Respiratory module

Session 3:

Lecture 1: **Mechanics of Breathing**

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Intended learning outcomes

By the end of this session, the student should be able to:

1. describe the mechanical system of the lungs and thorax

2.define the term 'compliance' of the lungs and state how, in principle, it is measured

3.describe the factors which affect the compliance of the lungs, including the role of surfactant

4.describe the factors which influence airway resistance in the normal lung and how airway resistance changes over the breathing cycle

Objective number 1

Describe the mechanical system of the lungs and thorax

Lecture 1: Mechanics of Breathing

Inspiration is an active process.

The space between the lungs and thoracic wall - the **pleural space -** is normally filled with a few milliliters of fluid, which forms a pleural seal holding the outer surface of the lungs to the inner surface of the thoracic wall. If, therefore the volume of the thorax cage changes so will the volume of the lungs.

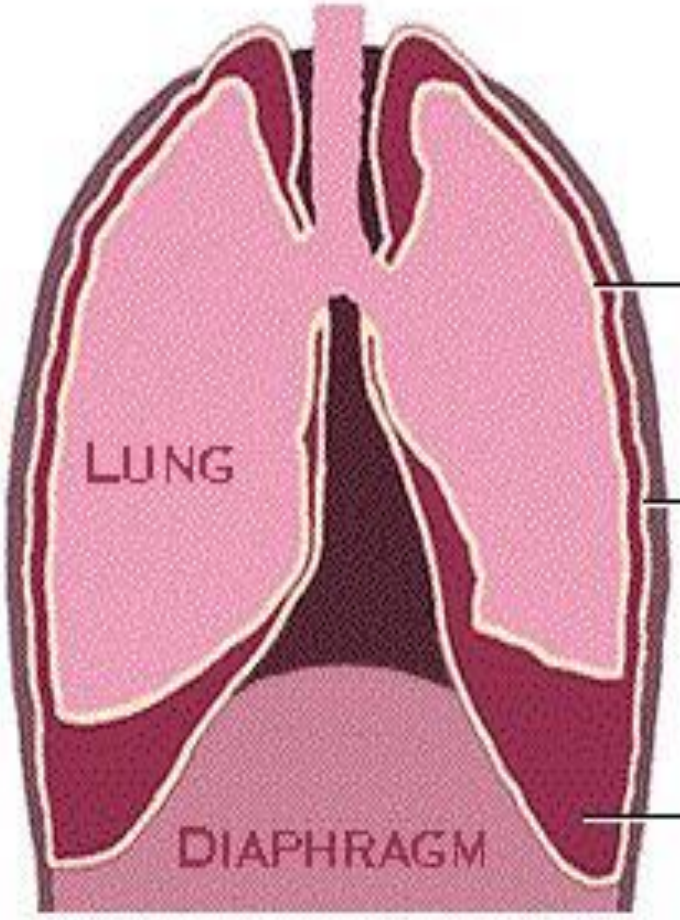
pleural space??

Pleurae and the Lungs

Each lung is surrounded by two layers of **serous membrane** known as the **pleurae**.

The visceral and parietal pleurae are actually a continuation of the same membrane.

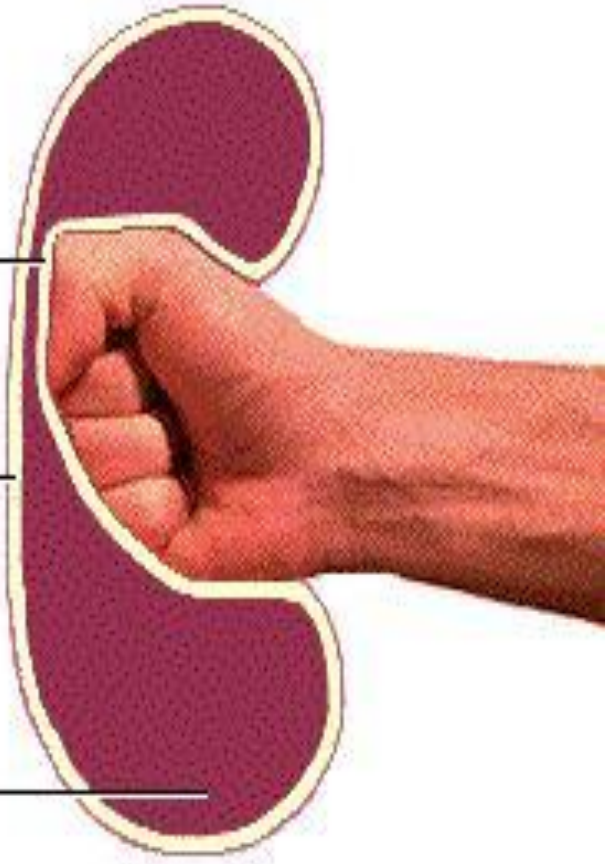
The relationship between the pleurae and the lungs can be demonstrated by pushing a fist into a water-filled balloon.



