Respiration

Pulmonary Structure and Function

Introduction

- **Respiration has two meanings in biology.**
  - At the cellular level, it refers to the O_2 requiring chemical reactions that take place in the mitochondria and are the chief source of energy in the eukaryotic cells.
  - At the level of the whole organism, it designates the process of taking in O_2 from the environment and returning CO_2 to it.
- O_2 consumption is directly related to energy expenditure.
  - Energy requirements are usually calculated by measuring O_2 intake or CO_2 release.
  - Energy expenditure at rest is known as **basal metabolism**.

Diffusion and Air Pressure

- In every organism from amoeba to elephant, gas exchange--the exchange of O_2 and CO_2 between cells and the surrounding environment--takes place by diffusion.
  - Diffusion--the net movement of particles from a region of higher concentration to a region of lower concentration as a result of their random movement.
- In describing gases, scientists speak of the pressure of a gas rather than its concentration.
  - At sea level, air exerts a pressure of one (1) atm. (15 lb/in2)
    - This pressure is enough to support a column of mercury 760 mm high.

Dalton's Law of Partial Pressure-

-The total pressure of a mixture of gases is sum of the pressures of the separate gases in the mixture.

The pressure of each gas is proportional to its concentration. O_2 makes up 21% of the composition of dry air therefore 21% of the total air pressure or 160 mm of Hg results from the pressure of O_2--partial pressure of O_2--designated as pO_2 --if H_2O is present then pO_2 =155 mm Hg.

•If a liquid containing no dissolved gases is exposed to air at atmospheric pressure, each of the gases in the air diffuses into the liquid until the partial pressure of each gas in the liquid is equal to the partial pressure of the gas in the air.

•pO_2 of blood means the pressure of dry gas with which the dissolved O_2 in the blood is in equilibrium.

For example, blood with a pO_2 of 40 mm Hg would be in equilibrium with air in which the partial pressure of O_2 was 40 mm Hg.

If blood with a pO_2 of 40 mm Hg was exposed to the usual mixture of air, O_2 will move from the air to the blood until the pO_2 = 155 mm Hg.

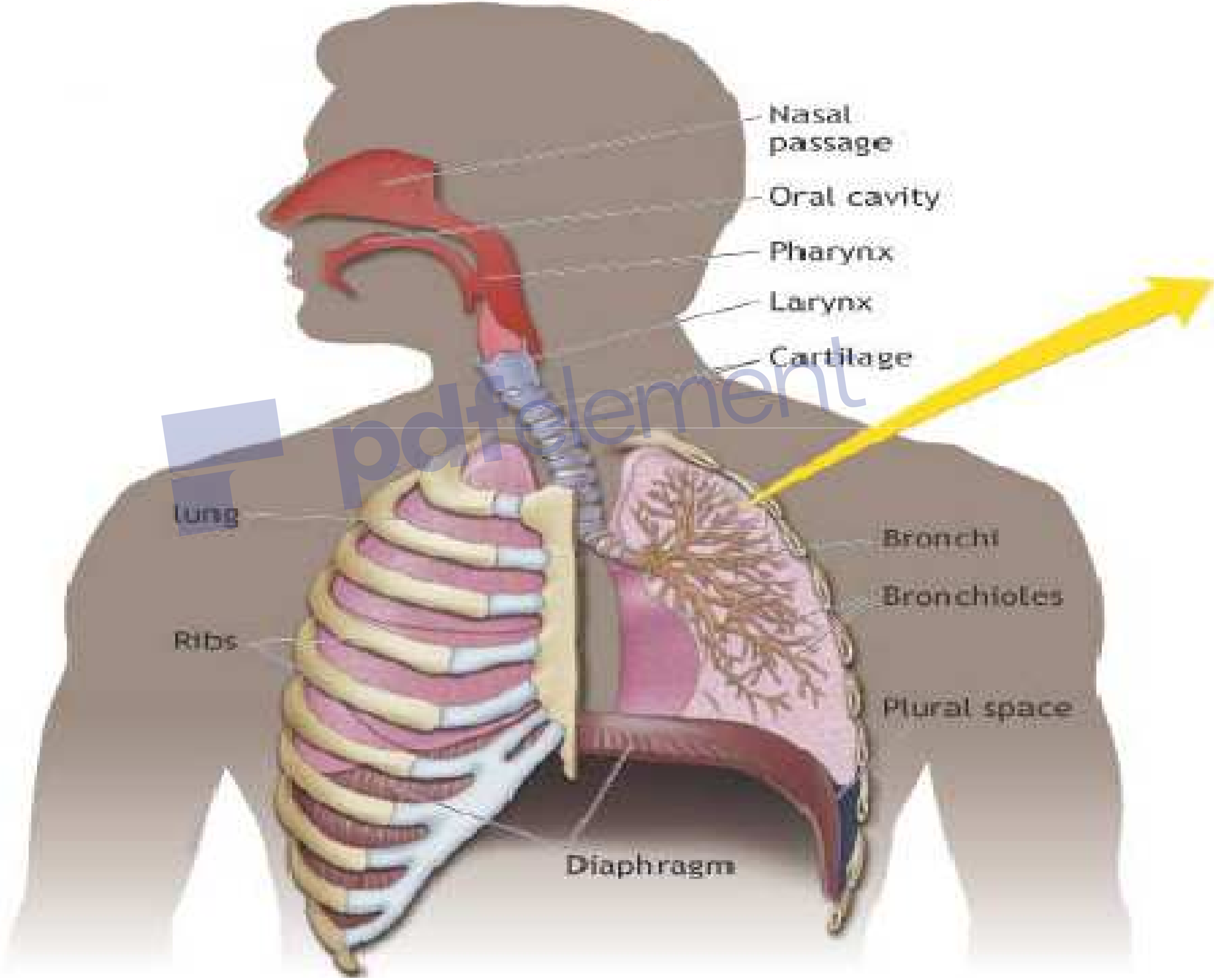
Conversely, if a liquid containing a dissolved gas is exposed to air in which the partial pressure of that gas is lower than the liquid, the gas will leave the liquid until the partial pressures of the air and the liquid are equal.

