Surface Tension of the Alveoli

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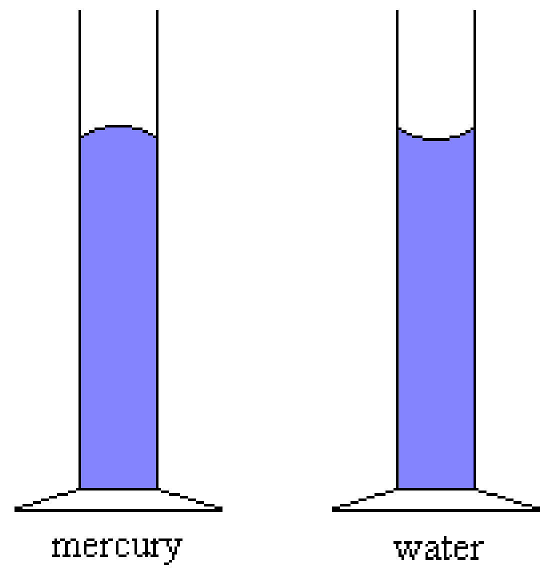
Learning Objectives

- Define surface tension and use Laplace’s law to understand how the pressure inside a bubble is related to the radius and surface tension
- State how the surfactant reduces surface tension and stabilizes the size of the alveoli

Surface Tension. Cohesion and Adhesion

- Tendency of the lungs to CONTRACT as a result of surface tension
- **Cohesion and Adhesion**
- Liquids⇒ strong attractive forces between indivual molecules

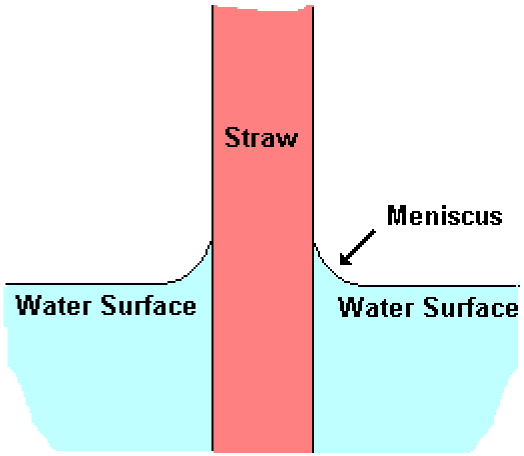
- COHESIVE FORCES⇒ forces between LIKE molecules
- ADHESIVE FORCES⇒ forces between UNLIKE molecules

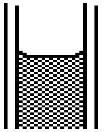


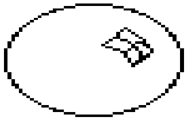
cohesion〉 adhesion   adhesion〉 cohesion

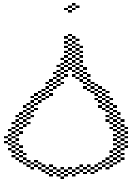
Examples

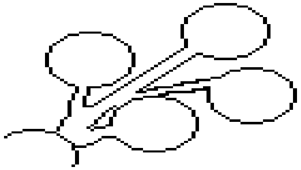
1. capillary action
2. two pieces of microscope slides with water between them

