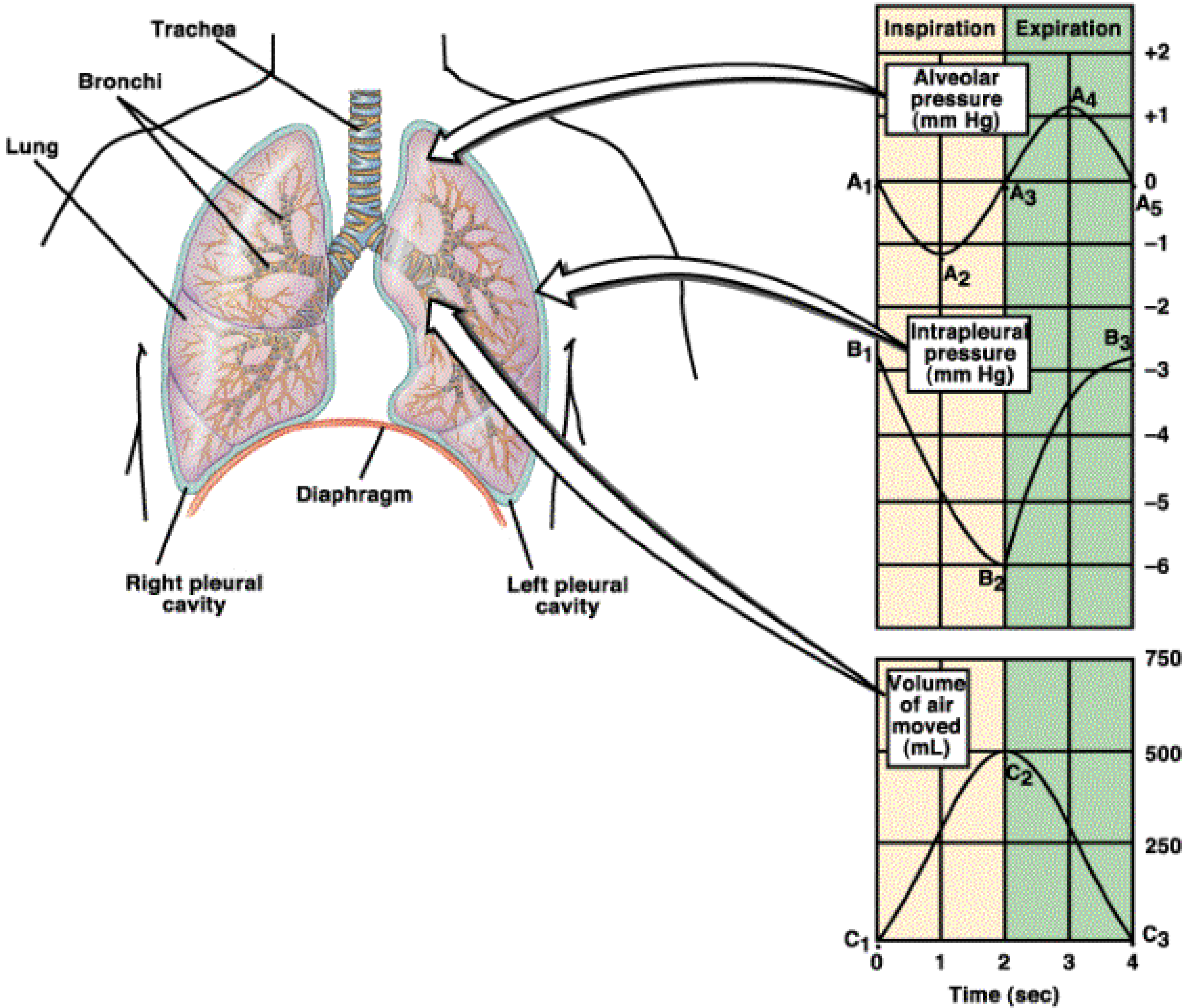
- Direct method



Measurement of intrapleural pressure

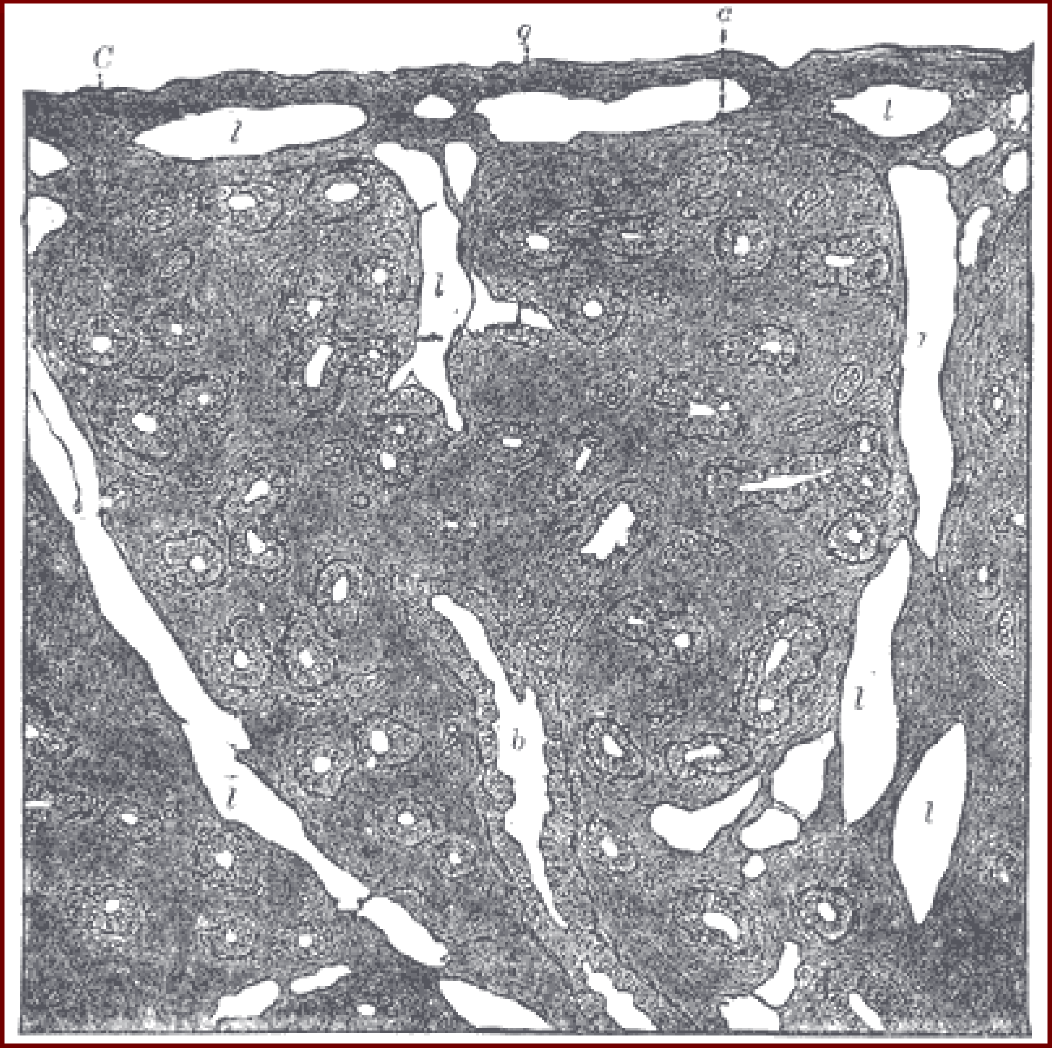
- Indirect method:
  - Measurement of the pressure inside the esophagus




Trachea
Bronchi
Lung
Diaphragm
Right pleural cavity
Left pleural cavity
Inspiration
Expiration
Alveolar pressure (mm Hg)
Intrapleural pressure (mm Hg)
Volume of air moved (mL)
A1
A2
A3
A4
A5
B1
B2
B3
C1
C2
C3
+2
+1
0
−1
−2
−3
−4
−5
−6
750
500
250
0
1
2
3
4
Time (sec)

Formation of intrapleural pressure

- Fetus lung

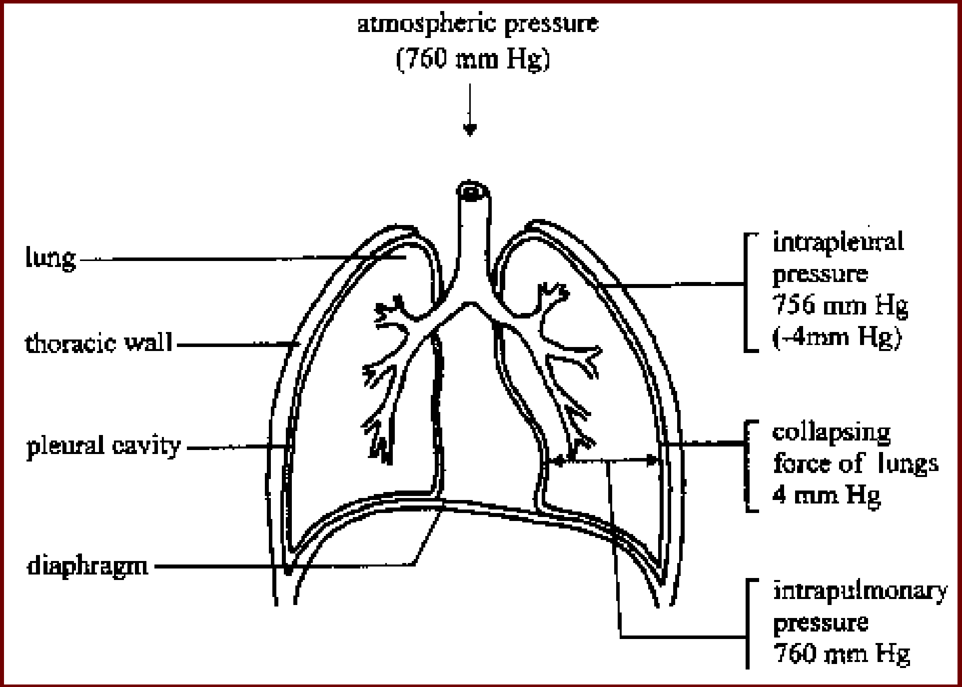


Formation of intrapleural pressure

- Air in lungs after delivery
- Because the elastic recoil causes the lungs to try to collapse, a negative force is always needed to the outside of the lungs to keep the lungs expanded. This force is provided by negative pressure in the normal pleural space.

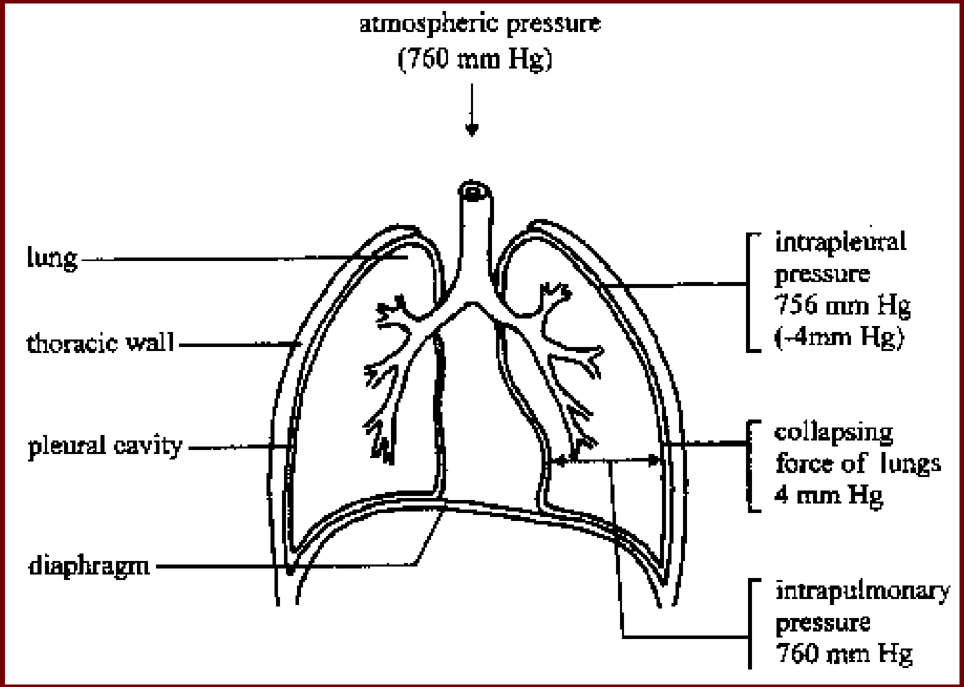
Intrapleural pressure

- Pressures involved
  - Intrapulmonary pressure
    =Atmospheric (760 mmHg) pressure
  - Elastic recoil
  - Intrapleural pressure



Intrapleural pressure

- Intrapleural pressure = Intrapulmonary pressure – the recoil pressure of the lung
- Intrapleural pressure = – the recoil pressure of the lung