In summary, gases move from a region of higher partial pressure to a region of lower partial pressure

Respiration in Humans--Some Principles

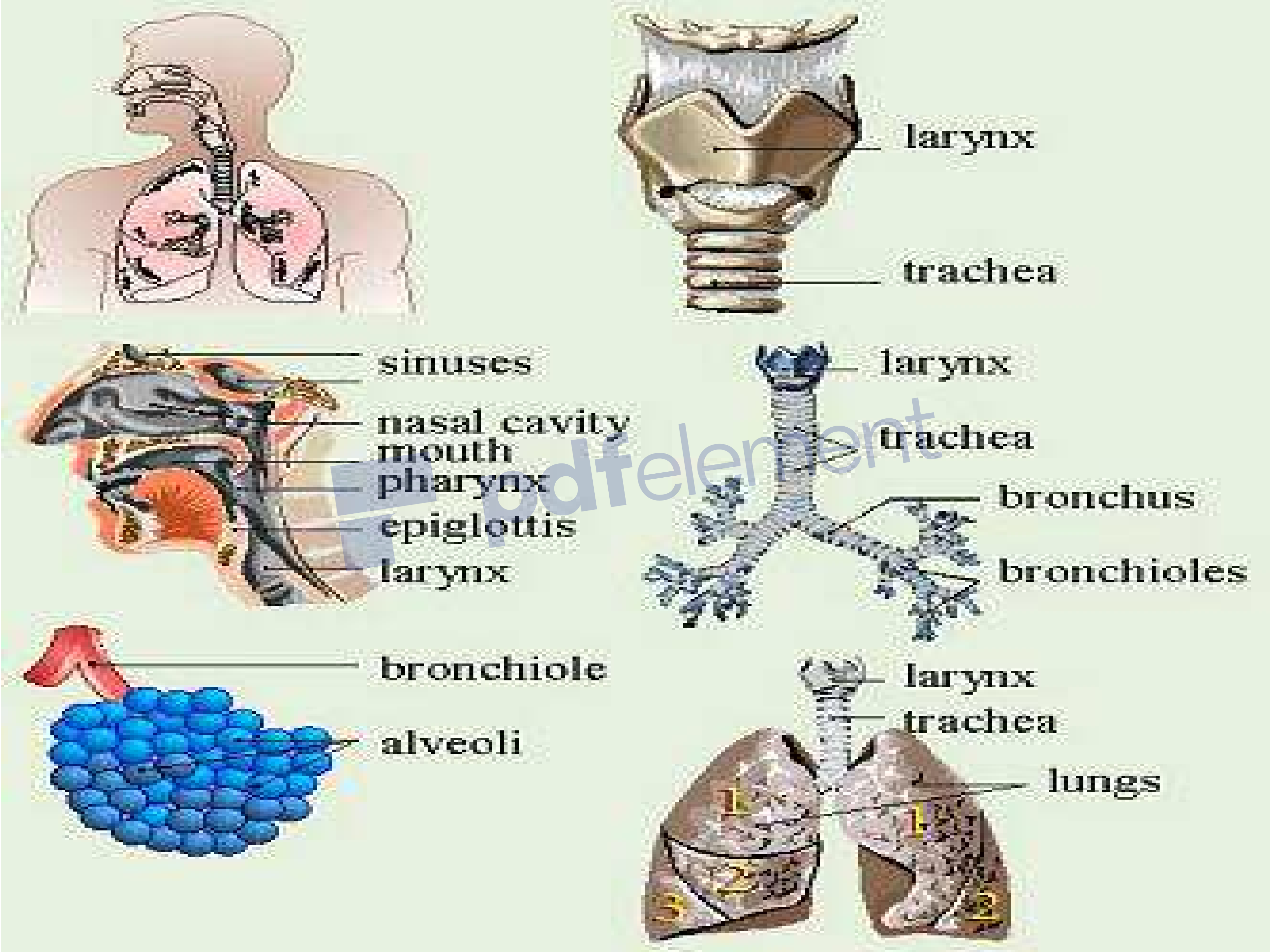
- In humans both diffusion and bulk flow move O2 molecules between the external environment and actively metabolizing tissues.
- This movement occurs in four (4) stages:
  - . Movement by bulk flow of the O2 containing air to a thin, moist epithelium close to small blood vessels in the lungs.
  - Diffusion of the O2 across the epithelium into the blood.
  - Movement by bulk flow with the circulating blood to the tissues where it will be used.
  - Diffusion of the O2 from the blood into the interstitial fluids, from which it diffuses into the individual cells.
- CO2--produces in the tissue cells, follows the reverse path as it is eliminated from the body.