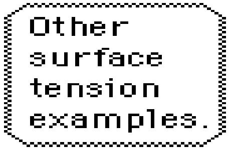






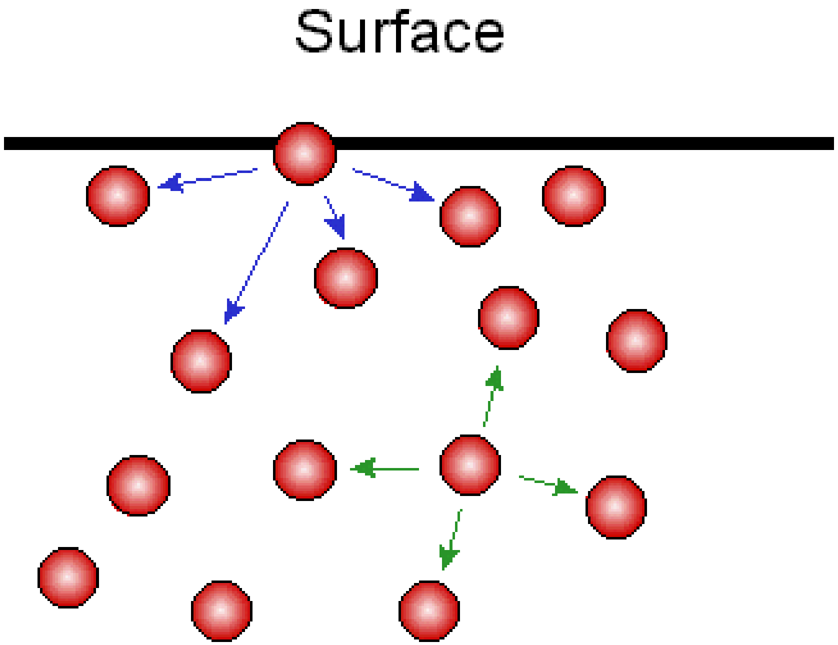






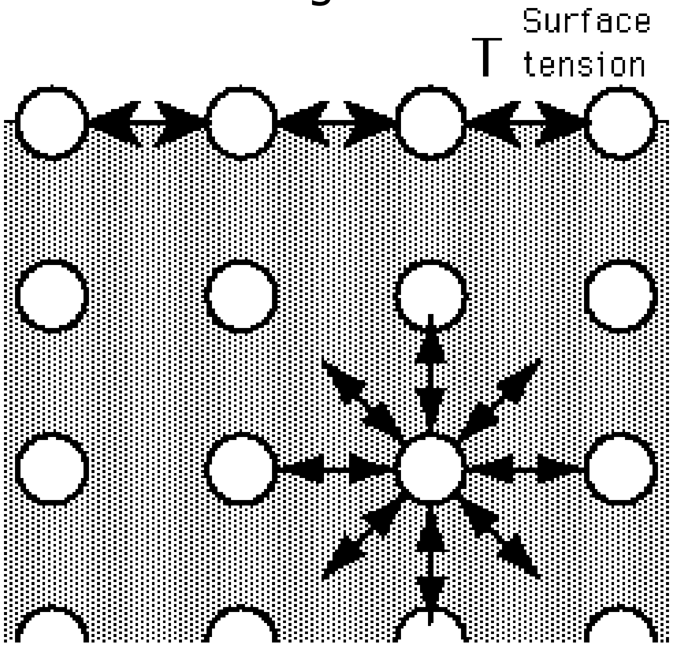
Surface Tension

- Enhancement of the intermolecular attractive forces at the surface. Strong cohesive forces at the surface.



Surface Tension

A molecule that moves outside the surface of a liquid tends to be pulled back in by the attractive forces of its neighbours. An interior molecule is pulled about the same in all directions by its neighbours and thus has no net force on it on the average.



Surface Tension: Definition

- The ‘inward’ molecular attraction forces which must be overcome to increase the surface area. ST is the energy required to increase the surface area of a liquid by a unit amount.

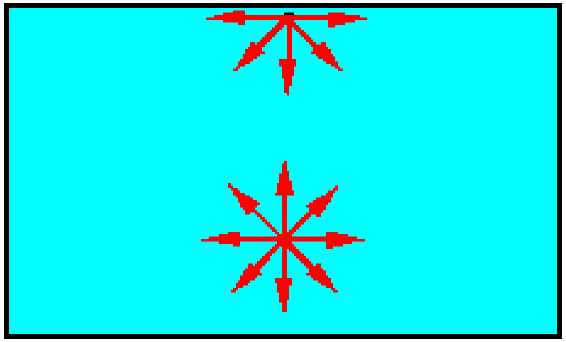


Figure 1

Surface 1 Bo Lou

- It requires work to move molecules to the surface against the net inward cohesive force that is perpendicular to the surface.
- Due to ST, the surface of a liquid tends to behave like a stretched elastic membrane. The surface molecules will be ‘more ordered’ and resistant to molecular disruption

Surface Tension Examples: Walking on Water

Small insects such as the water strider can walk on water because their weight is not enough to penetrate the surface.

When an object is on the surface of the fluid, the surface under tension will behave like an elastic membrane. There will be a small depression on the surface of the water.

The vertical components of the forces by the molecules on the object will balance out the weight of the object. Depressing the surface under the foot of the insect gives an upward component to the surface-tension forces, which supports the insect on the surface of water.

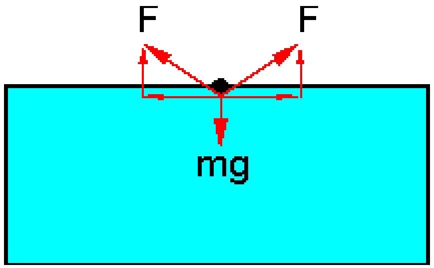


Figure 2

Surface2 Bo Lou

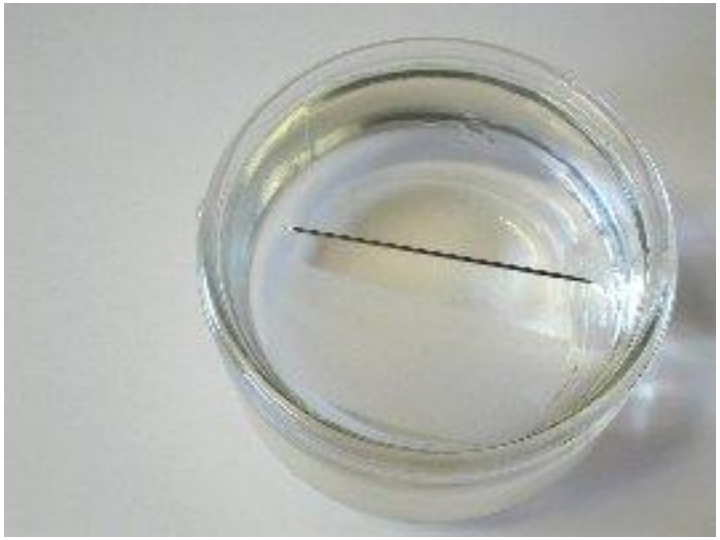
groups.physics.umn.edu *R Nave*

Surface Tension Examples: Don't touch the tent!

- Common tent materials are somewhat rainproof in that the surface tension of water will bridge the pores in the finely woven material.
- But if you touch the tent material with your finger, you break the surface tension and the rain will drip through.

