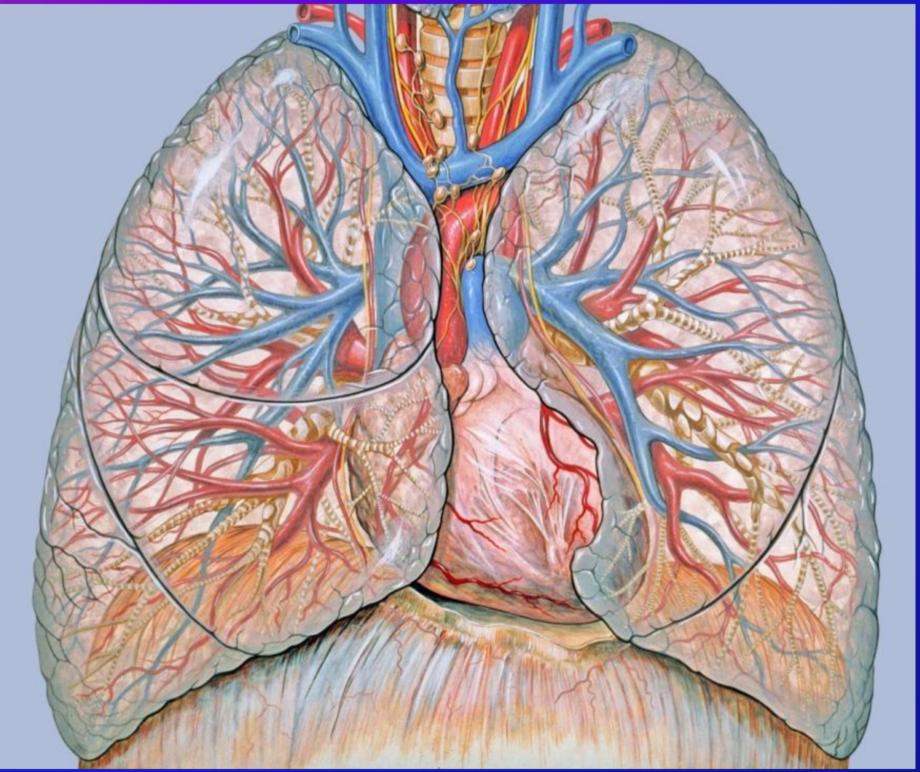

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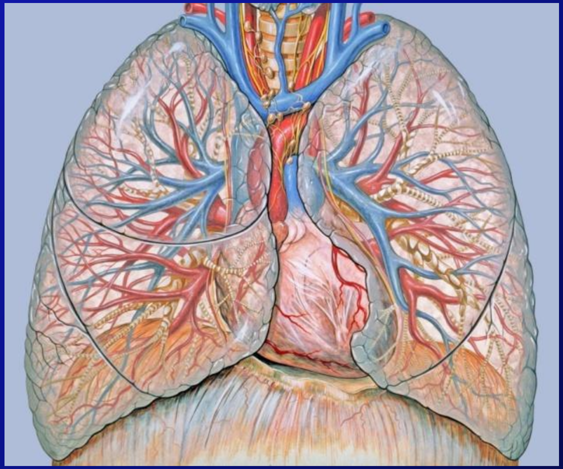
# Respiratory System

*Prepared by:*
*Dorota Marczuk-Krynicka, MD, PhD*

*Poznan University of Medical Sciences*

# Lungs:



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- Ventilation
- Perfusion
- Gas Exchange - Diffusion

# Respiratory System

1. Airways

   and Airway Resistance (AWR)

2. Mechanics of Breathing

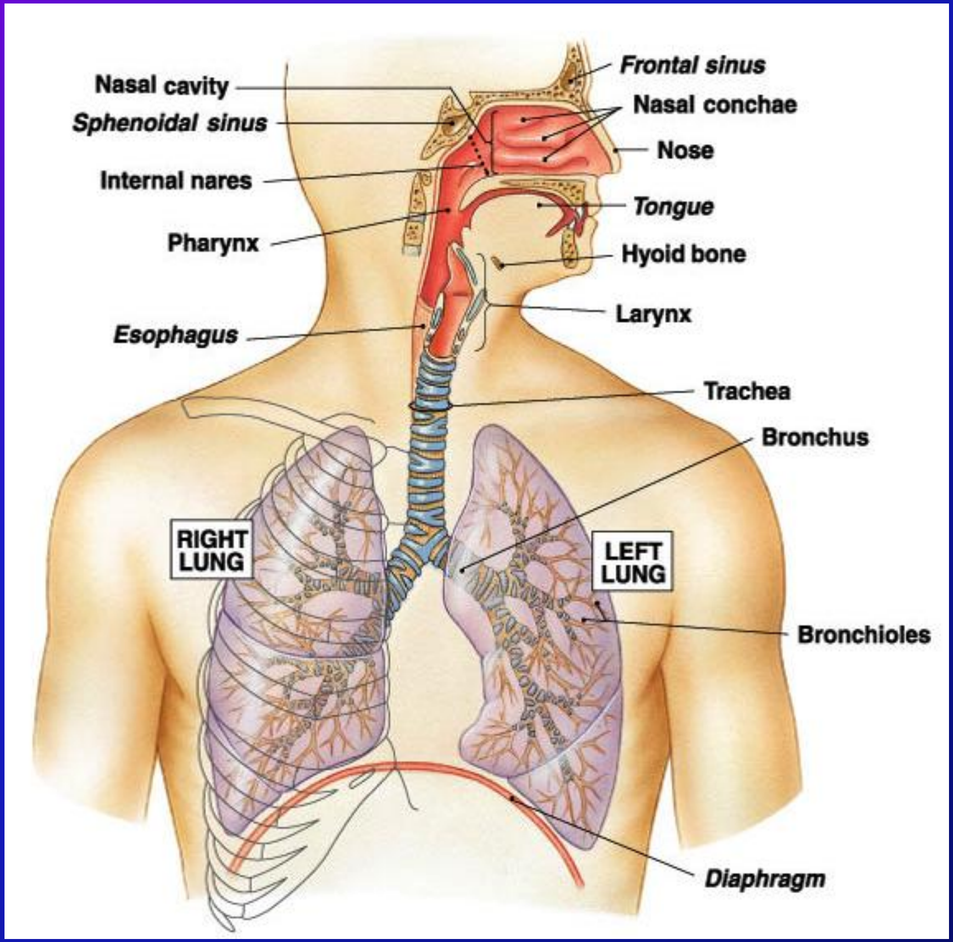
   and  Lung (Elastic) Recoil



# Airways

# and Airway Resistance (AWR)

# Anatomic Division of Respiratory System




- Upper tract
  - Nose, pharynx and associated structures
- Lower tract
  - Larynx, trachea, bronchi, lungs

# Tracheobronchial Tree - Physiologic Division

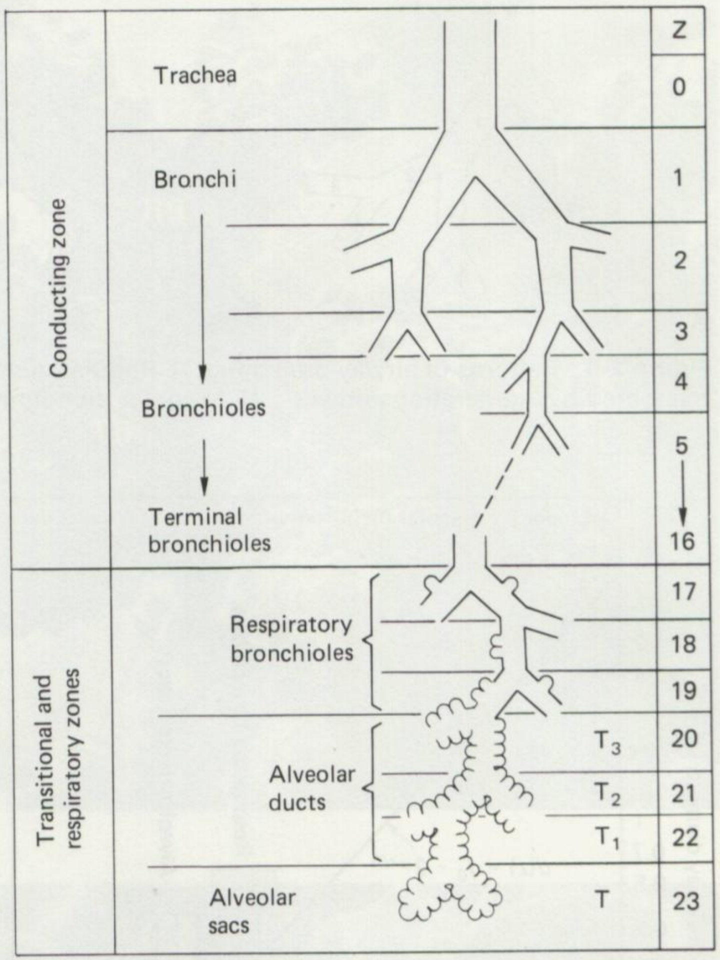
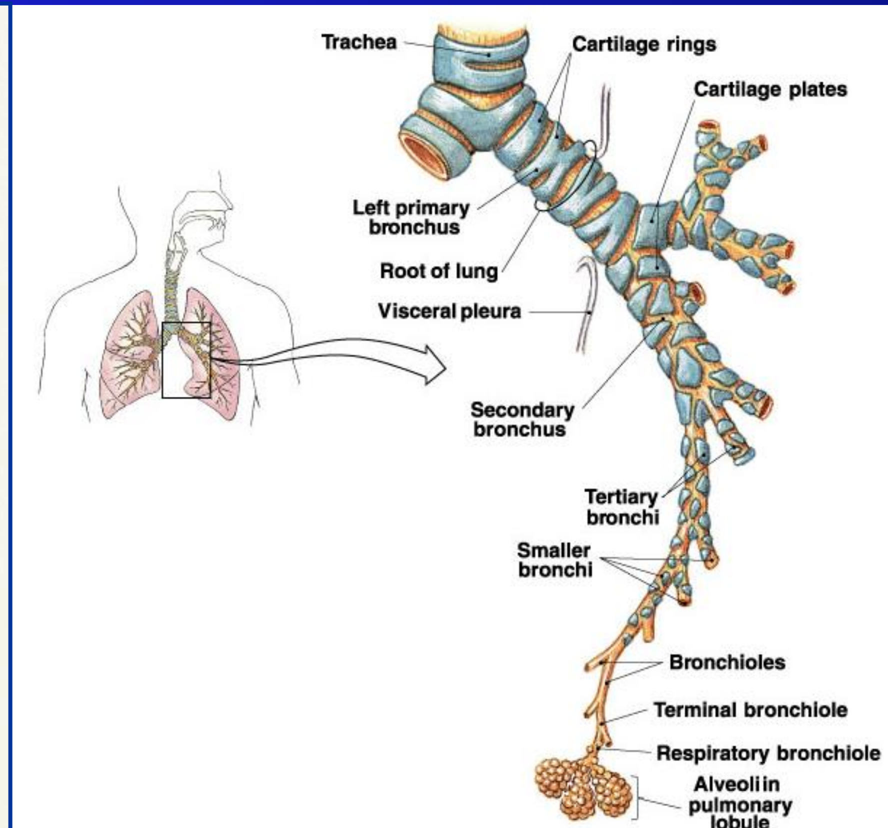


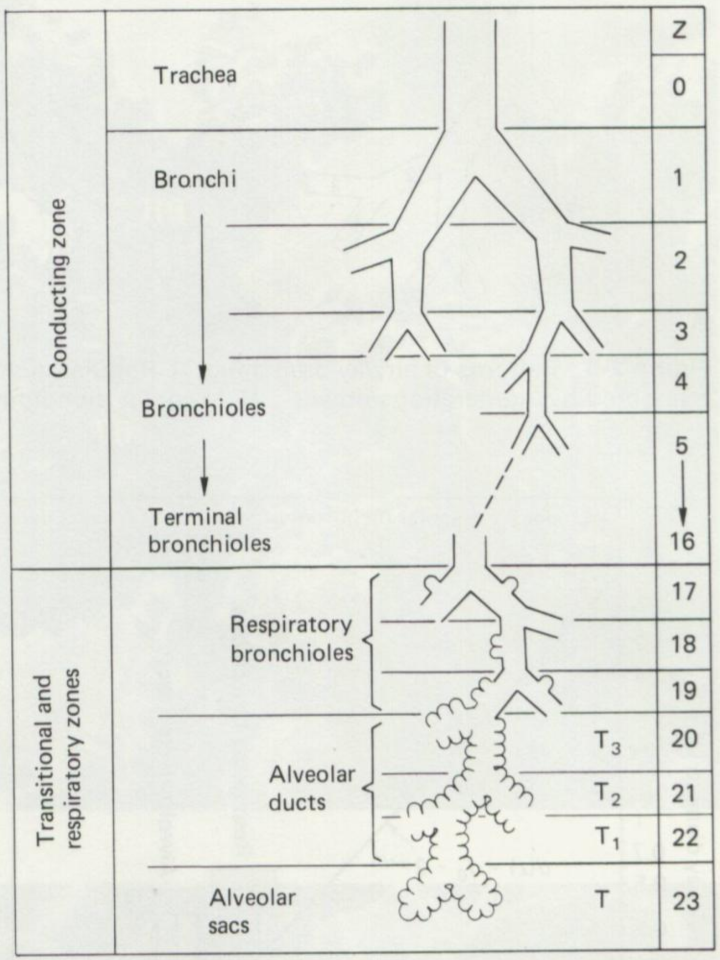

**Figure 2-5** Airway branching in human lung by regularized dichotomy from trachea (generation $z = 0$) to alveolar ducts and sacs (generations 20 to 23). The first 16 generations are purely conducting; transitional airways lead into the respiratory zone made of alveoli. (*After Weibel* [*21*])




- Conducting zone
- Transitional zone
- Respiratory (gas exchange) zone

Assessment of Pulmonary Function. A.P. Fishman McGraw-Hiill 1980

# Physiologic Division – Conducting Zone

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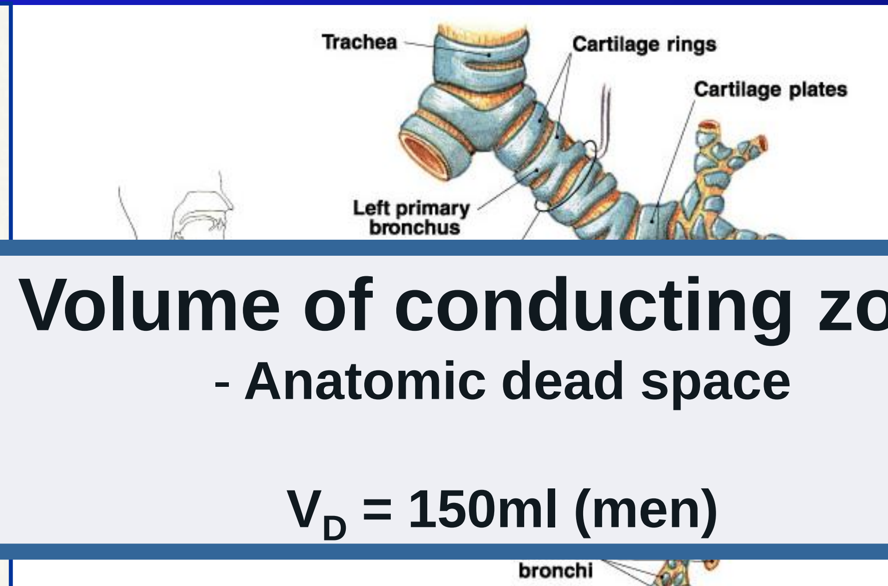



**Volume of conducting zone**

**- Anatomic dead space**

**$V_D$ = 150ml (men)**

***Dead space volume never reaches the alveoli***

*No gas exchange!*

Assessment of Pulmonary Function. A.P. Fishman McGraw-Hiill 1980



# The Airways
# Conducting Zone

Roles:

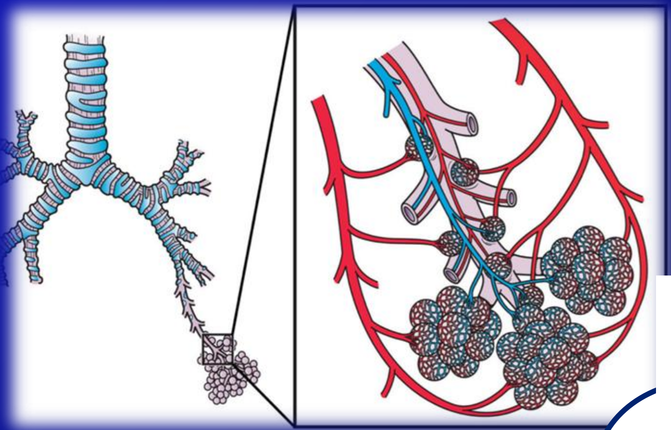
- Air distribution to the gas exchange surface
- Warming and humidifying the air
- Serving as a part of body defence system
- Preventing the alveolar oxygen and carbon dioxide partial pressures from extreme changing

# Atmospheric Air versus Alveolar Air

- <u>Atmospheric air (dry) - *fresh air*</u> (*Sea level* - TBP = 760 mm Hg)

Concentration of $O_2$ - 21%, $P_{O_2}$ = 760 mm Hg x 0,21 = 159,6 mmHg

Concentration of $CO_2$ - 0,04%, $P_{CO_2}$ = 760 mm Hg x 0,0004 = 0,3 mmHg



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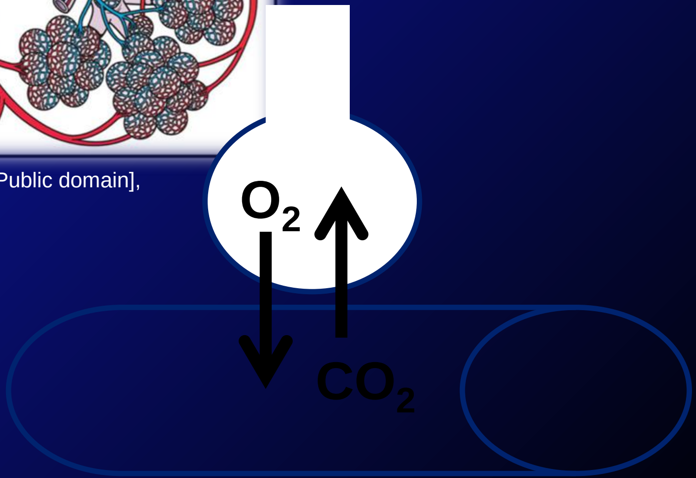



- <u>Alveolar air - *old air*</u>

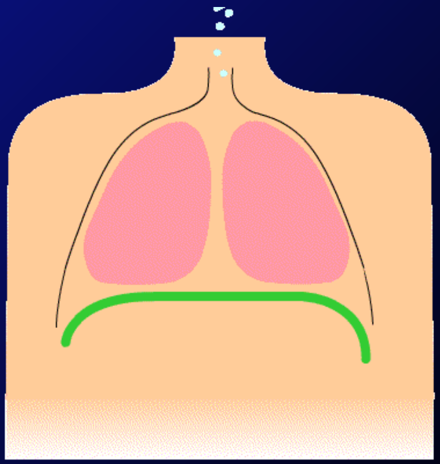
$P_{AO_2}$ = 100 mm Hg $P_{ACO_2}$ = 40 mm Hg

# Minute Volume (Ventilation) $MV_E$

## Minute volume (ventilation)

total volume of air that enters (or leaves) the respiratory system each minute

| Tidal volume | | Breathing frequency | | Minute volume |
|---|---|---|---|---|
| TV | | BF | | MV |
| 500 ml | x | 12 times/min | = | 6000 ml |



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# Minute Ventilation (MV)
# Minute Alveolar Ventilation ($\dot{V}_A$)

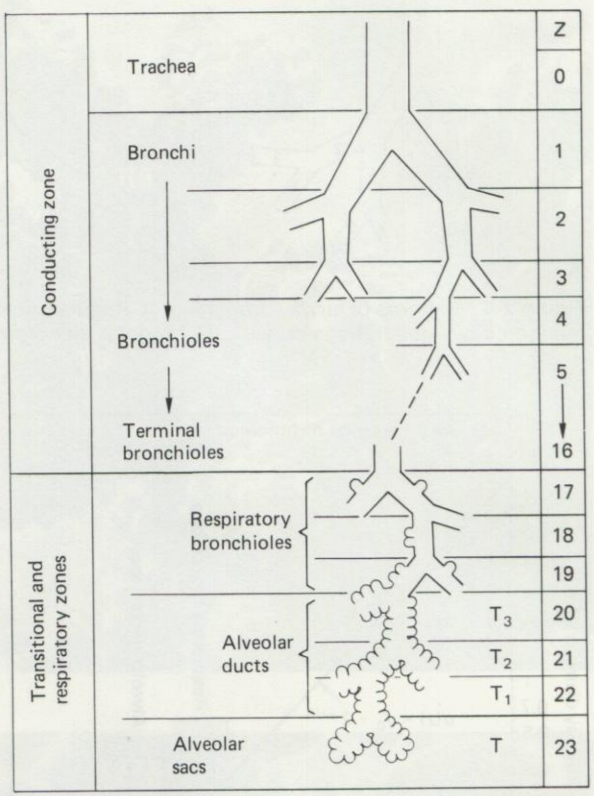



**Figure 2-5** Airway branching in human lung by regularized dichotomy from trachea (generation $z = 0$) to alveolar ducts and sacs (generations 20 to 23). The first 16 generations are purely conducting; transitional airways lead into the respiratory zone made of alveoli. (*After Weibel* [21])

Assessment of Pulmonary Function. A.P. Fishman McGraw-Hiill 1980

| TV | | BF | | $MV_E$ |
|---|---|---|---|---|
| 500 ml | x | 12 /min | = | 6000 ml |

**Volume of conducting zone**

**- Anatomic dead space**

**$V_D$ = 150ml (men)**

## Alveolar ventilation

volume of fresh air that reaches the alveoli each minute

- minute ventilation corrected for dead space ventilation

| **($TV - V_D$)** | | BF | | $\dot{V}_A$ |
|---|---|---|---|---|
| (500 ml - 150 ml) | x | 12 /min | = | 4200 ml |
| 350 ml | | | | |