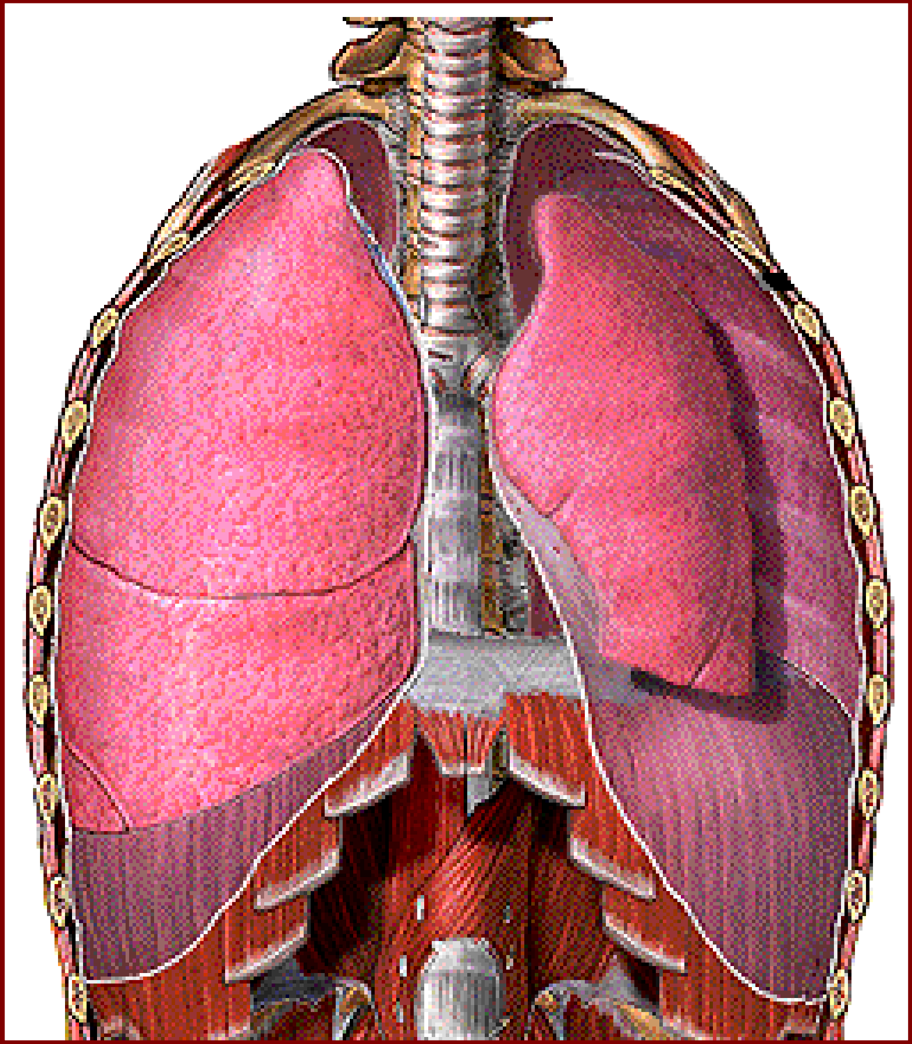


Physiological significance of intrapleural negative pressure

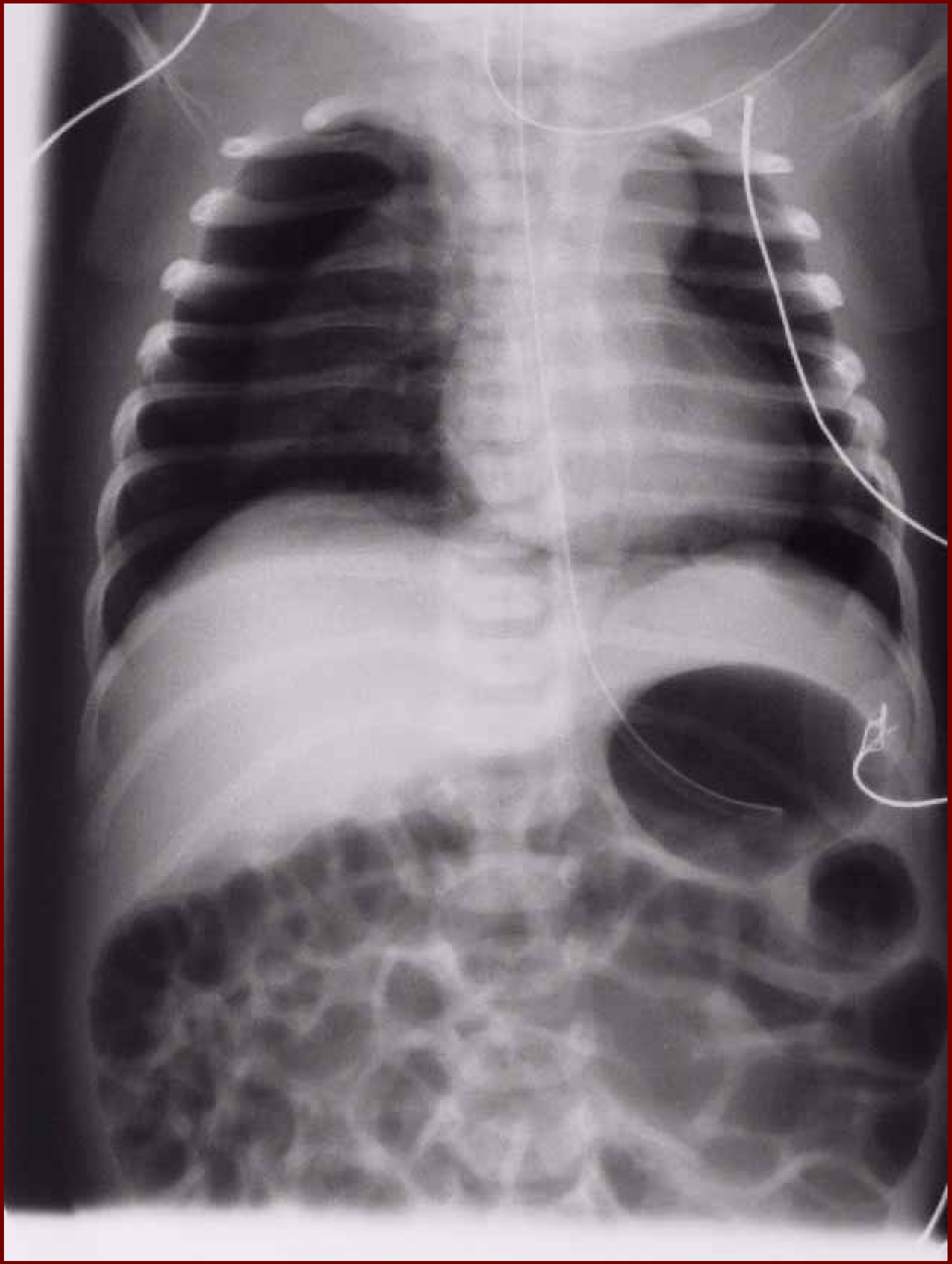
- Allow expansion of the lungs
- Facilitate the venous & lymphatic return

Pneumothorax

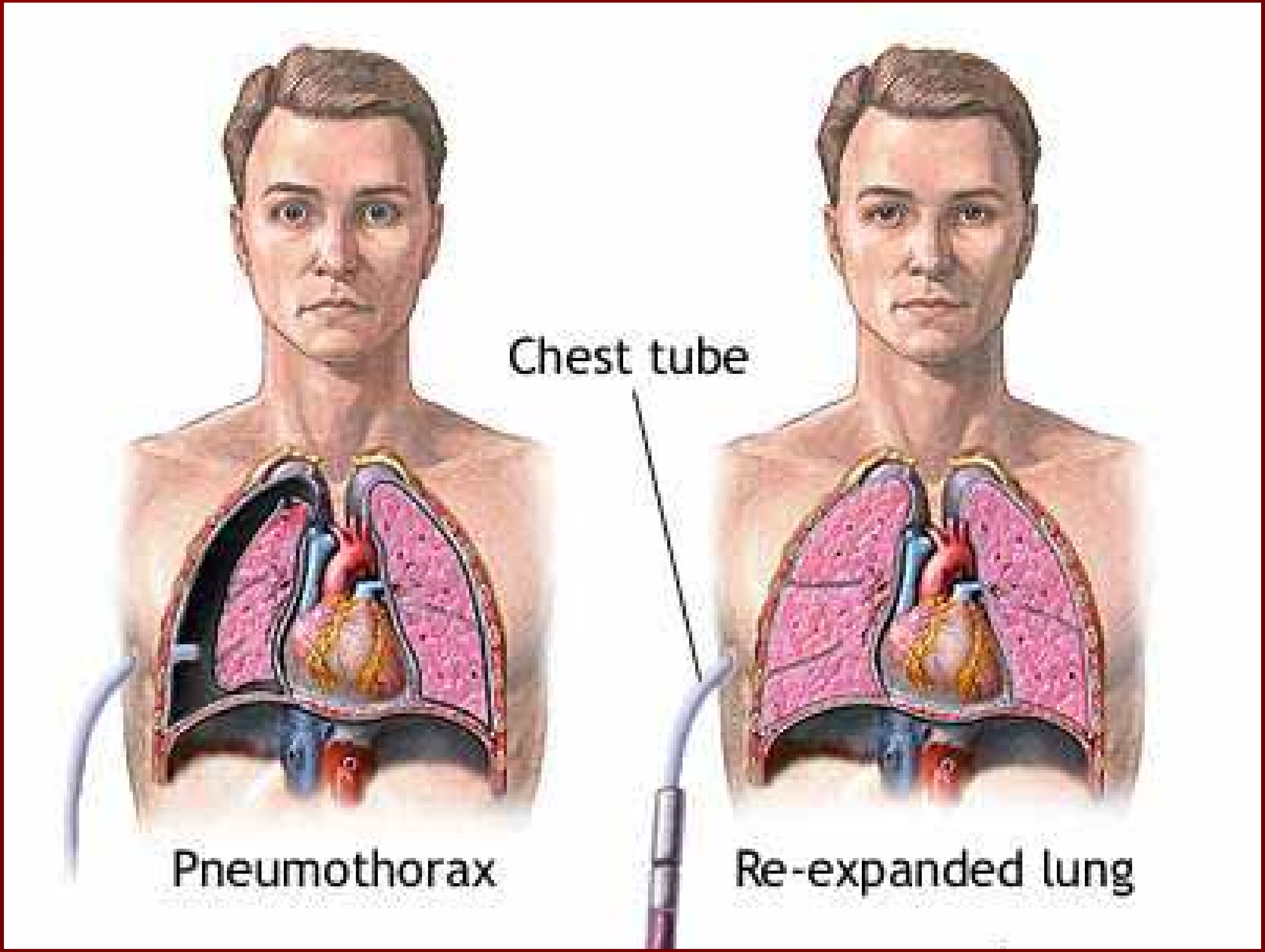
- Air escapes from the lungs or leaks through the chest wall and enters the pleural cavity---Pneumothorax



Lateral

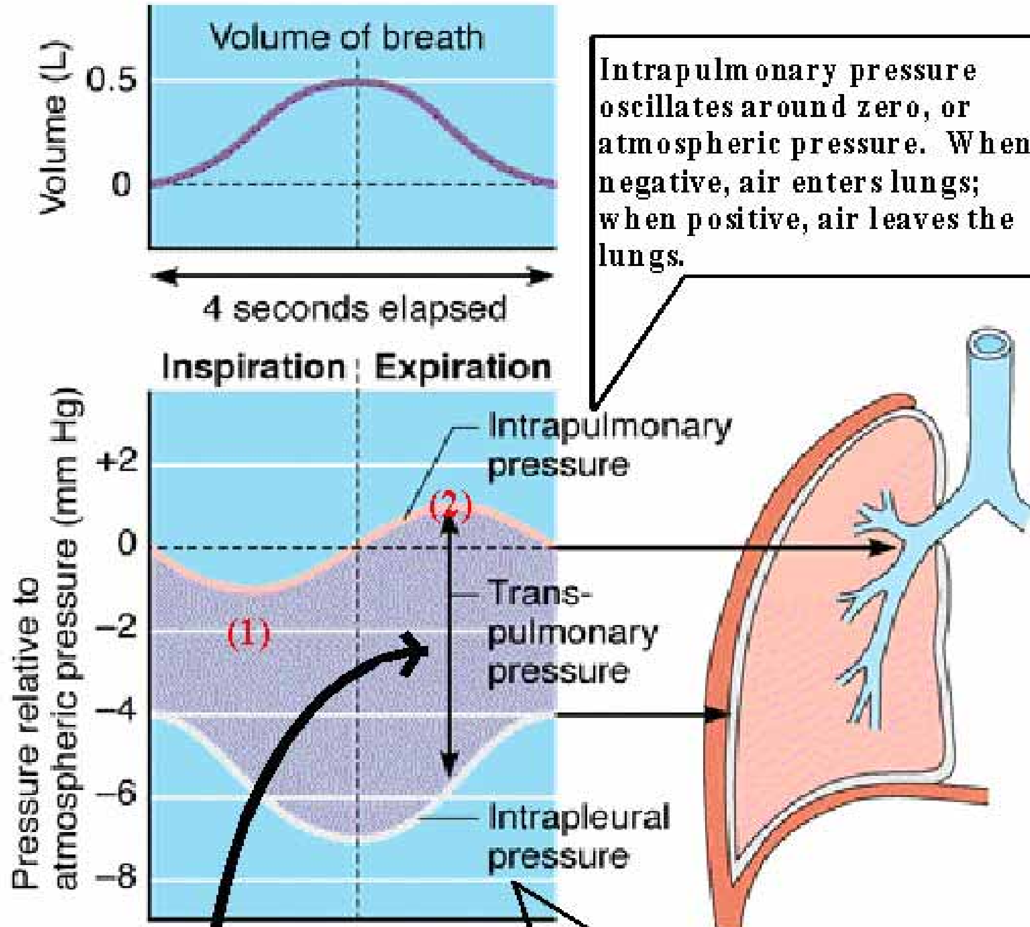


Bilateral



the goal of therapy for spontaneous pneumothorax is to eliminate air from the pleural space and to terminate an air leak

Pressure Changes During Respiration



Intrapulmonary pressure oscillates around zero, or atmospheric pressure. When negative, air enters lungs; when positive, air leaves the lungs.

Always a negative pressure compared to the atmosphere. This exerts an expanding effect on the lungs called compliance.

The pulling pressure of the pleurae.

(1) The lowest intrapulmonary pressure is reached halfway into inspiration. After that air entering the lungs raises the pressure.
(2) The highest intrapulmonary pressure is reached halfway into expiration. After that air leaving the lungs reduces the pressure.