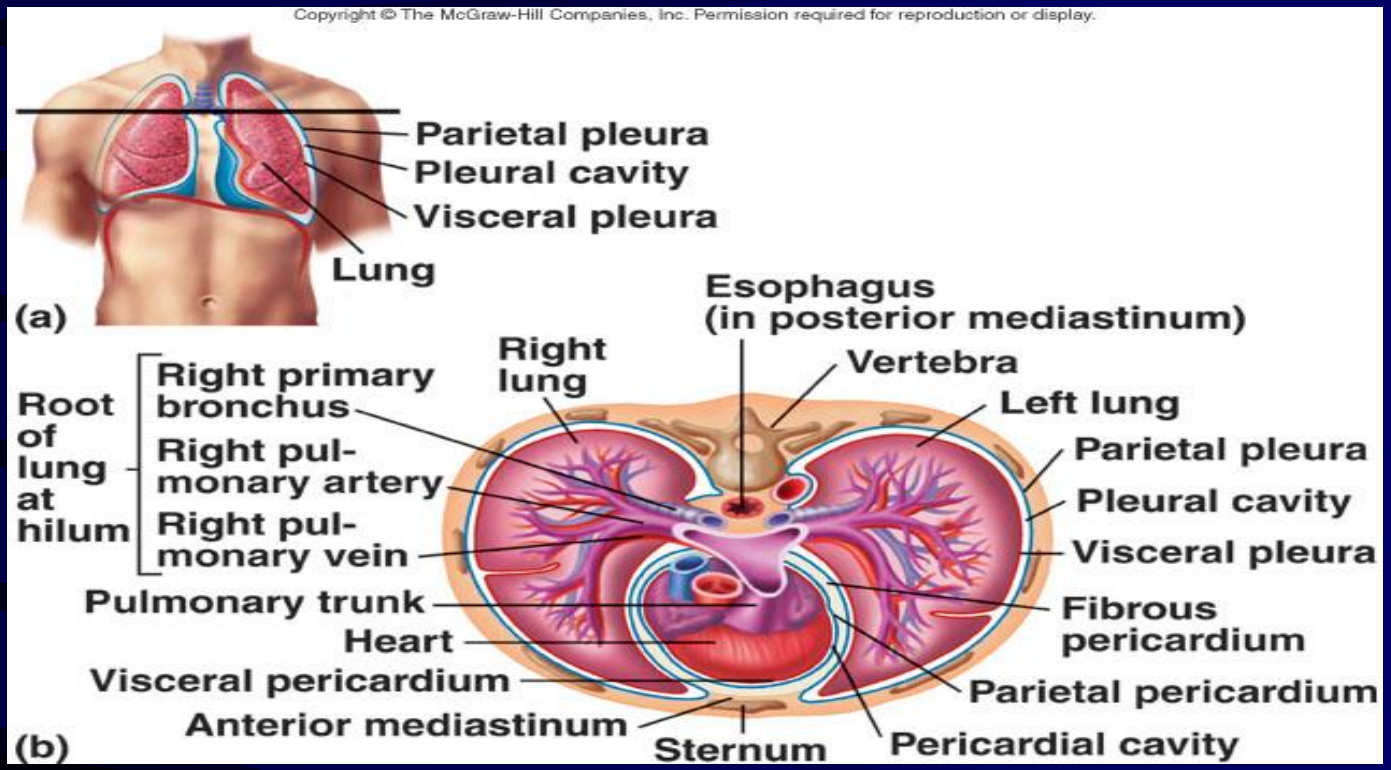
Visceral pleura covers surface of lungs

Parietal pleura lines
- **mediastinum**
- diaphragm
- thoracic wall

Pleural cavity with **pleural fluid**



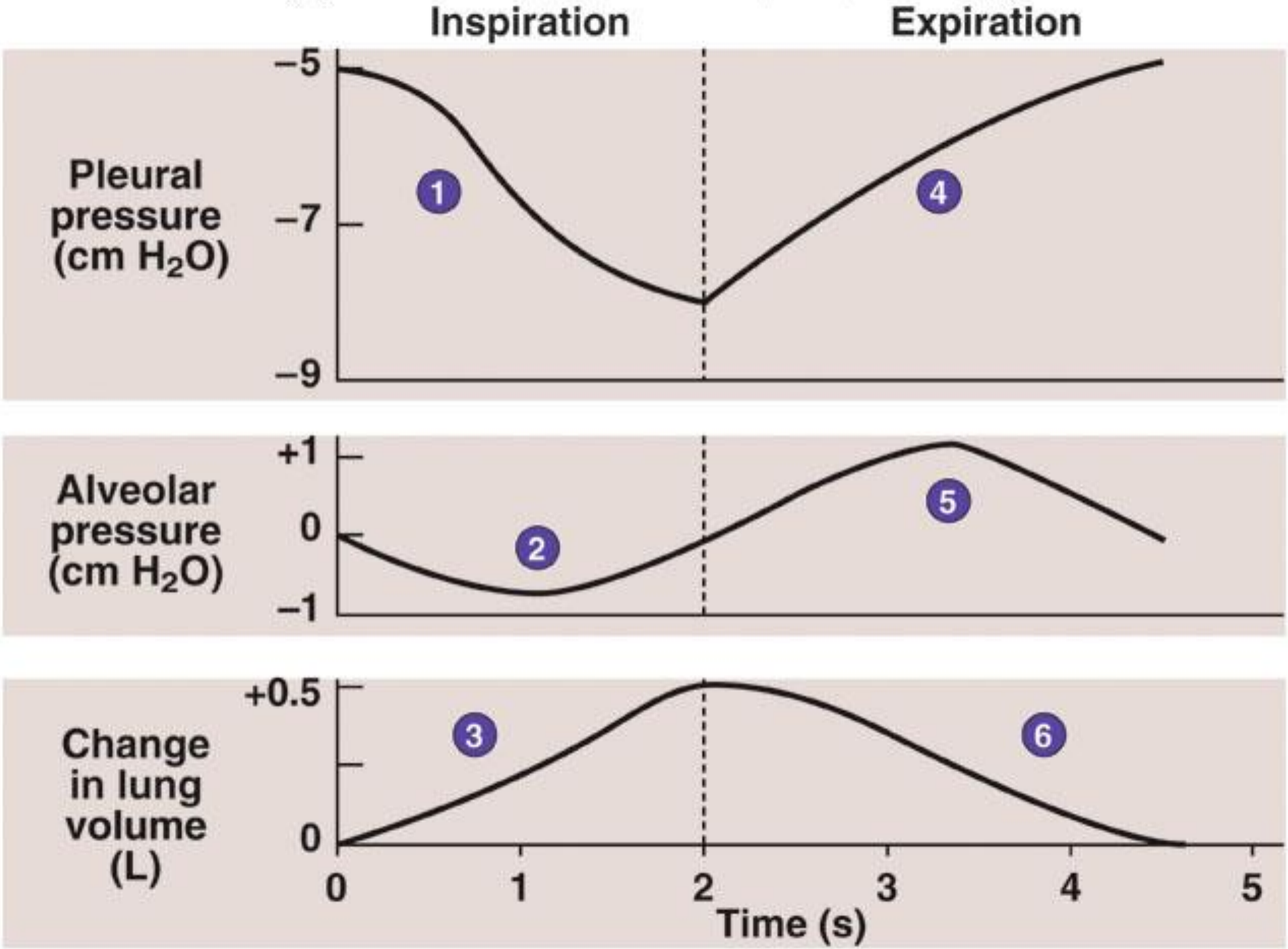
Pleura



- Pleural fluid produced by pleural membranes
  - Acts as lubricant
  - Helps hold parietal and visceral pleural membranes together

The resting expiratory level?

Pleural pressures??



Muscles of Inspiration

In quiet breathing:

The ***Diaphragm***

External intercostal

In forced inspiration

These are the sternocleidomastoid and scalene muscles of the neck, and serratus anterior and pectoralis major muscles.

I- Inspiration

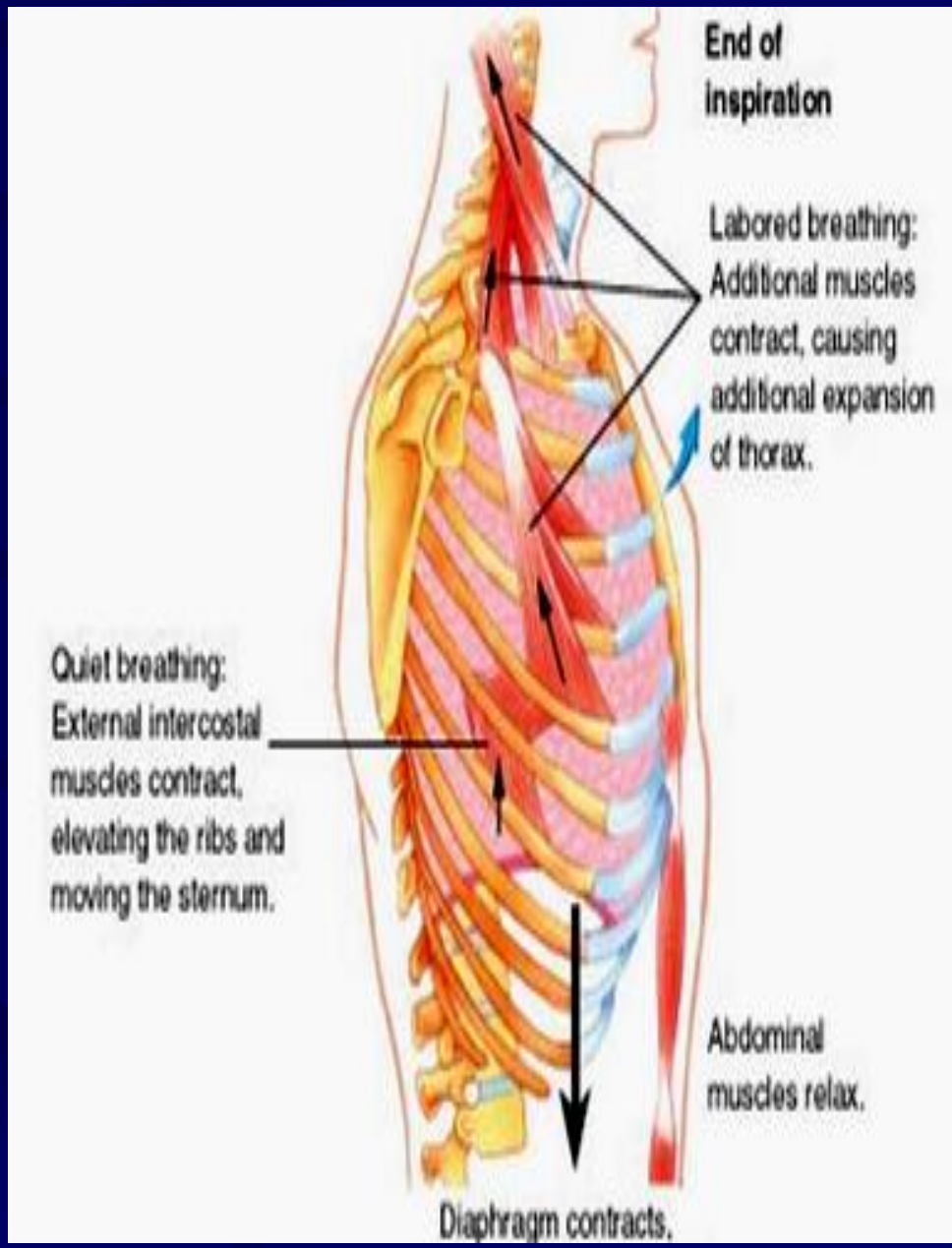
On DEEP inspiration there will be:

1. More contraction of the **diaphragm** (7 cm descent) and the **external intercostal**.
2. Contraction of the **accessory muscles of inspiration** :

- ***Sternocleidomastoid***: that elevates the sternum .
- ***Serratus anterior*****:** that elevates many ribs more.
- ***Scaleni muscles*****:** that elevates first rib.

