Al-Mustaqbal University

College of Technology and Health Sciences

Medical physics Department

Medical Physics

First Semester

3rd stage

# Lesson 8

# Physics of the Lungs and Breathing

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# Introduction

The source of energy in the body is food; it's processed in the digestive system and then combined with $O_2$ in the cells to release energy. The human machine consists of billions of very small engines (the cells of the body). Each of these engines must be provided with fuel, $O_2$ and a method of getting rid of the by-products.

The lungs (pulmonary system) serve as the supplier of $O_2$ and the disposer of $CO_2$. The blood takes $O_2$ to the tissue and remove $CO_2$. Then the blood comes in close contact with the air in the lungs in order to exchange its load of $CO_2$ for a fresh load of $O_2$ (figure 1).

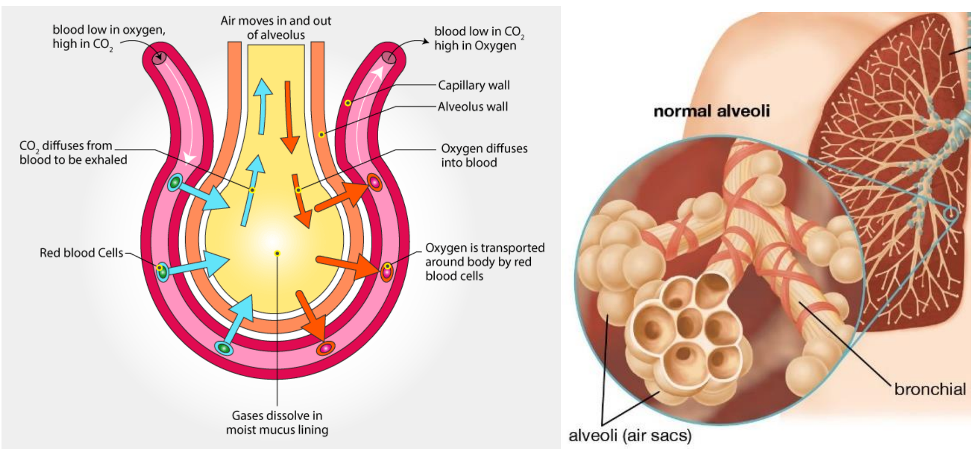


Figure 1. The exchange of $O_2$ and $CO_2$ in the lungs

We breathe 6 liters of air per minute (this is also about the volume of blood the heart pumps each minute). Men breathe 12 times per minute at rest while women and infants breathe 20 times, 60 times per minute respectively.

The air we inspire about 80 % $N_2$ and 20 % $O_2$. Expired air is about 80 % $N_2$, 16 % $O_2$ and 4% $CO_2$.

## The Airways

The air path is as follows;

- ***Nose***; where it is warmed, filtered and moisturized.
- ***Windpipe (trachea)***
- The trachea is divided into two ***bifurcates*** to reach each ***lung*** through ***bronchi***
- Each bronchus divides and re-divides about 15 times
- The resulting ***bronchioles*** supply air to millions of small sacs called ***alveoli*** (small interconnected bubbles)

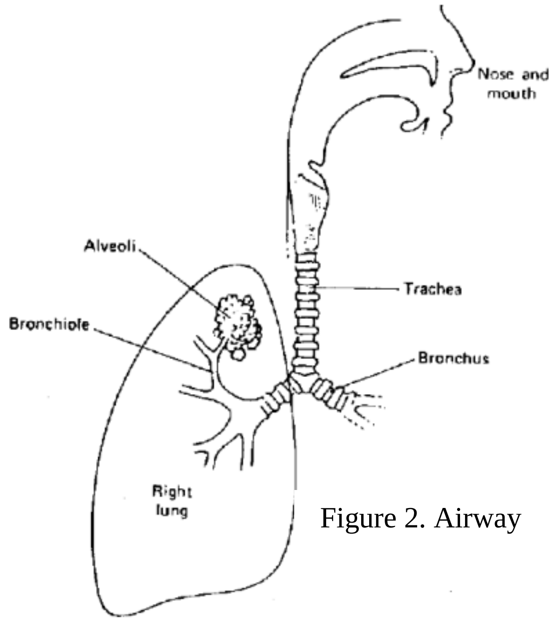

Figure 2. Airway

Alveoli are about 0.2mm diameter and 0.4 $\mu m$ wall thickness, each alveolus surrounded by blood capillary. So $O_2$ can diffuse from alveolus into red blood cells and $CO_2$ diffuse from blood into air in the alveolus.

## How the Blood and Lungs Interact

The blood pressure pumped to lungs is at low pressure (~20 mmHg). About on fifth (~1 liter) of the body blood goes to lungs, but only about 70 ml of that blood passes the capillaries of the lungs getting $O_2$ at one time. Since the blood in the pulmonary capillaries stay for less than 1 second, the lungs must be well designed for gas exchange. The alveoli of the lungs have thin walls and surrounded by the blood in the capillary system.

The surface area between air and blood in the lungs is about 80 $m^2$.