Resistances to Ventilation

- Elastic resistance: The ability of an elastic structure to resist stretching or distortion. 70%

- Non-elastic resistance: 30%

Compliance of the lungs

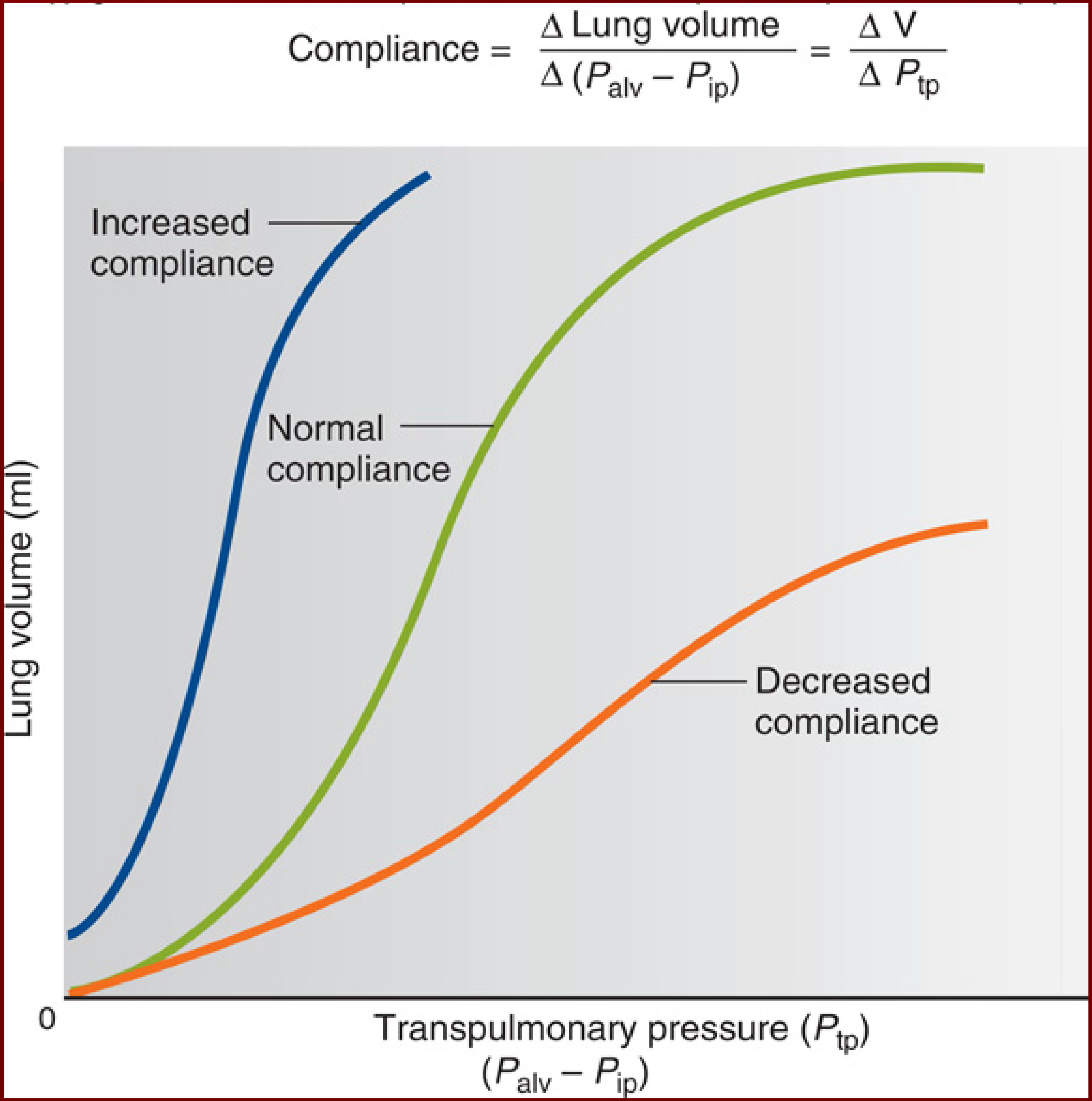
- Compliance: the expand ability of elastic tissues when acted on by foreign forces or the extent to which the lungs expand for each unit increase in pressure.
- $C = \Delta V / \Delta P$ (L/cmH_2O)
- Elastic Resistance (R)

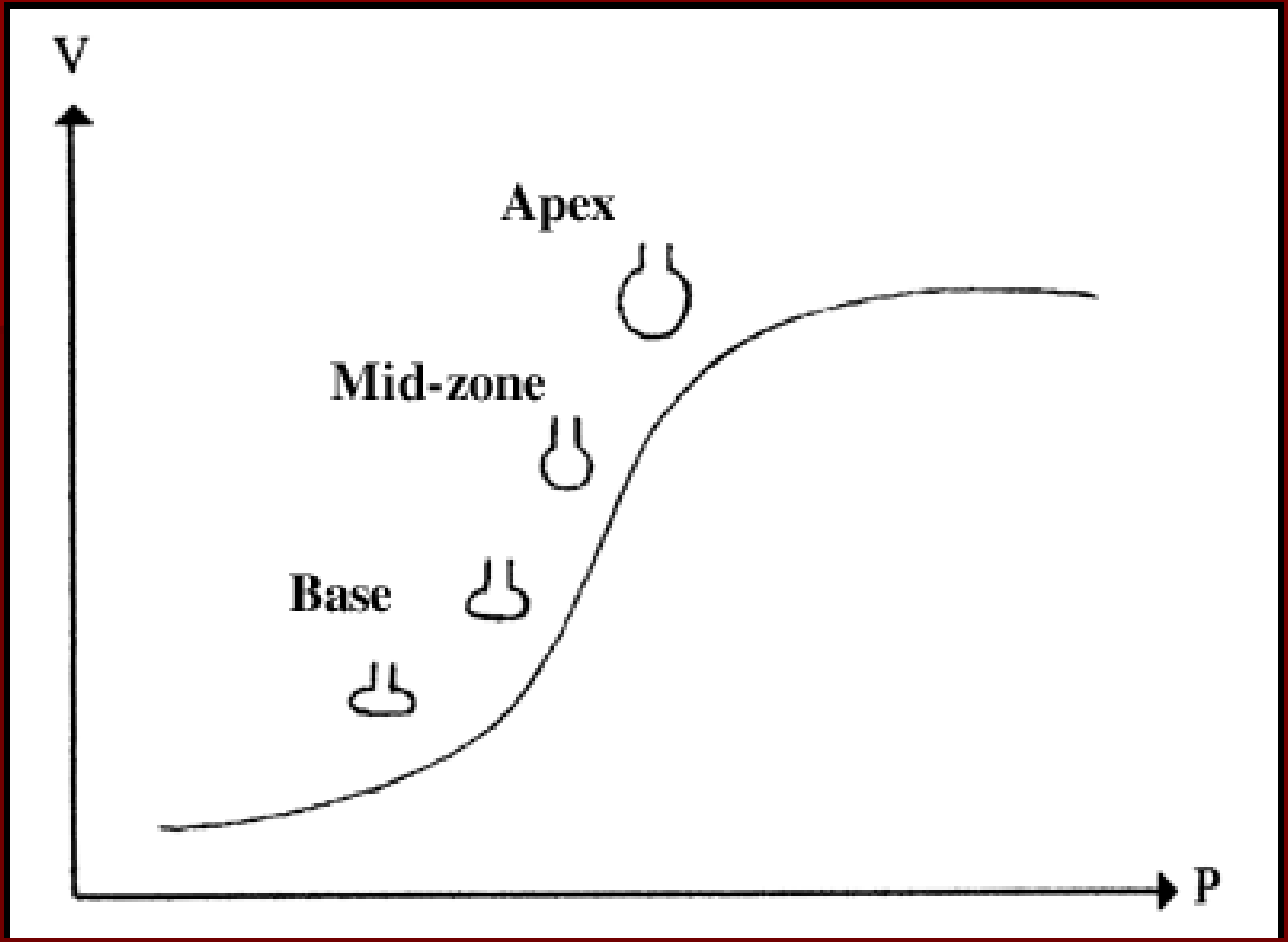
  $C = 1/R$

Lung compliance is a measure of the lung's "stretchability."

When compliance is abnormally high, the lungs might fail to hold themselves open, and are prone to collapse.

When compliance is abnormally low, the work of breathing is increased.





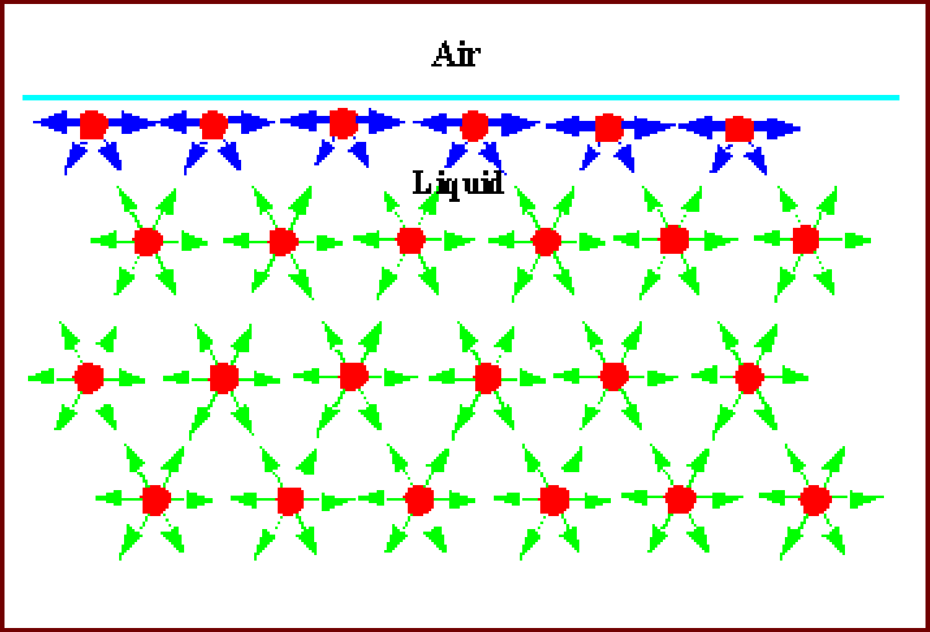
Compliance varies within the lung according to the degree of inflation. Poor compliance is seen at low volumes (because of difficulty with initial lung inflation) and at high volumes (because of the limit of chest wall expansion), with best compliance in the mid-expansion range.

The sources of elastic resistance of the lung

- Elastic resistance of the lungs
  - 1/3 Elastic forces of the lung tissue itself
  - 2/3 Elastic forces caused by surface tension of the fluid that lines the inside walls of the alveoli

Surface tension

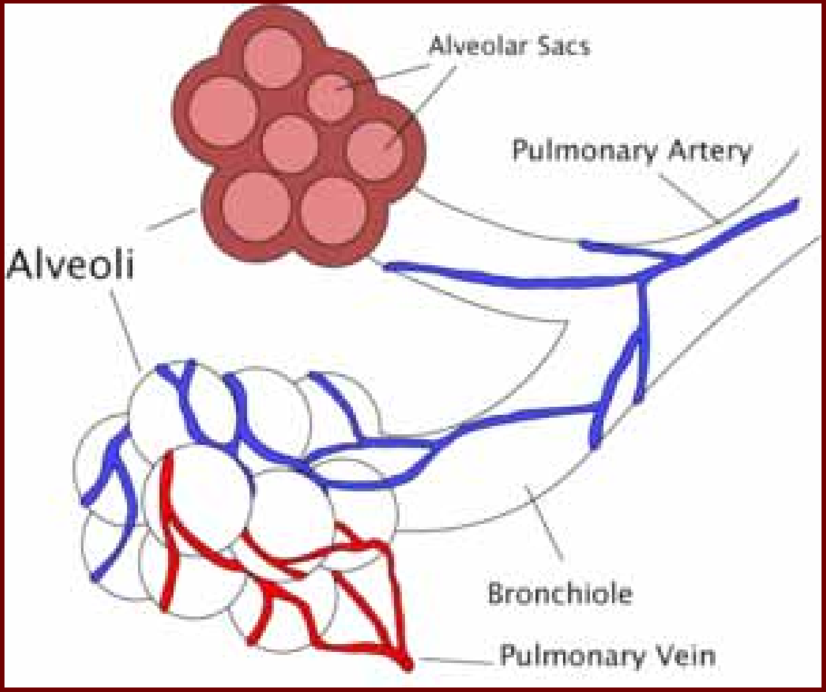
- Tension of a liquid's surface. Due to the forces of attraction between molecules



Surface tension

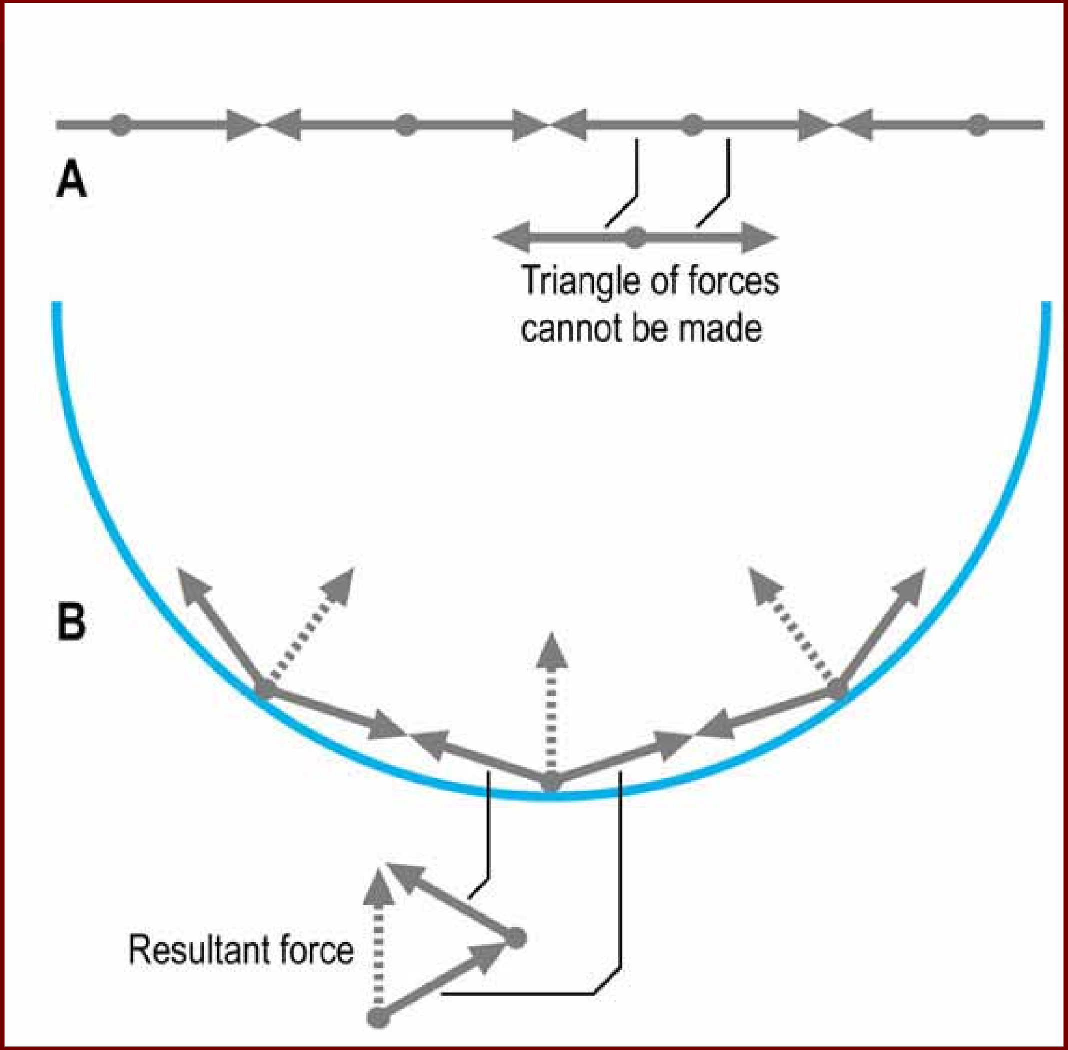
- The surface tension at the air-water interfaces within the alveoli.