- Lungs follow passively the movements of the chest wall due to presence of a thin layer of fluid between the parietal and the visceral pleurae. So, the two layers of pleura slide on each other but resist separation.

- The diaphragm is responsible for 75 % of inspiration, yet , when it is paralysed the external intercostal alone can produce inspiration needed for moderate activity .

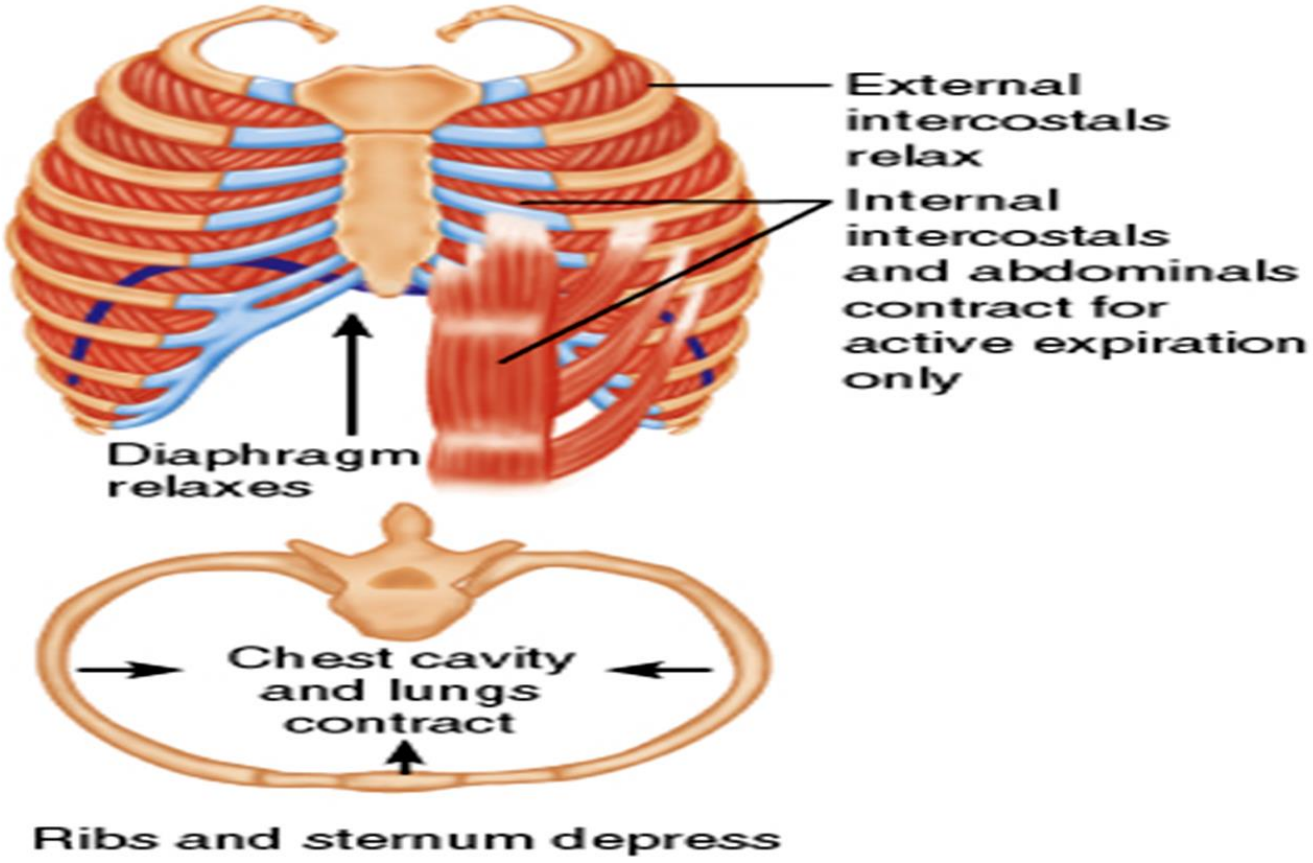


Muscles of expiration

These are the internal intercostal muscles & the abdominal wall muscles

(internal oblique muscles and the rectus abdominis muscles).

EXPIRATION


External intercostals relax
Internal intercostals and abdominals contract for active expiration only
Diaphragm relaxes
Chest cavity and lungs contract
Ribs and sternum depress

II- Expiration

Now expiration will be caused by contraction of:

1- *Abdominal muscles* : that will increase the pressure inside the abdominal cavity pushing the diaphragm upward.

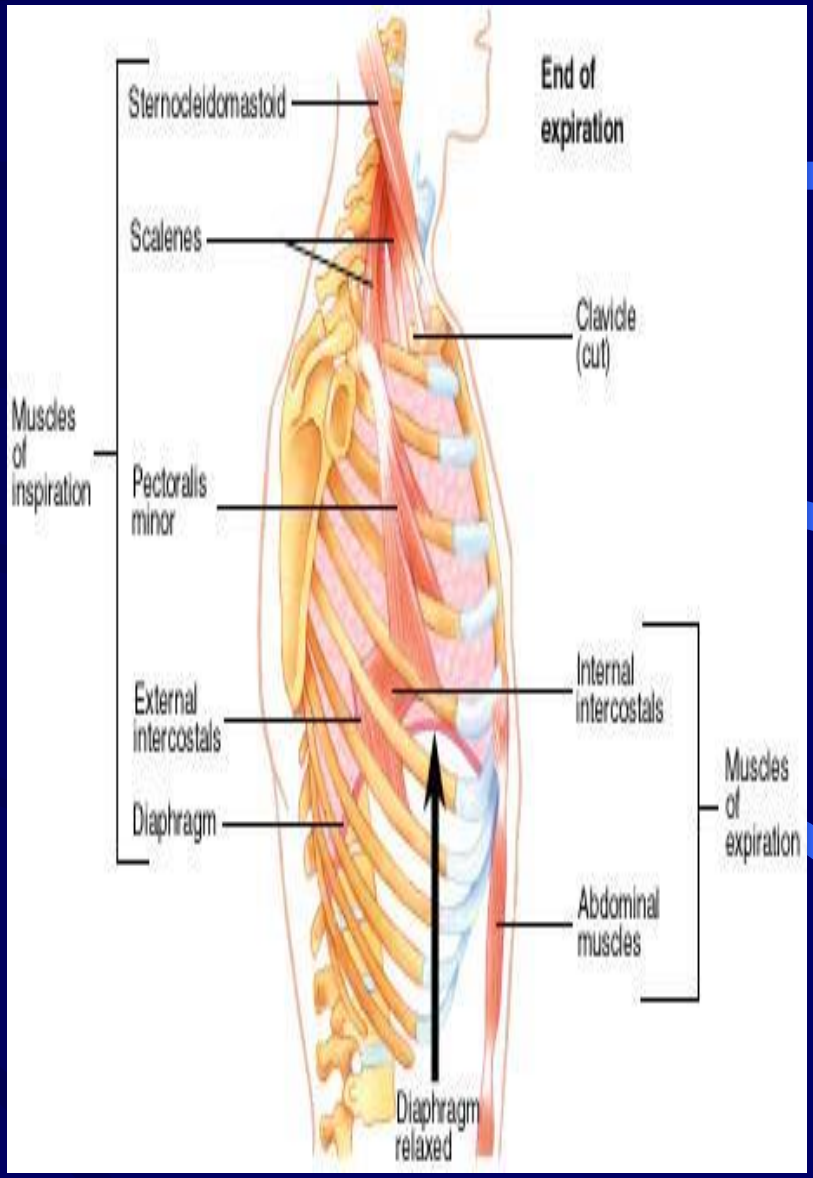
2- *Internal intercostal* muscles : that causes "lowering" of the ribs leading to decreased transverse & A-P chest diameters.