The transfer of $O_2$ and $CO_2$ is controlled by the law of ***diffusion***. Molecules of gas diffuse from the region of high concentration to a region of lower concentration until the concentration is balanced (for example, a drop of perfume).

Consider what happens in closed container of blood and oxygen. Some $O_2$ molecules collide with blood and are dissolved. After a while, the blood is saturated with $O_2$. However, if the pressure of $O_2$ is doubled, the amount of dissolved $O_2$ in the blood is also doubled.

## Measurement of Lungs Volume

During normal breathing we inhale 500 $cm^3$ of air with each breathe. If a person cough or sneeze hard the velocity of air in the trachea can reach the velocity of sound in air. This high velocity can cause partial collapse of air ways because of Bernoulli Effect.

In coughing to dislodge foreign object, this partial collapse increases air velocity and increase the force on foreign object.

Inspired and expired lung volumes measured by spirometry are useful for detecting, characterizing and quantifying the severity of lung disease.

Spirometry is the most common type of pulmonary function or breathing test. This test measures how much air you can breathe in and out of your lungs, as well as how easily and fast you can the blow the air out of your lungs.

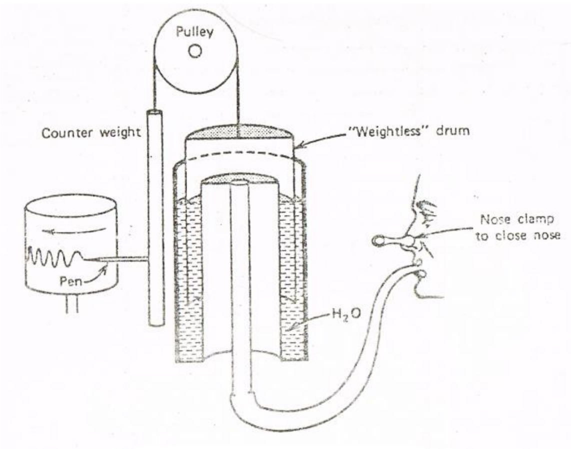

Figure 3. Spirometry

Measurement of lungs volume can help diagnose problems such as COPD, asthma, pulmonary fibrosis, and sarcoidosis.

# Physics of Alveoli

The alveoli like millions of small interconnected bubbles, have tendency to get smaller due to surface tension of unique fluid lining. This lining called surfactant. The absence of surfactant in the lungs of some new born infant is the cause of respiratory distress syndromes (RDS) called hyaline membrane disease which causes death.

To understand the physics of alveoli we have to understand physics of bubble. The pressure inside bubble is inversely proportional to the radius (R) and directly to the surface tension ($\gamma$).

$$P = 4\gamma/R$$

The surface tension of the surfactant that lines the alveoli is not constant. The large decrease in $\gamma$ as the area decreases. This cause the surface tension of alveoli to decrease as alveoli size decrease during expiration. There is a size for alveoli at which the $\gamma$ decreases fast causes drop the size instead of continuing to increase.

Alveoli not covered with surfactant, such as those infants with RDS, collapse like small bubbles, and quite a large pressure is needed to reopen them. An infant with RDS may not have the energy to breath with its low compliance lungs.

## Two Forces Keep Lungs from Collapsing

1. Surface tension between lungs and chest
2. Air pressure inside the lungs.

Since each lung is its own sealed compartment, it is possible to collapse one lung only. This is done by inserting a hollow needle between ribs and allowing air to flow into intrathoracic space, the air trapped in the space is gradually absorbed by tissue and lung expand to normal over few weeks, sometimes lung collapses spontaneously with no known cause.

The lungs returns to normal as the air is absorbed into surrounding tissues. Since both lung and chest are elastic we can represent them with springs.

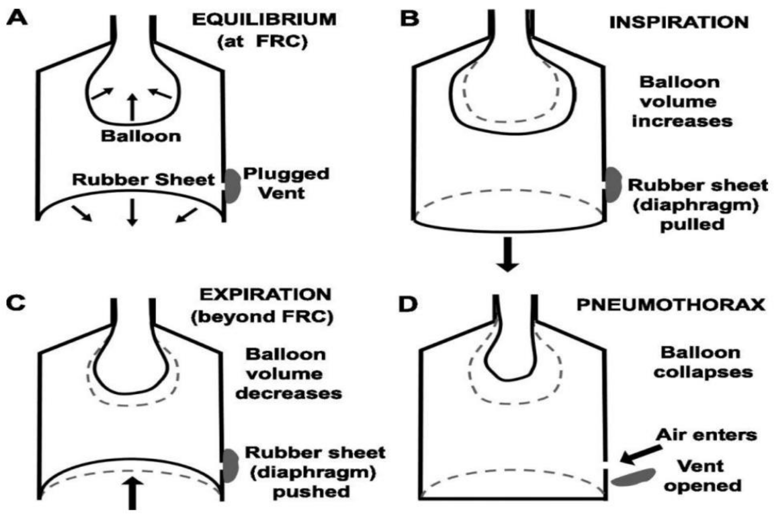


Figure 4. Simple model for mechanism of breathing during (A) normal conditions, B inspiration, C expiration and D pneumothorax.