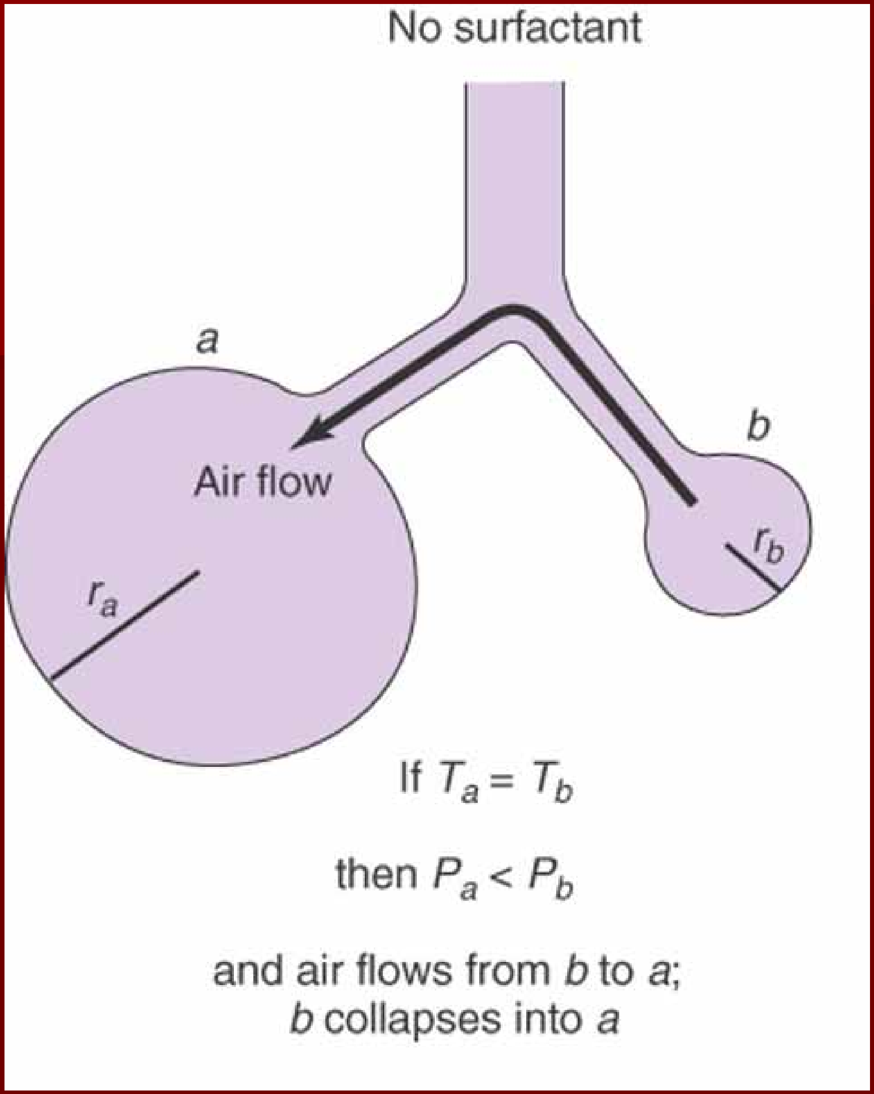
- At an air-water interface, the attractive forces between the water molecules (surface tension) make the alveoli like stretched balloons that constantly try to shrink and resist further stretching.



Pierre Simon Laplace
(1749 - 1827)

Laplace's law: P=2T/r





Laplace's law: $P=2T/r$

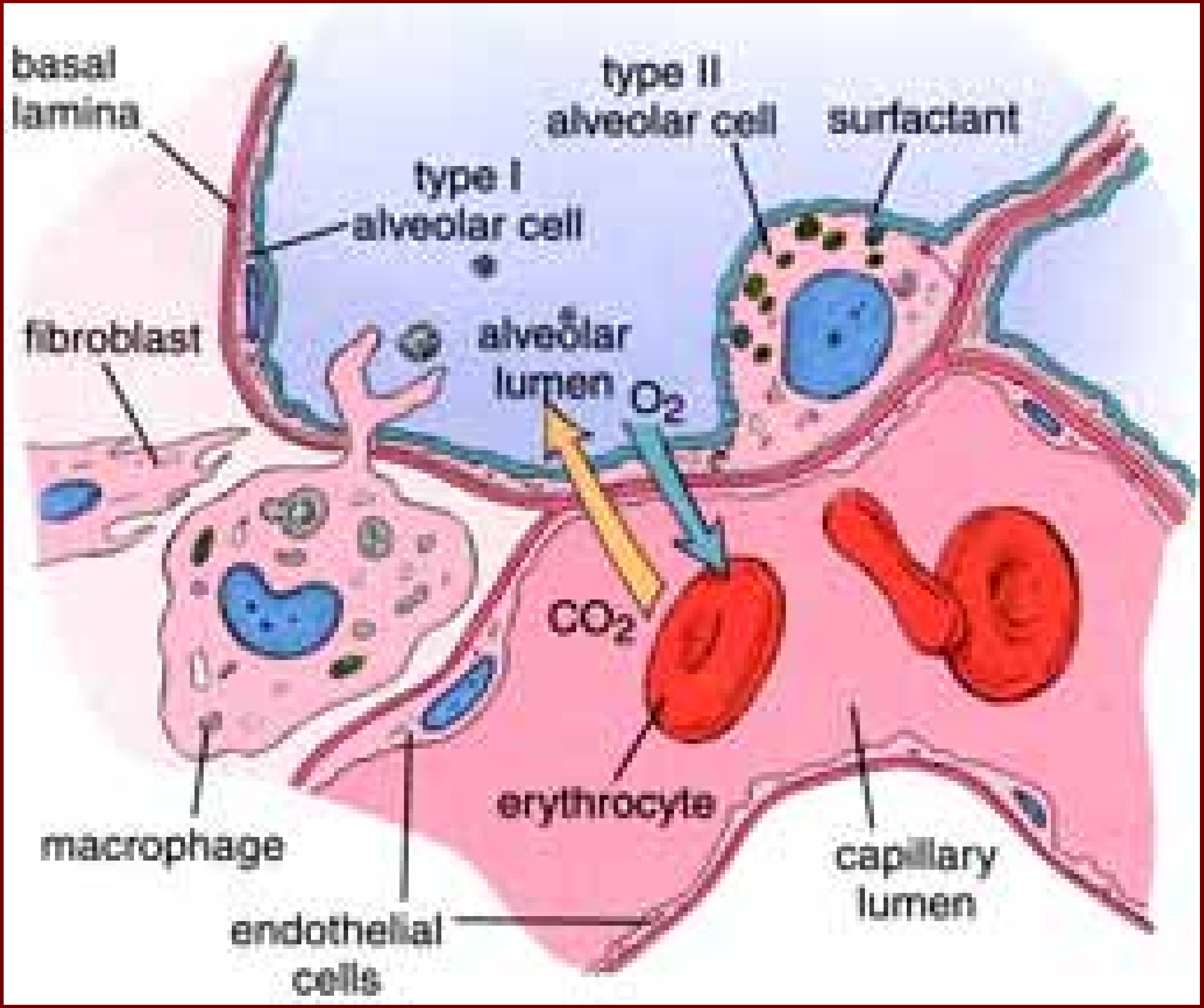
In the absence of surfactant, the attraction between water molecules can cause alveolar collapse.

Alveolar surfactant

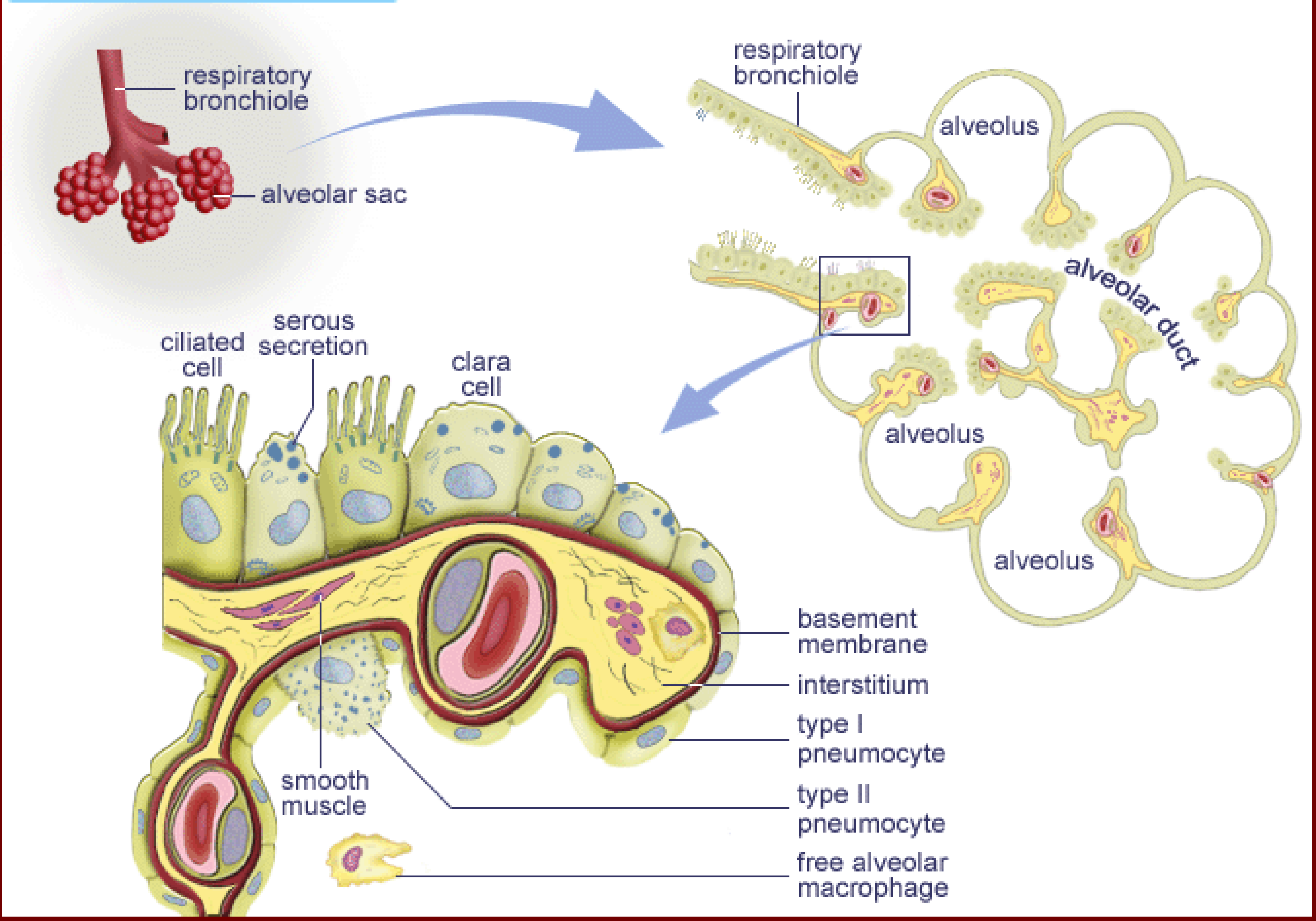
- Secreted by type II alveolar epithelial cells

- Surfactant is a complex mixture of
  - Several phospholipids (dipalmitoyl phosphatidyl choline, DPPC)
  - Surfactant-associated proteins
  - Ions (calcium)