Surface Tension Examples: Floating a Needle

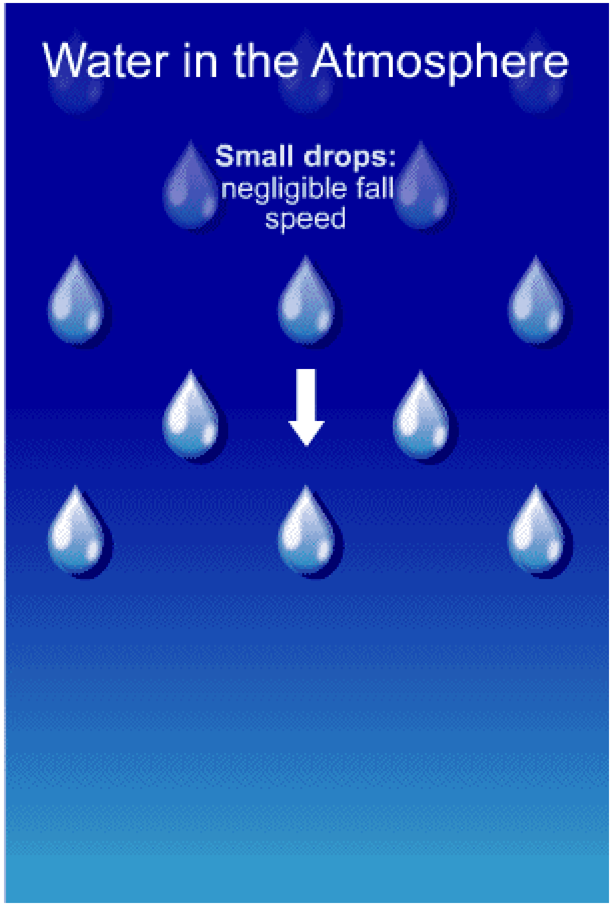
- If carefully placed on the surface, a small needle can be made to float on the surface of water even though it is several times as dense as water.
- If the surface is agitated to break up the surface tension, then needle will quickly sink.
- At the bottom of the pot you can see the sunken strip of tissue paper.



Surface Tension Examples: Raindrops

- Surface tension makes the surface contract to its smallest possible area

- smallest surface area for a given volume ⇒ SPHERE



Surface Tension: Measurement

- Anologous to PRESSURE but
  P of a fluid exerts an **OUTWARD FORCE** and tends to **EXPAND** a volume
- **ST** of a fluid exerts an **INWARD FORCE** and tends to **SHRINK** a surface
- The surface tension strength of a liquid is defined as the FORCE PER UNIT LENGTH that the surface exerts on any line in the surface.
-

$$\gamma = \mathbf{F / l}$$

Units: Newton/meter

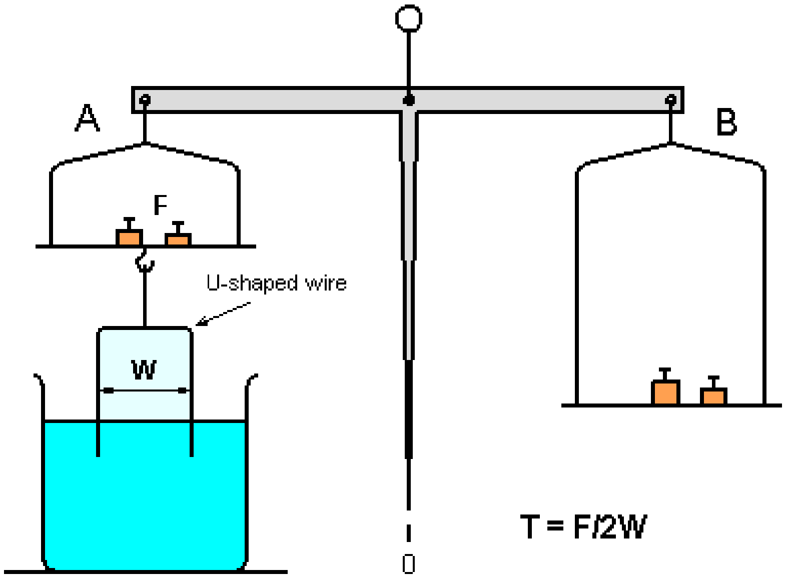


Figure 5 - Experimental device to measure the surface tension of a liquid.

This force lies on the surface and is PERPENDICULAR to the line

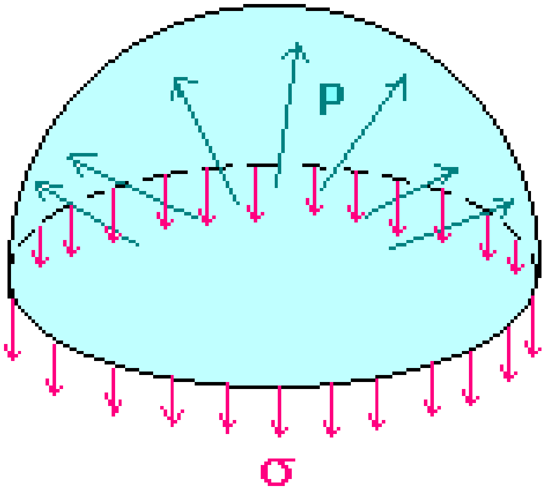
Surface Tension of Various Liquids

LIQUID	SURFACE TENSION (N/m, 20^oC)
water	72.8×10^{-3}
blood plasma	50×10^{-3}
lung surfactant	1×10^{-3}
benzene	28.8×10^{-3}
mercury	464×10^{-3}

- ST depends on the molecular properties of the liquid ---- **intrinsic property**

Pressure in a Bubble

- Surface tension tends to shrink a bubble , but it is resisted by the pressure **(P_i)** inside the bubble which is greater than the pressure outside **(P_o)** the bubble.
- This pressure difference results in an OUTWARD FORCE on the bubble that equals the INWARD FORCE of surface tension.