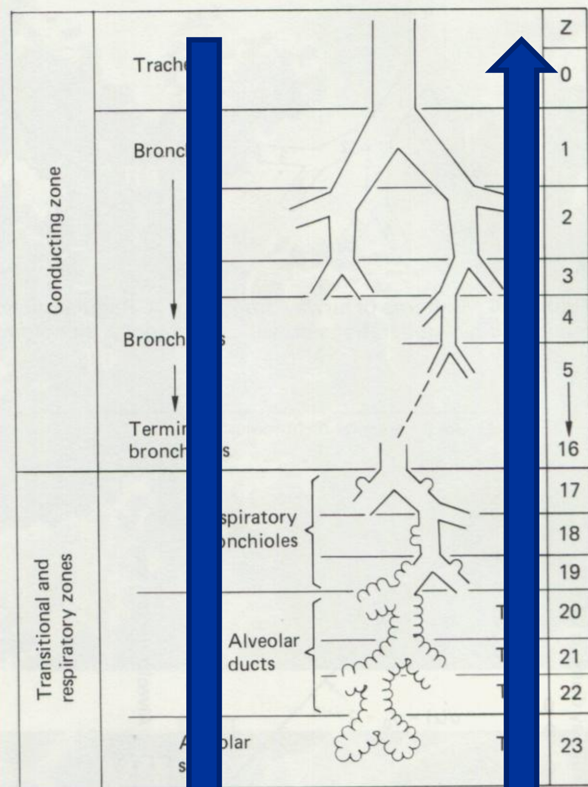
# Conducting zone buffers the alveolar air

End of inspiration:

- 150 ml of fresh atmospheric air remains in the conducting zone

Inspiration

- 350 ml of fresh atmospheric air enters the alveoli

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Assessment of Pulmonary Function. A.P. Fishman McGraw-Hiill 1980

End of expiration:

- **150 ml of old alveolar** air remains in the conducting zone

Beginning of inspiration:

- **150 ml of old alveolar air left in the conducting zone** at the end of expiration moves back to alveoli (as the first portion of air)

# Effect of Breathing Patterns on Alveolar Ventilation

| | TV (ml) | | BF (breaths/min) | | $MV_E$ (ml/min) | | $\dot{V}_D$ (ml/min) | | $\dot{V}_A$ (ml/min) |
|---|---|---|---|---|---|---|---|---|---|
| ***A*** | 1000 | x | 6 | = | 6000 | - | 900 (150ml x 6) | = | **5100** |
| ***B*** | 500 | x | 12 | = | 6000 | - | 1 800 (150ml x 12) | = | **4200** |
| ***C*** | 250 | x | 24 | = | 6000 | - | 3 600 (150ml x 24) | = | **2400** |
| | 150 | x | 40 | = | 6000 | - | 6 000 (150ml x 40) | = | **0** |

*The more rapid and shallow breathing the worse the alveolar ventilation*

# Breathing during Physical Activity

↑ Ventilation

(↑ TV    i    ↑ BF)

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Adaptation to exercise

Lack of adaptation to exercise

# Airway Resistance (AWR)

- **Airway resistance (AWR, R):**

$$R = \frac{8\eta l}{\pi r^{4\,(5)}}$$

- 85% - trachea and 10 first generations

- Airflow per minute (Ventilation)

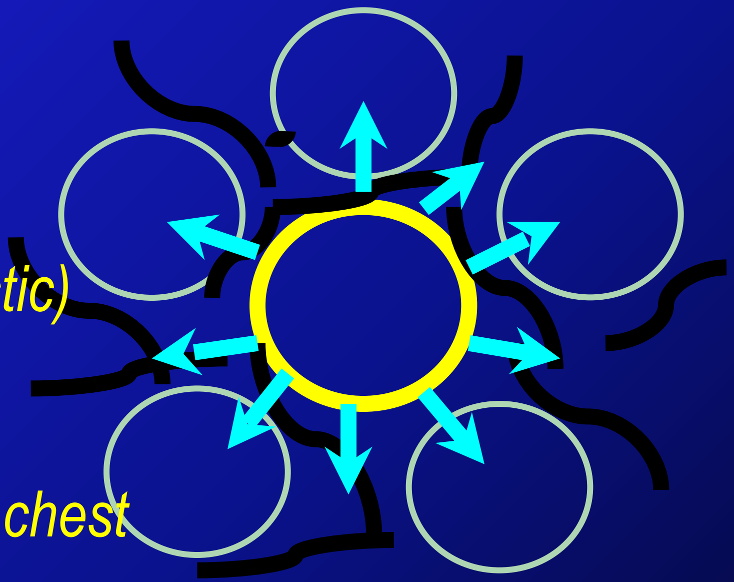
$$\dot{V} = \frac{\Delta p}{R}$$

- *If r decreases by the factor of **4**,*
  *the airway resistance will increase at least by a factor **256 !!!***

- *At the same pressure gradient ($\Delta p$)*
  *the air flow per minute (ventilation) will decrease by a factor of **256** !!!*

# Factors Affecting AWR (Physiologic)

❑ Lung volume



- *Passive radial traction exerted on the airways by the surrounding (elastic) lung tissue (↑ during inspiration)*

- *Subatmospheric pressure inside the chest (↓ during inspiration)*

- *Impulses from vagus (↓ during inspiration)*

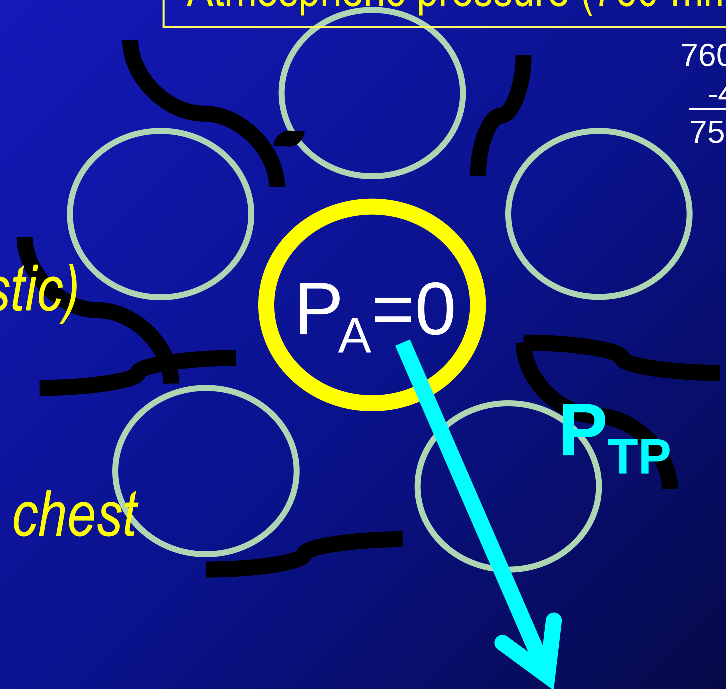
# Factors Affecting AWR (Physiologic)

Atmospheric pressure (760 mm Hg) – zero

760 mm Hg
-4 mm Hg
756 mm Hg

## ❑ Lung volume

- *Passive radial traction exerted on the airways by the surrounding (elastic) lung tissue (↑ during inspiration)*
- *Subatmospheric pressure inside the chest (↓ during inspiration)*



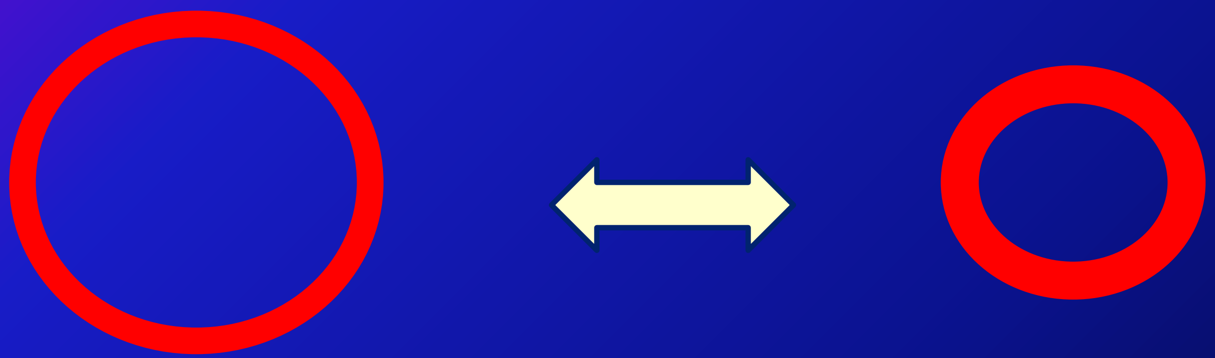

$Ppl = - 5\ cm\ H_2O$

$- 5 cmH_2O = - 3{,}7 mmHg$

Respiratory S.- units for pressure: **mm Hg or cm $H_2O$**
1 mm Hg = 13,6 mm $H_2O$ (1,36 cm $H_2O$), **1 cm $H_2O$ = 0,74 mm Hg**

# Factors Affecting AWR

## Contraction or relaxation of bronchial smooth muscles



RELAXATION (dilation, $\downarrow$AWR)

CONTRACTION (narrowing, $\uparrow$AWR)

*Stimulation:*

*-Sympathetic (adrenergic)*
*- $\beta_2$ adrenergic receptors*
*Epinephrine*
*$\beta_2$ -agonists*

*- Parasympathetic (cholinergic)*
*- Muscarinic receptors*
*Irritants*

# Factors Affecting AWR

*Inspiration*:

The airways dilate

Airway resistance decreases

*Expiration*:

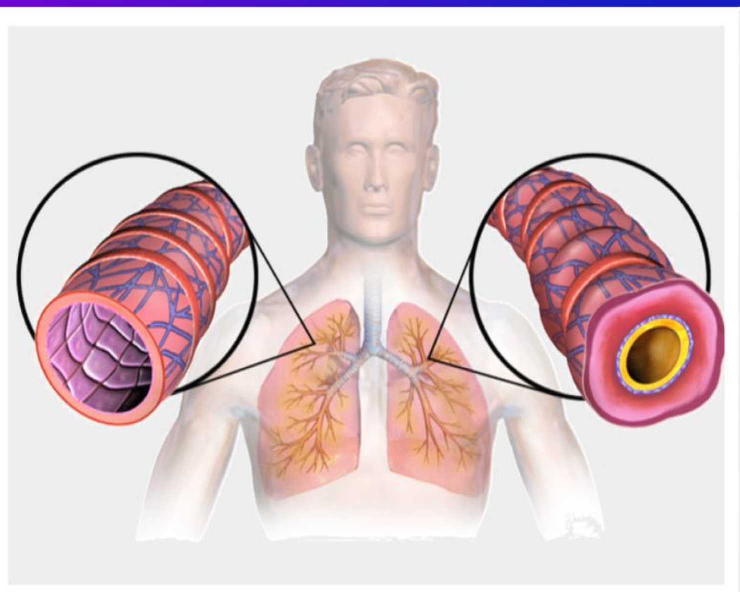
The airways narrow

Airway resistance increases

*Reffers to the airways located inside the chest*

# Obstructive diseases

- ↑ airway resistance
- ↓ ventilation (flow rate)



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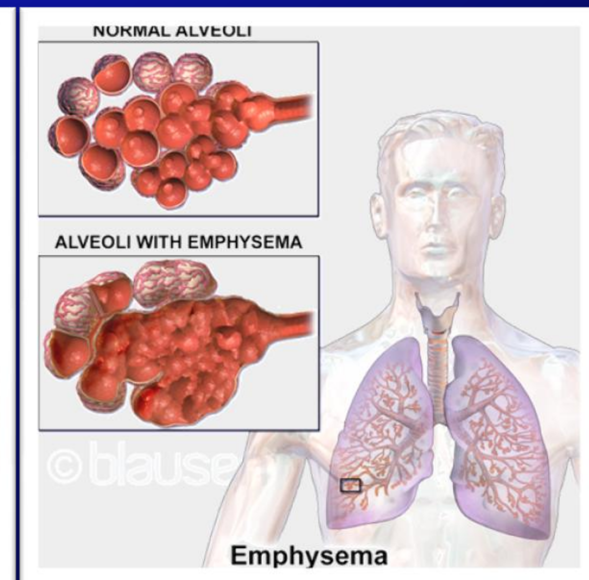


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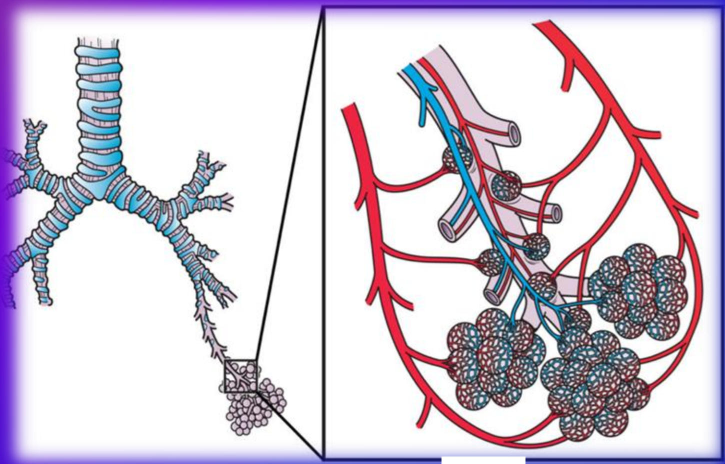
Asthma

Chronic bronchitis Emphysema

COPD

# Respiratory (Gas Exchange) Zone



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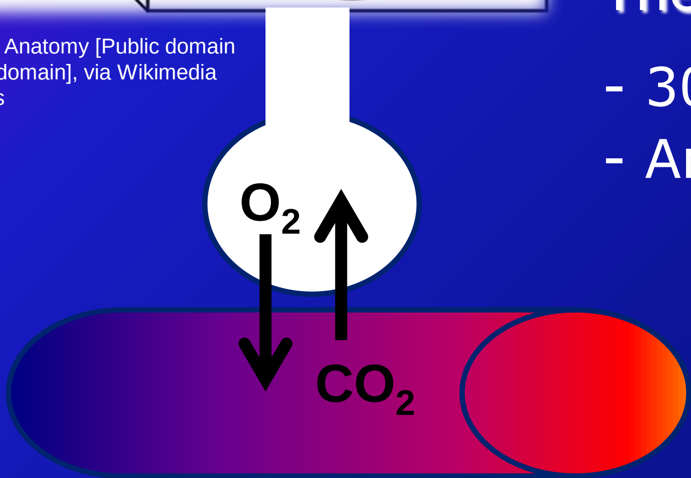
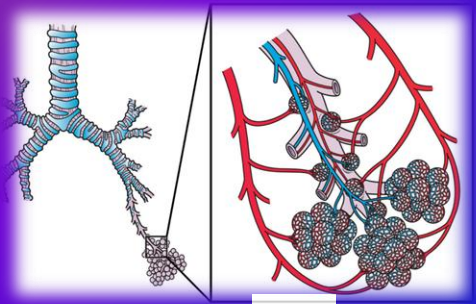



**The Alveoli:**

- 300 million in both lungs
- An average diameter: 0,1 - 0,3 mm

# Respiratory (Gas Exchange) Zone



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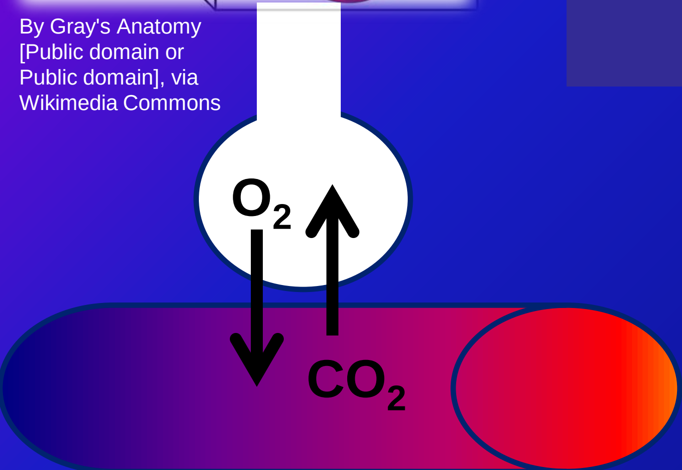



The alveolar - capillary membrane
(0,2 - 0,6 $\mu$m)

## Transfer of gasses

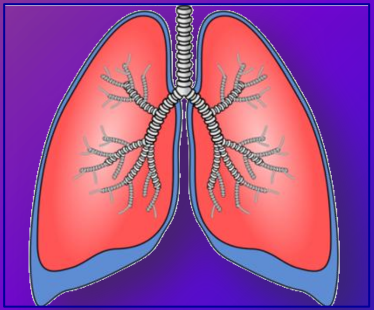
Directly related to:

- Driving pressure across the alveolar - capillary membrane
- Area of membrane (70 $m^2$)
- Solubility of gas

Inversely related to:

Length of diffusion pathway

Square root of molecular weight of gas



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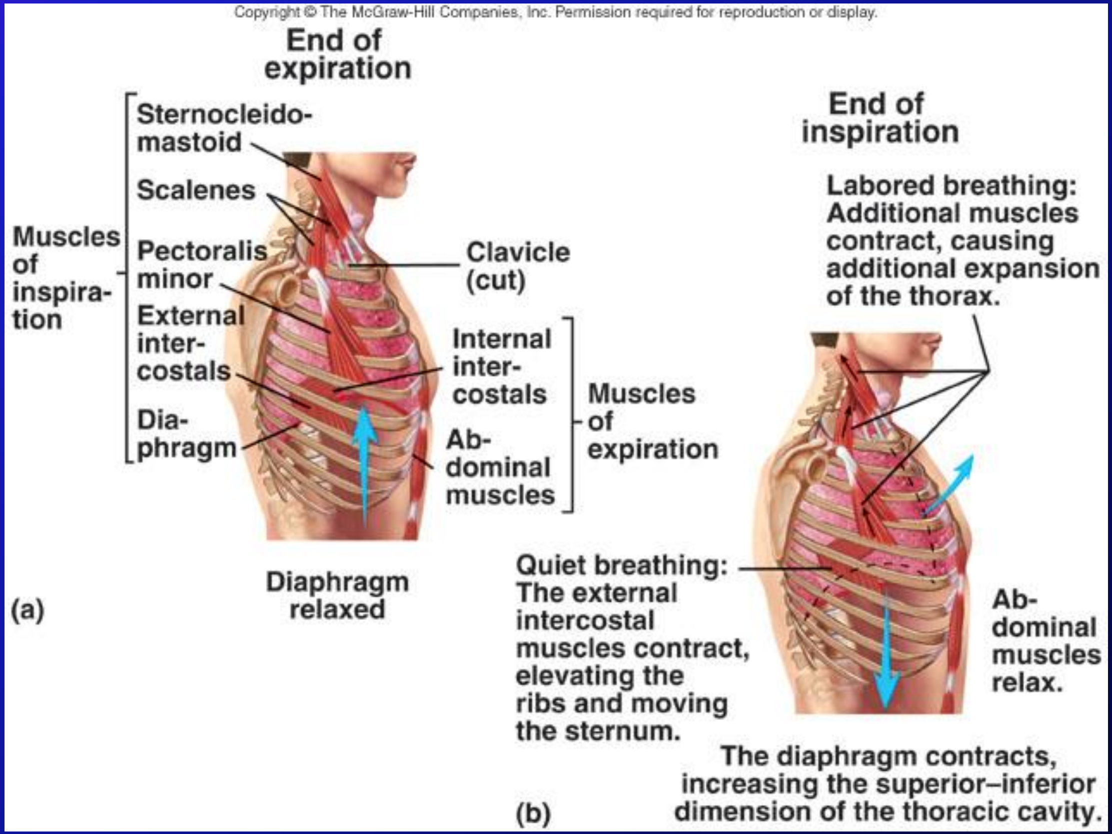
# Mechanics of Breathing