Type II alveolar epithelial cells



Respiratory Bronchiole



Alveolar surfactant

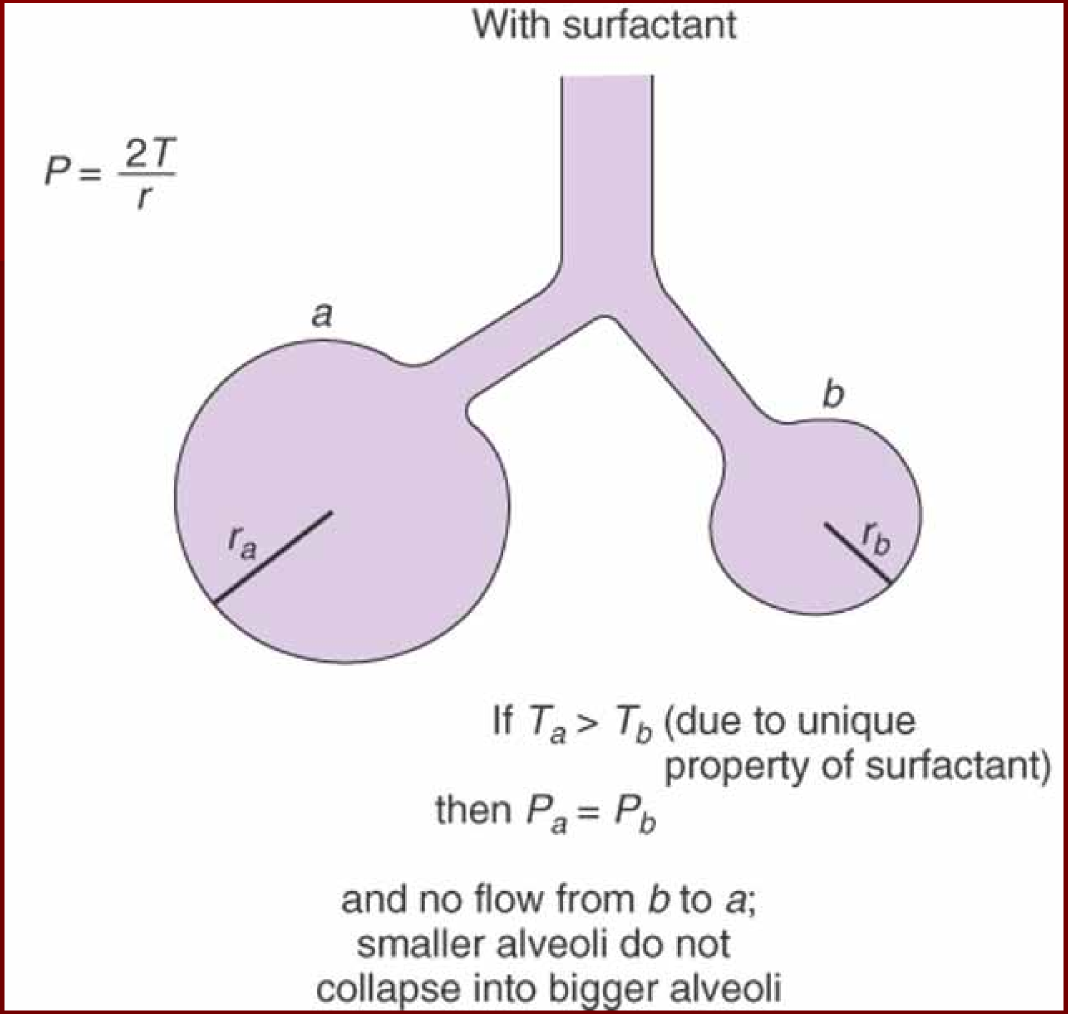
- Physiological effect of surfactant

  Reduces surface tension

  – Maintains the stability of the alveoli in different size

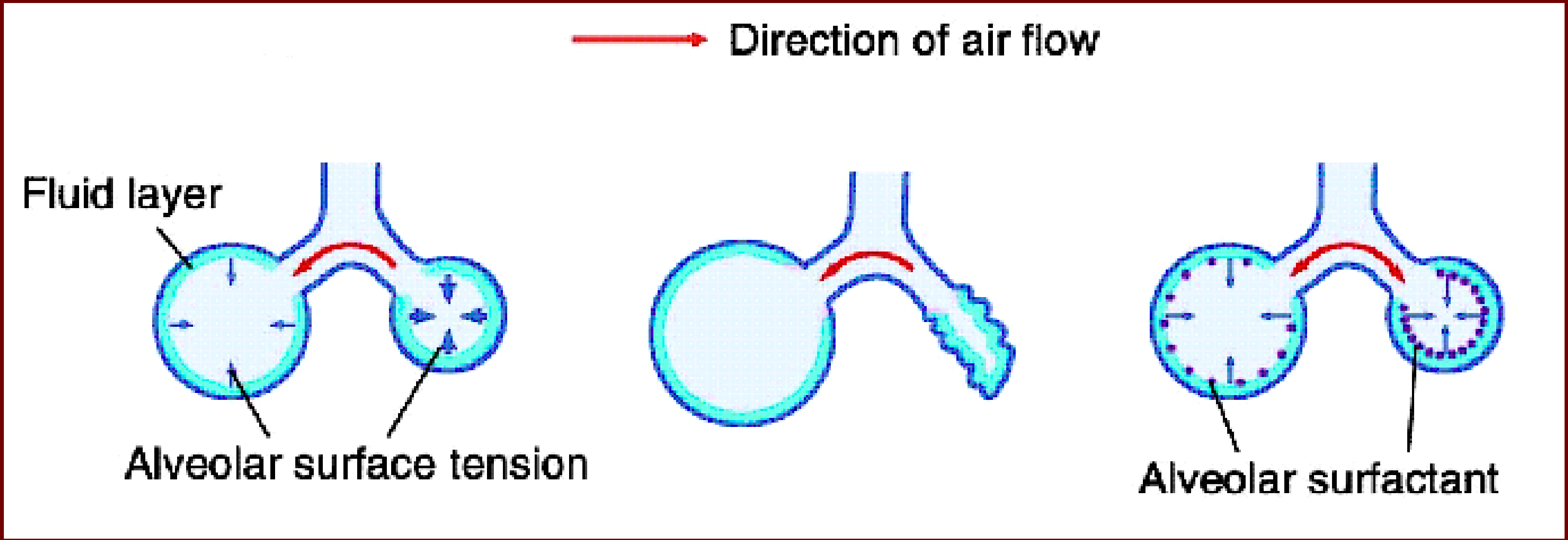
  – Keeps the dryness of the alveoli

  – Eases expansion of lung (increases compliance)



By reducing the surface tension of water, surfactant helps prevent alveolar collapse.

Laplace's law: P=2T/r



$$\begin{cases} T_a = T_b \\ ra > rb \\ Pa < Pb \end{cases}$$

$$\begin{cases} T_a > T_b \\ ra > rb \\ Pa = Pb \end{cases}$$

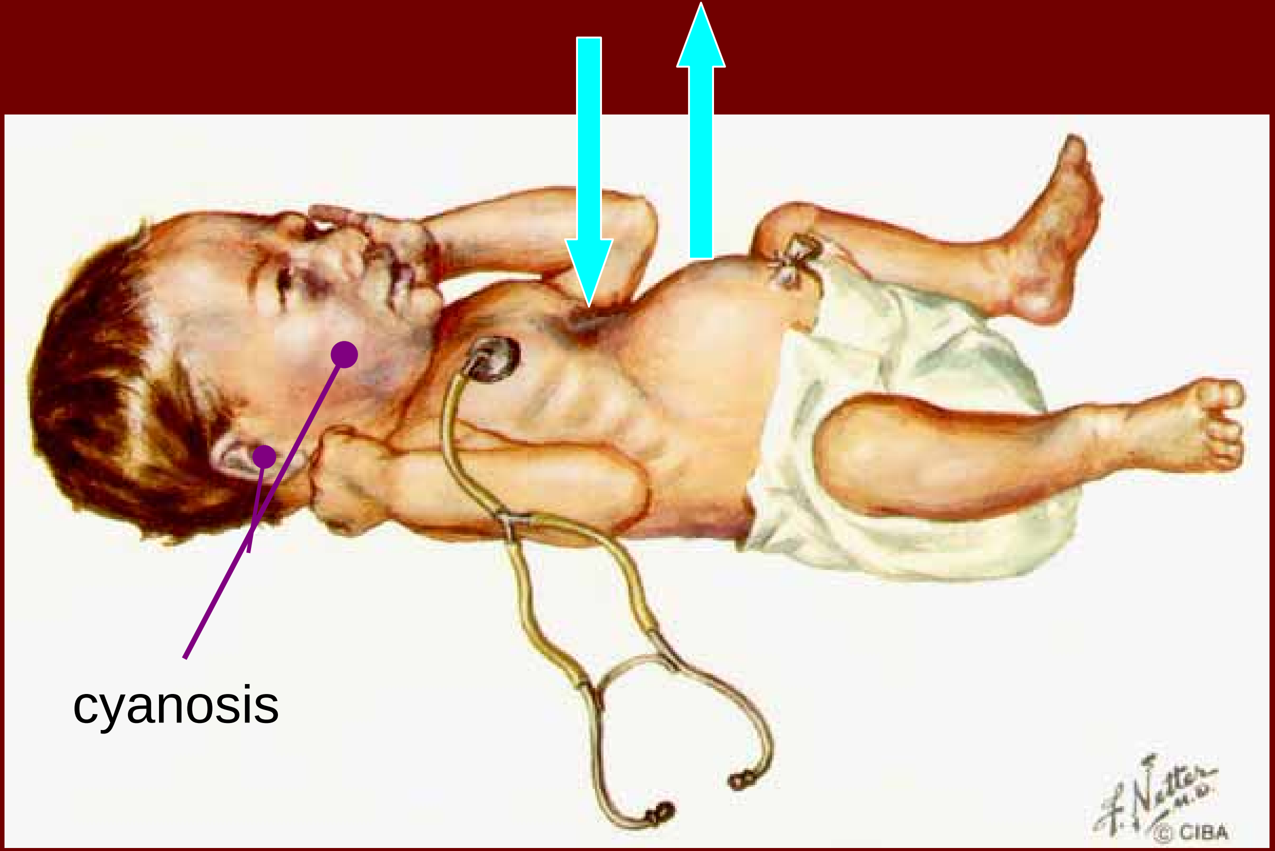
TABLE 13–4 *Some Important Facts About Pulmonary Surfactant*

1. Pulmonary surfactant is a mixture of phospholipids and protein.
2. It is secreted by type II alveolar cells.
3. It lowers the surface tension of the water layer at the alveolar surface, which increases lung compliance (i.e., makes the lungs easier to expand).
4. Its surface tension is lower in smaller alveoli thus stabilizing alveoli.
5. A deep breath increases its secretion (by stretching the type II cells). Its concentration decreases when breaths are small.
6. Production in the fetal lung occurs in late gestation.

Neonatal respiratory distress syndrome (NRDS):

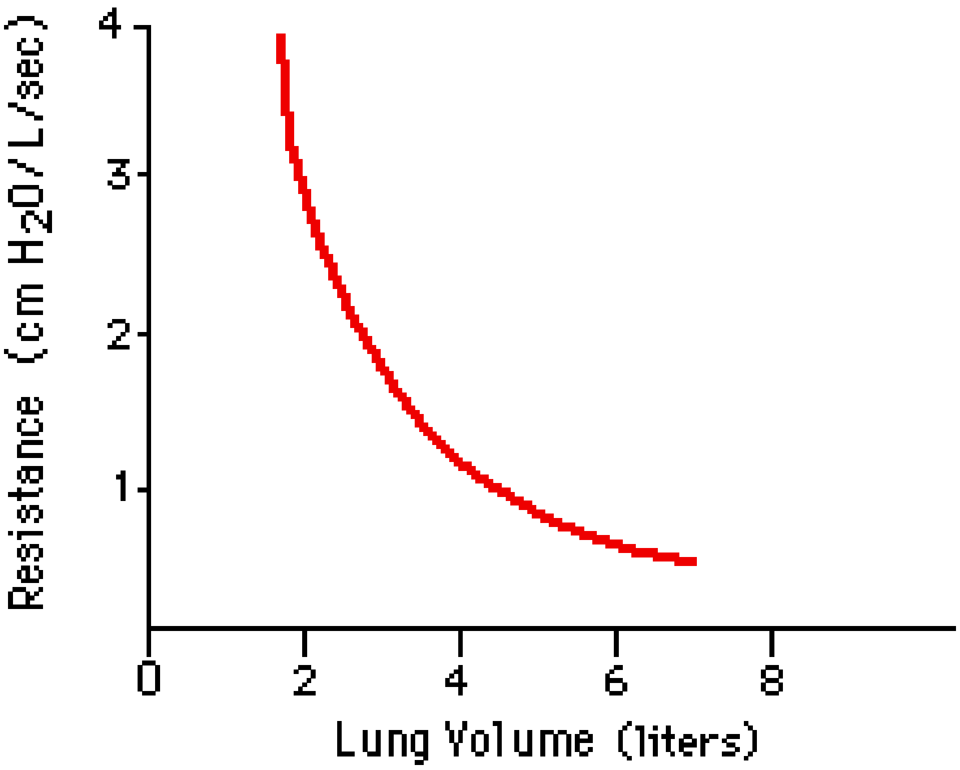
lack of surfactant

retraction of soft tissue on inspiration

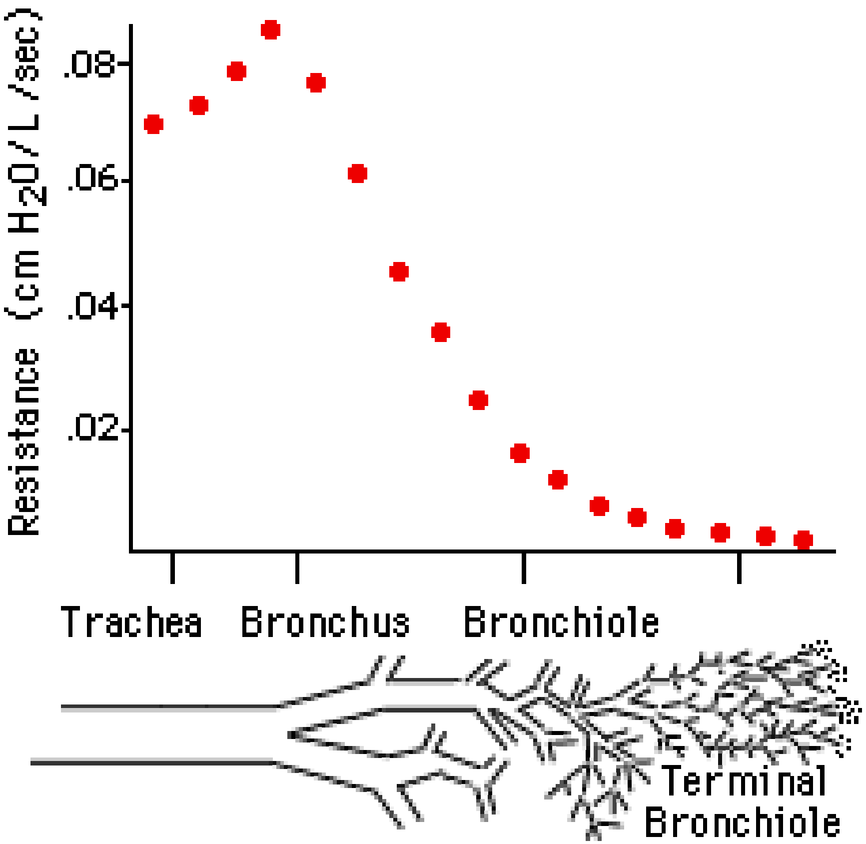


Non-elastic resistance

- Airway resistance: 80~90%
  - Is caused by friction among gas molecules and between gas molecules and the inner wall of airway.
  - $R \propto 1/r^4$
- Inertial resistance
- Viscous resistance: The effect of surface friction between a particle and a liquid when the particle moves through the liquid.