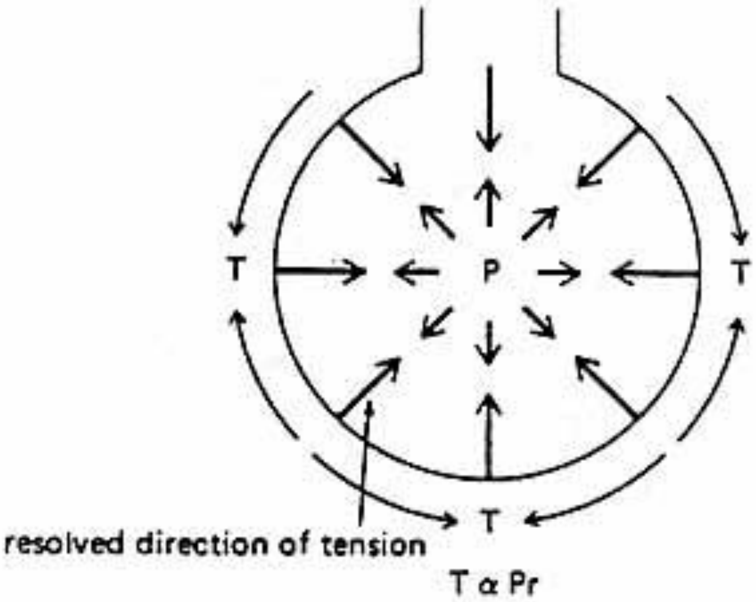


P_t = transmural pressure **$P_i - P_o = \dfrac{2\gamma}{r}$**

Pressure in a Bubble

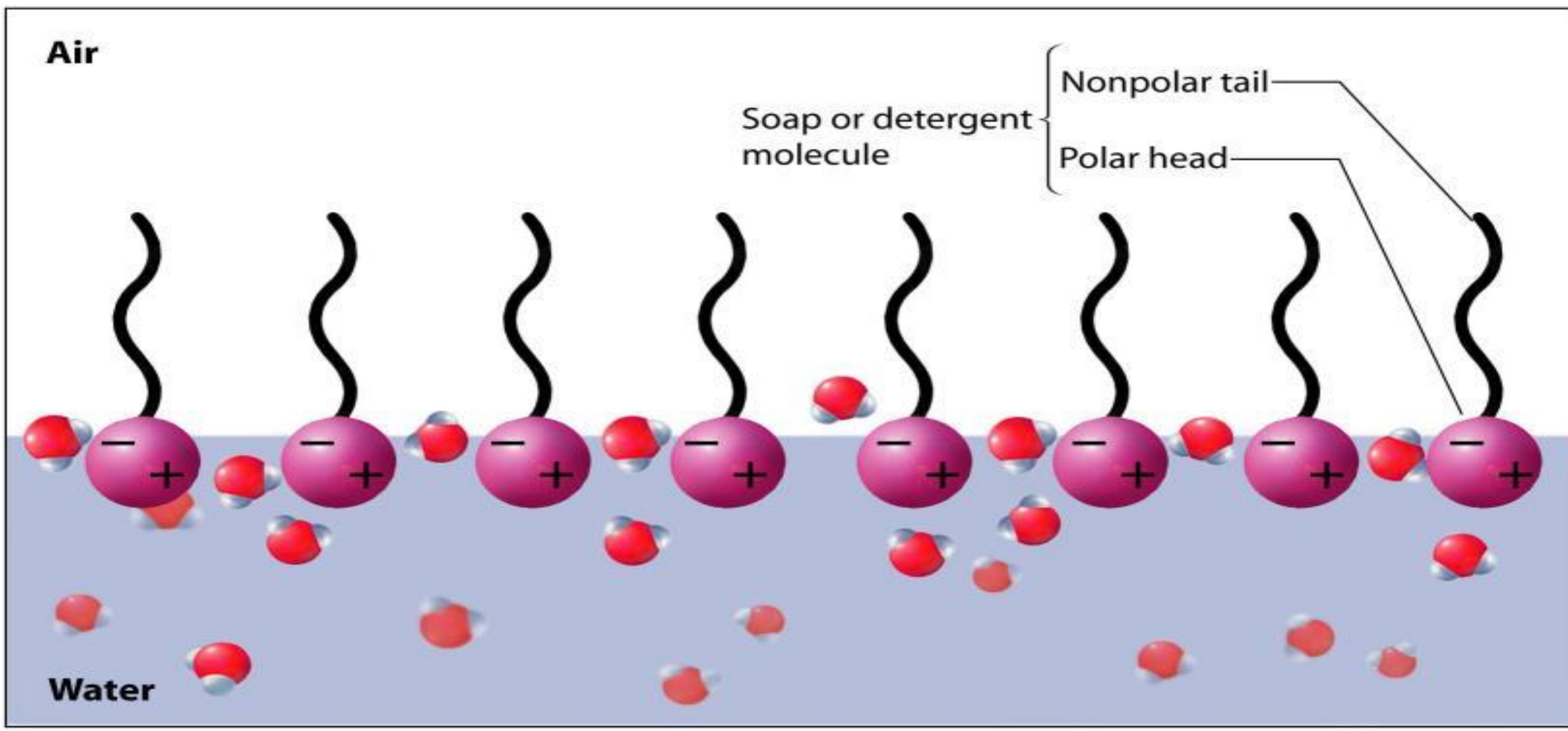
- P difference is proportional to ST. In other words, a larger P is needed to form a bubble in a liquid with a large ST.
- P difference is INVERSELY proportional to the RADIUS of the bubble.
- Means that the P difference is <u>greater </u>in a <u>small bubble</u> than a large one.