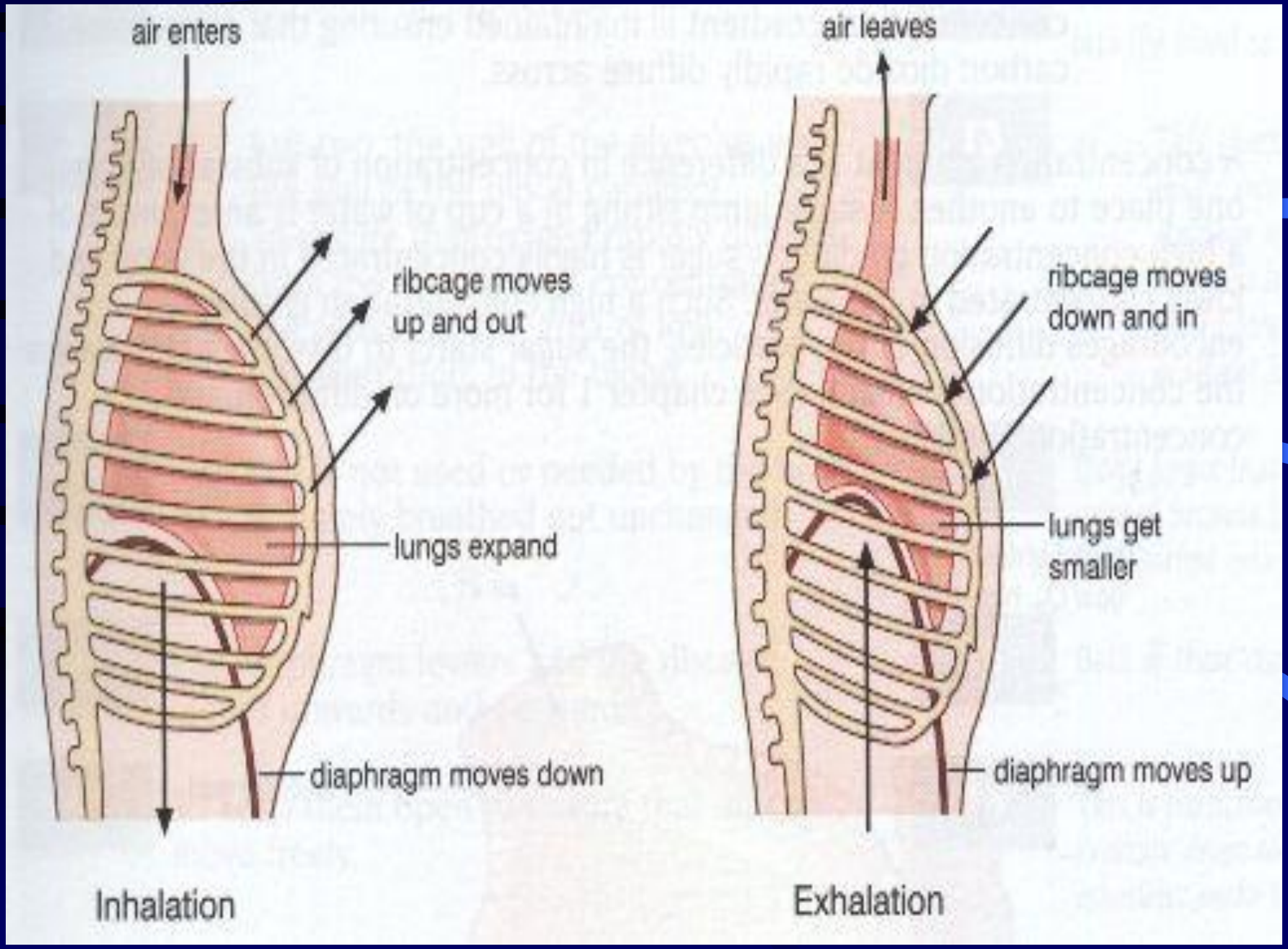
- **Respiratory Rate :** normally it is about 12- 16 cycles /min.
- **Respiratory cycle :** is composed of :

1-Short inspiration (I)

2- Longer expiration (E)

3-Expiratory pause (during which the glottis is "closed").




air enters
ribcage moves
up and out
lungs expand
diaphragm moves down
Inhalation
air leaves
ribcage moves
down and in
lungs get
smaller
diaphragm moves up
Exhalation

Pulmonary Ventilation.mp4

Objective 2

Define the term 'compliance' of the lungs and state

how, in principle, it is measured

Compliance

The stretchiness of the lungs is known as compliance.

Compliance is defined as the volume change per unit pressure change.

$$\frac{\text{Volume change per unit pressure change}}{\text{Starting volume of lung}}$$

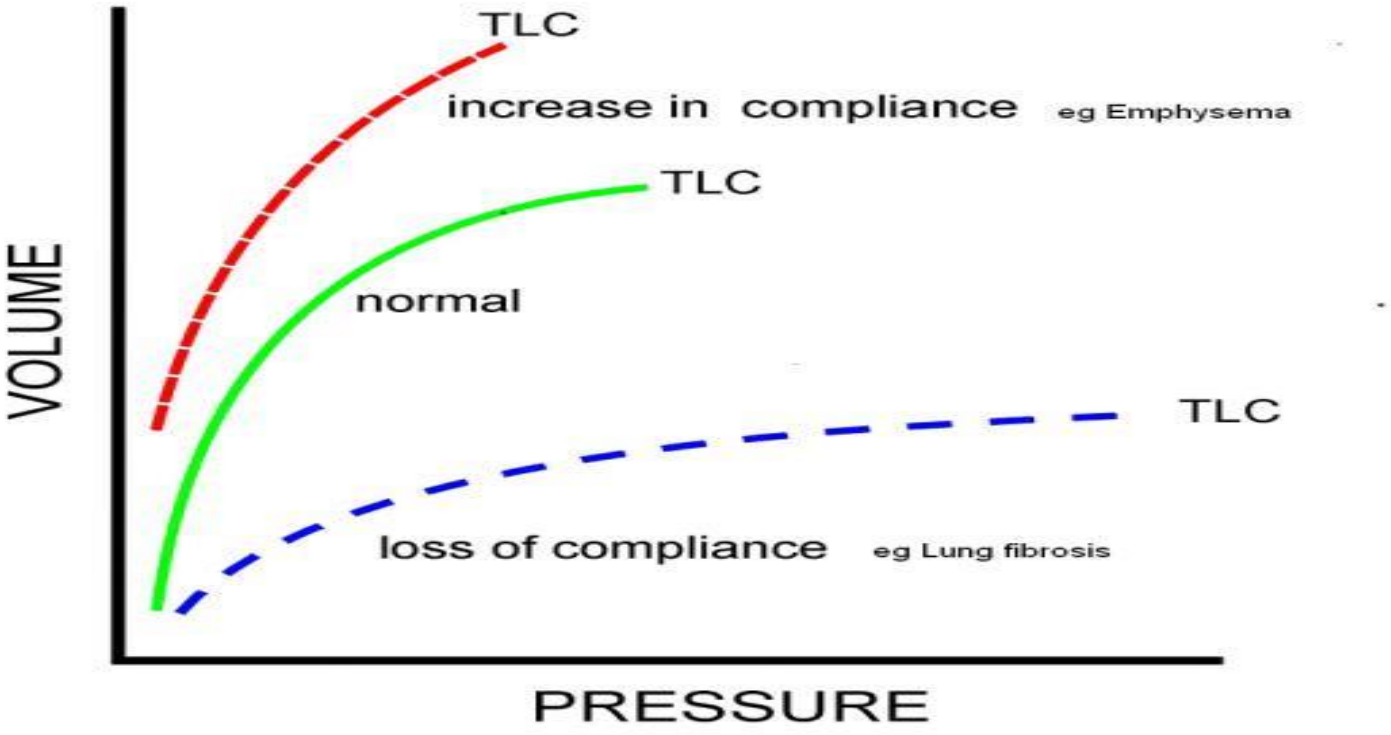
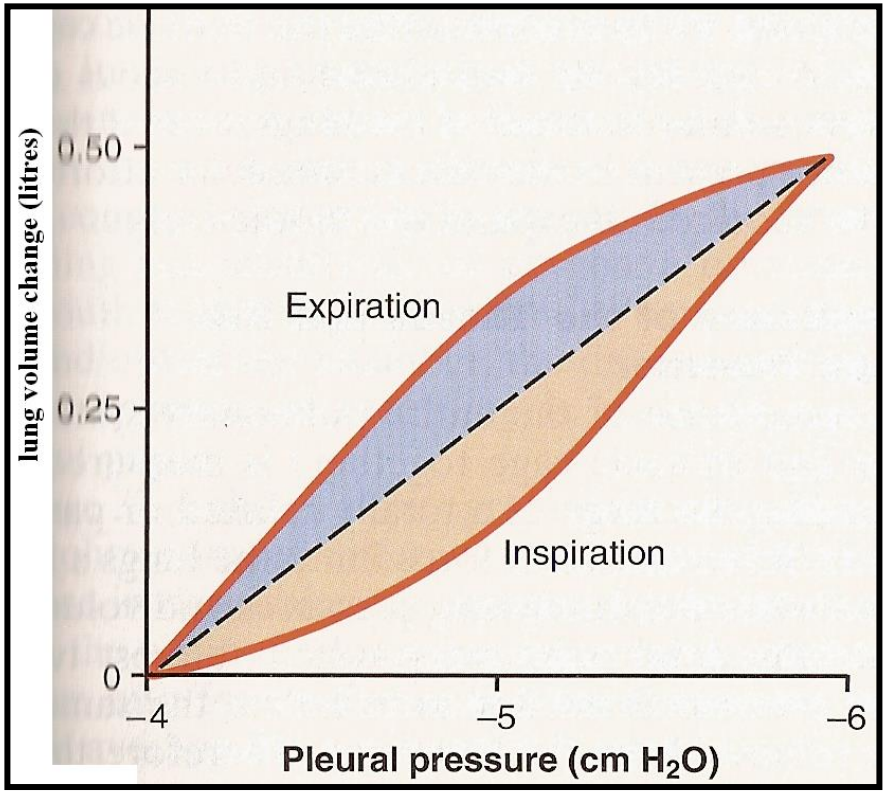