Resistance:Volume



Resistance:Generation

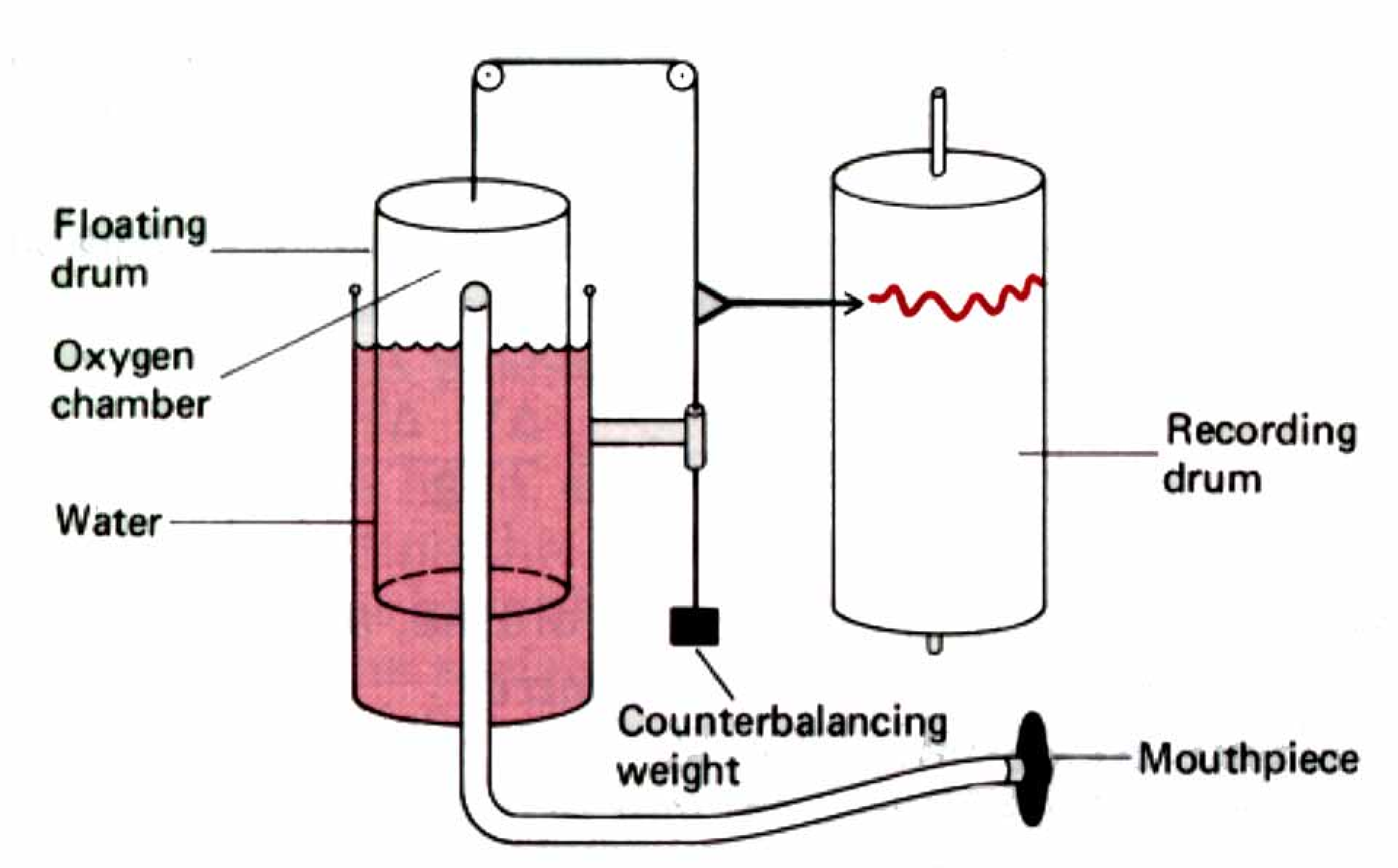
- Regulation of the respiratory smooth muscle by autonomic nervous system:
  - Vagus nerve: Ach → M receptor → Contraction
  - Sympathetic nerve: NE → β_2-receptor → Relaxation

- Regulation of the respiratory smooth muscle by endocrine or paracrine factors:
  - Histamine, Bradykinin → Contraction
  - NE, E, Isoproterenol → Relaxation

Pulmonary volumes and capacities

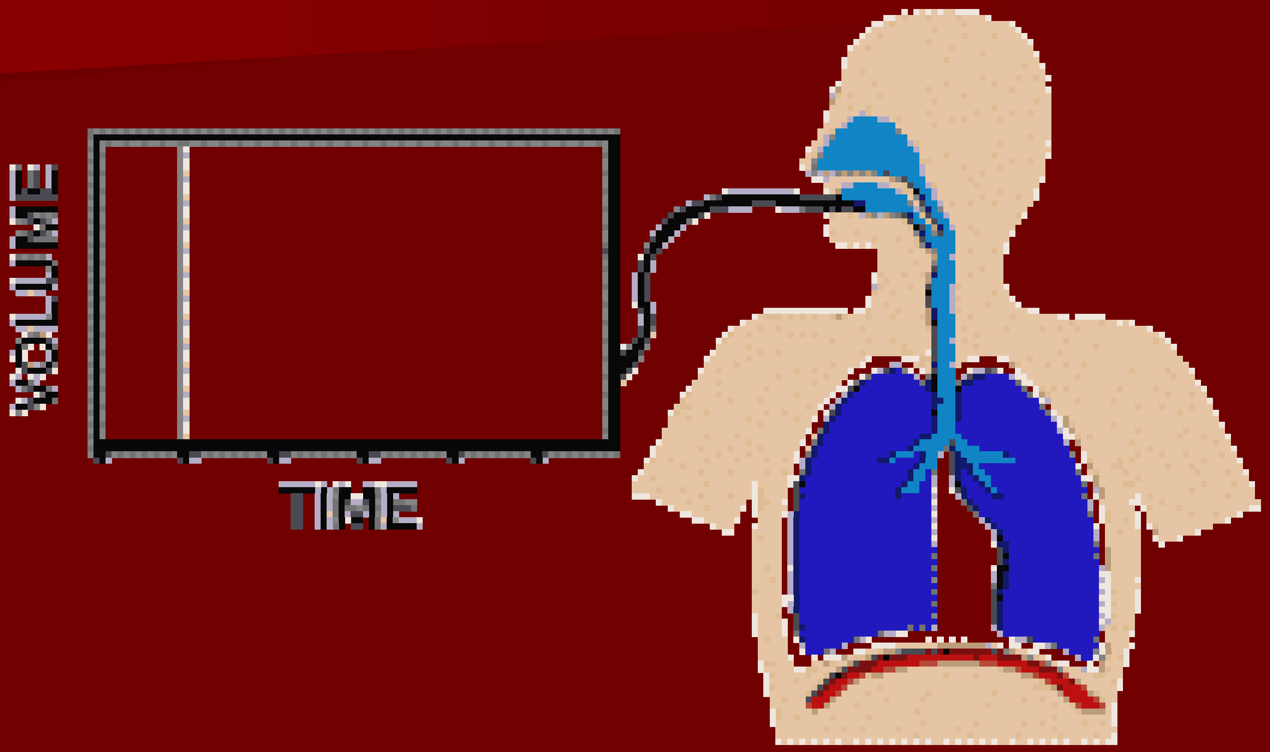
- Spirometer

a spirometer---a device used to measure lung health.



Blowing forcefully into the tube provides a quick, easy measure of FEV.

To learn your FEV, you will be asked to hold the tube of a spirometer in your mouth, inhale as much air as possible, then exhale forcefully into the spirometer.


VOLUME
TIME

Pulmonary volumes

- Tidal volume (TV)
  - Volume of air inspired or expired with each normal breath

    Normal value: 400~500 ml
- Inspiratory reserve volume (IRV)
  - Amount of air that can be inspired above and beyond TV