  Example : harder to blow up a balloon first



Surfactants (Surface Active Agents)

- Some chemicals change the adhesive and cohesive forces in a liquid.
- SURFACTANT : Any substance that reduces the surface tension of a liquid



Surfactant Molecules in Water

[www.funsci.com/fun3_en/ exper2/exper2.htm](www.funsci.com/fun3_en/exper2/exper2.htm)

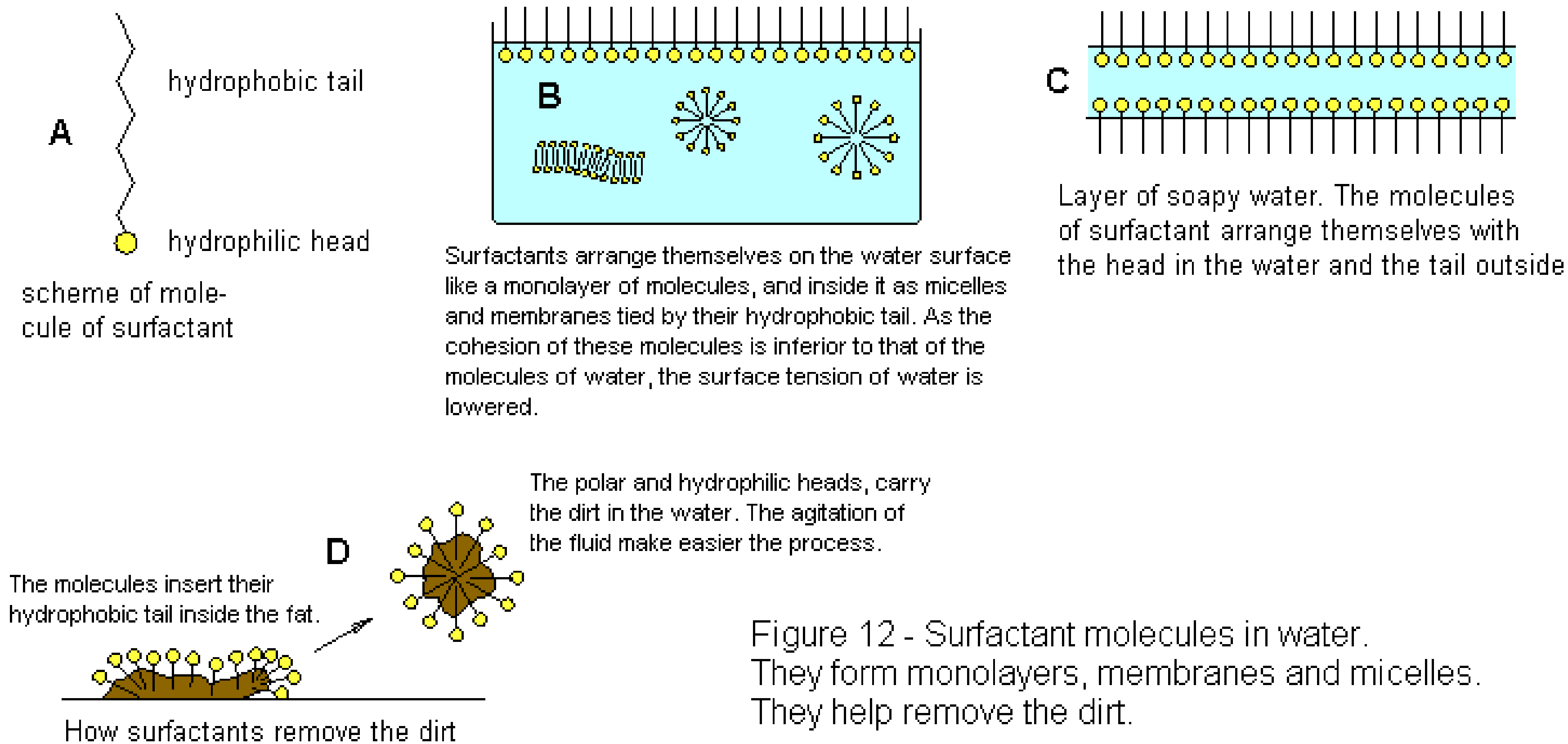
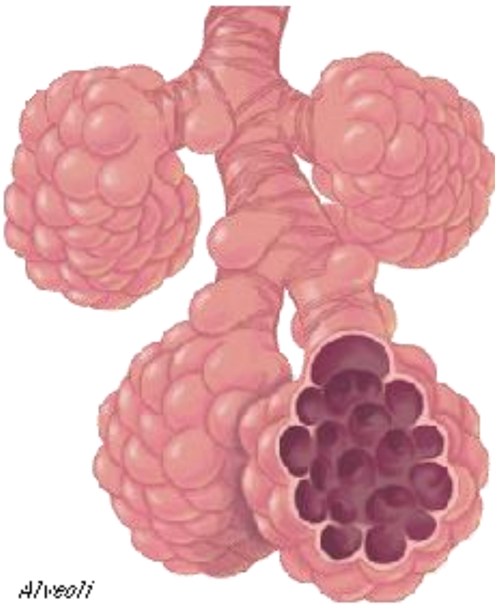