Figure: Compliance, - normal, increased & decreased

Compliance diagram of lungs

- There are 2 different curves according to different phases of respiration.
- The curves are called :
  - Inspiratory compliance curve
  - Expiratory compliance curve
- Shows the capacity of lungs to “adapt” to small changes of transpulmonary pressure.
- 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)
- The total work of breathing of the cycle is the area contained in the loop.



Objective 3

Describe the factors which affect the compliance of the lungs, including the role of surfactant

The elastic properties of the lungs arise from two sources:

- Elastic tissues in the lungs
- Surface tension forces of the fluid lining the alveoli

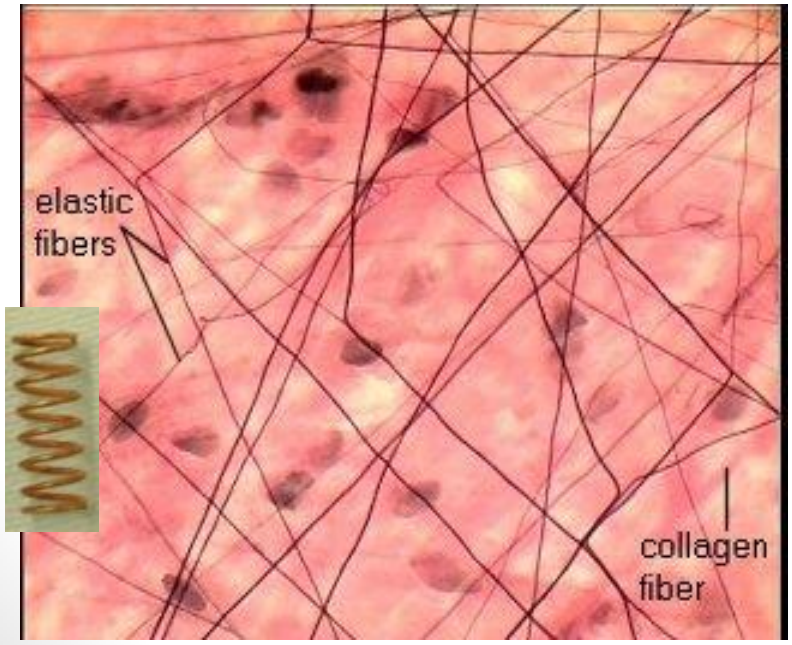
Compliance of lungs occurs due to elastic forces.

A. Elastic forces of the lung tissue itself

B. Elastic forces of the fluid that lines the inside walls of alveoli and other lung air passages

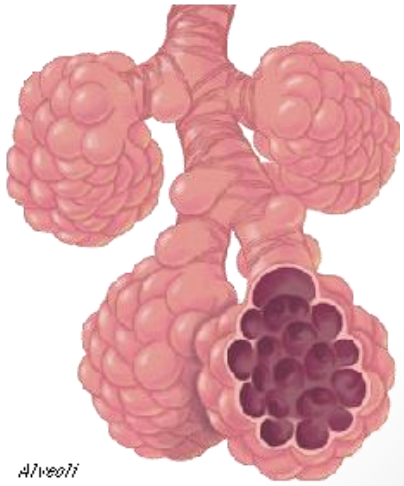
A

Elastin + Collagen fibres



B

Is provided by the substance called surfactant that is present inside walls of alveoli.



Compliance is reduced when

(1) The pulmonary venous pressure is increased and the lung becomes engorged with blood

(2) There is alveolar edema due to insufficiency of alveolar inflation

(3) The lung remains unventilated for a while e.g. atelectasis and

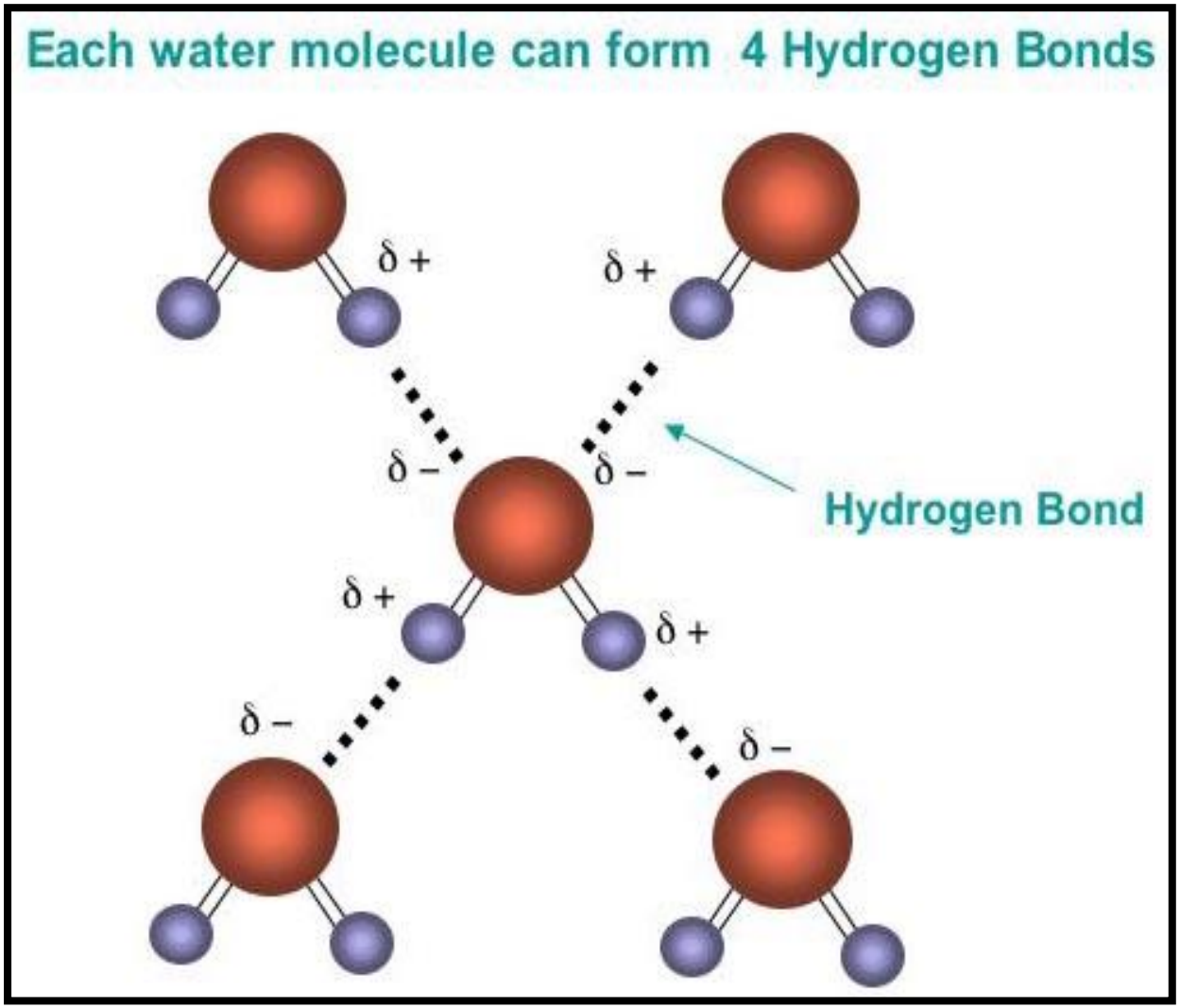
(4) Because of diseases causing fibrosis of the lung e.g. chronic restrictive lung diseases.