## Work of Breathing

The amount of work done in breathing accounts for a small fraction of total energy consumed by the body (~2% at rest). The work of breathing can be thought of as the work done in stretching the spring (figure 5). During normal breathing, no work is done during expiration. During exercise, muscles are used to expel air. The work of breathing during heavy exercise may amount to 25% of the body total energy consumption.

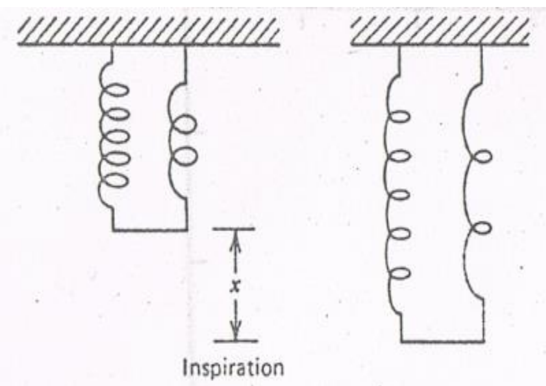


Figure 5. Model of breathing work

## Some Common Lungs Diseases

***Emphysema*** the division between alveoli break down produces large lung spaces, this destruction of lung tissue reduces the springiness of lungs (figure 6). The lungs become more complaint, small change in pressure produces larger than normal change in volume.

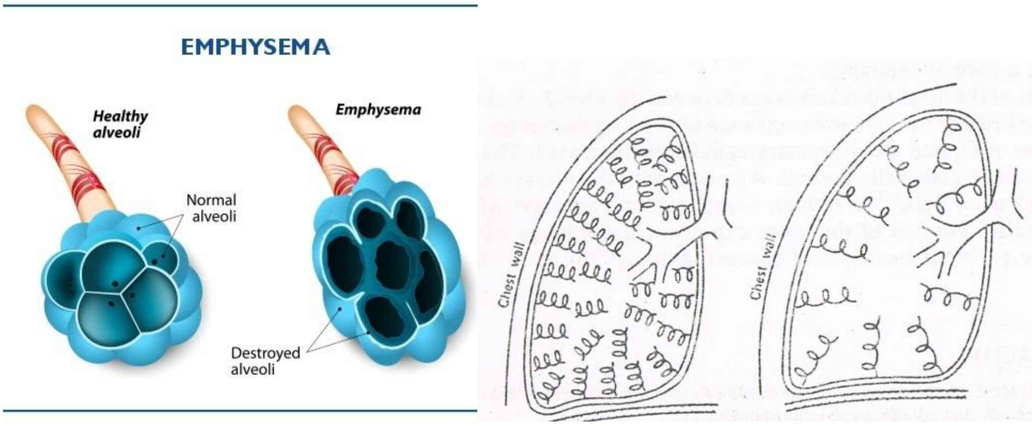


Figure 6. Emphysema disease

In ***asthma***, the basic problem expiratory difficulty due to increased airway resistance as a result of contraction of the smooth muscle around the airways (figure 7).

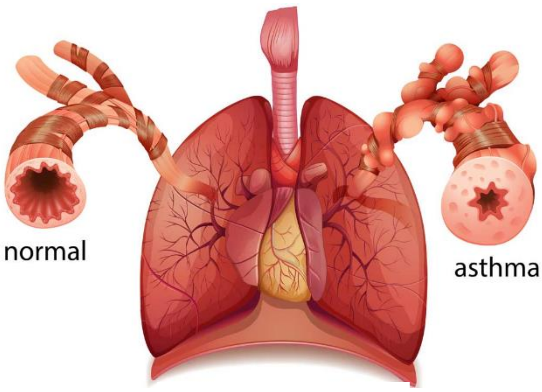


Figure 7. Asthma

***Fibrosis*** of lungs, the membranes between alveoli thicken. This has two effect; (1) the compliance of the lungs decreases and (2) the diffusion of $O_2$ into capillary decreases

## Exercises

1 **The small interconnected bubbles in the lungs are called**

(a) Alveoli

(b) Bronchial

(c) Trachea

(d) Cells

(e) None of them

2 **The blood is pumped to lungs at a pressure of about**

(a) 120 mmHg

(b) 80 mmHg

(c) 40 mmHg

(d) 20 mmHg

(e) 5 mmHg

3 **The surface area between blood and air in the lungs is about**

(a) 20 $m^2$

(b) 40 $m^2$

(c) 80 $m^2$

(d) 100 $m^2$

(e) 200 $m^2$

4 **During normal breathing we inhale**

(a) 50 $cm^3$ of air

(b) 100 $cm^3$ of air

(c) 300 $cm^3$ of air

(d) 350 $cm^3$ of air

(e) 500 $cm^3$ of air

5 **Absence of surfactant in the lungs of some new born infant causes**

(a) Asthma
(b) Fibrosis
(c) Respiratory distress syndromes
(d) Sneeze
(e) High blood pressure