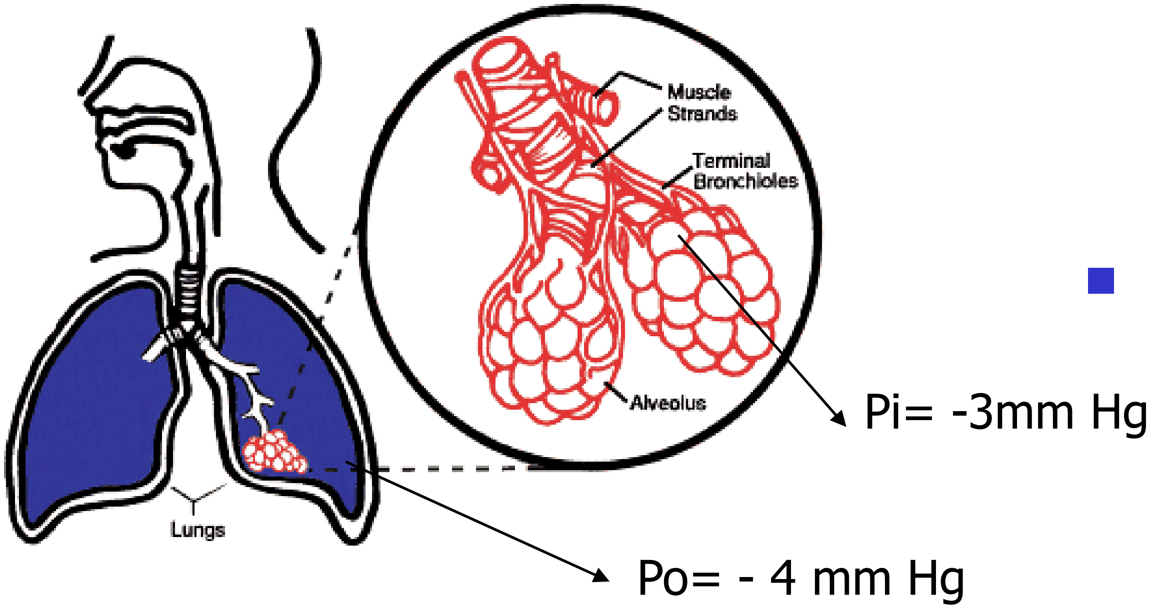
Figure 12 - Surfactant molecules in water.
They form monolayers, membranes and micelles.
They help remove the dirt.

Surface Tension of the Alveoli

- Surfactant decreases surface tension which:
  - increases pulmonary compliance (reducing the effort needed to expand the lungs)
  - reduces tendency for alveoli to collapse
  - stabilizes the size of the alveoli
  - prevents edema (movement of fluid into alveoli)



Surface Tension of the Alveoli



- During inhalation
  r= 0.5 X 10^{-4} to 1.0 X 10^{-4} m
- mucous tissue fluid lining the alveoli normally has a ST of 0.050 N/m

http://www.niehs.nih.gov/oc/factsheets/ozone/ithurts.htm

Surface Tension of the Alveoli

- with this ST:

$$P_t = P_i - P_o = \frac{2\gamma}{r} = \frac{2\ (0.050\ \text{N/m})}{0.5 \times 10^{-4}\ \text{m}}$$

$$= 2 \times 10^{3}\ \text{N/m}^{2} = 2000\ \text{Pa}$$

$$= \mathbf{15\ mmHg}$$

- Since $P_i = -\ 3$ mm Hg , then
  $P_o = -18$ mm Hg

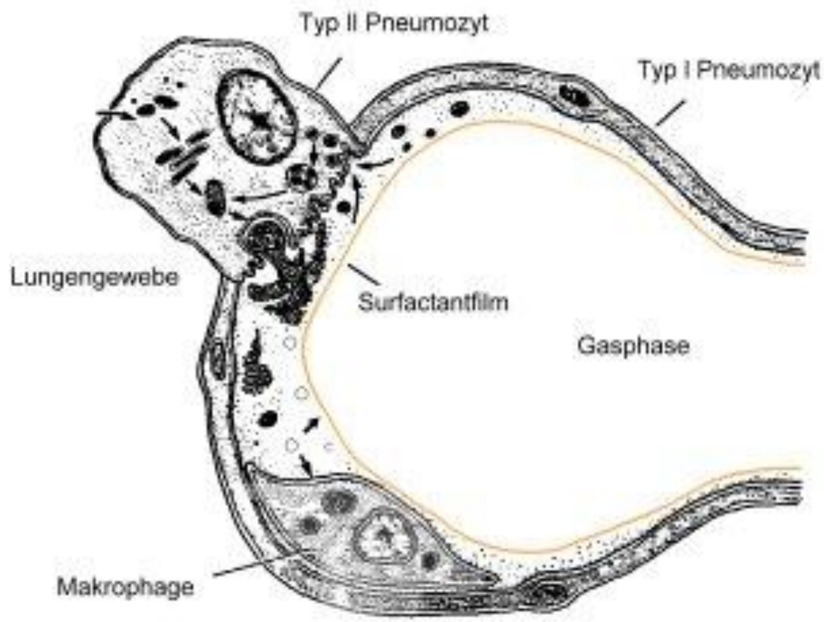
Surface Tension of the Alveoli

- However, P_o is only -4 mm Hg so that the actual pressure difference,

  $P_i - P_o = 1$ mm Hg only,or **15 fold less** than that would be required to expand the alveolus with a ST of 0.05 N/m.
- The walls of the alveoli secrete a SURFACTANT which reduces the surface tension.:
- Lipoprotein mixture secreted by special cells, type II granular pneumocytes: dipalmitoyl phosphatidylcholine