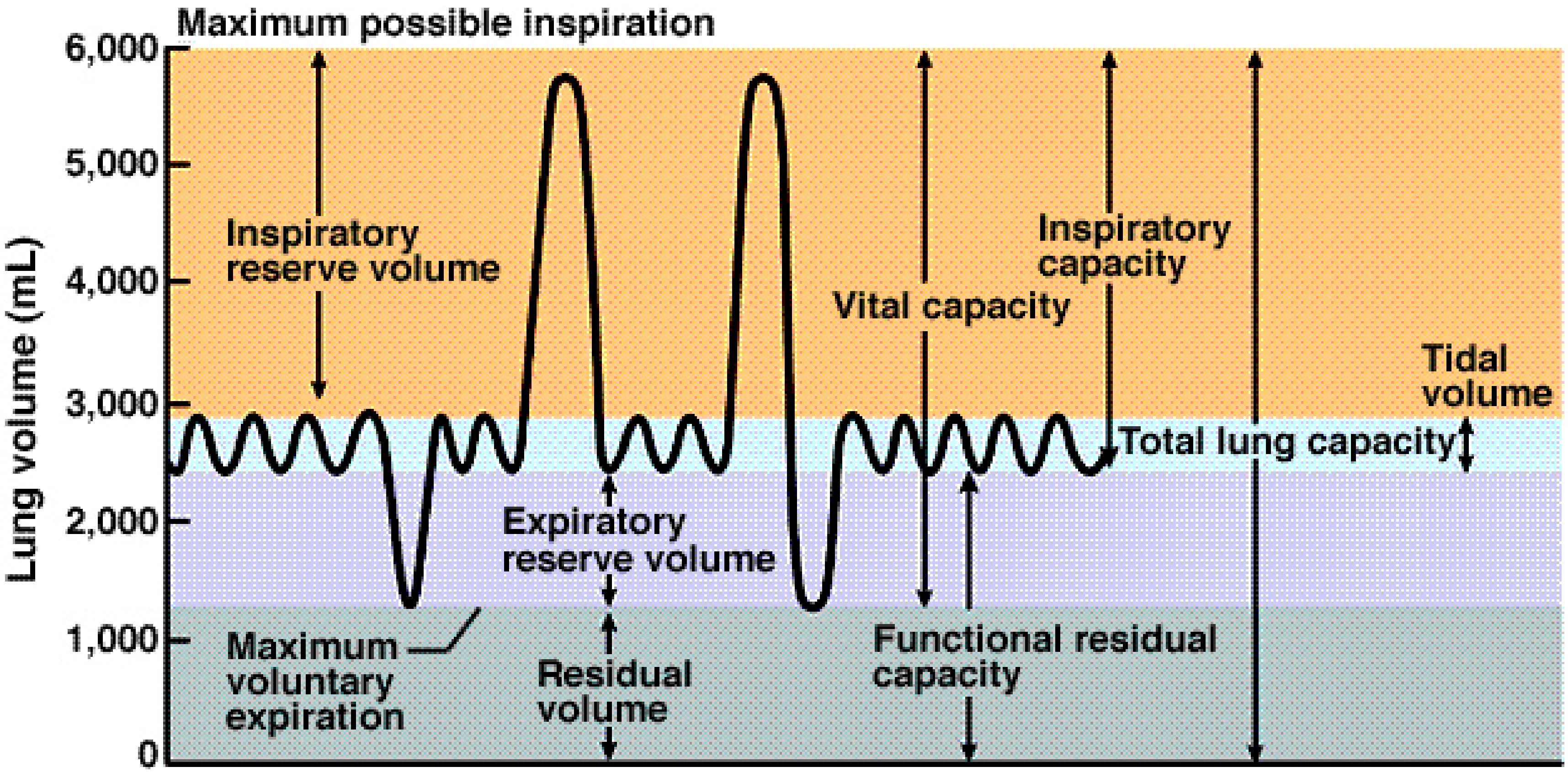
    Normal value: 1500~2000 ml

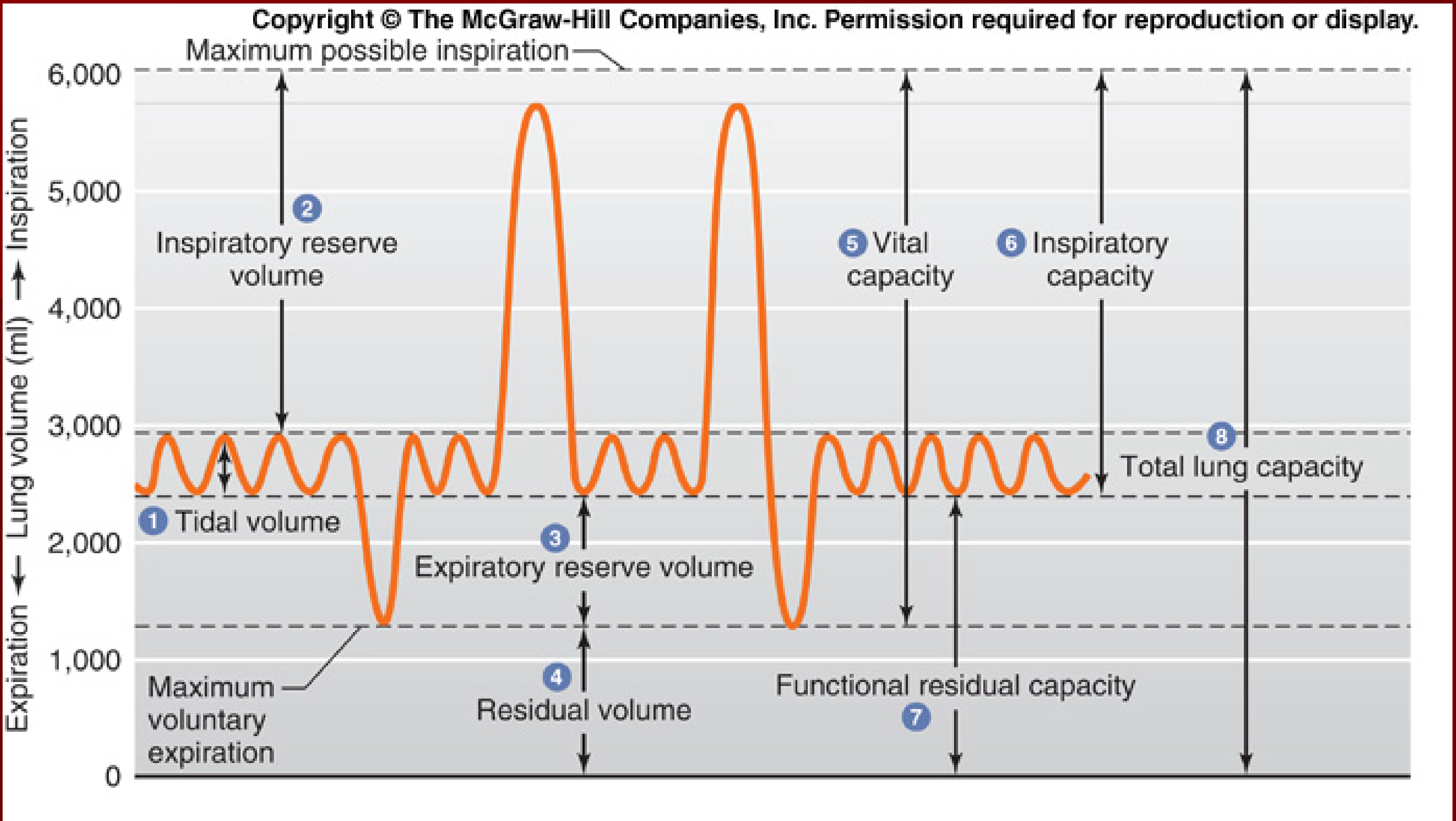
- Expiratory reserve volume (ERV)
  - Amount of air that can be expired after a tidal expiration

    Normal value: 900~1200 ml
- Residual volume (RV)
  - the volume of air remaining in the lungs at the end of a maximal exhalation

    Normal value: M 1500 ml, F 1000 ml

Lung Volumes and Capacities





The **tidal volume** is the amount of air moved in (or out) of the airways in a single breathing cycle. **Inspiratory and expiratory reserve volumes**, are, respectively, the additional volume that can inspired or expired; all three quantities sum to the lung's **vital capacity**. The **residual volume** is the amount of air that must remain in the lungs to prevent alveolar collapse.

Pulmonary capacities

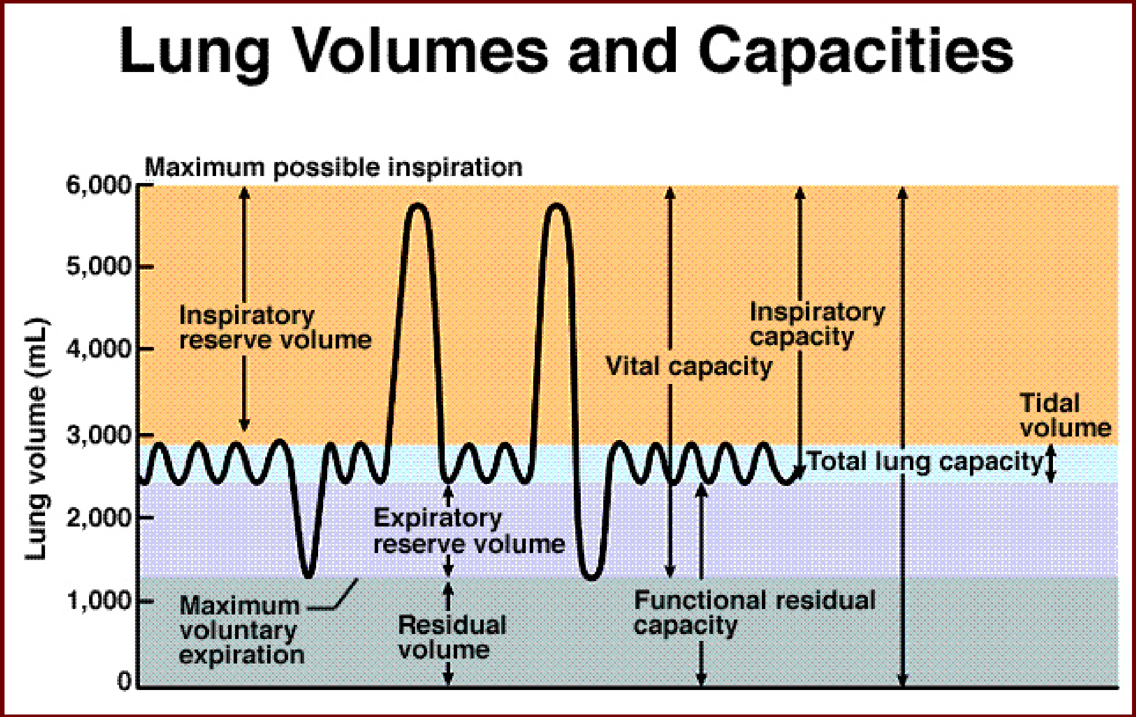
- Inspiratory capacity

  =IRV+TV

- Functional residual capacity
  - Is the volume of air that still remains in the lungs after expiration of a resting tidal volume.
  - FRC=ERV+RV
- Vital volume (Vital capacity, VC)
  - Is the maximal of air that a person can expire after a maximal inspiration
  - VC=TV+IRV+ERV
  - Normal value: M 3500 ml, F 2500 ml

Pulmonary capacities

- Total lung capacity
  - The maximal volume of air the lungs can accommodate
  - =VC+RV



Respiratory Volumes and Capacities for an Average Young Adult Male		
Measurement	Typical Value	Definition
Respiratory Volumes		
1 Tidal volume (TV)	500 ml	Amount of air inhaled or exhaled in one breath during relaxed, quiet breathing
2 Inspiratory reserve volume (IRV)	3,000 ml	Amount of air in excess of tidal inspiration that can be inhaled with maximum effort
3 Expiratory reserve volume (ERV)	1,200 ml	Amount of air in excess of tidal expiration that can be exhaled with maximum effort
4 Residual volume (RV)	1,200 ml	Amount of air remaining in the lungs after maximum expiration; keeps alveoli inflated between breaths and mixes with fresh air on next inspiration
Respiratory Capacities		
5 Vital capacity (VC)	4,700 ml	Amount of air that can be exhaled with maximum effort after maximum inspiration (ERV + TV + IRV); used to assess strength of thoracic muscles as well as pulmonary function
6 Inspiratory capacity (IC)	3,500 ml	Maximum amount of air that can be inhaled after a normal tidal expiration (TV + IRV)
7 Functional residual capacity (FRC)	2,400 ml	Amount of air remaining in the lungs after a normal tidal expiration (RV + ERV)
8 Total lung capacity (TLC)	5,900 ml	Maximum amount of air the lungs can contain (RV + VC)

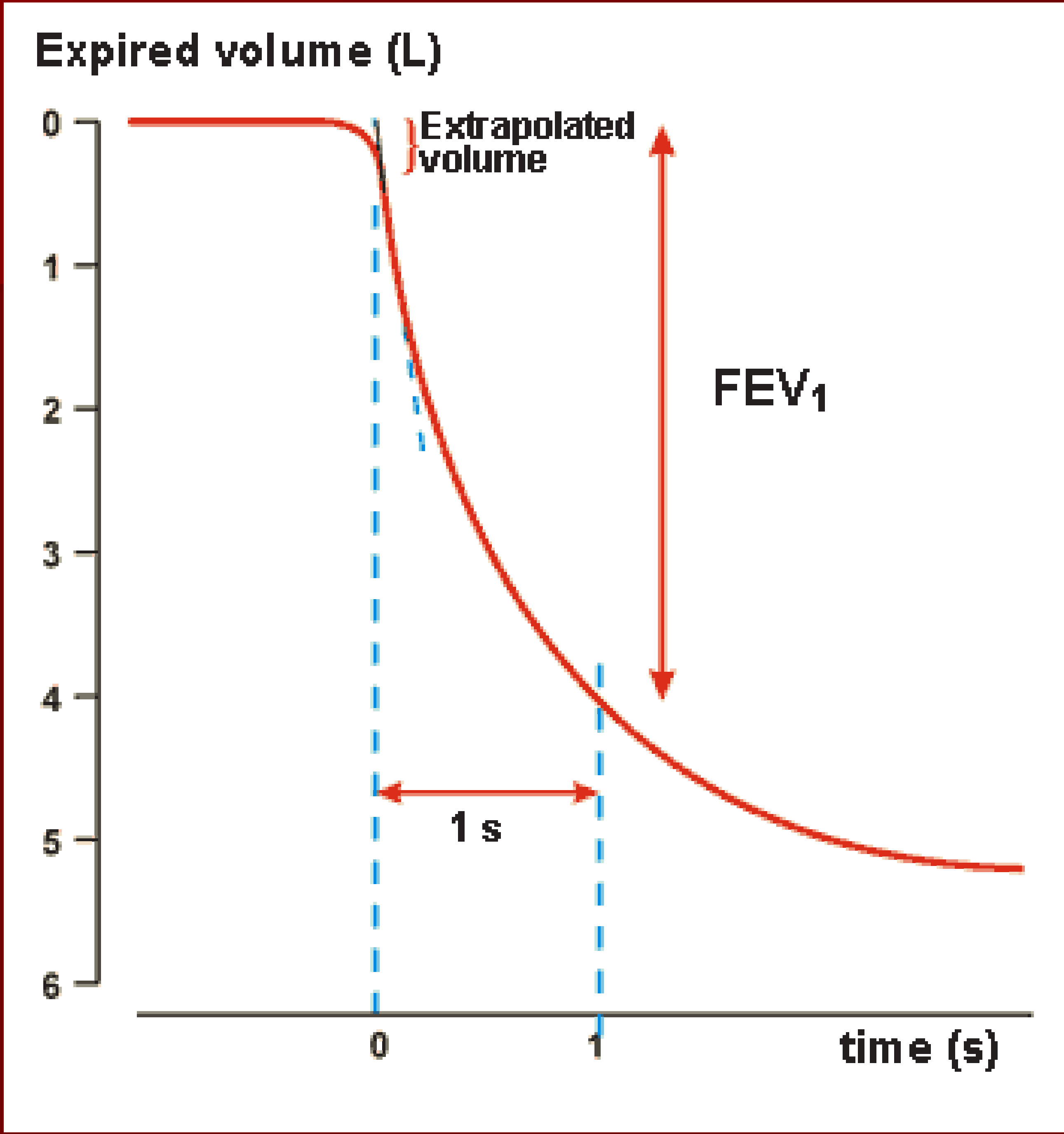
Pulmonary capacities

- Forced expiratory volume (**FEV**, timed vital volume)
  - The maximal volume of air that can be exhaled as fast as possible from the lungs following a maximal inspiration
  - Normal value:

    1st sec. (FEV1) -- 83%

    2nd sec. (FEV2) -- 96%

    3rd sec. (FEV3) -- 99%



Expired volume (L)
0
1
2
3
4
5
6
Extrapolated volume
FEV1
1 s
0
1
time (s)