On the contrary in chronic obstructive pulmonary disease (COPD, e.g. emphysema) the alveolar walls progressively degenerate, which increases the compliance.

In asthma (hyperactive airway smooth muscle) the lung compliance is usually normal

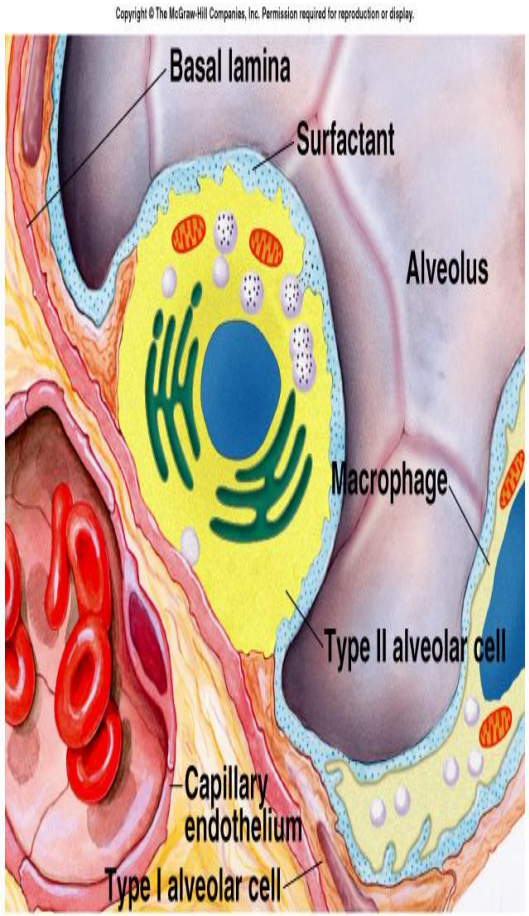
Surface Tension

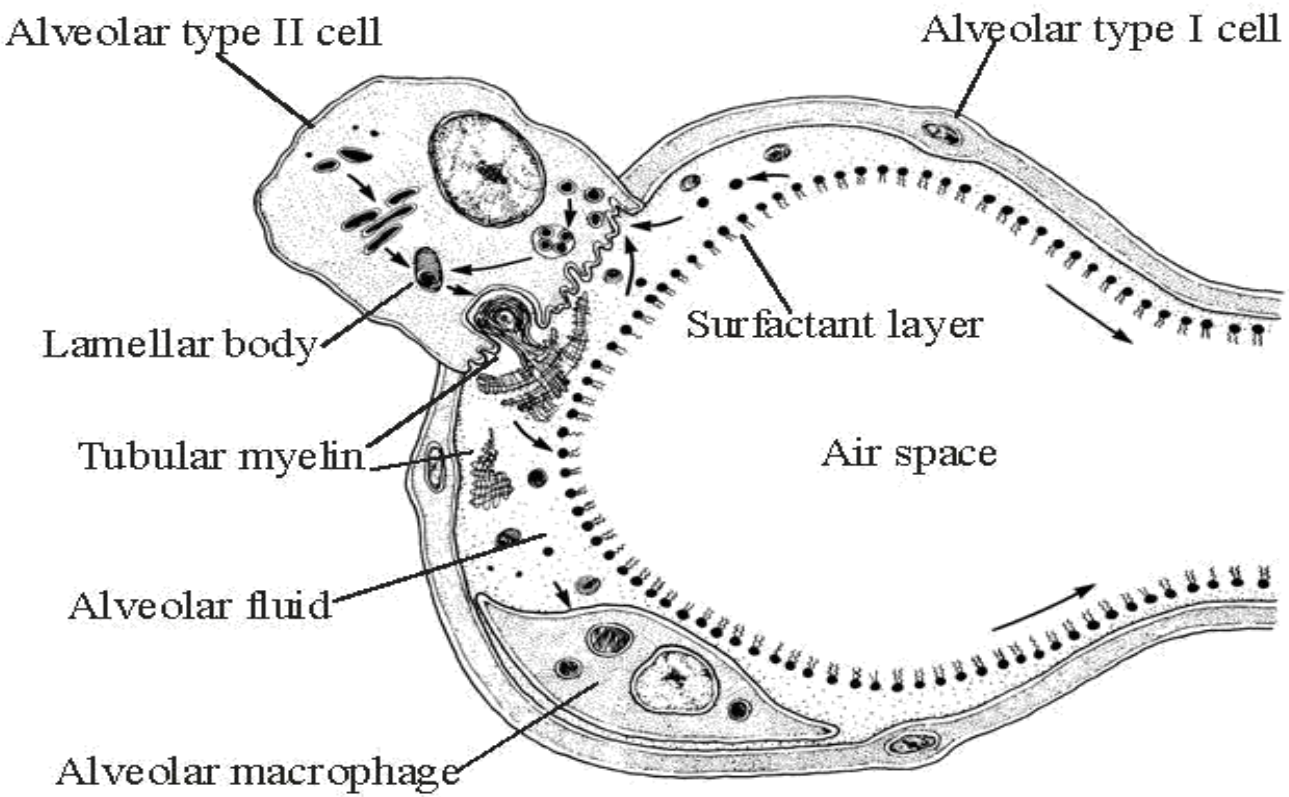
The airways and alveoli of the lungs are lined with a film of fluid which is increased in area as the lungs expand.