# and Lung (Elastic) Recoil

# Muscles of Respiration

*Inspiration*

*-always active*

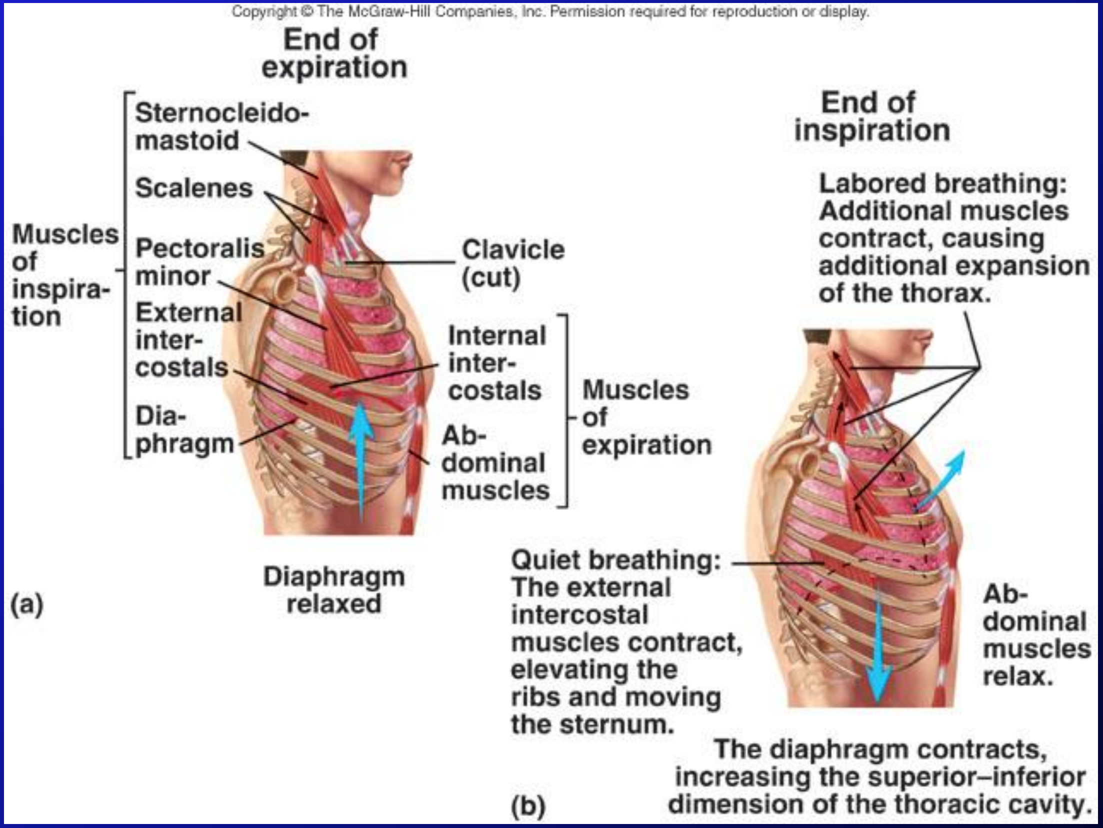


# Muscles of Respiration

*Expiration*

*- Quiet = passive*

*None expiratory muscles contract !!!*

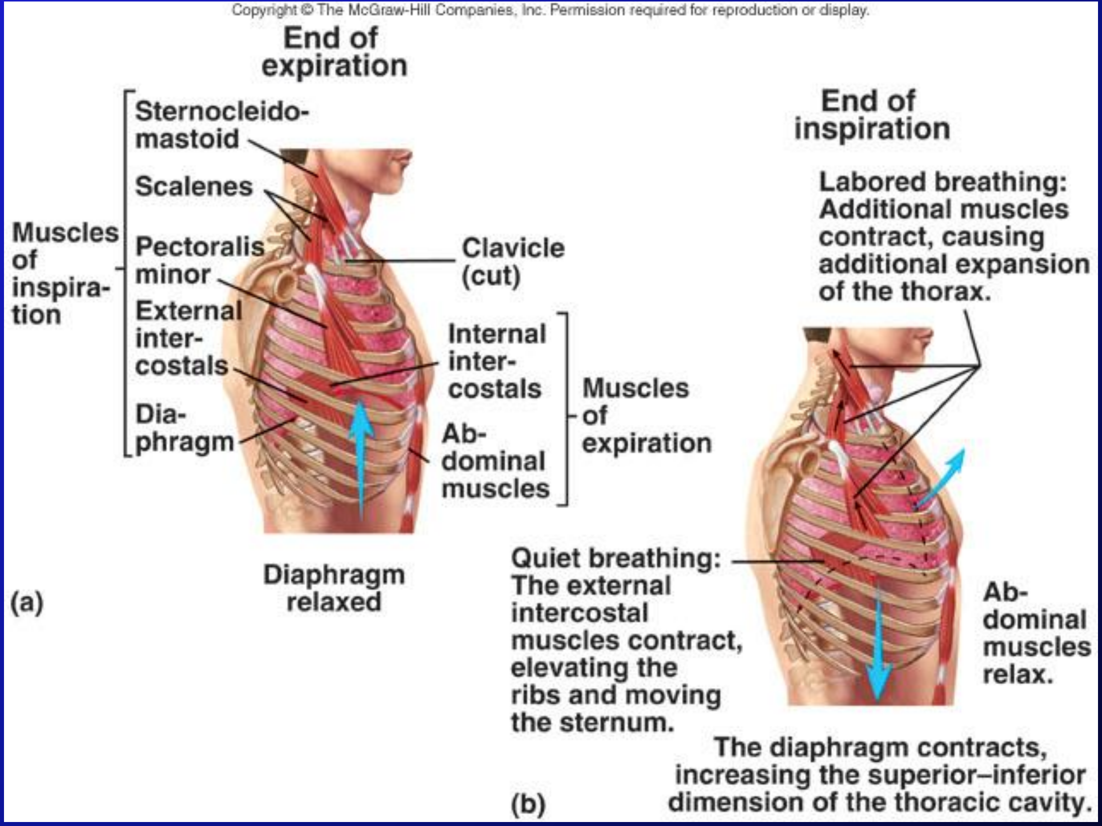


# Muscles of Respiration

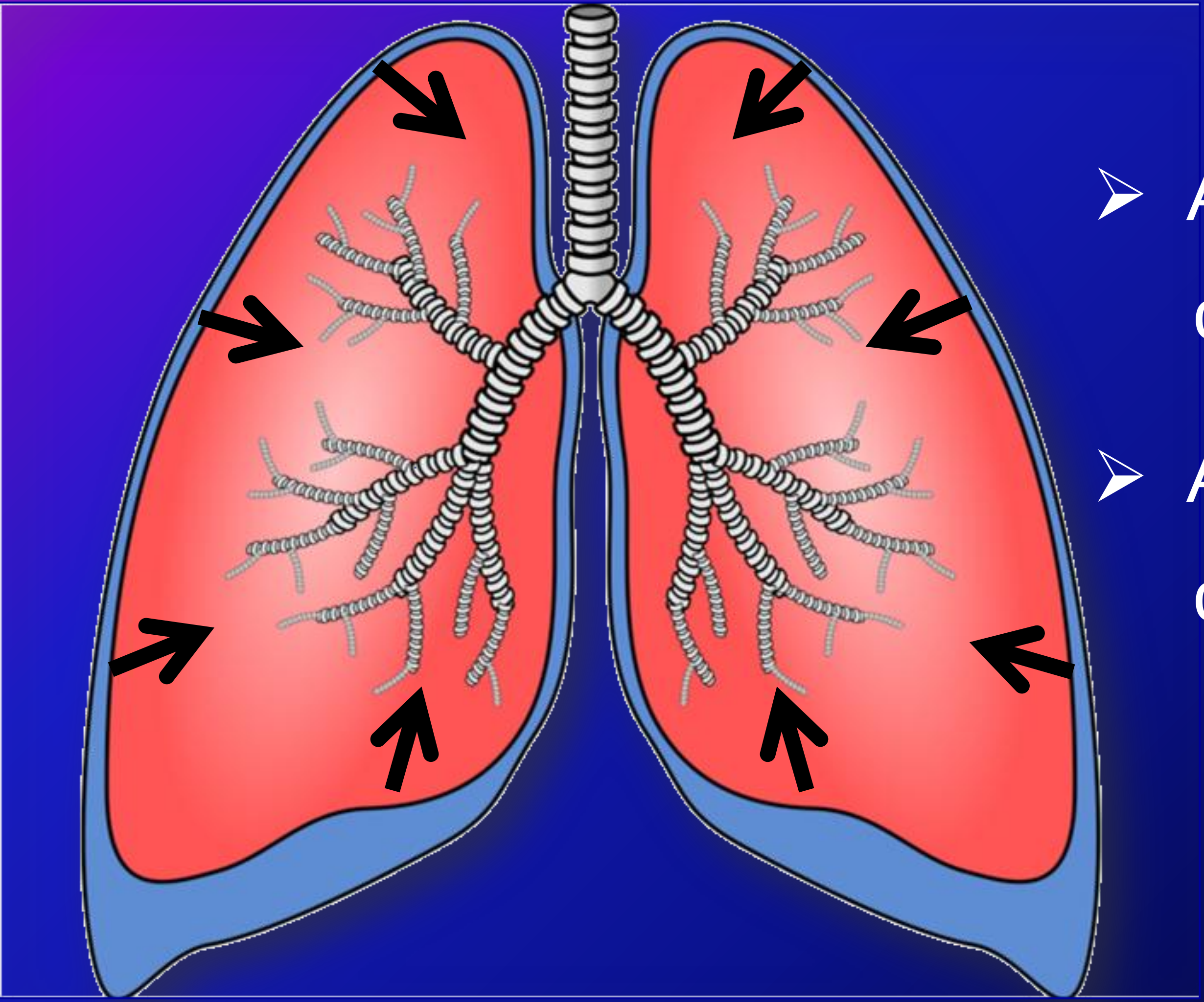
*Expiration*

*- Deeper = active*

*Expiratory muscles contract !!!*



# Lung Elastic Forces



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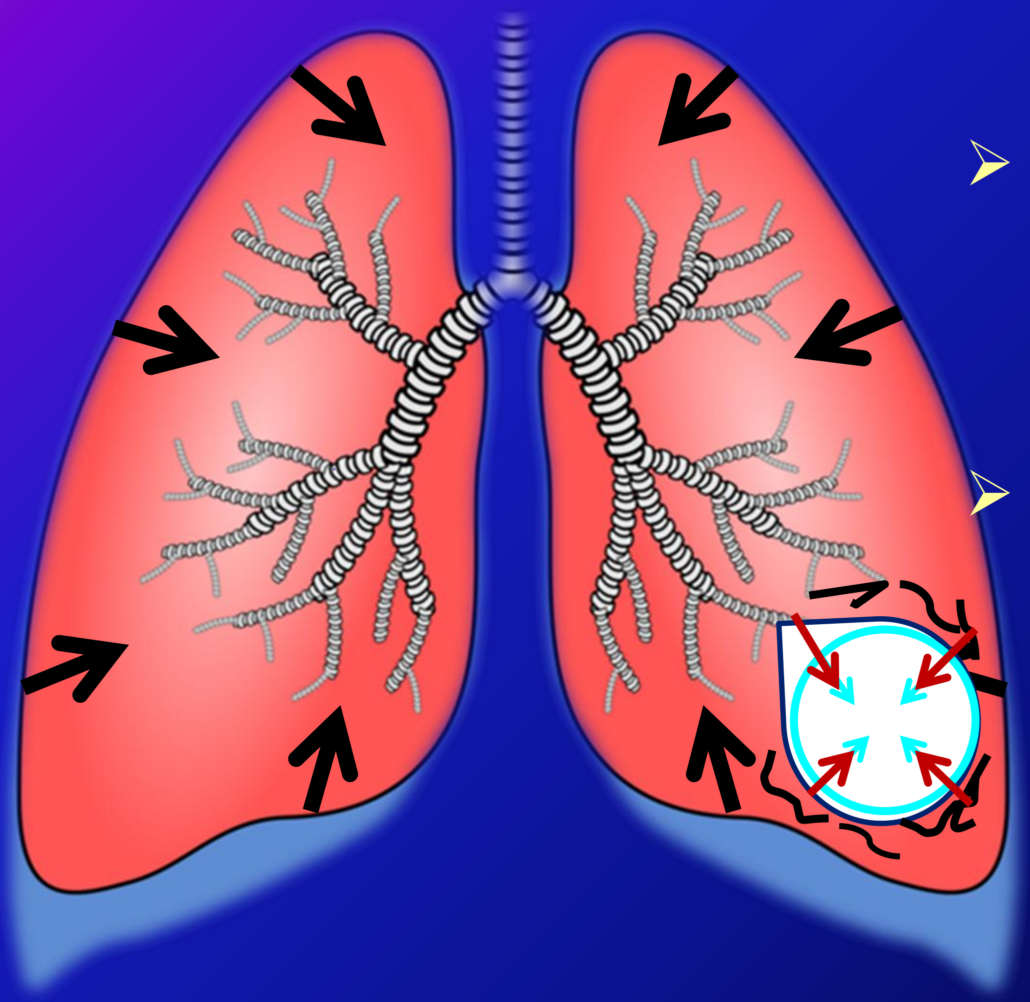
- Always directed centripetally
- Always tent to collapse the lung

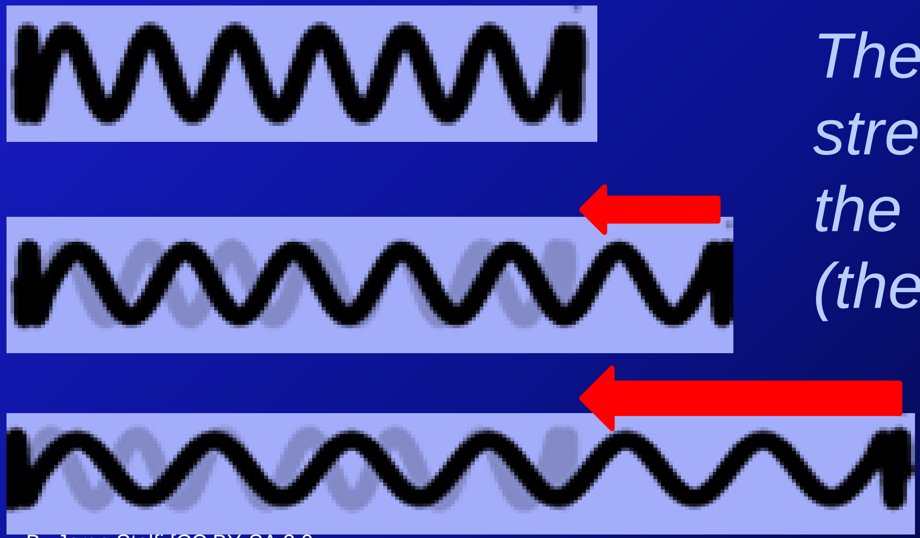
# Lung Elastic Forces



- *Elastic forces of the lung tissue itself (elastic, collagen fibres)*
- *Surface tension of the fluid that lines the inside walls of the alveoli*

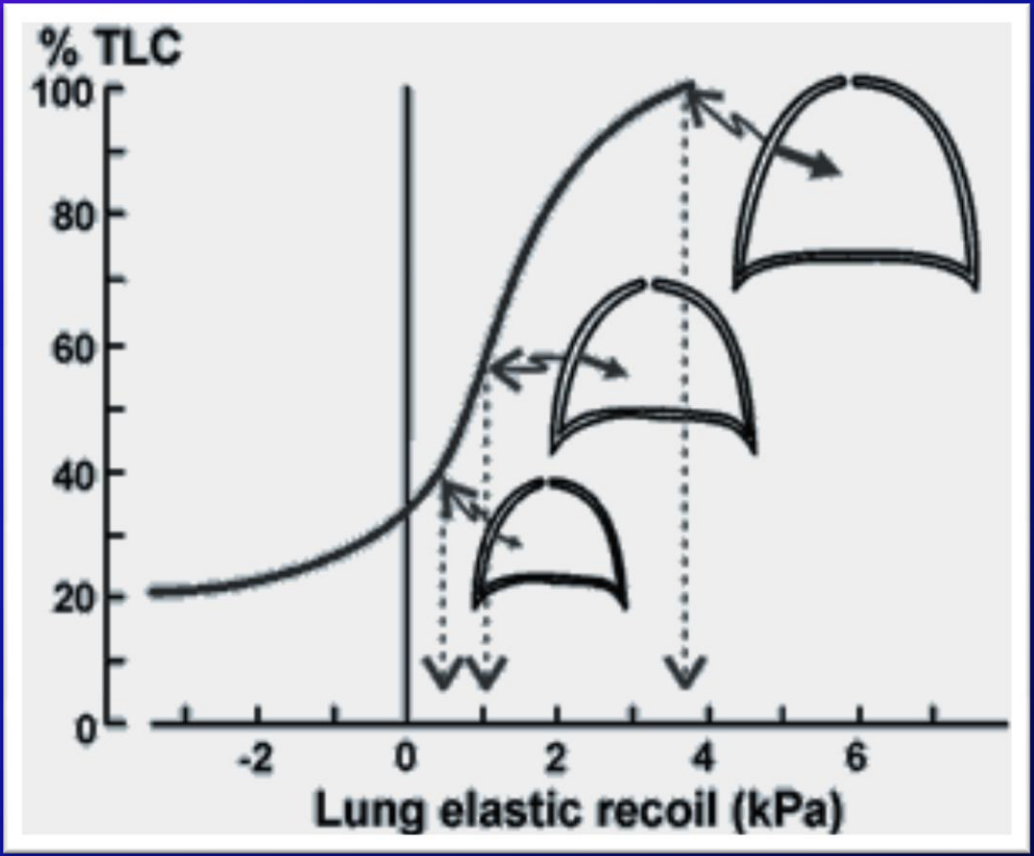
# Lung Elastic Forces

- Anatomic dimensions of the chest are bigger than those of the lungs
- Lungs are distended even during expiration
- III physic law: „action causes reaction”



*The more the lungs are stretched*
*the more they tent to recoil*
*(the bigger the lung recoil)*

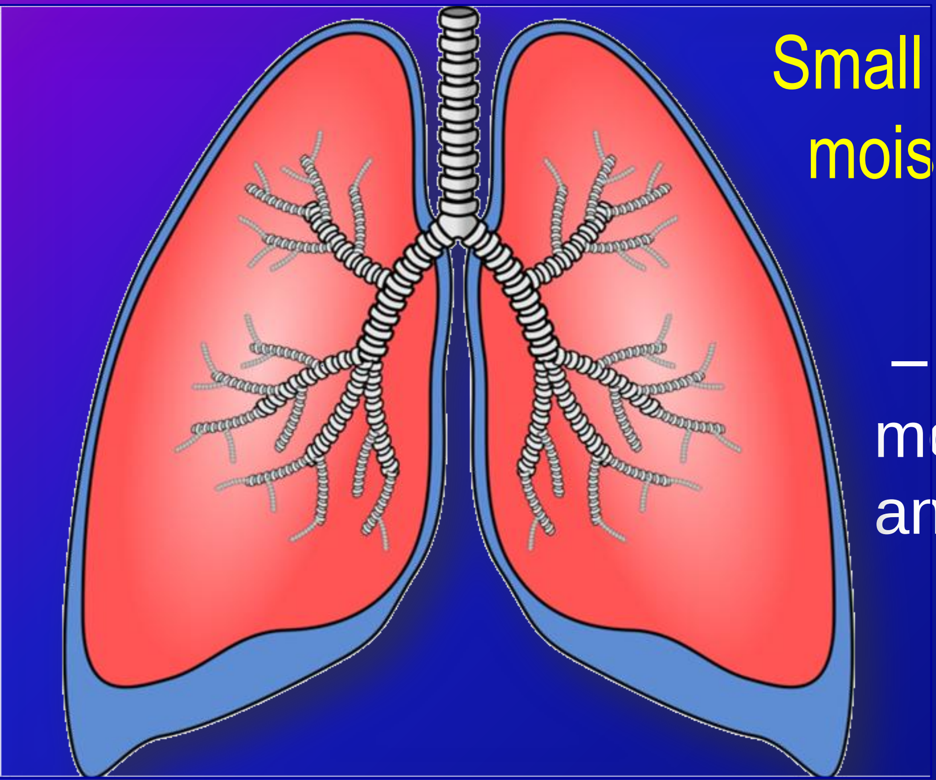
# Lung Elastic Forces – Lung (Elastic) Recoil




*The more the lungs are stretched*
*the more they tent to recoil* ***(the bigger the <u>lung recoil</u>)***

# Lung Elastic Forces

- Lungs always follow the chest wall



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Small amount of fluid in the pleural cavity moistens the surfaces of both visceral and parietal pleura

– Attractive forces of fluid molecules cause that the lungs and chest wall act as union

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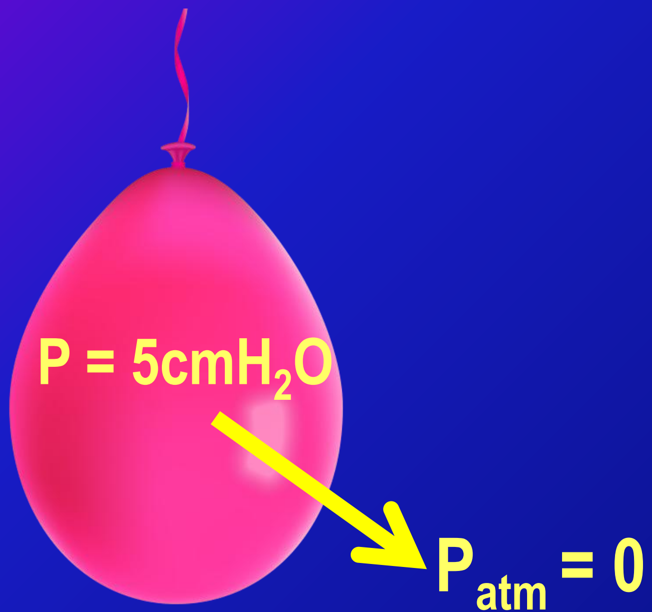
# Pleural Pressure

Pleural pressure is (almost always) subatmospheric

i.e. lower than the atmospheric pressure (at sea level = 760 mm Hg - set as 0)

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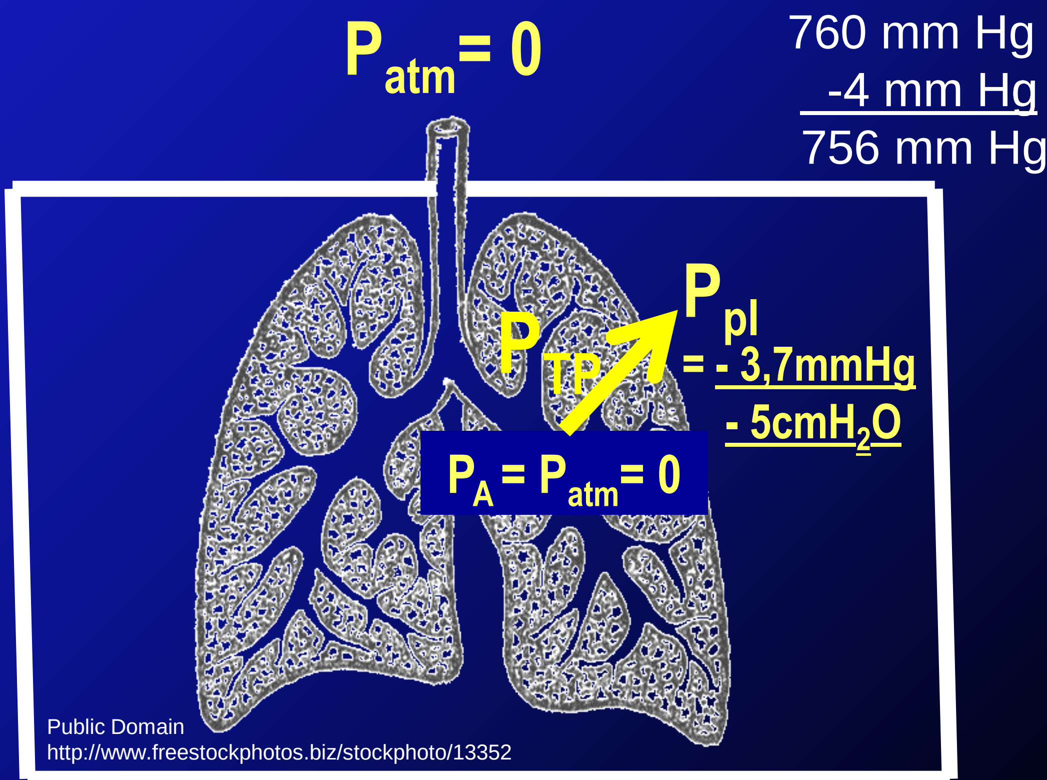