Surface Tension of the Alveoli

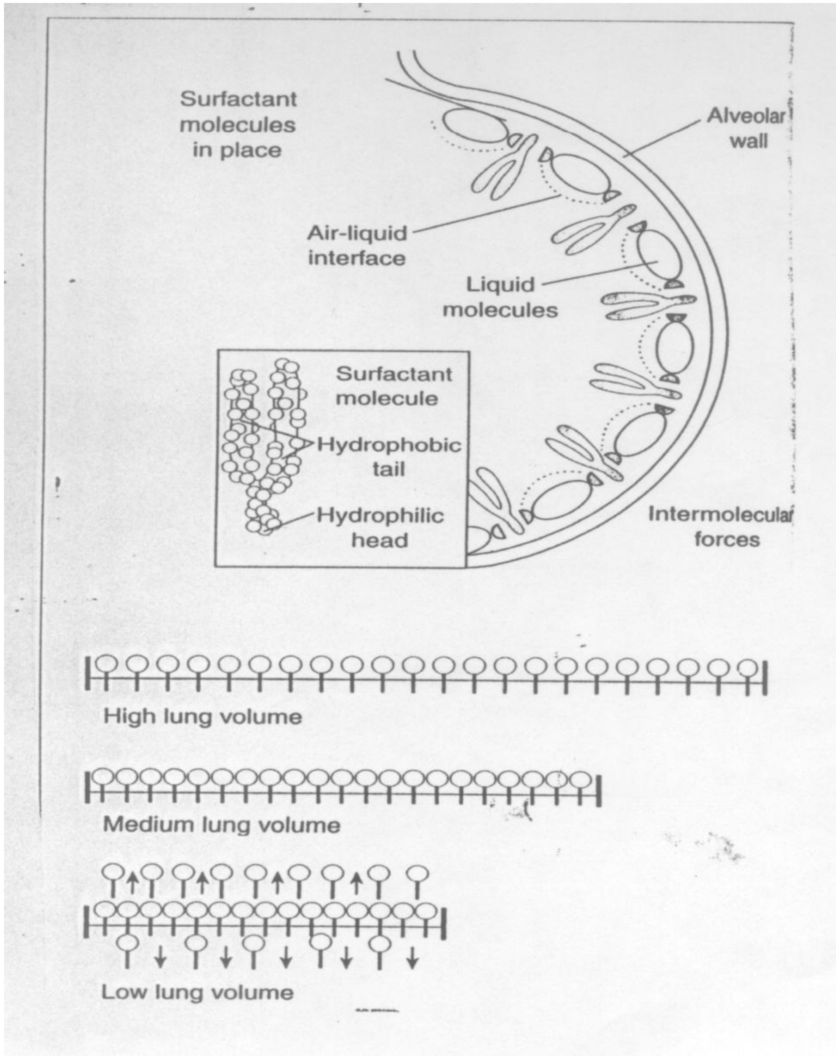
- The surfactant is very important in minimizing the effect of ST in causing collapse of the lungs.
- Some newborns, especially premature ones do not secrete enough of this surfactant:⇒ **HYALINE MEMBRANE DISEASE (RESPIRATORY DISTRESS SYNDROME).**



Surface Tension of the Alveoli

There is a FIXED AMOUNT of surfactant in each alveolus and its ability to reduce ST depends on its CONCENTRATION.

- a. Alveolus deflated⇒ conc. of surfactant per unit area is high⇒ ST is low⇒ therefore alveolus expands without difficulty (inhaling).
- b. Alveolus expands⇒ conc. of surfactant per unit area is low⇒ ST is high⇒ therefore this helps collapse of the alveolus and expel air (exhaling).



Surfactant Stabilizes the Size of the Alveoli

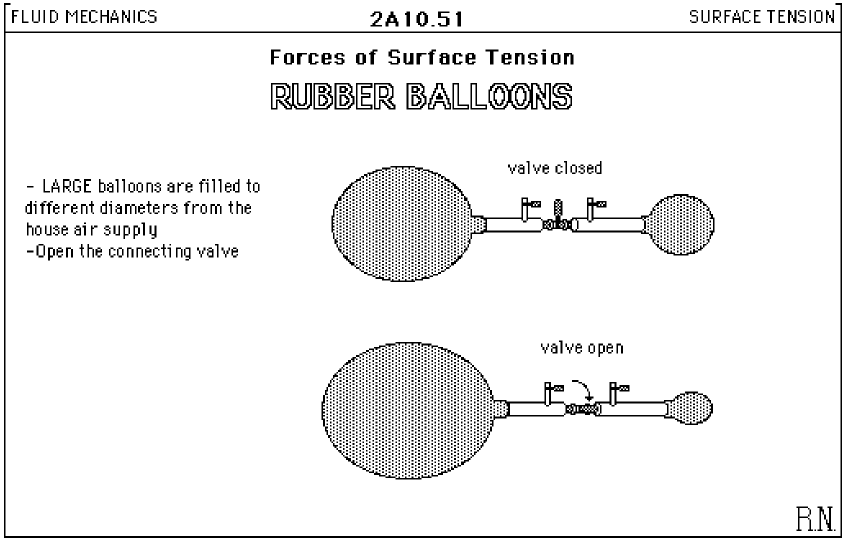
- Second function of the surfactant: to prevent the small alveoli from collapsing and discharging their contents into larger alveoli.
- **LAPLACE's LAW**: For a given wall tension, the internal pressure rises as the radius of the alveolus decreases

$$\mathbf{P} = \frac{\gamma}{\mathbf{r}}$$

- As the diameter becomes less, the pressure required to keep the alveolus from collapsing further becomes proportionately GREATER.