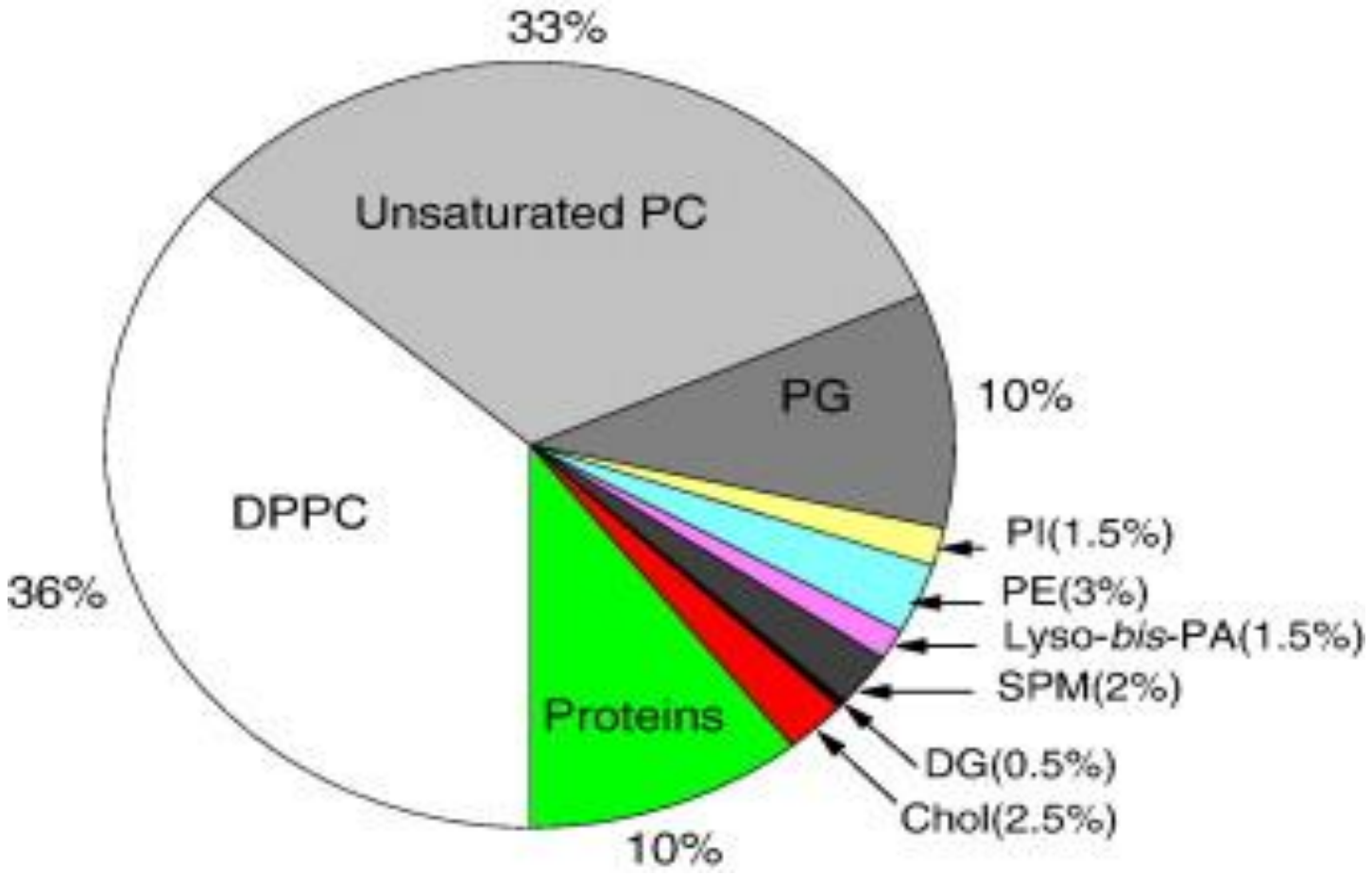

Each water molecule can form 4 Hydrogen Bonds
δ +
δ +
δ –
δ –
Hydrogen Bond
δ +
δ +
δ –
δ –

Surfactant

- Phospholipid produced by alveolar type II cells.
- Lowers surface tension.
  - Reduces attractive forces of hydrogen bonding by becoming interspersed between H_20 molecules.
- As alveoli radius decreases, surfactant's ability to lower surface tension increases.
- Disorder:
  - Acute respiratory distress syndrc
  - ARDS.




Alveolar type II cell
Alveolar type I cell
Lamellar body
Surfactant layer
Tubular myelin
Air space
Alveolar fluid
Alveolar macrophage


33%
Unsaturated PC
PG
10%
DPPC
36%
PI(1.5%)
PE(3%)
Lyso-*bis*-PA(1.5%)
SPM(2%)
Proteins
DG(0.5%)
Chol(2.5%)
10%

Surface tension of the alveolar fluid varies with the surface area of the alveolus

as the alveolus expands the surface tension of the fluid lining it increases.

As an alveolus **shrinks**, the surfactant molecules come closer together increasing their concentration on the surface and act *more efficiently* to reduce the surface tension. Hence, ***the effect of surfactant is to reduce surface tension forces greatly as area of the alveolus decreases***.

The alveoli are, in effect, an interconnected series of bubbles. The pressure within a bubble is determined by the Law of Laplace:

$P = 2T/r$

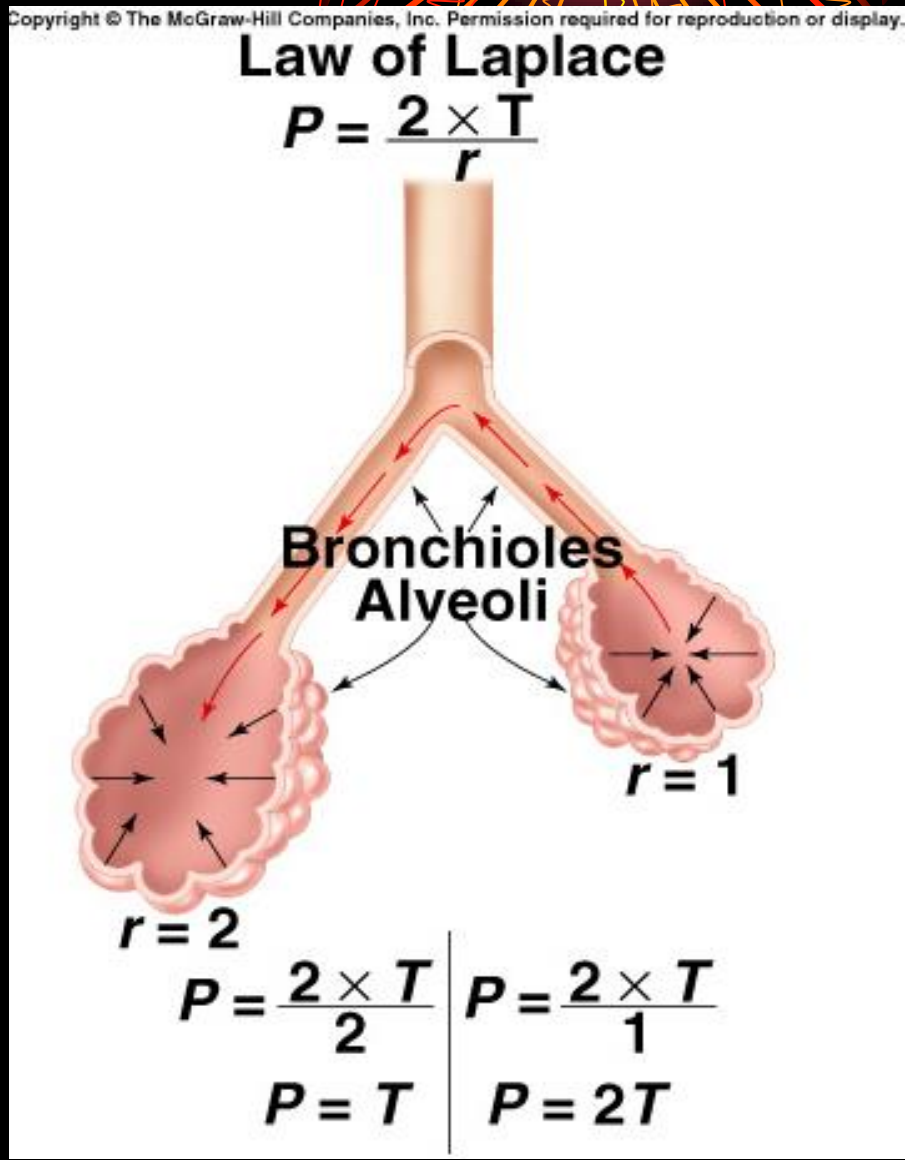
p= pressure in the alveolus,

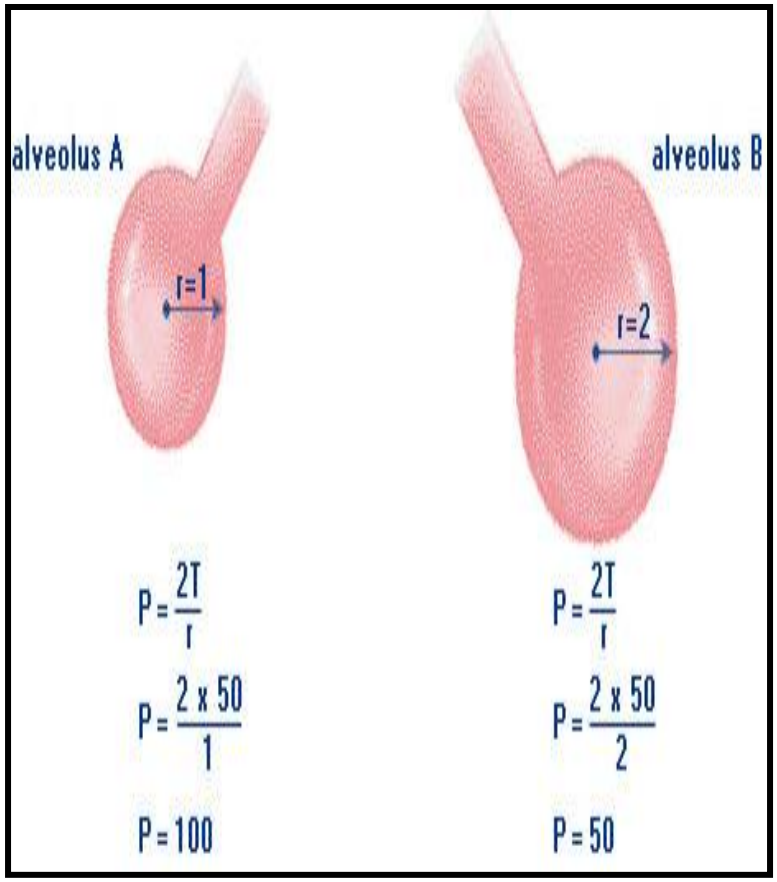
T = surface tension

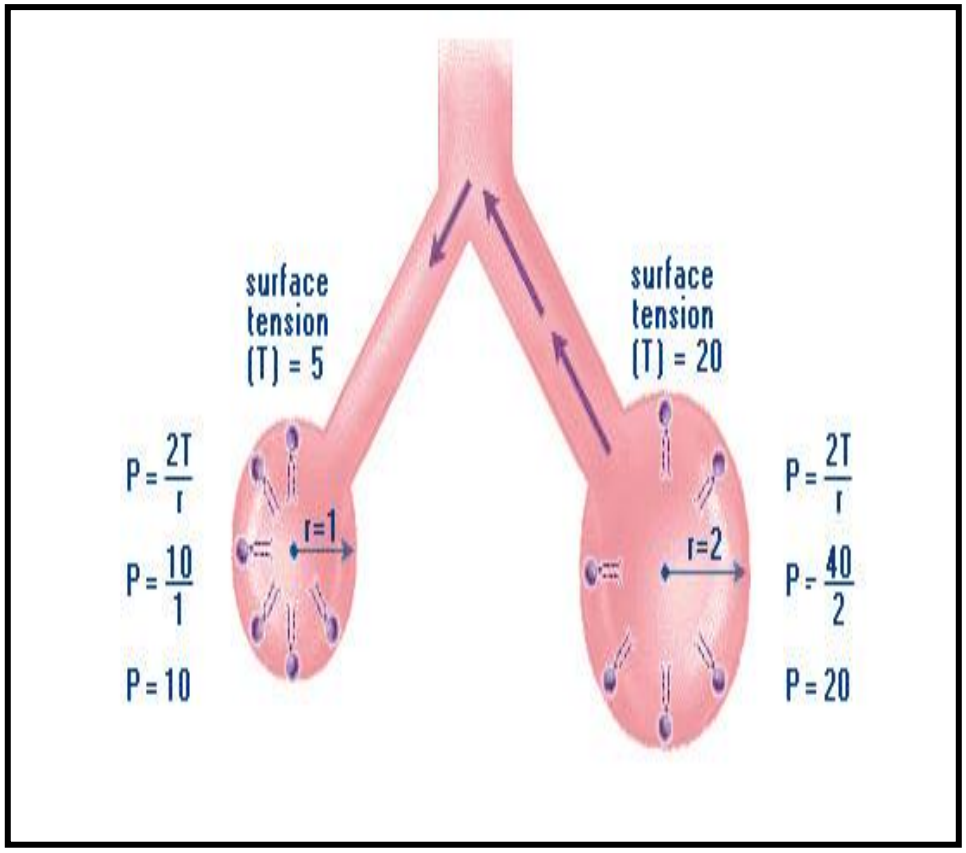
r= radius of alveolus

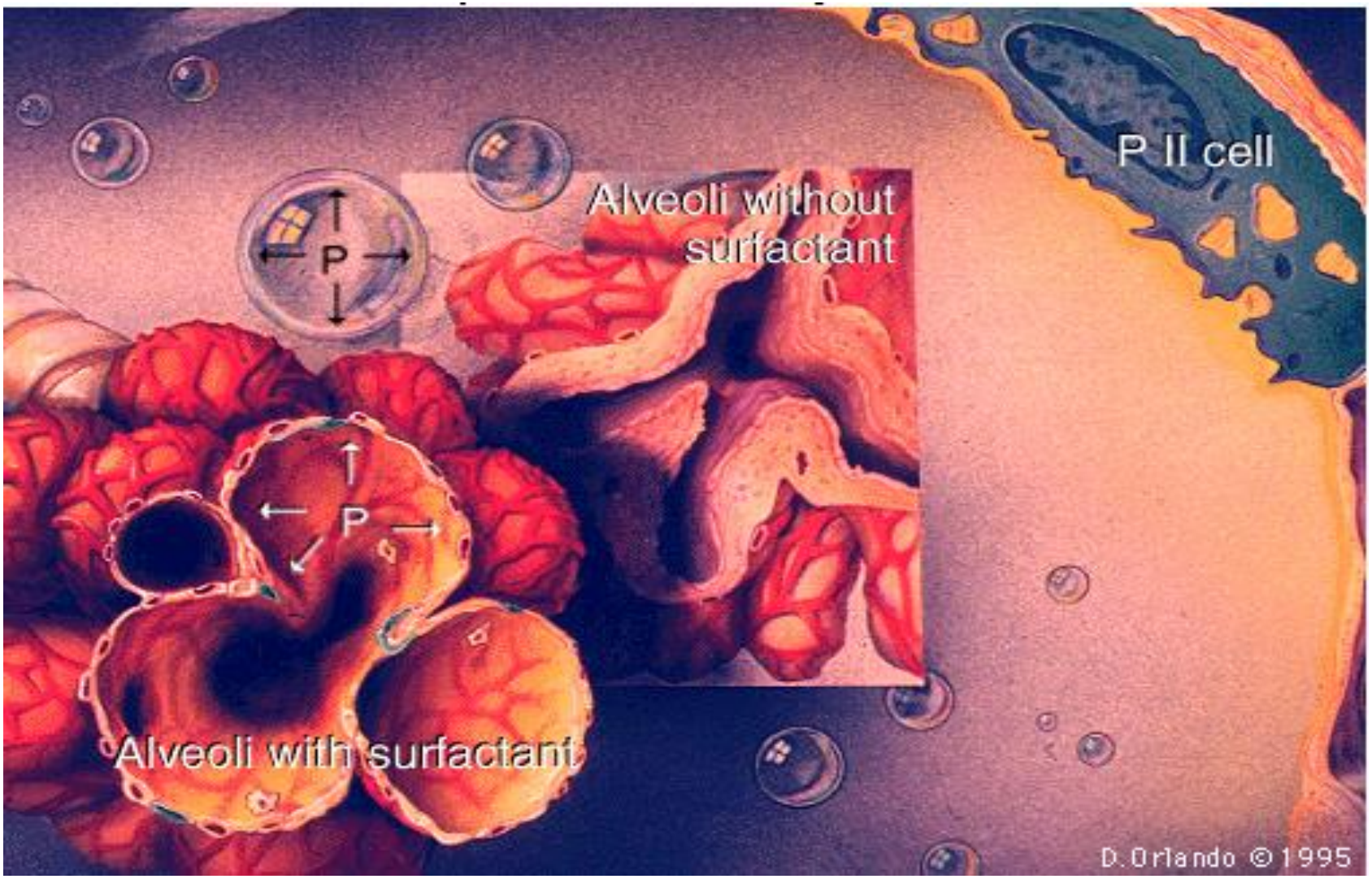
Surface Tension

- Law of Laplace:
  - Pressure in alveoli
    - directly proportional to surface tension
    - inversely proportional to radius of alveoli
  - if surface tension were the same in all alveolus....




alveolus A
alveolus B
r=1
r=2
$P = \frac{2T}{r}$
$P = \frac{2 \times 50}{1}$
$P = 100$
$P = \frac{2T}{r}$
$P = \frac{2 \times 50}{2}$
$P = 50$


surface tension (T) = 5
surface tension (T) = 20
$P = \frac{2T}{r}$
$P = \frac{10}{1}$
$P = 10$
r=1
r=2
$P = \frac{2T}{r}$
$P = \frac{40}{2}$
$P = 20$



Disorder:

ARDS.

Objective 4

describe the factors which influence airway resistance in the normal lung and how airway resistance changes over the breathing cycle

Airway Resistance

The resistance of an airway to flow is determined by Poiseulles Law when flow

$$\text{Resistance} = \frac{\text{Pressure}}{\text{Rate of flow}} = \frac{8 \times \text{viscosity of air} \times \text{length of tube}}{P \times (\text{radius})^4}$$

Resistance of a single tube increases sharply with falling radius. *However, the combined resistance of the small airways is normally low because they are connected in parallel* over a branching structure where the total resistance to flow in the downstream branches is less than the resistance of the upstream branch.

Most of the resistance to breathing therefore resides in the upper respiratory tract, except when the small airways are compressed during forced expiration.

Overall:

Work is done against the elastic recoil of lungs and thorax, greatest part of work being against more or less equally **the elastic properties of lung tissues** and **surface tension forces in the alveoli.**

Resistance to flow through airways is of little significance to total work load of breathing in healthy subjects, though it can often be affected by disease.