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Respiratory S.- units for pressure: **mm Hg or cm $H_2O$**

1 mm Hg = 13,6 mm $H_2O$ (1,36 cm $H_2O$), **1 cm $H_2O$ = 0,74 mm Hg**

# Elastic Forces of the Lungs and Chest Wall

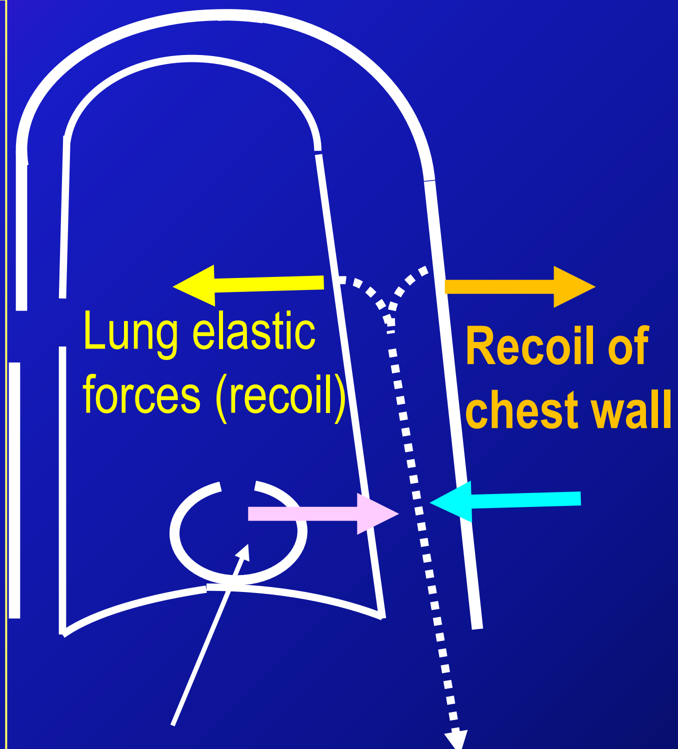
## END OF QUIET EXPIRATION

**Lung elastic forces**
(directed centripetally)

are balanced by

- subatmospheric pleural pressure ($P_{pl}$)
- transpulmonary (distending) pressure ($P_{TP}$)

$P_{TP} = P_A - P_{PL}$




$P_A = 0$ $\quad$ $P_{pl} = \underline{-5\ cm\ H_2O}$

*„lymphatic pump”*

$P_{TP} = +5\ cm\ H_2O$

**Recoil of chest wall**
(directed centrifugally)

are balanced by

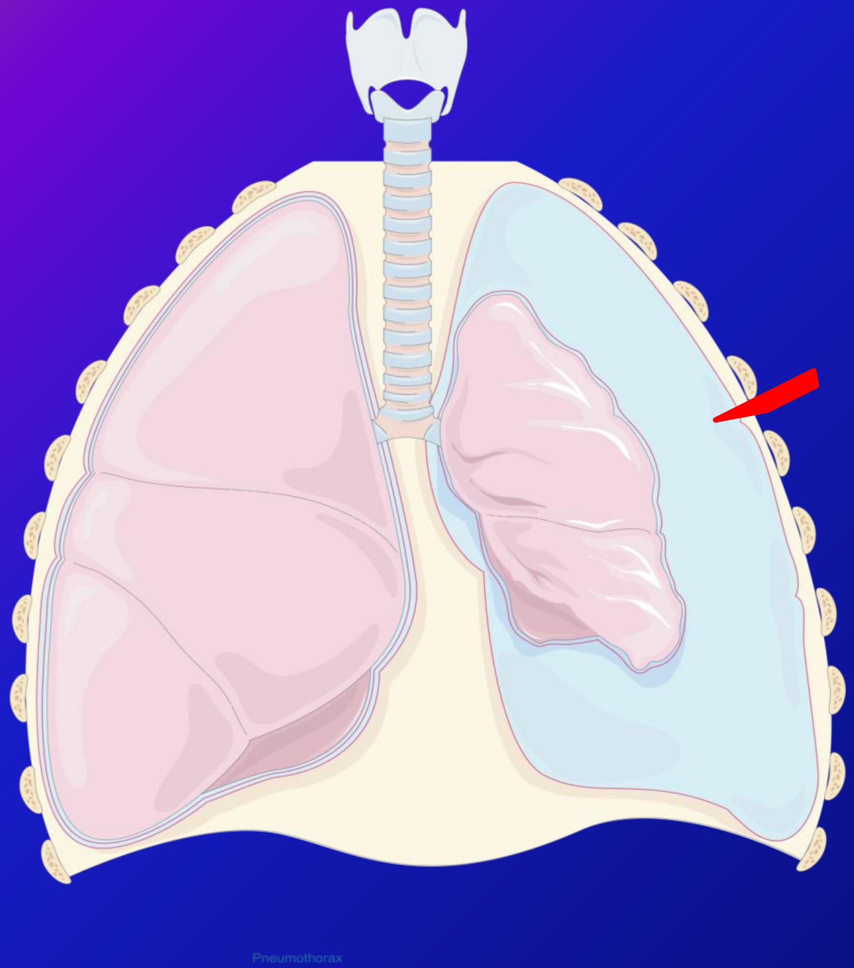
- subatmospheric pleural pressure ($P_{pl}$)
- transthoracal pressure ($P_{TC}$, $T_W$)

$P_{TC} = P_{PL} - P_{atm}$

Lung elastic recoil increases during inspiration

Recoil **of chest wall** decreases during inspiration
(at 70%TLC it becomes centripetal)

# Pneumothorax



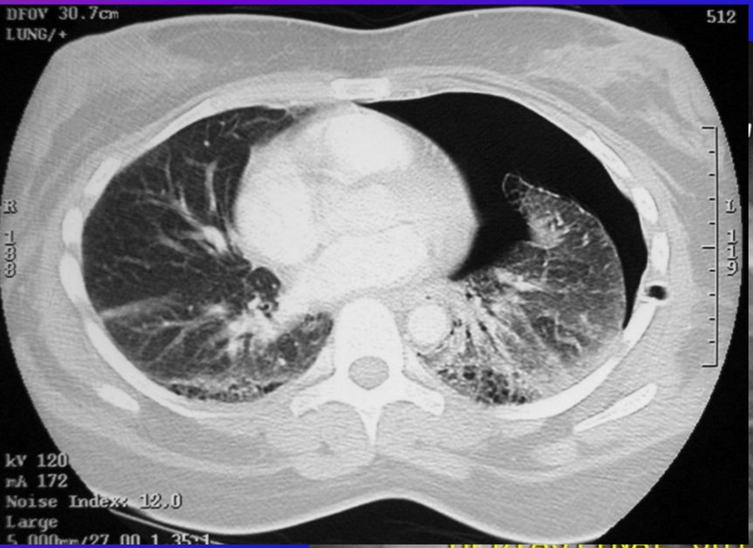

An opening between
the pleural cavity and
an external environment

The air flows from the site of a
higher  to a lower pressure

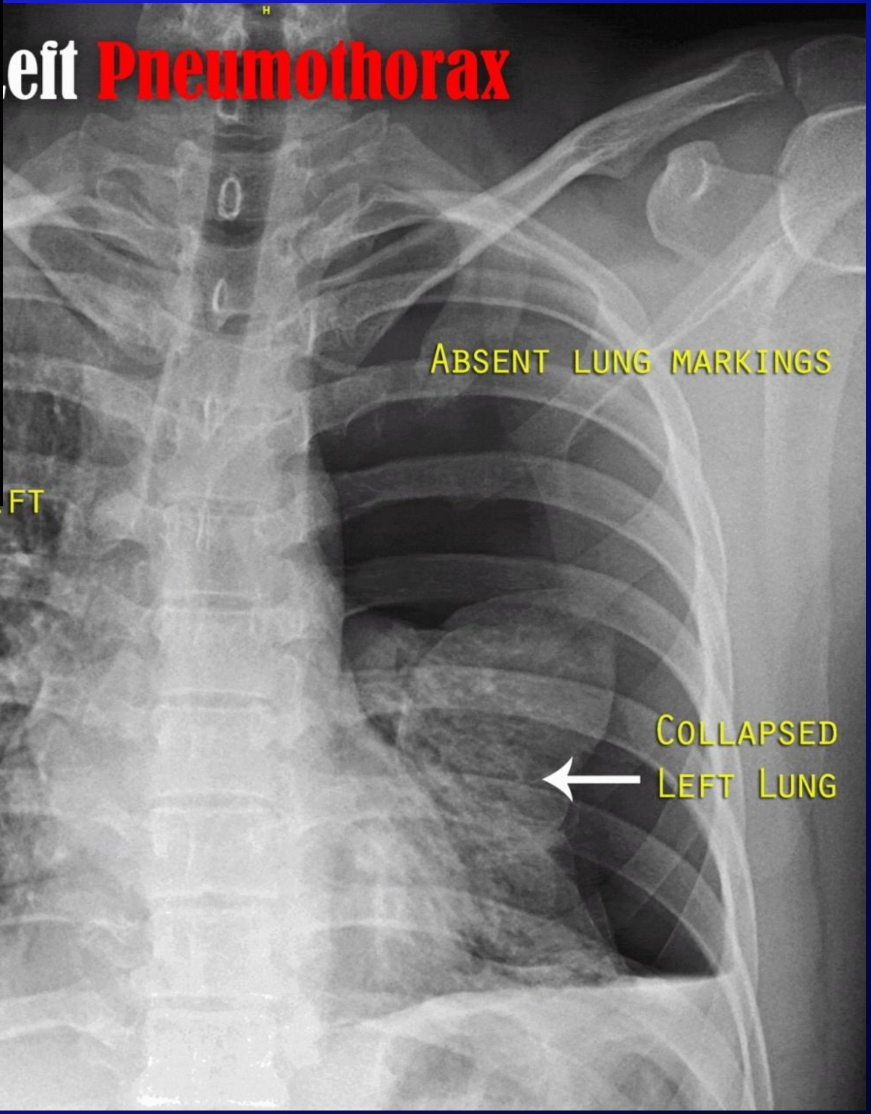
The lung collapses
Chest wall (on affectes side)
expands

https://www.flickr.com/photos/serviermedicalart/10084453633

# Pneumothorax




[Clinical Cases](http://en.wikipedia.org/wiki/User:Clinical_Cases)
*Pneumothorax CXR http://clinicalcases.blogspot.com/2004/02/tension-pneumothorax.html [http://en.wikipedia.org/wiki/User:Clinical_Cases Clinical_Cases]: I made the photo myself, licensed under Creative Commons license*



# Pressures during a Breathing Cycle

## Boyle`s Law:

The pressure of a given quantity of gas is inversely proportional to its volume (assuming a constant temperature)

# INSPIRATION – a Sequence of Events

Inspiratory muscles contract

Thoracic cavity expands (volume ↑)

Pleural pressure ($P_{pl}$) ↓
(becomes more subatmospheric)

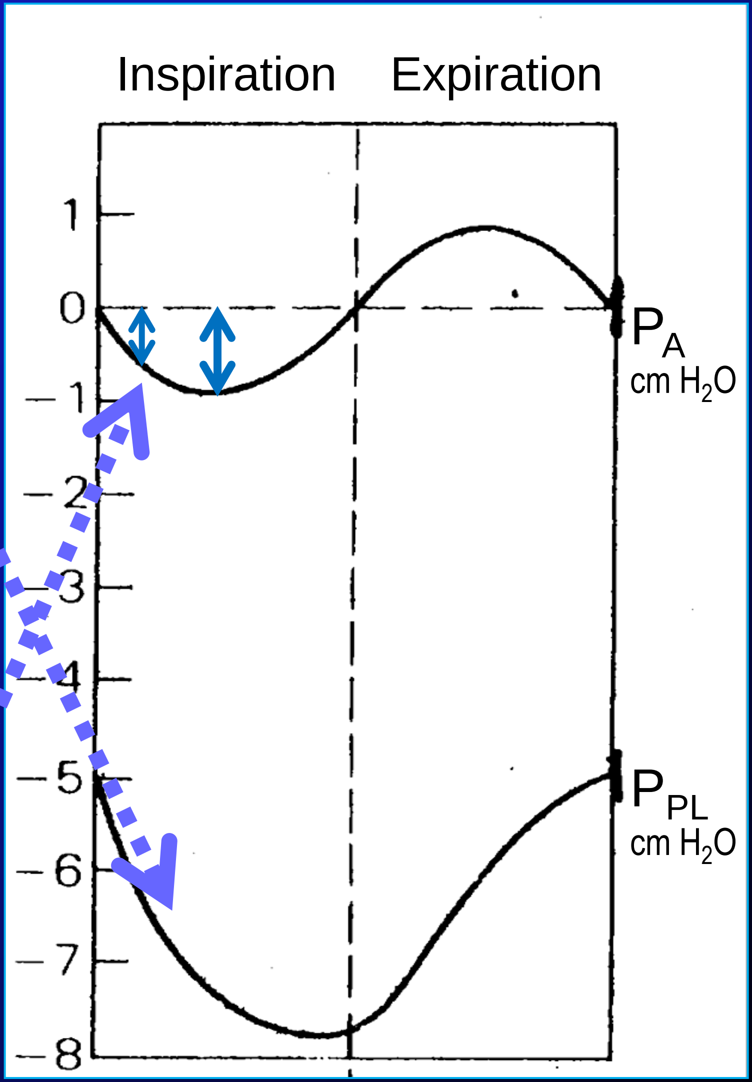
Transpulmonary pressure ($P_{TP}$) ↑

Lungs expand (volume ↑)

Alveolar pressure ($P_A$) ↓
(becomes subatmospheric)

Pressure gradient in airways
(lower pressure in alveoli)
Air flows into the lungs

Alveolar and Pleural Pressures
during a Breathing Cycle (Quiet Breathing)



# EXPIRATION – a Sequence of Events

Respiratory muscles relax

Chest volume ↓

Pleural pressure ($P_{pl}$) ↑
(becomes less subatmospheric)

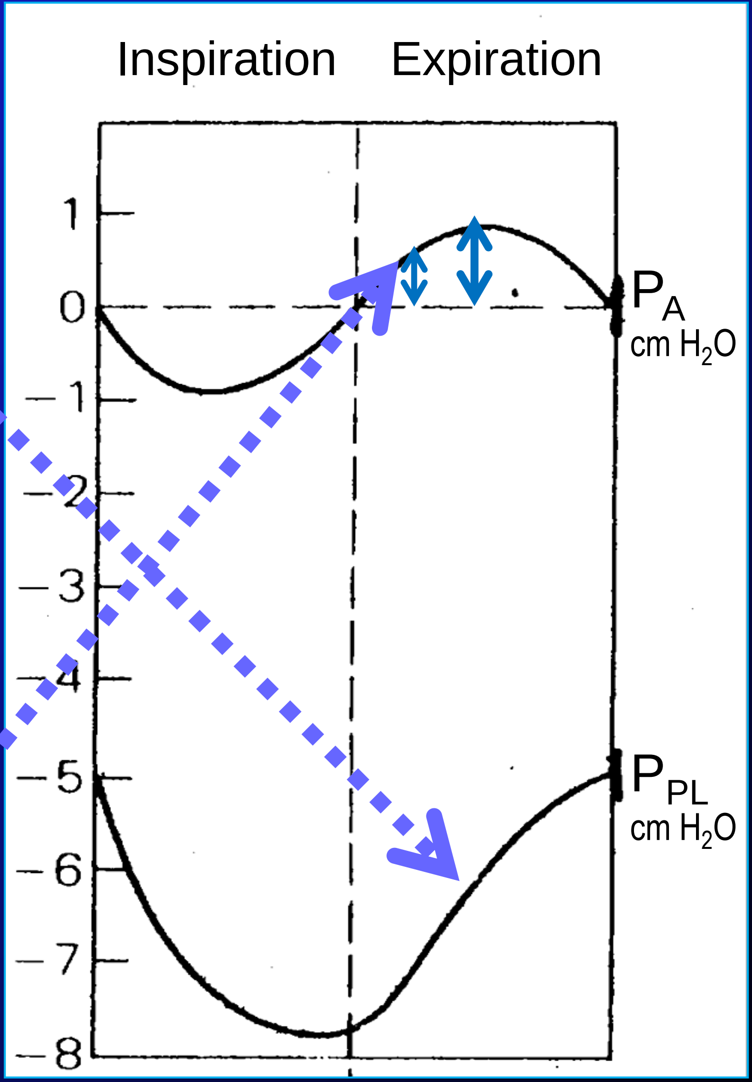
Transpulmonary pressure ($P_{TP}$) ↓

Lungs volume ↓

Alveolar pressure ($P_A$) ↑
(becomes possitive)

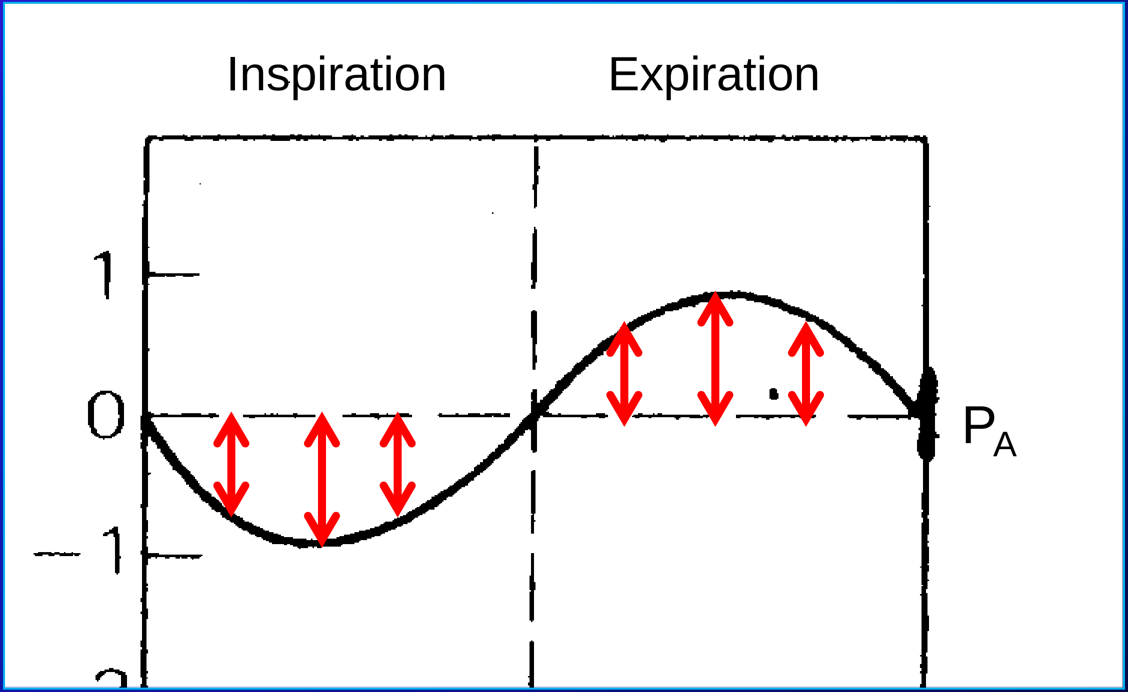
Pressure gradient in airways
(higher pressure in alveoli)
Air flows out of the lungs

Alveolar and Pleural Pressures
during a Breathing Cycle (Quiet Breathing)



# Pressures during a Breathing Cycle

*Pressure difference (gradient)*
*between upper airways ($P_{atm}$) and alveolar pressure ($P_A$)*
*is a driving pressure for air flow into or out of the lungs*




Pressure gardient = 0 → no air flow
→ airway resistance is 0

# Lung compliance ($C_L$)

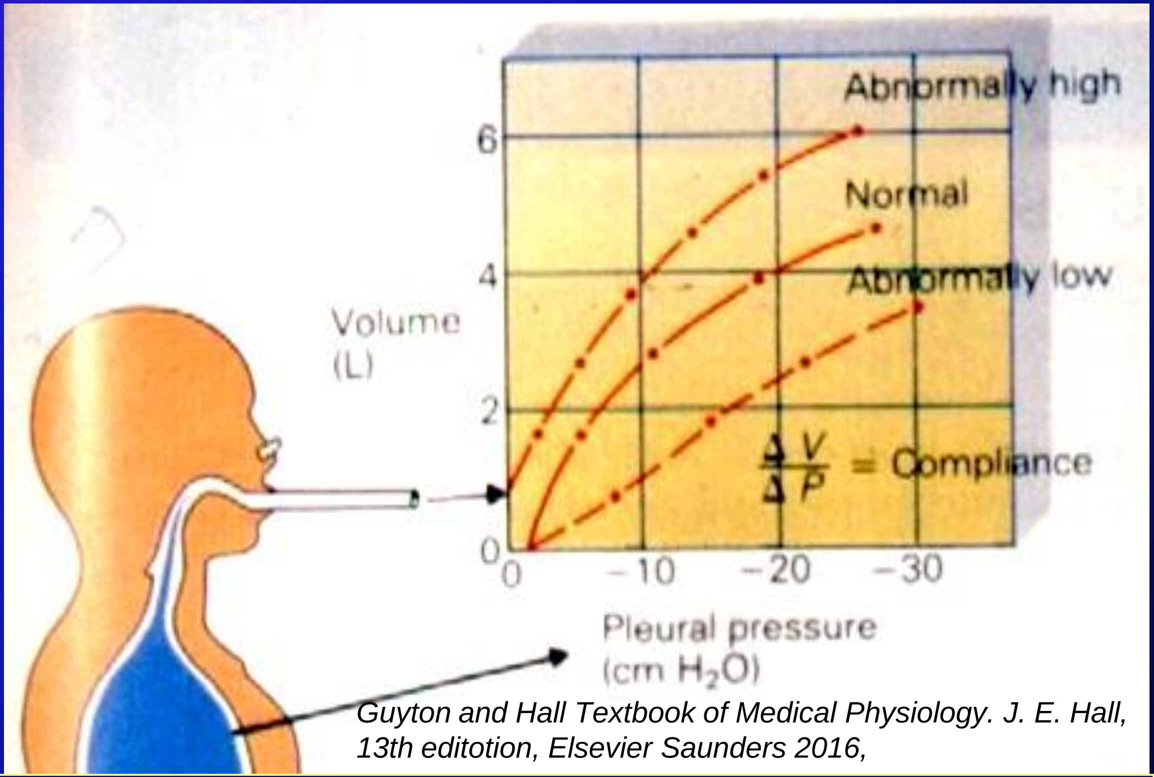
- describes distensibility of the lung and chest wall
- reflex the easy with which an object can be deformed