Pulmonary ventilation

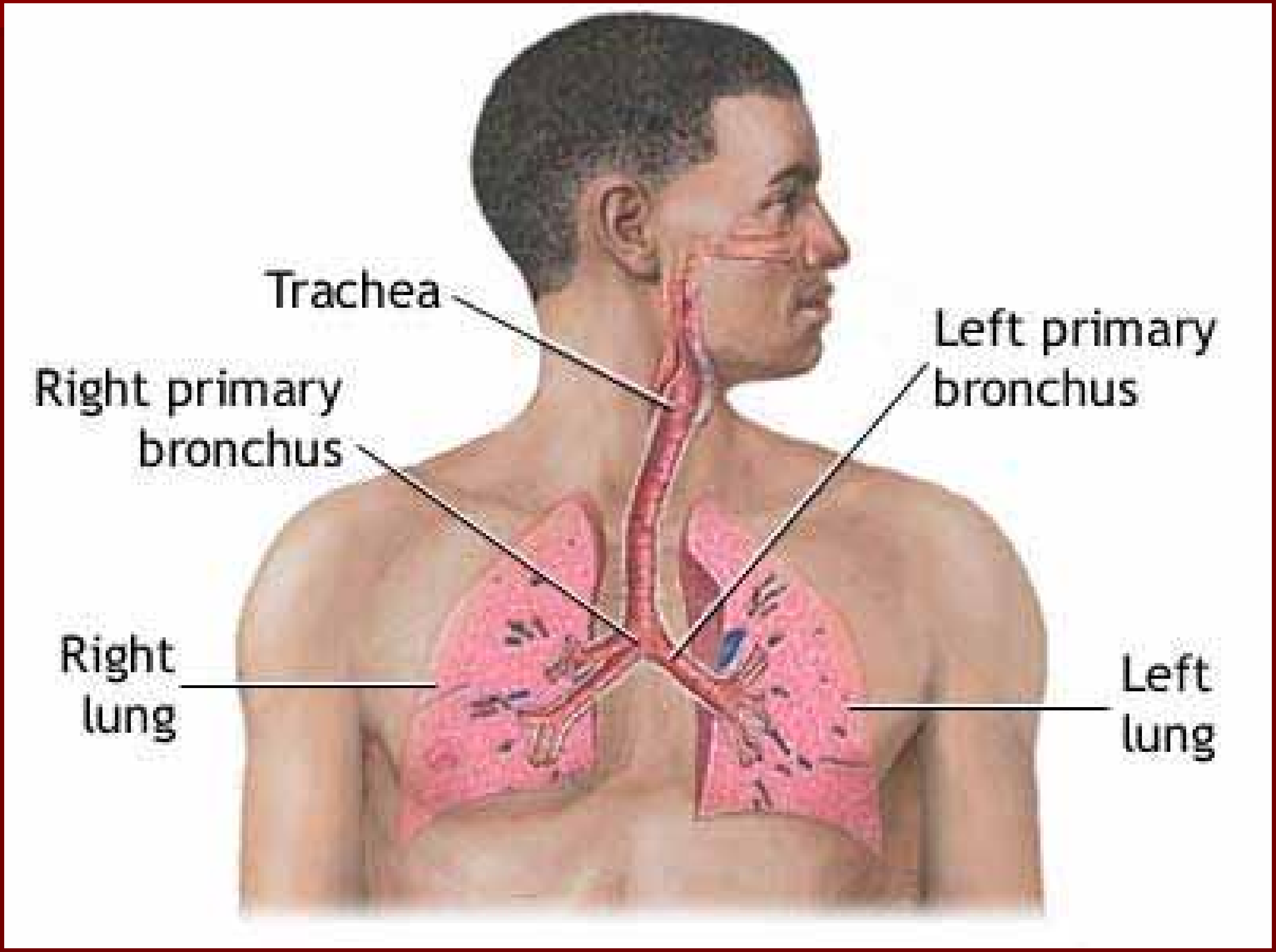
- Pulmonary ventilation (V_E)
  - The total amount of air inspired (or expired) during one minute
  - V_E = TV x breaths/min = 500 X12 = 6000 ml

Pulmonary ventilation

- Alveolar ventilation (V_A)
  - The amount of inspired air that is available for gas exchange each minute
  - V_A = (TV - dead space) x breaths/min

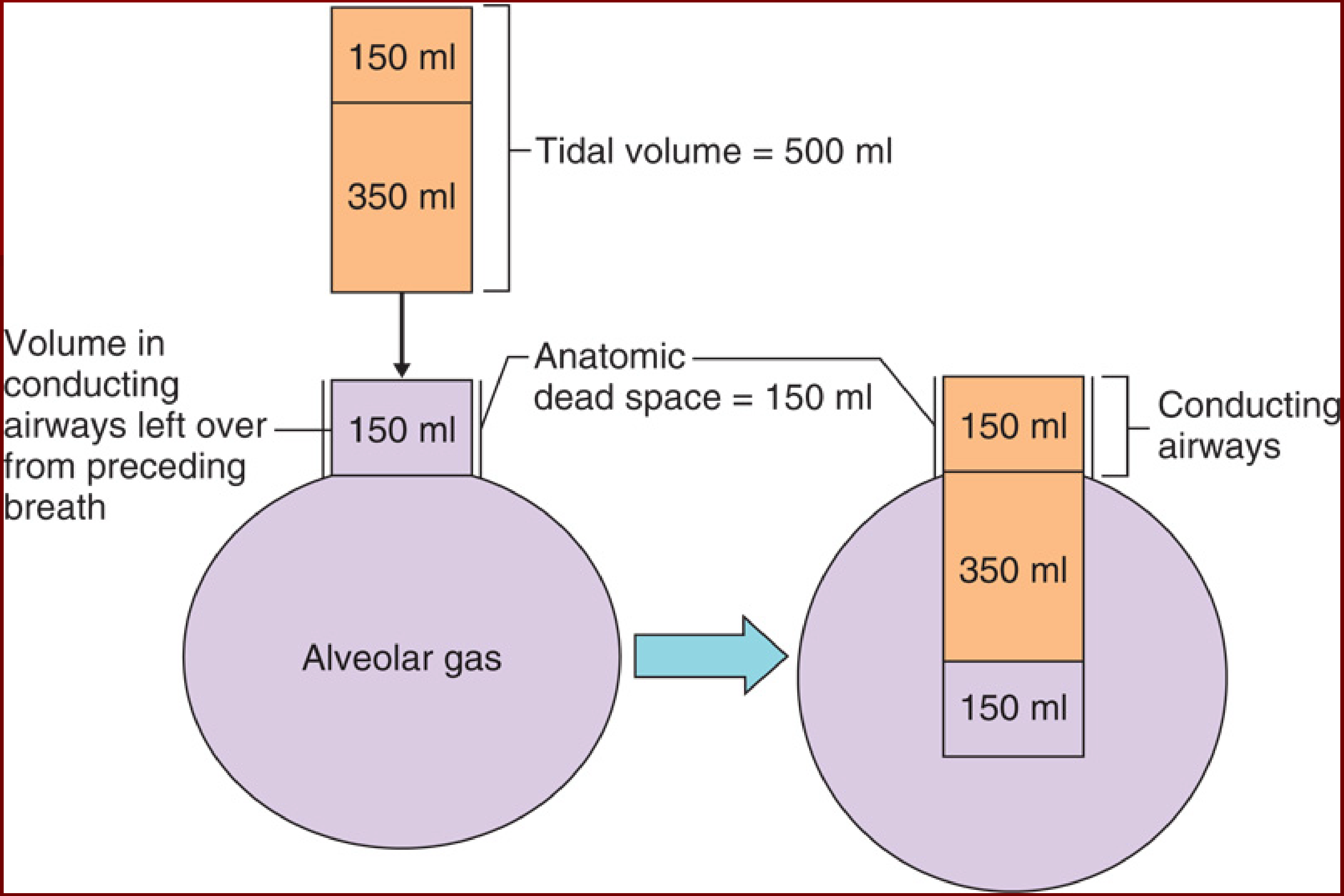
    = (500-150) X12 = 4200 ml

Dead space

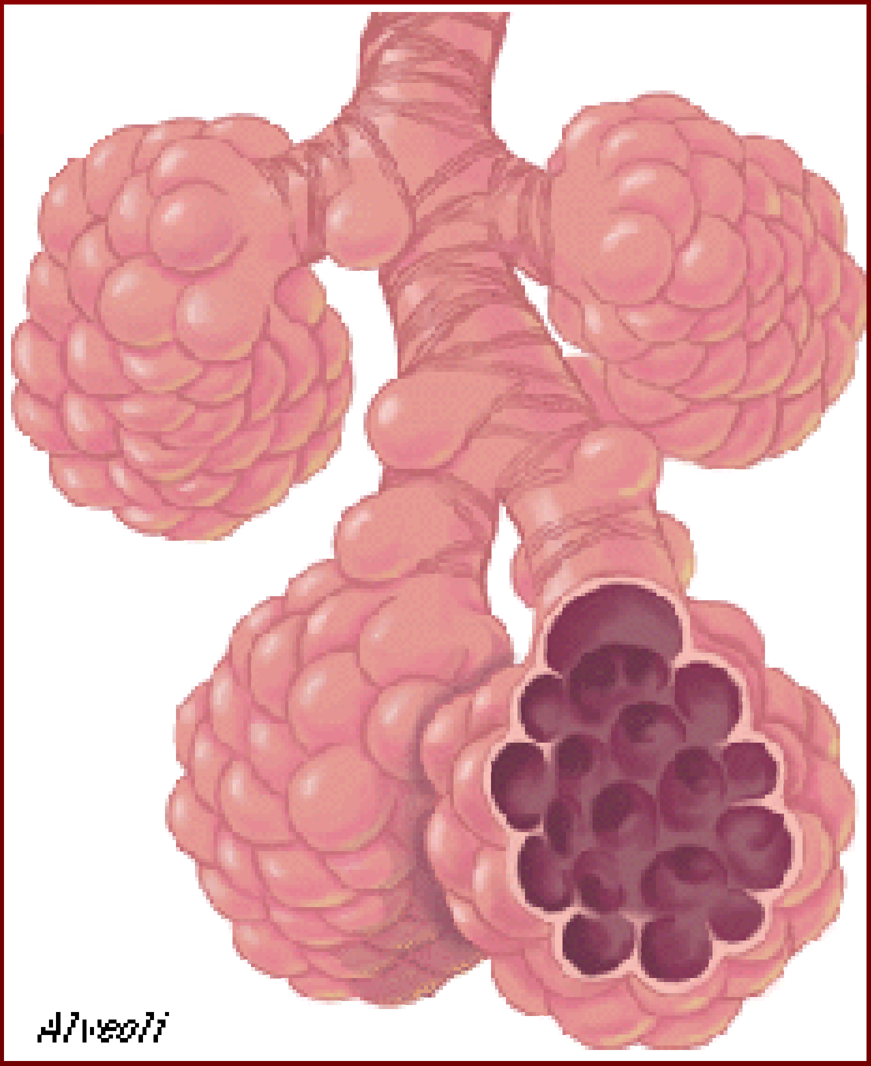

Trachea
Right primary bronchus
Left primary bronchus
Right lung
Left lung

Dead space

- Anatomical dead space
  - Volume in respiratory passageways which can not be exchanged
  - ~150ml
- Alveolar dead space
  - Alveoli which have little or no blood supply and cease to function in gas exchange
  - Normally ~0



Because of the anatomic dead space, "Fresh" inspired air is diluted by the left over air remaining in the lungs from the previous breathing cycle.


Alveoli

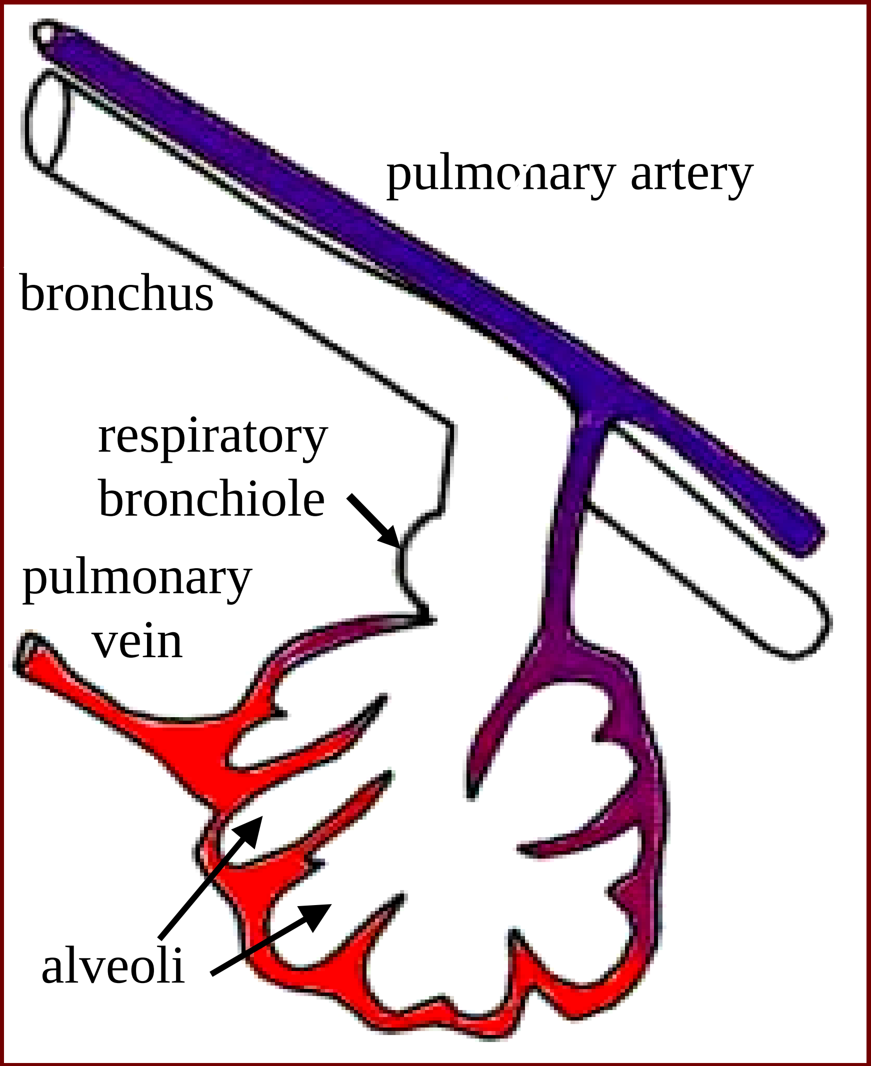

pulmonary artery
bronchus
respiratory
bronchiole
pulmonary
vein
alveoli

TABLE 13–5 *Effect of Breathing Patterns on Alveolar Ventilation*

SUBJECT	TIDAL VOLUME (ML/BREATH)	×	FREQUENCY (BREATHS/MIN)	=	MINUTE VENTILATION (ML/MIN)	ANATOMIC DEAD-SPACE VENTILATION (ML/MIN)	ALVEOLAR VENTILATION (ML/MIN)
A	150		40		6000	150 × 40 = 6000	0
B	500		12		6000	150 × 12 = 1800	4200
C	1000		6		6000	150 × 6 = 900	5100

Increased depth of breathing is far more effective in evaluating alveolar ventilation than is an equivalent increase in breathing rate.