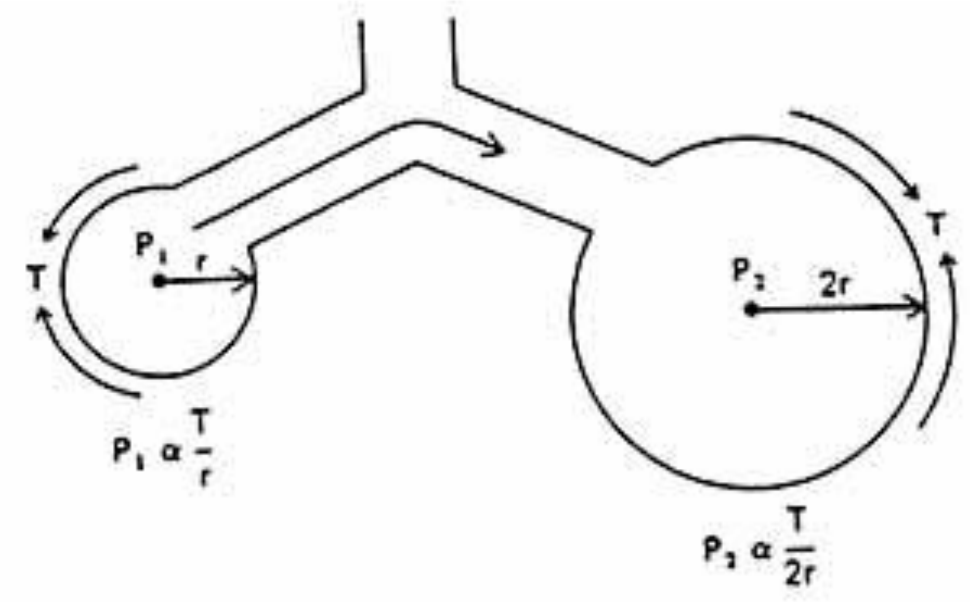
Pressure inside a Bubble

- The presure inside a soap bubble depends on its radius. When the valve between the two bubbles is closed, the pressure is greater in the smaller bubble ($P= 4\gamma/R$).
- When the valve is opened, the smaller bubble empties into the larger, leaving a spherical cap with the same radius of curvature as the new large bubble.



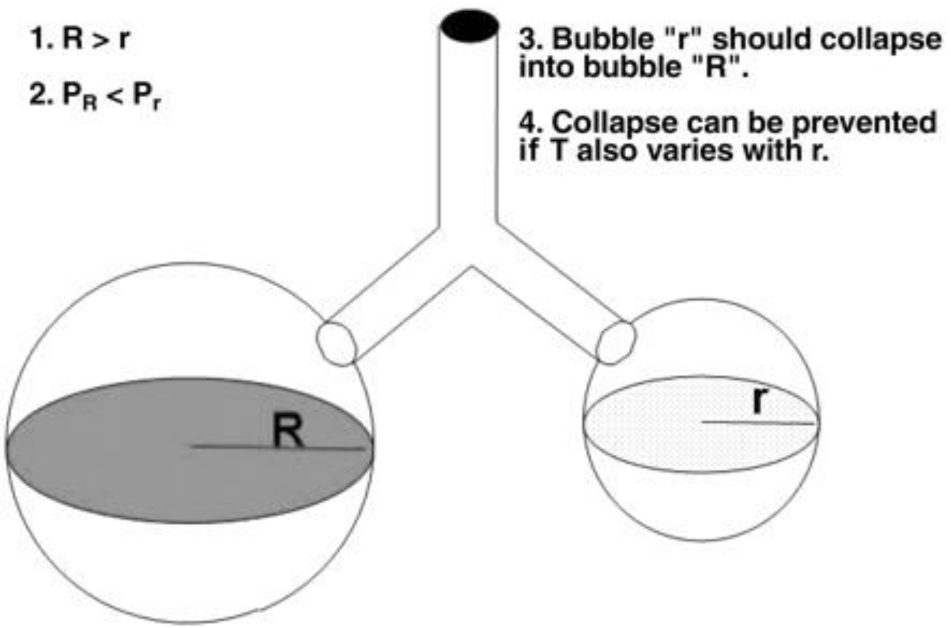
Instability of the Alveoli: Without Surfactant

- Air displaced from the smaller bubble to the larger one: collapse of the alveolus.
- The reason why most alveoli do not collapse is because as the alveolar radius decreases, the ST is also reduced. $\Rightarrow$ due to unique properties of the surfactant: not constant



Instability of the Alveoli: With Surfactant. Laplace's Law

- The **larger** alveoli contract **more** (high ST)
- The **smaller** alveoli contract **less** (low ST)
- Alveolus **larger**$\Rightarrow$ conc of surfactant $\downarrow \Rightarrow$ ST $\uparrow \Rightarrow$ contract **more**
- Alveolus **smaller**$\Rightarrow$ conc of surfactant $\uparrow \Rightarrow$ ST $\downarrow \Rightarrow$ contract **less**
- As applied to the grape-like alveolus, where only the inner wall has a liquid surface exposed to gas, the formula is P = 2T/r.



Laplace's Law