Elastance (E)

reflex the opposition of an object to deformation by an external force

# Lung compliance ($C_L$)

- An index of lung distensibility
- $C_L = \Delta V/\Delta P$ (200 - 230 ml/ 1 cm $H_2O$)
- Lung volume change / unit intrapleural pressure change

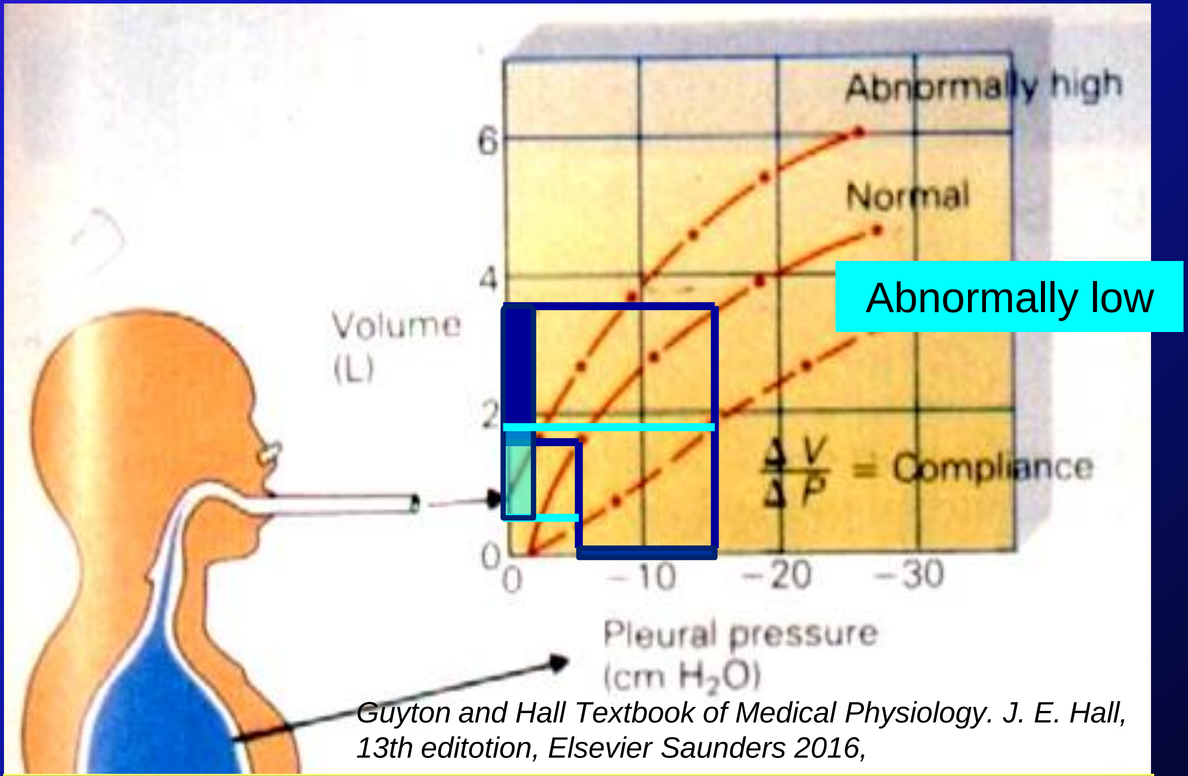



*Guyton and Hall Textbook of Medical Physiology. J. E. Hall, 13th editotion, Elsevier Saunders 2016,*

- a slope of the pressure - volume curve

# Lung compliance ($C_L$)

- An index of lung distensibility
- $C_L = \Delta V/\Delta P$ (200 - 230 ml/ 1 cm $H_2O$)
- Lung volume change / unit intrapleural pressure change

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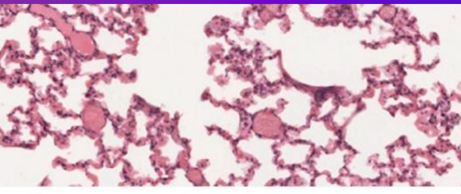
Lower compliance

# ↓ Lung Compliance ($C_L$)

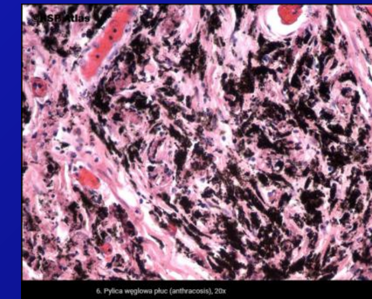
- Alveolar filling processes (pneumonia, alveolar edema)
- Interstitial pulmonary diseases (fibrosis, pneumonia, edema)
- Pulmonary congestion
- Respiratory distress syndrome

*Rapid, shallow breathing*



http://www.patologia.cm.umk.pl/atlas/

# ↓ Lung Compliance

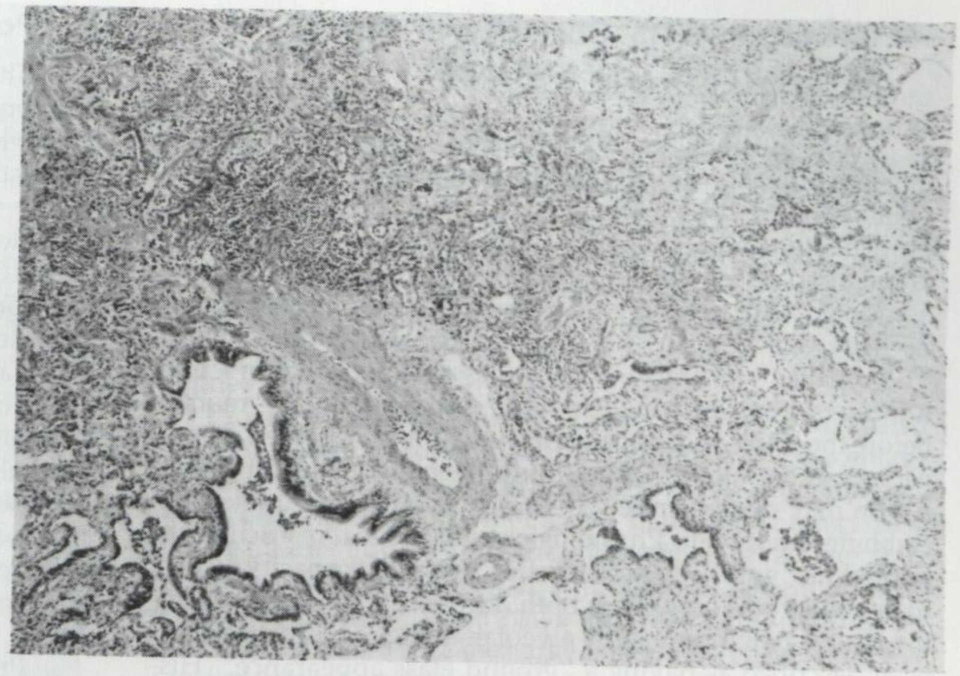


Pneumoconiosis: asbestosis

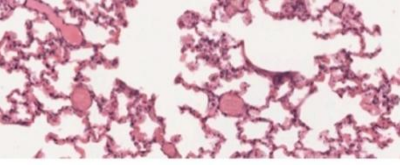
http://www.patologia.cm.umk.pl/atlas/

## *Interstitial pulmonary fibrosis*

**Figure 163–1.** Severe pulmonary fibrosis. The majority of the lung tissue is consolidated because of a combination of air space collapse and accumulations of nondistensible fibrous tissue within the interstitium and former air spaces. Little functional gas-exchange tissue is present except for a few partially collapsed alveoli. Compare with normal lung in Figure 160–1A. Original magnification = 75×. (Courtesy of Dr. Rodney Schmidt, Pathology Department, University of Washington)



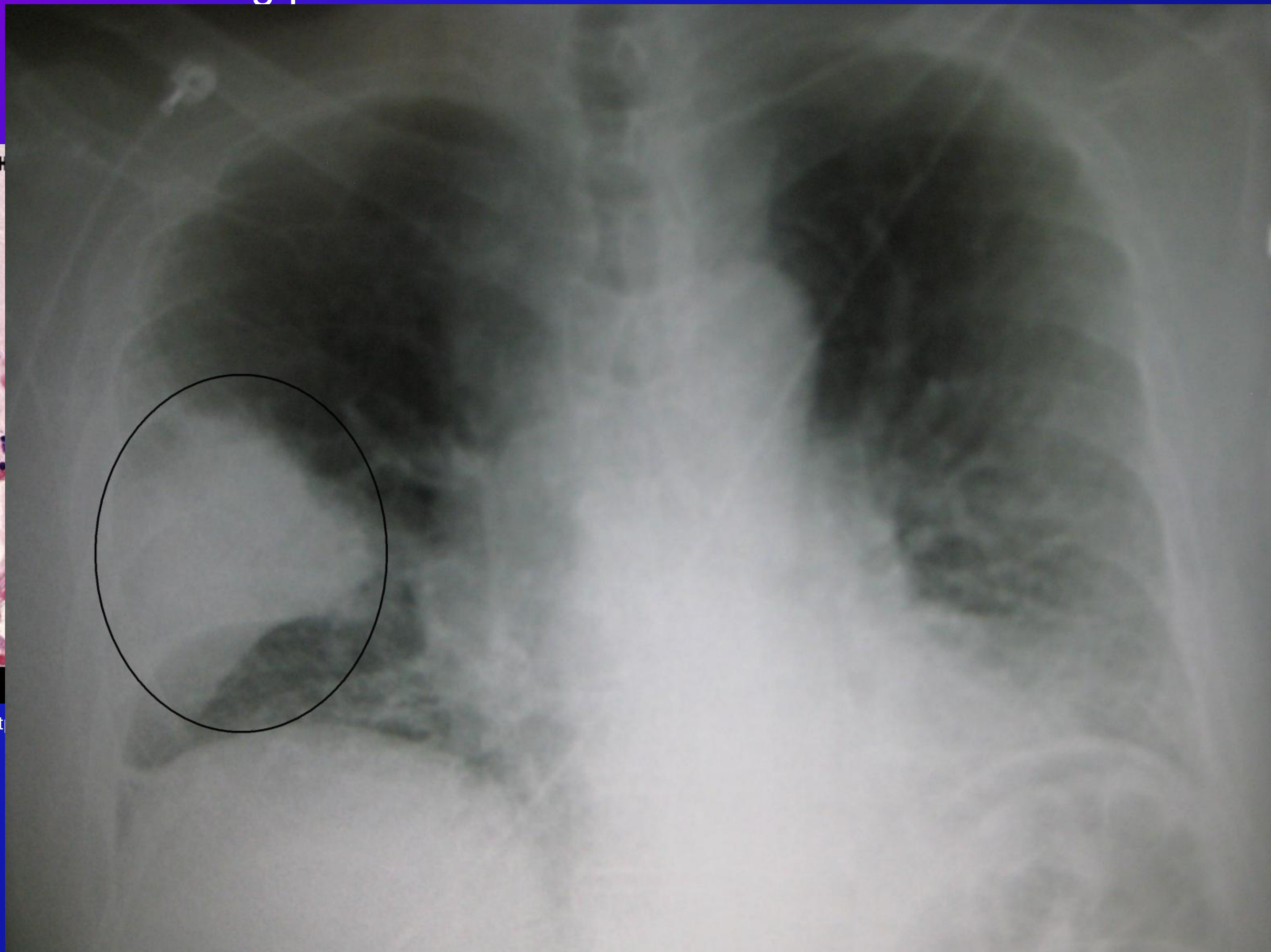
*Scarring throughout the lungs*



http://www.patologia.cm.umk.pl/atlas/

# ↓ Lung compliance

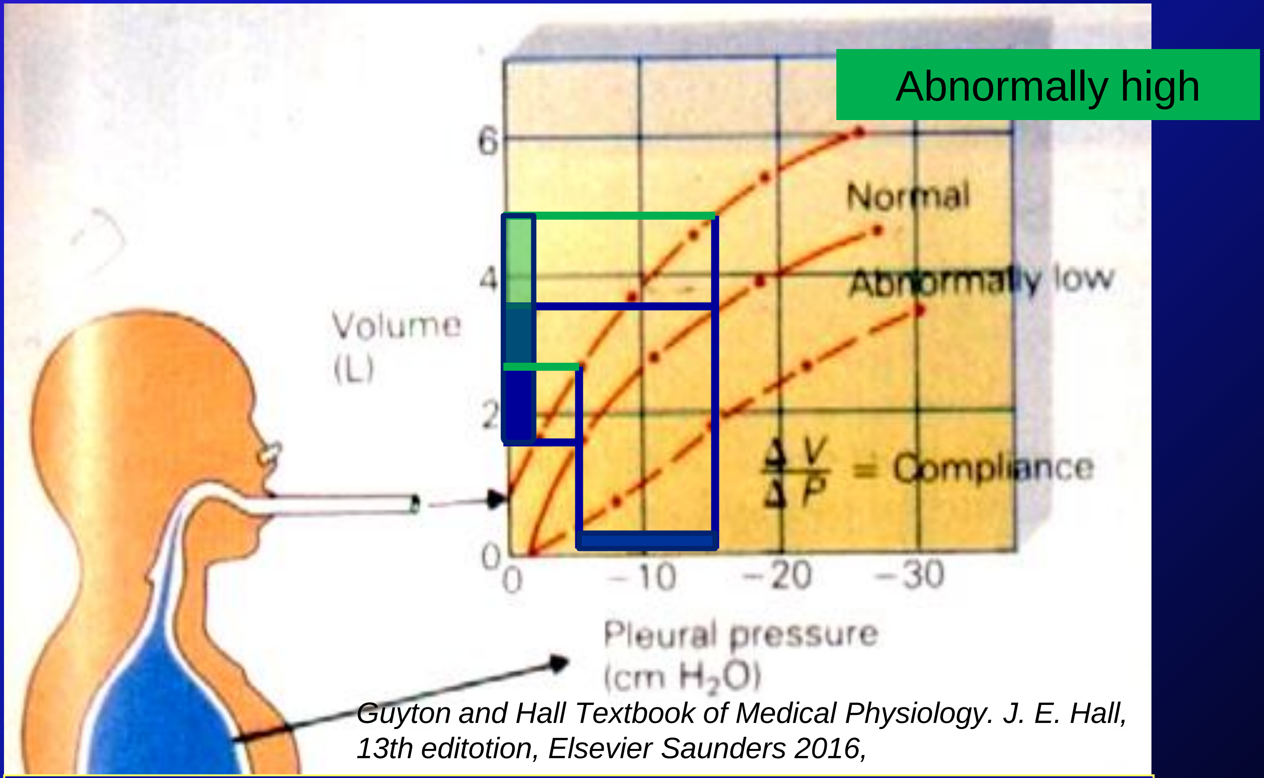
- alveolar filling processes



By James Heilman, MD [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], from Wikimedia Commons

# Lung compliance ($C_L$)

- An index of lung distensibility
- $C_L = \Delta V/\Delta P$ (200 - 230 ml/ 1 cm $H_2O$)
- Lung volume change / unit intrapleural pressure change

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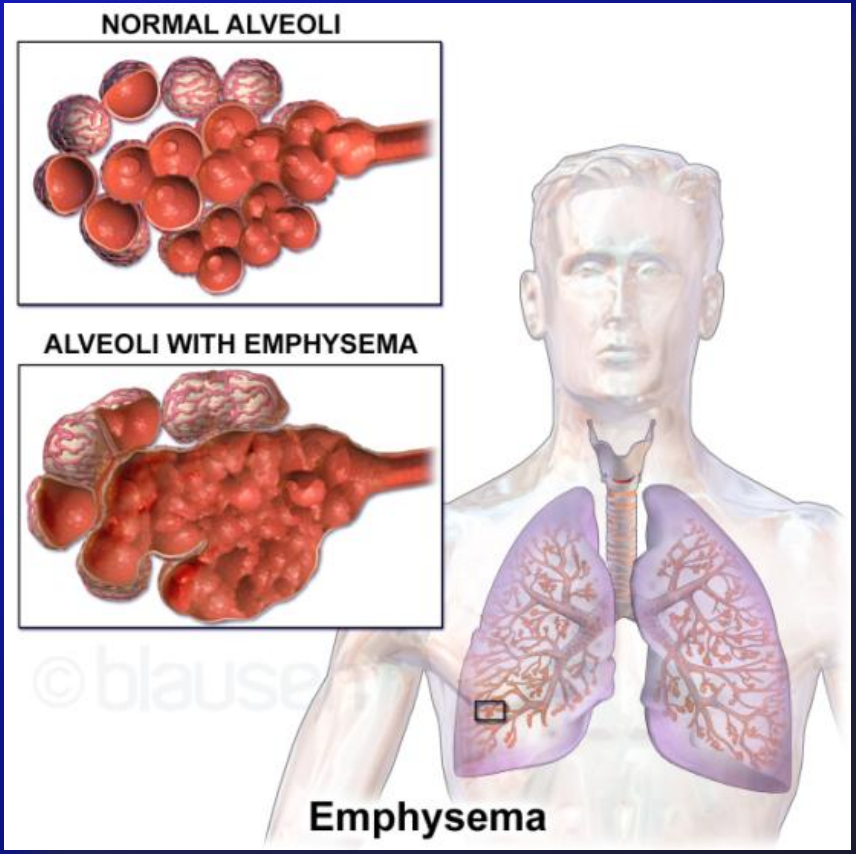
Higher compliance

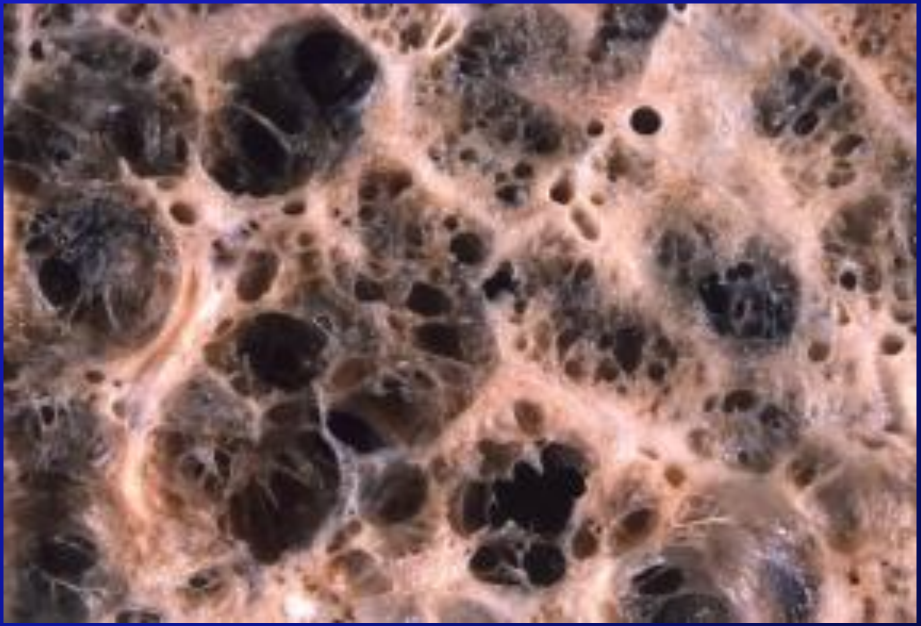
# ↑ Lung compliance

- Emphysema
- Ageing



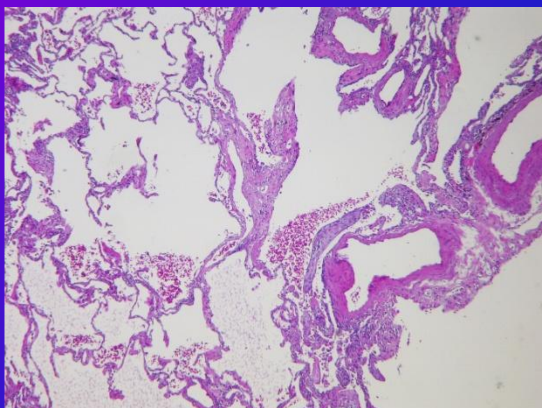
# Emphysema

- Destruction of lung elastic fibers
  - Smoking → ↑ proteases (elastase), ↓ α1-antytripsin
  - Congenital deficiency of α1-antytripsin

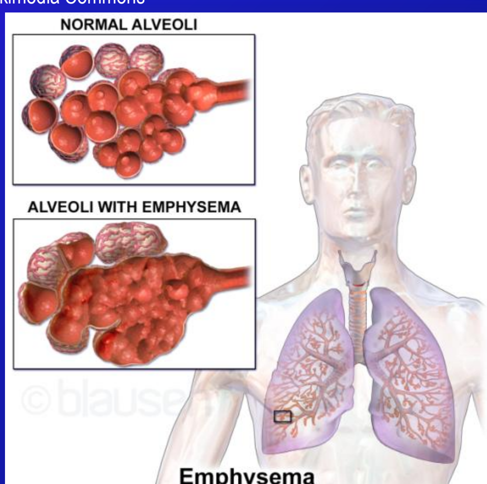


# Emphysema

- Destruction of lung elastic fibers



By Yale Rosen from USA (Emphysema, centrilobularUploaded by CFCF) [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons

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*What happens to*

1. *the tendency of the lungs to collapse?*
2. *lung recoil?*
3. *pleural pressure?*
4. *lung compliance?*
5. *airway resistance?*
6. *the easy with which the patient inspires?*
7. *the easy with which the patient expires?*

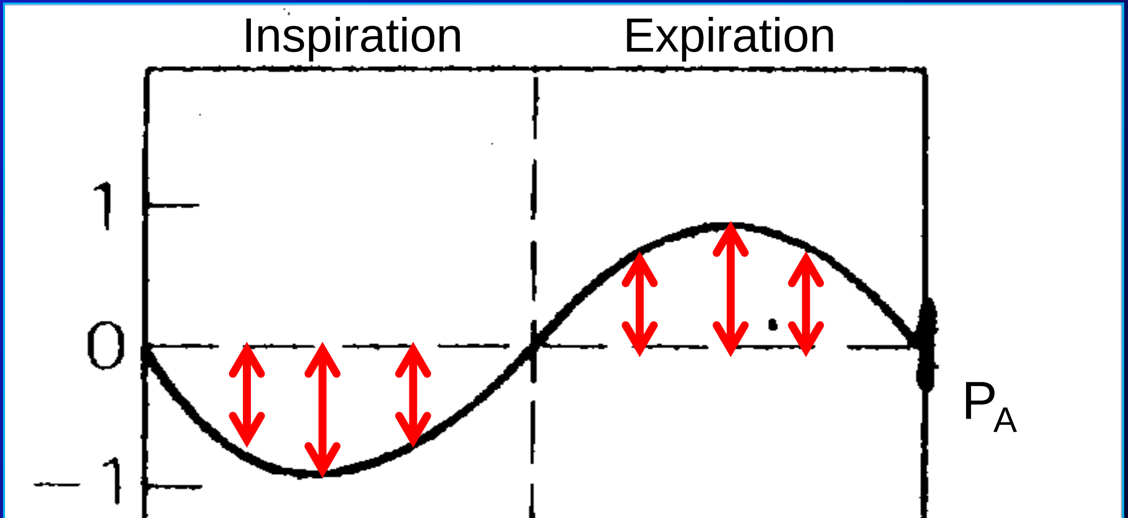
# Lung Recoil versus Airway Resistance

## 1. Lung Recoil

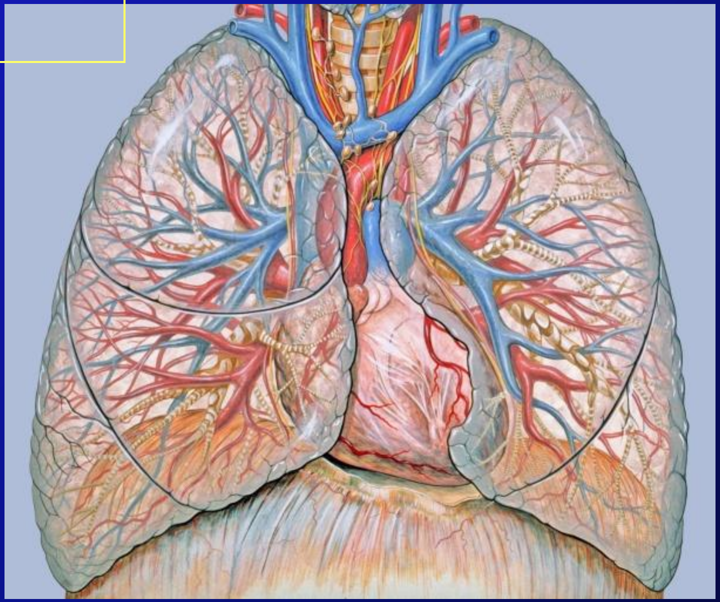
- ➢ results from lung distension
- ➢ caused by lung elastic forces and surface tension in the alveoli
- ➢ occurs <u>always</u> both under
  static conditions (breath holding, no air flow) and
  dynamic conditions (during air flow))

## 2. Airway Resistance

- ➢ occurs <u>only</u> under dynamic conditions (during air flow)



# Lungs:





- Ventilation
- Perfusion
- Gas Exchange - Diffusion

# Distribution of Ventilation

*Our lungs are NOT uniform !!!*

Upright Position

*In the lower parts of the lungs ventilation is ……….*
*than in the upper ones*

*Details – please wait for the lecture*

# Distribution of Blood Flow (Perfusion)

*Our lungs are NOT uniform !!!*

Upright Position

*In the lower parts of the lungs perfusion is ……….*
*than in the upper ones*

*Details – please wait for the lecture*

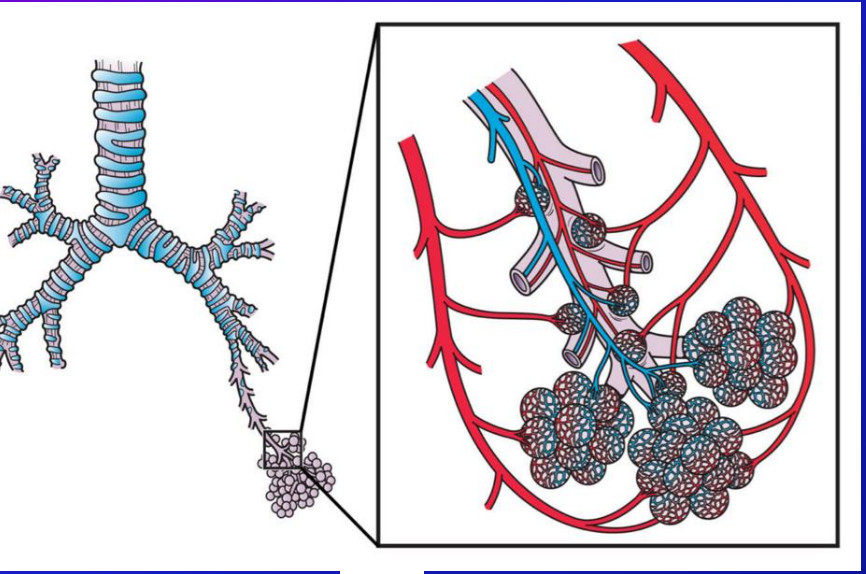
VENTILATION / PERFUSION RATIO

$$\dot{V}_A / \dot{Q}$$

The major determinant of gas exchange !!!

# VENTILATION / PERFUSION RATIO

$$\dot{V}_A / \dot{Q}$$



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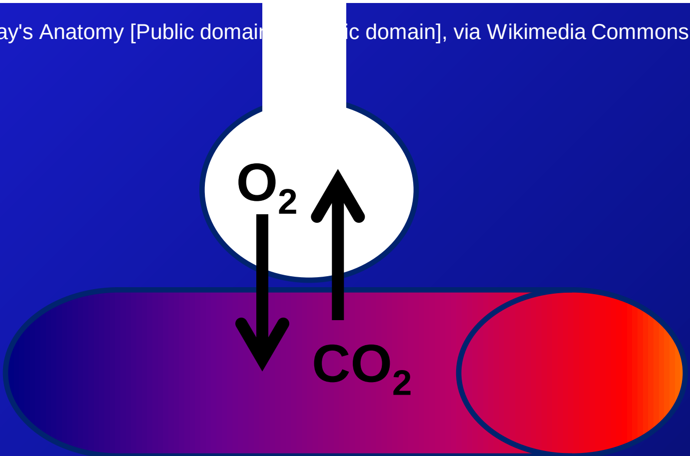
In the lungs:

*Ventilation of alveoli makes sense*
***<u>only if</u>***
*blood flow (perfusion) simultaneously occurs in this region*

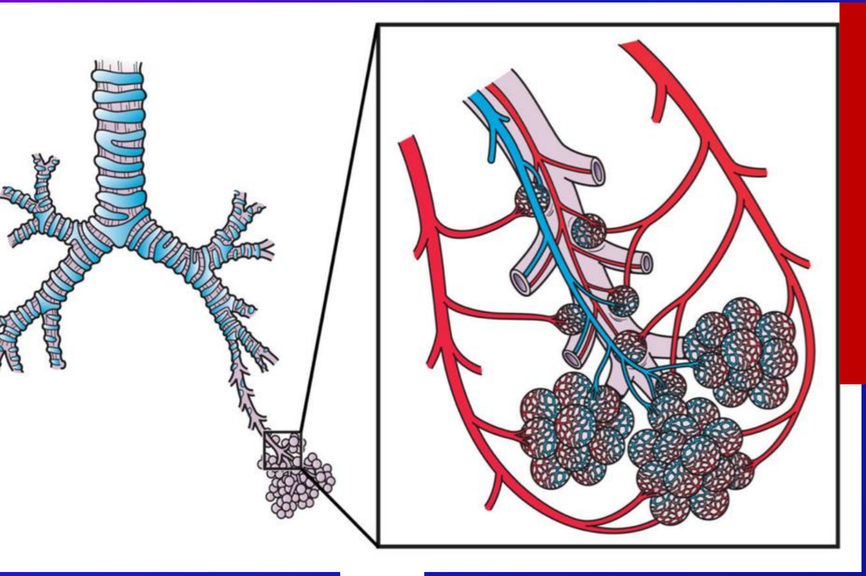
*Blood flow (perfusion) makes sense*
***<u>only if</u>***
*alveoli are simultaneously ventilated*




Both ventilation and perfusion <u>are essential</u> for gas exchange to occur

# VENTILATION / PERFUSION RATIO

$$\dot{V}_A / \dot{Q}$$



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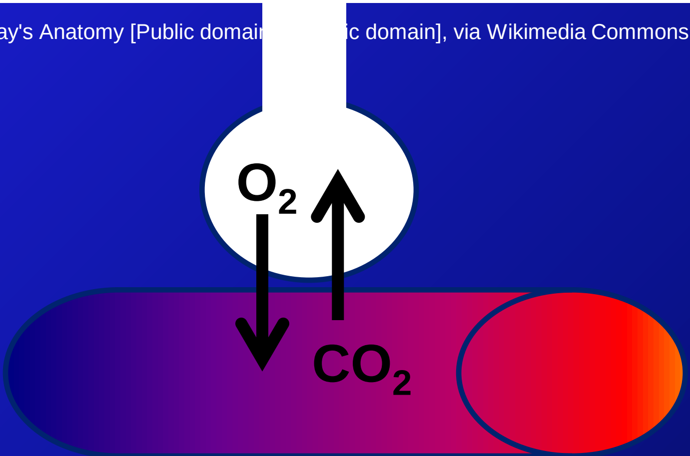



Ventilation/perfusion matching creates optimal conditions for gas exchange

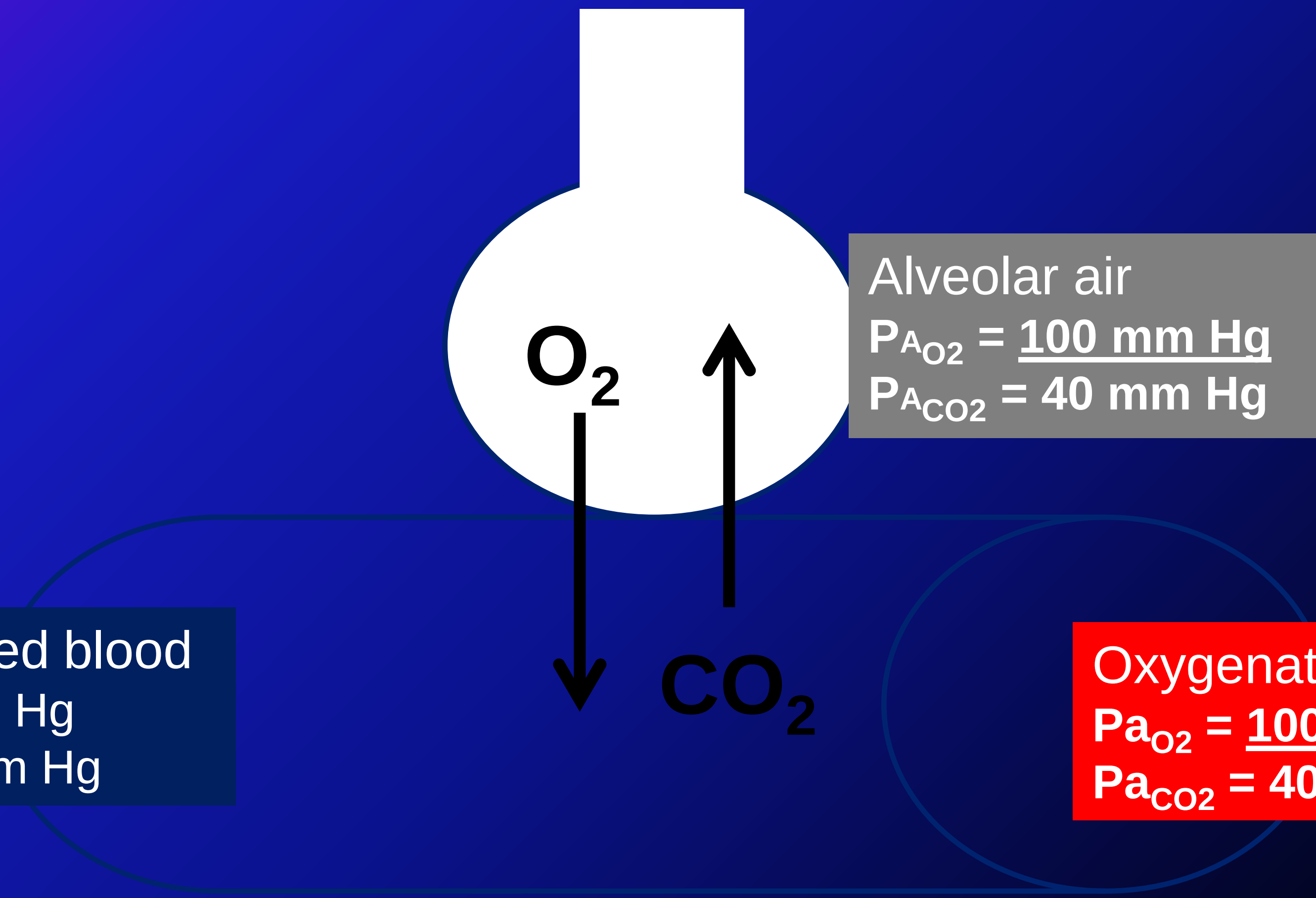
Ventilation Rate = Perfusion Rate

$$\boxed{\dot{V}_A / \dot{Q} = 1}$$

Both ventilation and perfusion are essential for gas exchange to occur

## Ventilation / Perfusion Ratio
## *Matching*

$\dot{V}_A / \dot{Q} = \underline{1}$ (ideal conditions for gas exchange)



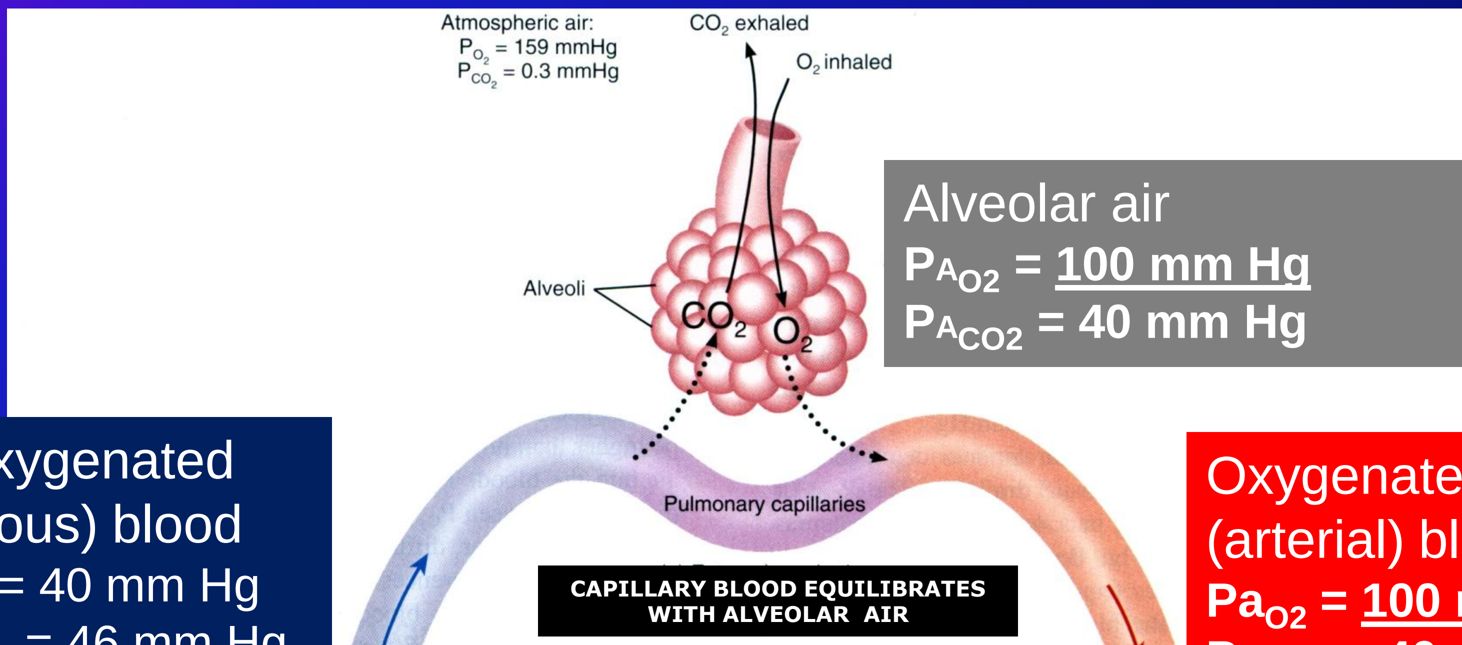

**Alveolar air**
$P_{A_{O2}}$ = **<u>100 mm Hg</u>**
$P_{A_{CO2}}$ = **40 mm Hg**

**Deoxygenated blood**
$Pv_{O2}$ = 40 mm Hg
$Pv_{CO2}$ = 46 mm Hg

**Oxygenated blood**
$Pa_{O2}$ = **<u>100 mm Hg</u>**
$Pa_{CO2}$ = **40 mm Hg**

# Ventilation / Perfusion Ratio
## *Matching*

$\dot{V}_A / \dot{Q} = \underline{1}$ (ideal conditions for gas exchange)




Alveolar air
**$P_{A_{O2}}$ = <u>100 mm Hg</u>**
**$P_{A_{CO2}}$ = 40 mm Hg**

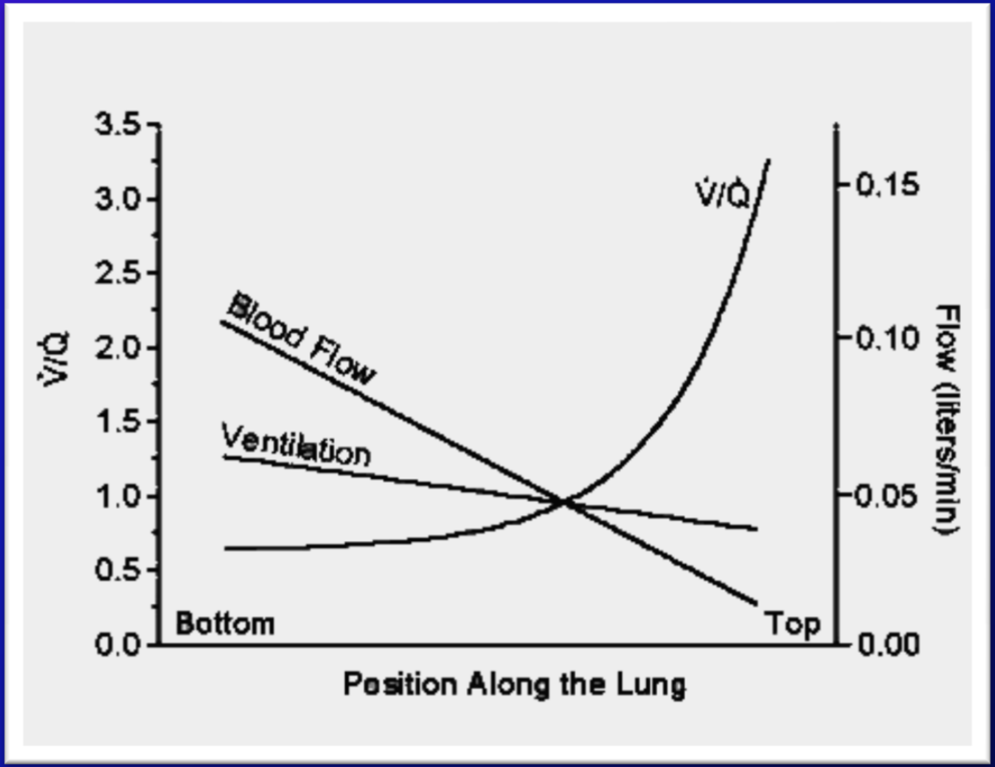
Deoxygenated (venous) blood
$Pv_{O2}$ = 40 mm Hg
$Pv_{CO2}$ = 46 mm Hg

Oxygenated (arterial) blood
**$Pa_{O2}$ = <u>100 mm Hg</u>**
**$Pa_{CO2}$ = 40 mm Hg**

Ventilation – perfusion relationship can be measured by calculating alveolar – arterial $P_{O2}$ difference

# Pulmonary Ventilation, Pulmonary Perfusion

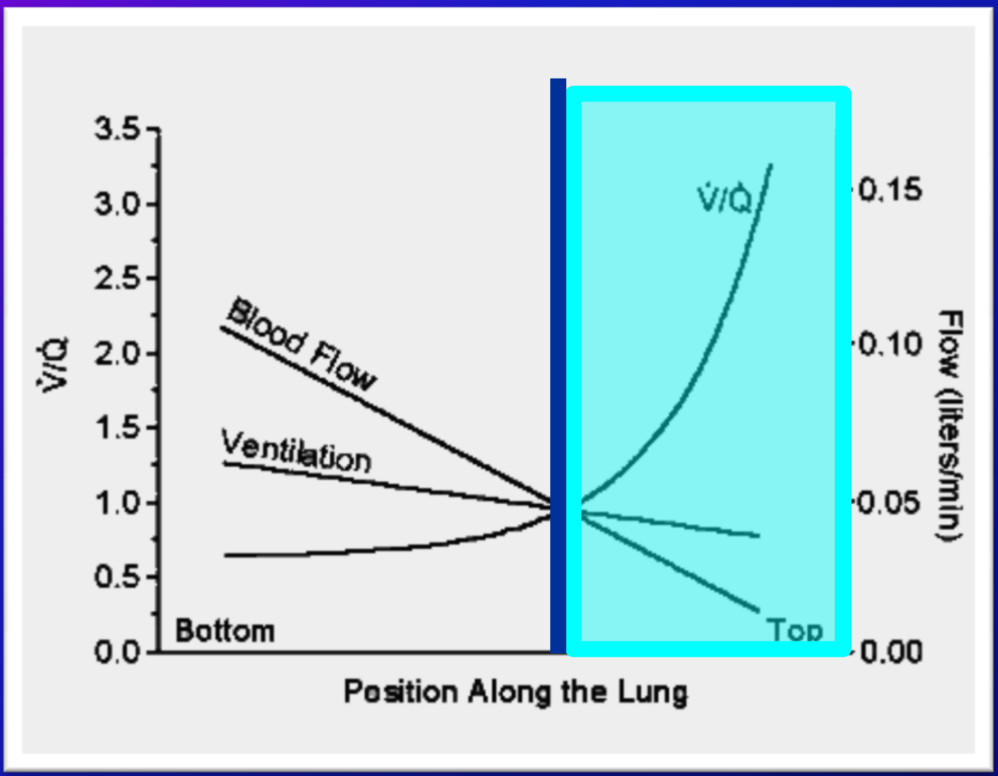
# Ventilation / Perfusion Ratio $\dot{V}_A / \dot{Q}$




Upright Position

# Ventilation / Perfusion Ratio
## *Mismatching (Imbalance)*

$\uparrow \dot{V}_A / \dot{Q}$




<u>Upper portions of lungs</u>

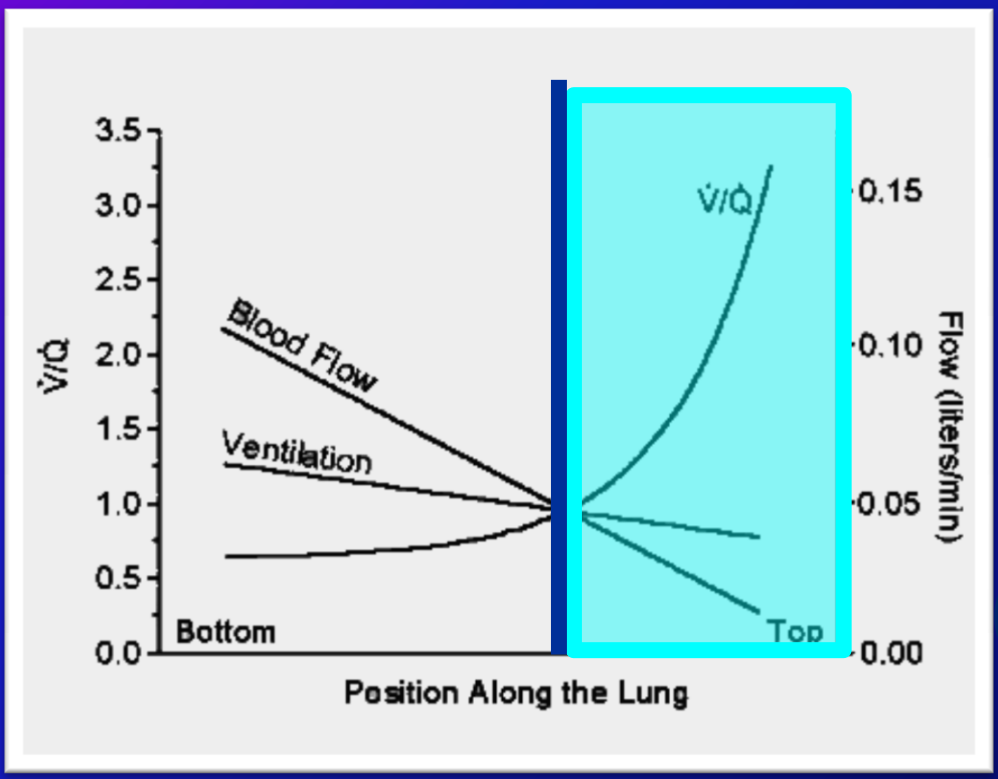
- Both blood flow and ventilation are much less than in the lower parts
- Blood flow is decreased considerably more than is ventilation

Excessive ventilation in relation to perfusion

Perfusion insufficient in relation to ventilation

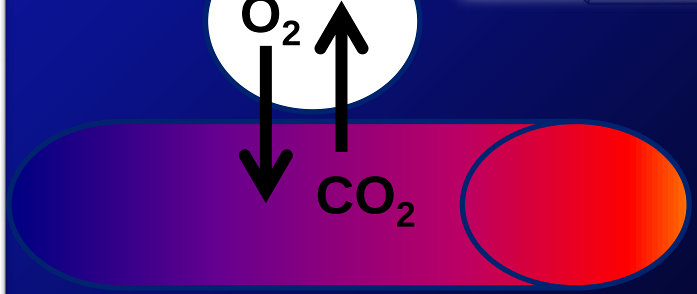
Ventilation / Perfusion Ratio

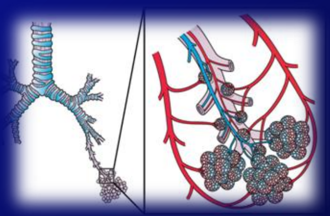
*Mismatching (Imbalance)*




$\uparrow \dot{V}_A / \dot{Q}$

Upper portions of lungs



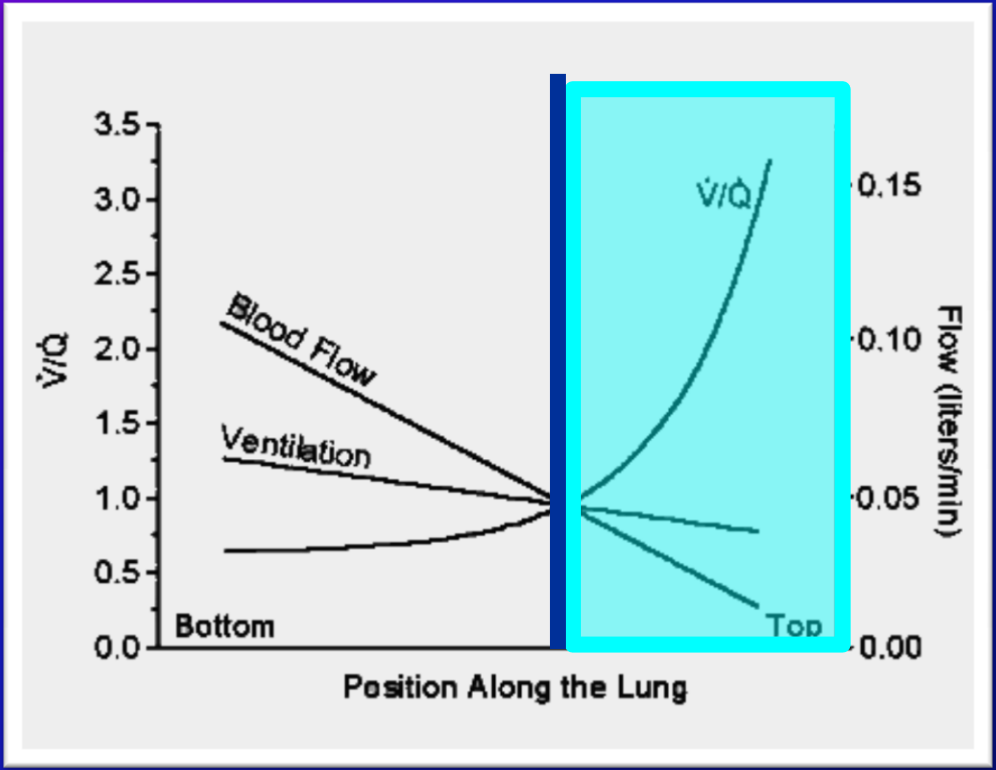



$\uparrow Po_2$ $\downarrow Pco_2$

Ventilation / Perfusion Ratio

*Mismatching (Imbalance)*

$\uparrow \dot{V}_A / \dot{Q}$




Upper portions of lungs

*Blood leaving upper portions of the lungs has higher $P_{O_2}$ than the optimal value (100 mg Hg).*

Does this phenomenon actually effect on average $P_{O_2}$ in blood leaving the lungs???

$\uparrow P_{O_2}$ $\downarrow P_{CO_2}$

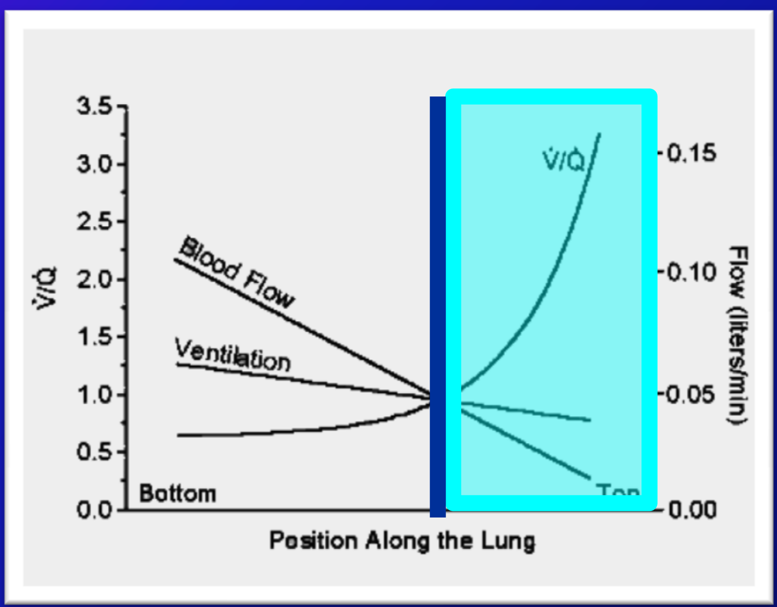
# Ventilation / Perfusion Ratio
# *Mismatching (Imbalance)*

Upper portions of lungs

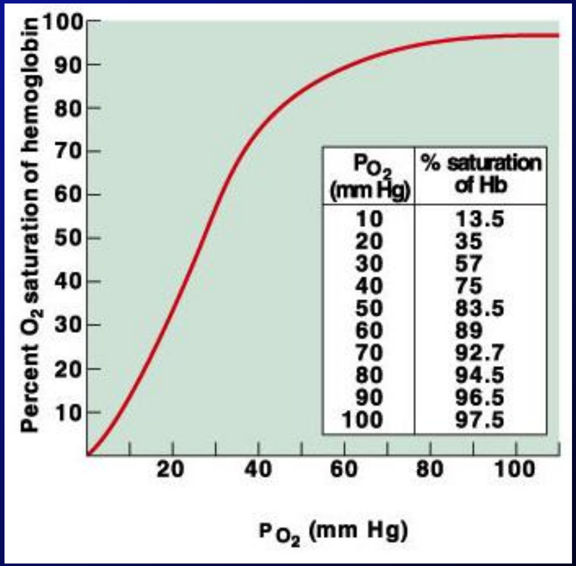
↑ $\dot{V}_A / \dot{Q}$

↑ $P_{O_2}$ ↓ $P_{CO_2}$

1. Minor distribution (7-10%) to the total amount of blood (low blood flow)




2. Hb is maximally saturated at $P_{O_2} \geq 100$ mm Hb

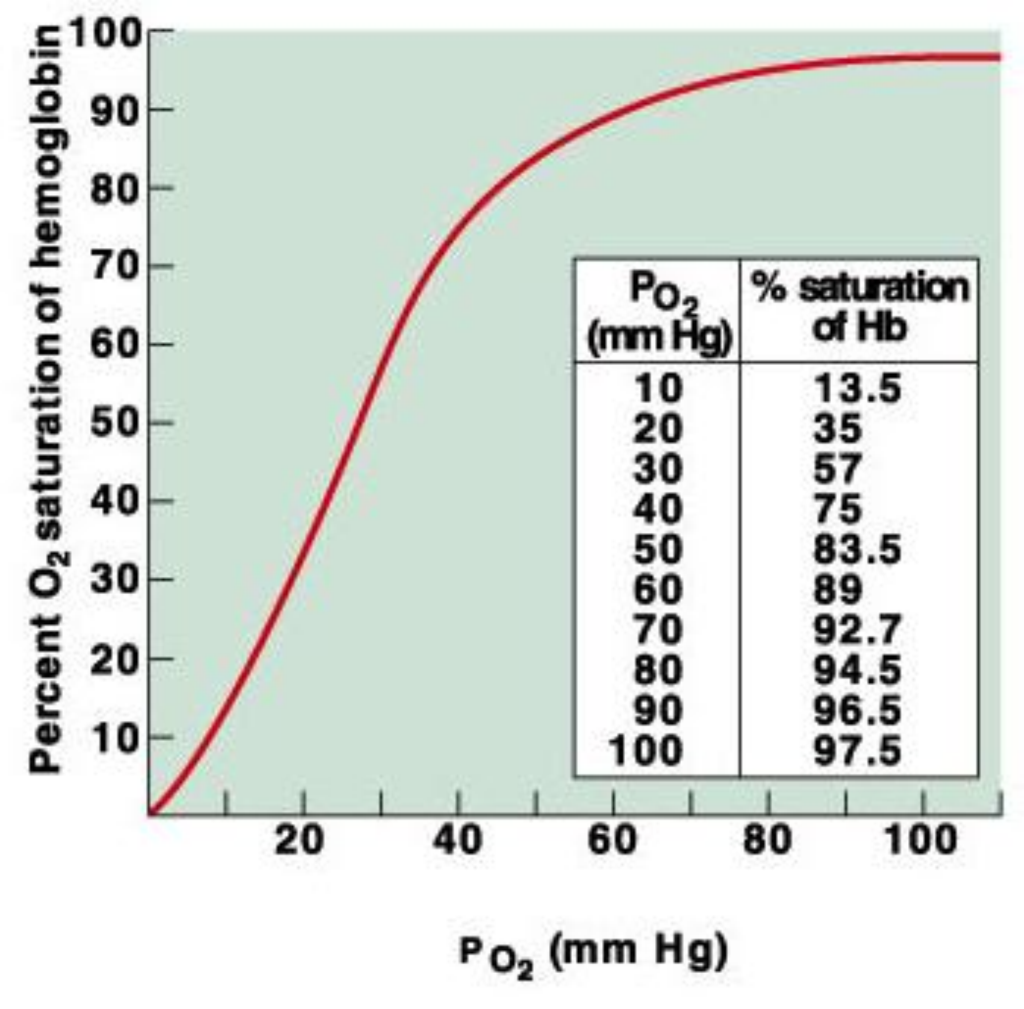



Oxygen-Hemoglobin Dissociation Curve at Rest

# Oxygen-Hemoglobin Dissociation Curve at Rest

Oxygen is transported
- by hemoglobin (98.5%)
- dissolved in plasma (1.5%)

Oxygen-hemoglobin dissociation curve shows that hemoglobin is almost completely saturated when $PO_2$ is 80 mm Hg or above.
At lower partial pressures, the hemoglobin releases oxygen




| $P_{O_2}$ (mm Hg) | % saturation of Hb |
|---|---|
| 10 | 13.5 |
| 20 | 35 |
| 30 | 57 |
| 40 | 75 |
| 50 | 83.5 |
| 60 | 89 |
| 70 | 92.7 |
| 80 | 94.5 |
| 90 | 96.5 |
| 100 | 97.5 |

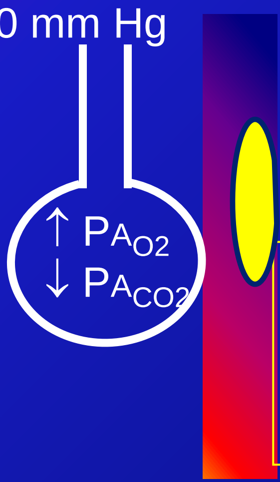
# ↑ $\dot{V}_A / \dot{Q}$ – Pathology

Over ventilated / Under perfused alveoli

- Obstruction (embolism) of pulmonary artery
- Compression (tumor, fluid, gas) of pulmonary artery
- Loss of capillary bed (emphysema), shock

$P_{I_{O2}}$= 150 mm Hg

$P_{I_{CO2}}$= 0 mm Hg




**Mixed venous blood**
$P_{v_{O2}}$= 40 mm Hg
$P_{v_{CO2}}$= 46 mm Hg

**Blood „leaving” the alveolus**
↑ $Pa_{O2}$

↓$Pa_{CO2}$ - hypocapnia

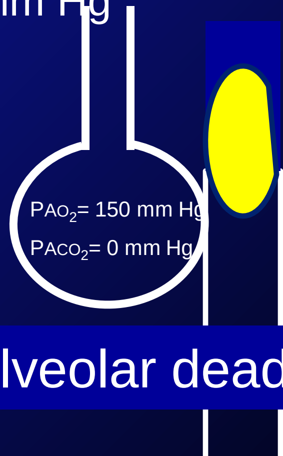
Q=0

Ventilated / No perfusion

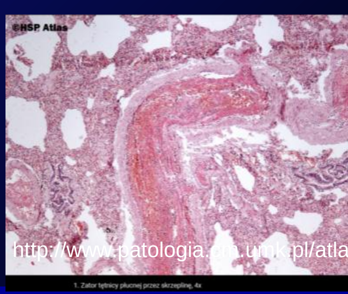
V/Q=infinity

$P_{I_{O2}}$= 150 mm Hg

$P_{I_{CO2}}$= 0 mm Hg




*No blood flow*




Alveolar dead space

# Dead space

Dead space – *a volume of the respiratory system that is ventilated but does not exchange gasses with pulmonary capillary blood:*

- Alveolar (functional) dead space

  Areas of the lung with high $\dot{V}_A / \dot{Q}$

  +

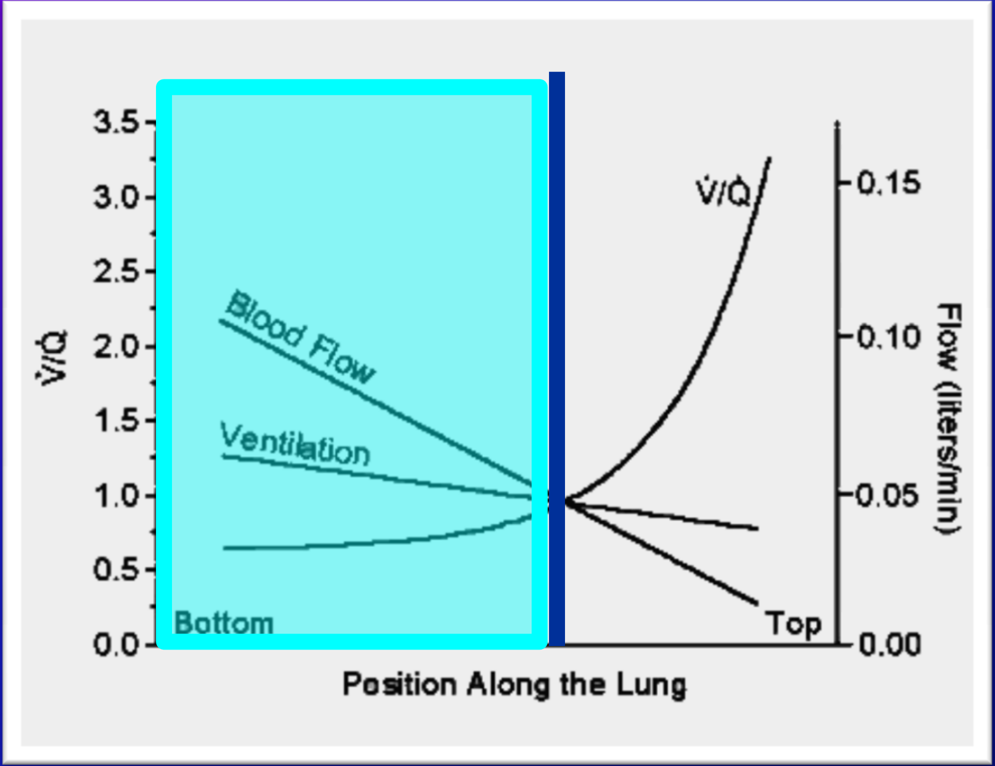
- Anatomic dead space

  =

*Physiologic dead space (wasted ventilation)*

# Ventilation / Perfusion Ratio
## *Mismatching (Imbalance)*

$\downarrow \dot{V}_A / \dot{Q}$




<u>Lower portions of lungs</u>

- Both blood flow and ventilation are much better than in the upper parts
- Blood flow is increased considerably more than is ventilation

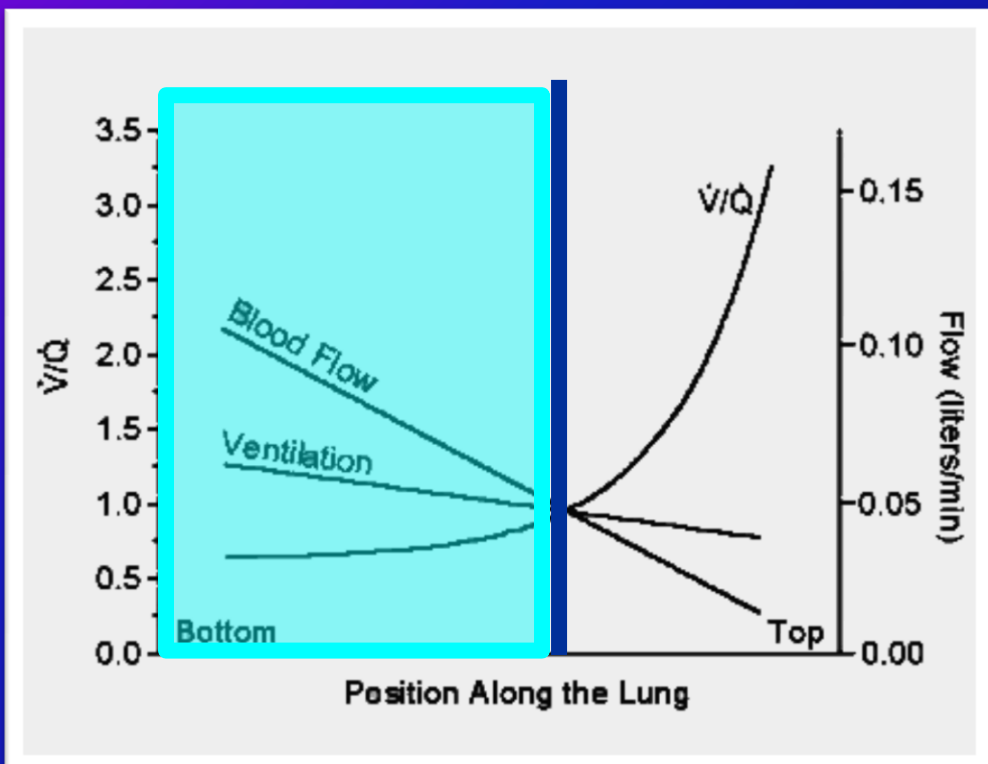
Excessive perfusion in relation to ventilation

Ventilation insufficient in relation to perfusion

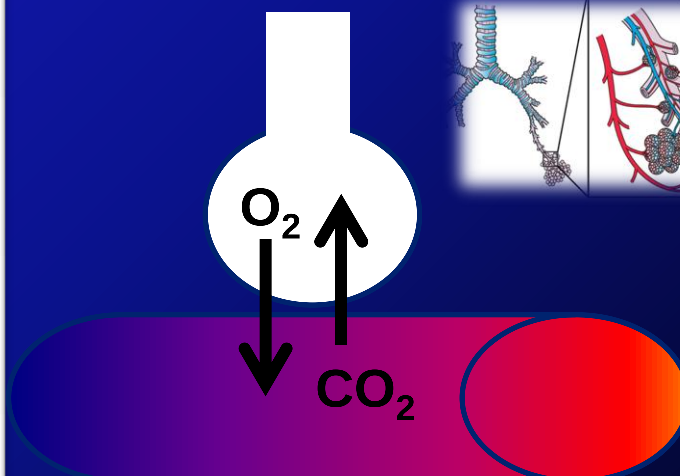
Ventilation / Perfusion Ratio

*Mismatching (Imbalance)*

$\downarrow \dot{V}_A / \dot{Q}$




Lower portions of lungs



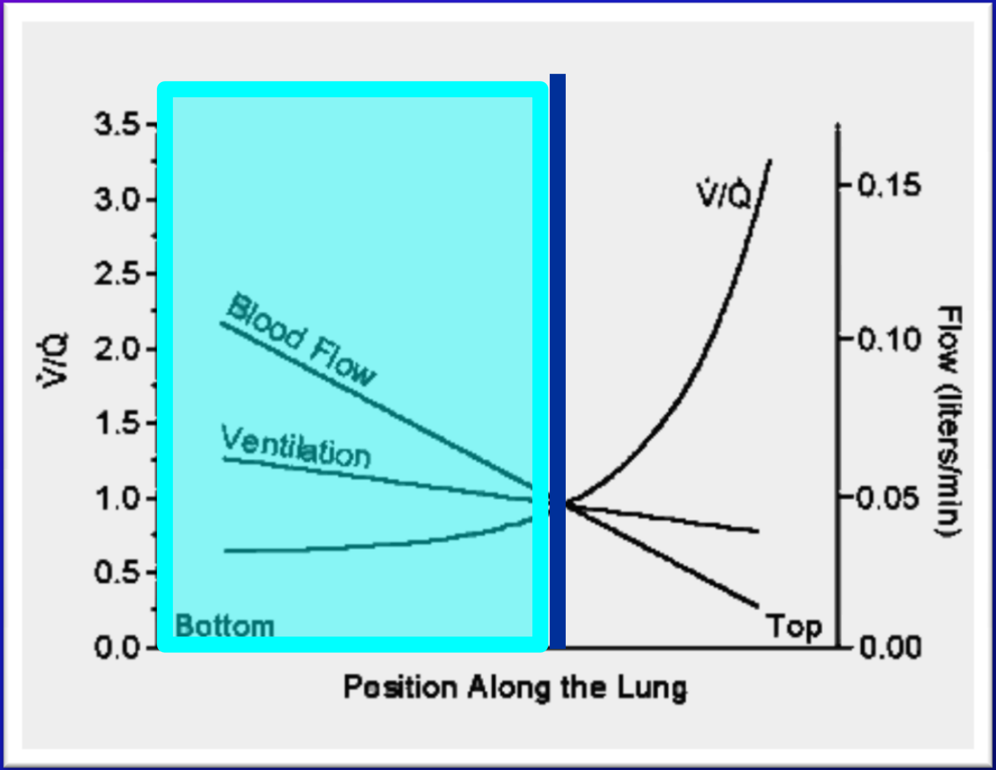

- A certain fraction of venous blood passing through the pulmonary capillaries does not become oxygenated **(Intrapulmonary shunt)**

$\downarrow PO_2 \quad \uparrow PCO_2$

Ventilation / Perfusion Ratio

*Mismatching (Imbalance)*

$\downarrow \dot{V}_A / \dot{Q}$




Lower portions of lungs

*Blood leaving lower portions of the lungs has lower $PO_2$ than the optimal value (100 mg Hg).*

Does this phenomenon actually effect on average $PO_2$ in blood leaving the lungs???

$\downarrow PO_2$ $\uparrow PCO_2$

# Ventilation / Perfusion Ratio
## *Mismatching (Imbalance)*

<u>Lower portions of lungs</u>

↓ $\dot{V}_A / \dot{Q}$

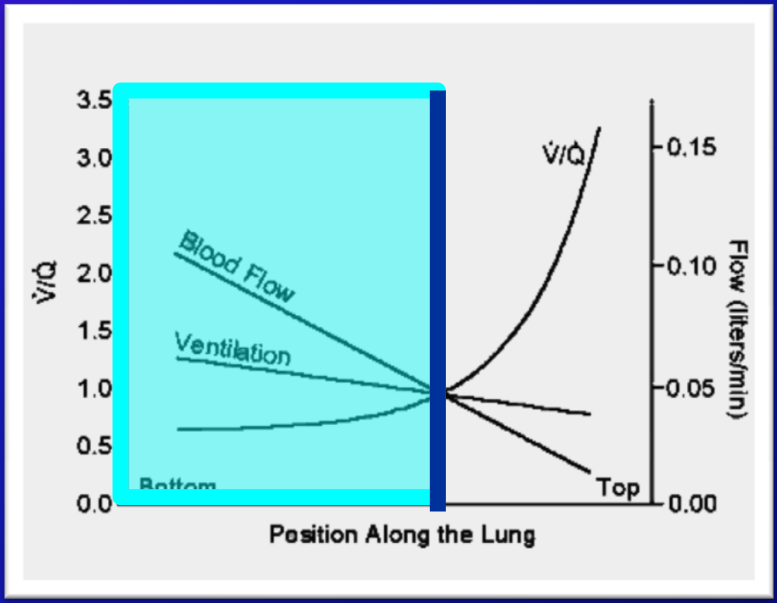
$\boxed{\downarrow P_{O_2} \uparrow P_{CO_2}}$

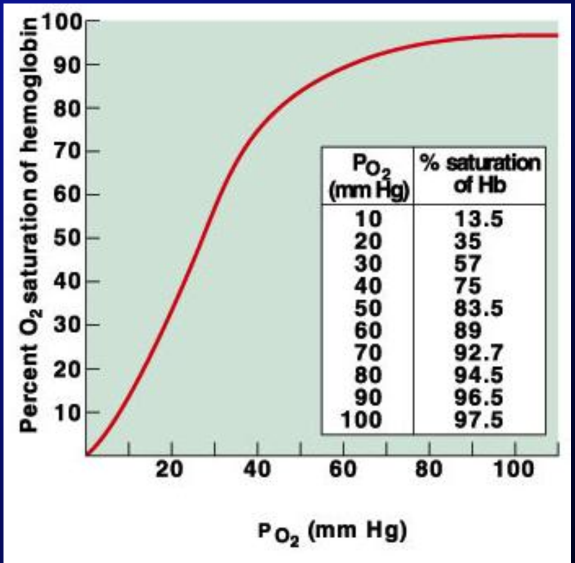
1. Major distribution (↑ 90%) to the total amount of blood (high blood flow)

2. A certain fraction of venous blood passing through the pulmonary capillaries does not become oxygenated

**(Intrapulmonary shunt)**

- A decrease in **$PO_2$ and $SO_2$** in blood leaving this region




Oxygen-Hemoglobin Dissociation Curve at Rest

# Shunt

*Blood that <u>bypasses</u> from systemic veins to systemic arteries without exchanging gas with alveolar air*

- Intrapulmonary shunts

  Areas of the lung with low $\dot{V}_A / \dot{Q}$

- Anatomic shunts :

  - Bronchopulmonary venous anastomoses

Bronchial circulation supplies: airways, supporting tissues, pulmonary arteries, veins

  - Intracardiac thebesian veins

Shunts – perfusion not used for gas exchange - 2%

# $\downarrow \dot{V}_A / \dot{Q}$ – Pathology

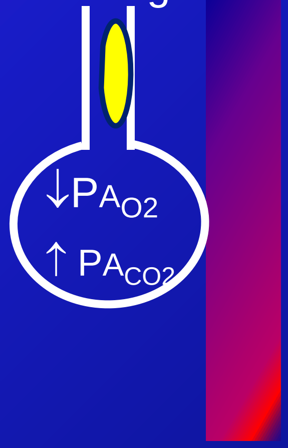
Under ventilated / Over perfused alveoli

- Narrowing of airways (asthma, bronchitis, emphysema)
- Compresion of airways (tumor, edema, fluid)

$PI_{O2}$= 150 mm Hg

$PI_{CO2}$= 0 mm Hg

Mixed venous blood
$Pv_{O2}$= 40 mm Hg
$Pv_{CO2}$= 46 mm Hg

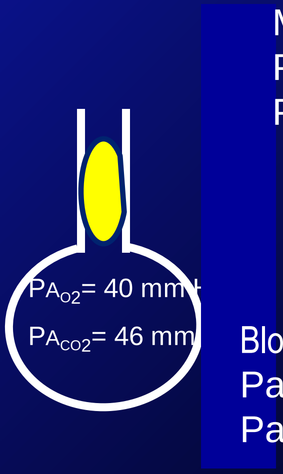



Blood „leaving” the alveolus
$\downarrow Pa_{O2}$- hypoxemia

$\uparrow Pa_{CO2}$ - hypercapnia

V=0
Unventilated / Perfused alveoli
V/Q= 0

Mixed venous blood
$Pv_{O2}$= 40 mm Hg
$Pv_{CO2}$= 46 mm Hg

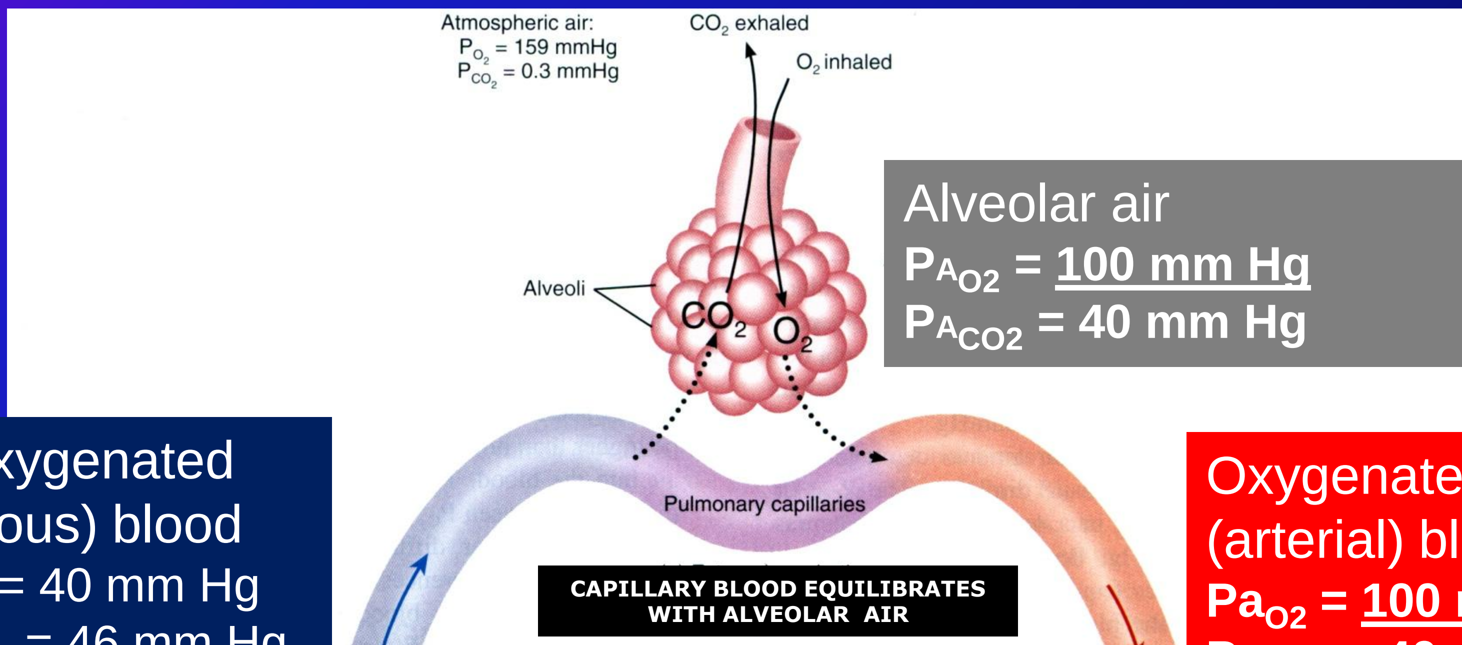



Blood „leaving” the alveolus
$Pa_{O2}$= 40 mm Hg
$Pa_{CO2}$= 46 mm Hg

Venous admixture –
Intrapulmonary shunt

# Ventilation / Perfusion Ratio
## *Matching*

$\dot{V}_A / \dot{Q} = \underline{1}$ (ideal conditions for gas exchange)




Alveolar air
**$PA_{O2}$ = <u>100 mm Hg</u>**
**$PA_{CO2}$ = 40 mm Hg**

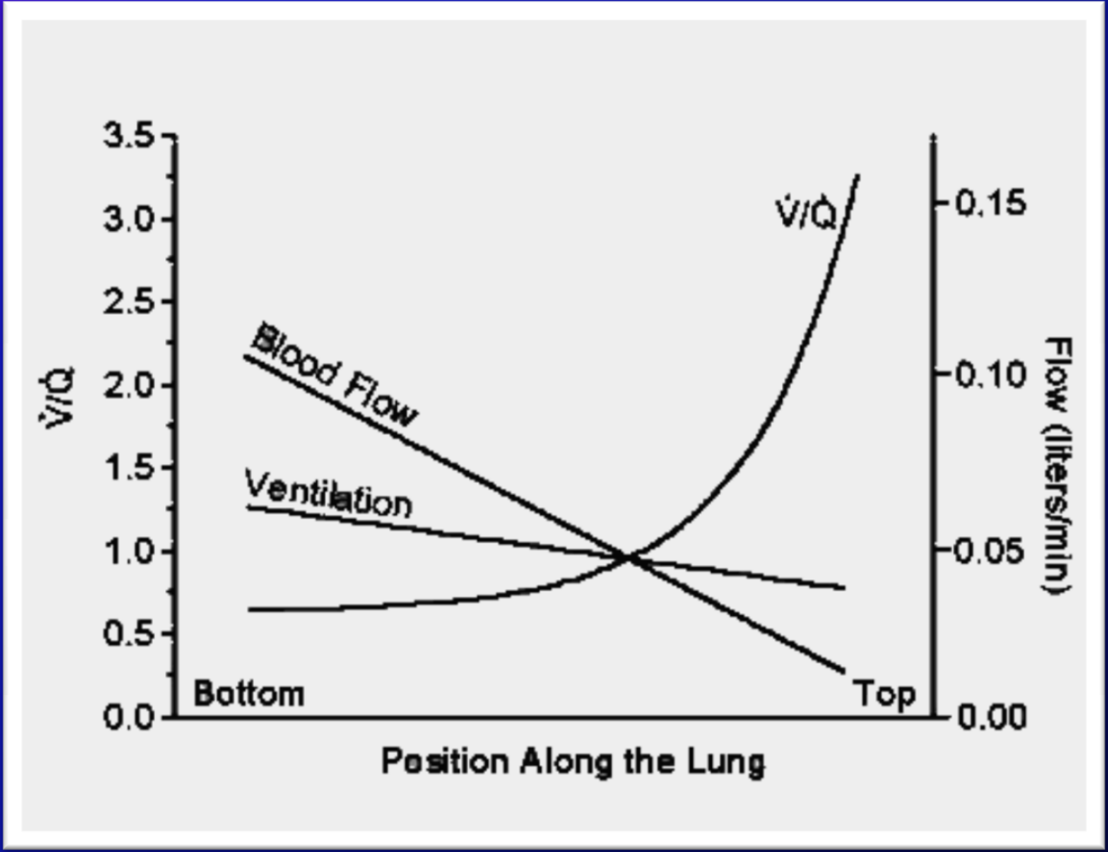
Deoxygenated (venous) blood
$Pv_{O2}$ = 40 mm Hg
$Pv_{CO2}$ = 46 mm Hg

Oxygenated (arterial) blood
**$Pa_{O2}$ = <u>100 mm Hg</u>**
**$Pa_{CO2}$ = 40 mm Hg**

Ventilation – perfusion relationship can be measured by calculating alveolar – arterial PO2 difference

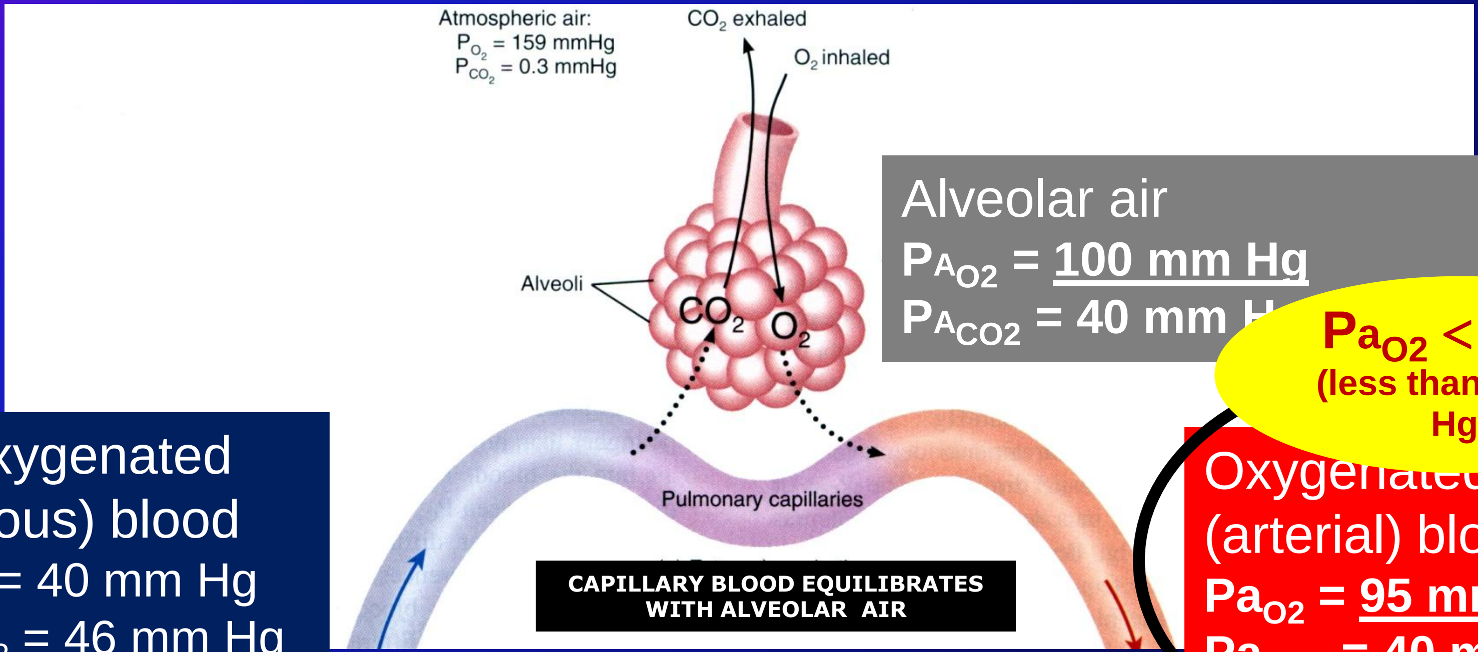
Ventilation / Perfusion Ratio

*Mismatching (Imbalance)*



# Ventilation / Perfusion Ratio *Mismatching*

$$\dot{V}_A / \dot{Q} = 4{,}2 \text{ L/min} / 5 \text{ L/min} = 0{,}85 \text{ (average)}$$




Alveolar air

**$PA_{O2}$ = 100 mm Hg**

**$PA_{CO2}$ = 40 mm H**

**$Pa_{O2} < PA_{O2}$**

**(less than 20 mm Hg)**

Deoxygenated (venous) blood

$Pv_{O2}$ = 40 mm Hg

$Pv_{CO2}$ = 46 mm Hg

Oxygenated (arterial) blood

**$Pa_{O2}$ = 95 mm Hg**

**$Pa_{CO2}$ = 40 mm Hg**

Ventilation – perfusion relationship can be measured by calculating alveolar – arterial $P_{O2}$ difference

Uneven matching of alveolar ventilation and alveolar blood flow –

*a major cause of systemic hypoxemia in patients with*

*cardiopulmonary diseases*

https://pixabay.com/pl/sprawowanie-bieganie-drzewa-zdrowe-24419/

*Thank you*