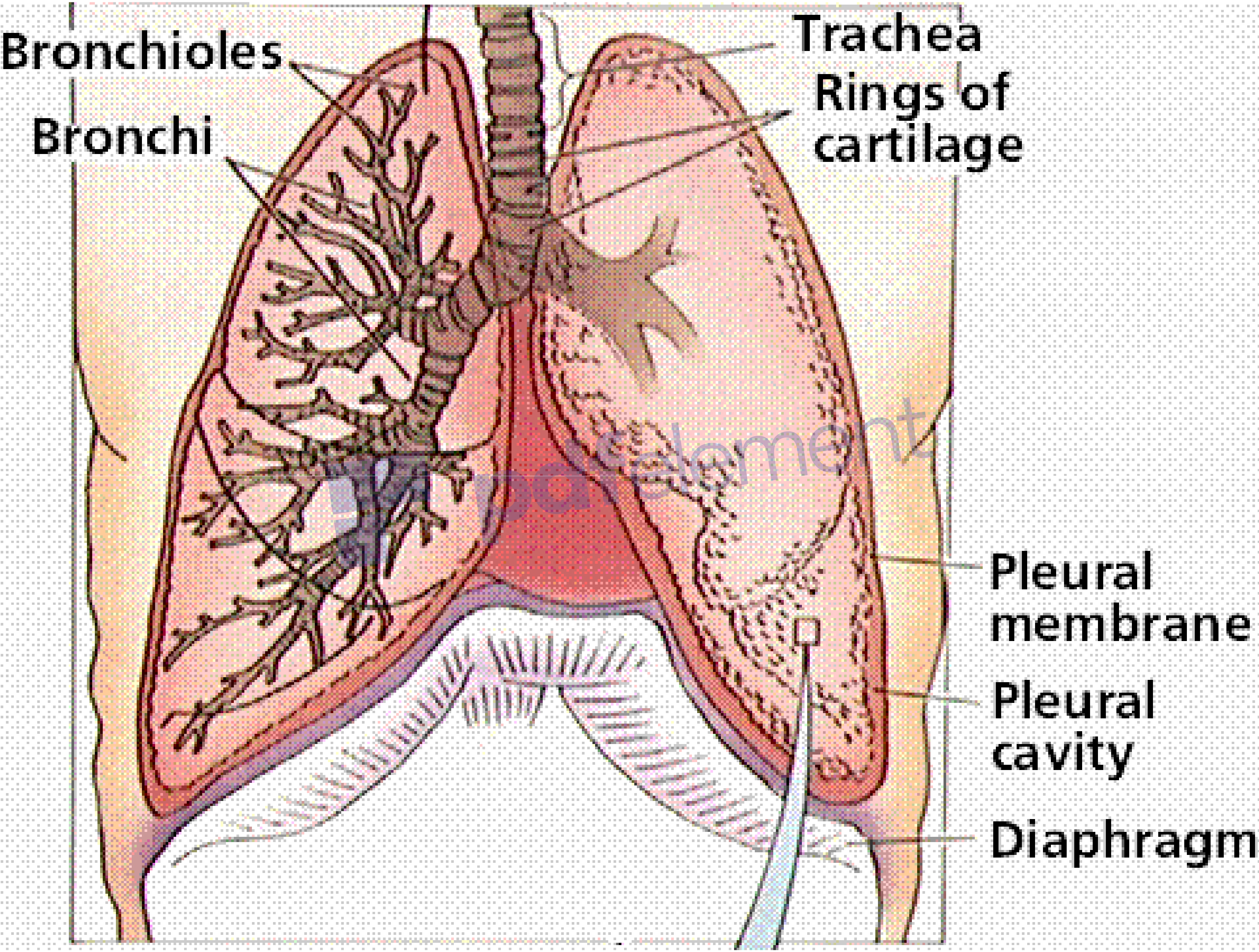
Anatomy of Ventilation



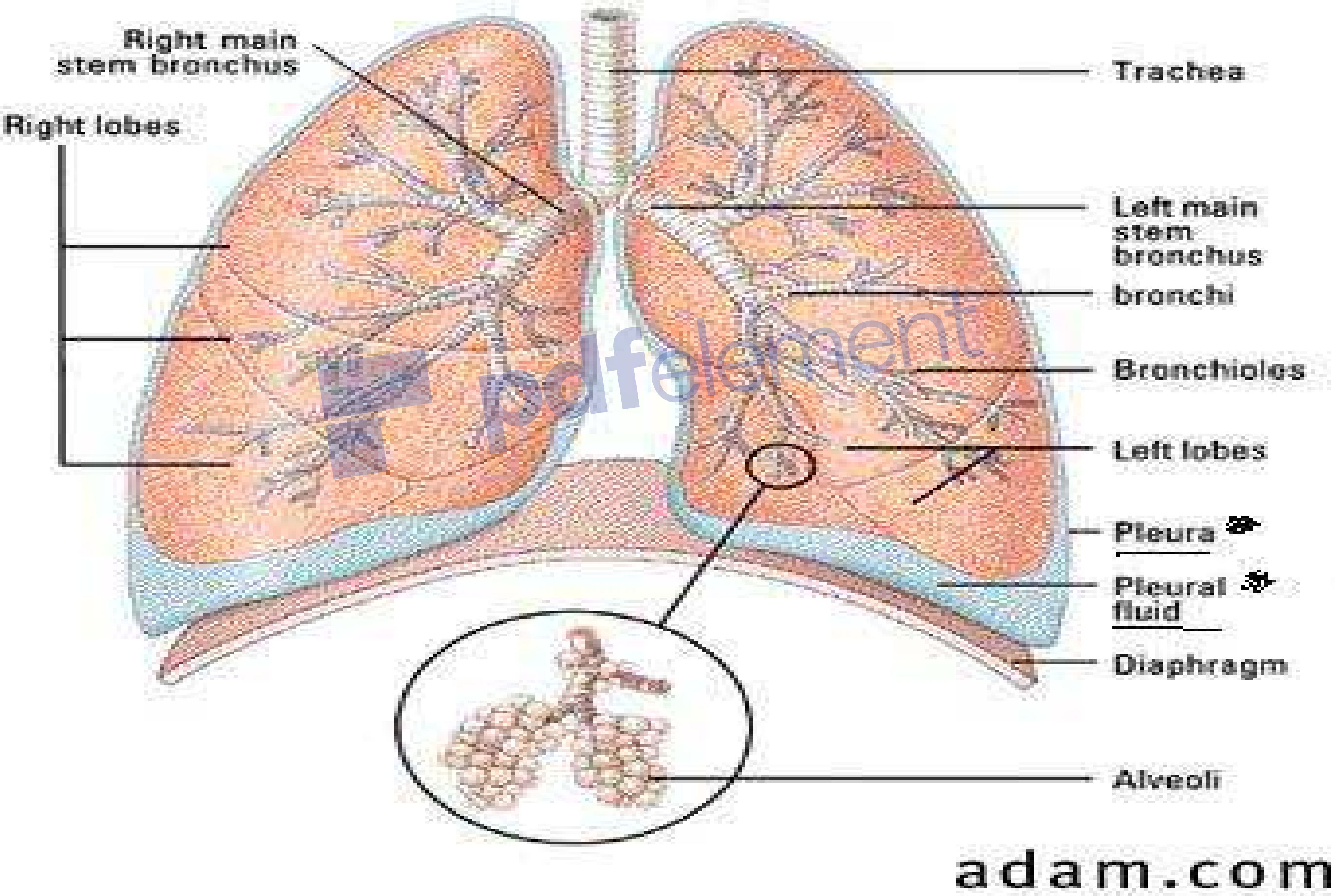
Anatomy of Ventilation

- The respiratory system consists of the **nasal cavity**, **pharynx**, **larynx**, **trachea**, **bronchi**, and **lungs**.
- Upper respiratory tract refers to:
  - Nasal cavity, pharynx, and associated structures.
- Lower respiratory tract refers to:
  - Larynx, trachea, bronchi, and lungs
- Respiratory movements are accomplished by the diaphragm and the muscles of the thoracic wall.

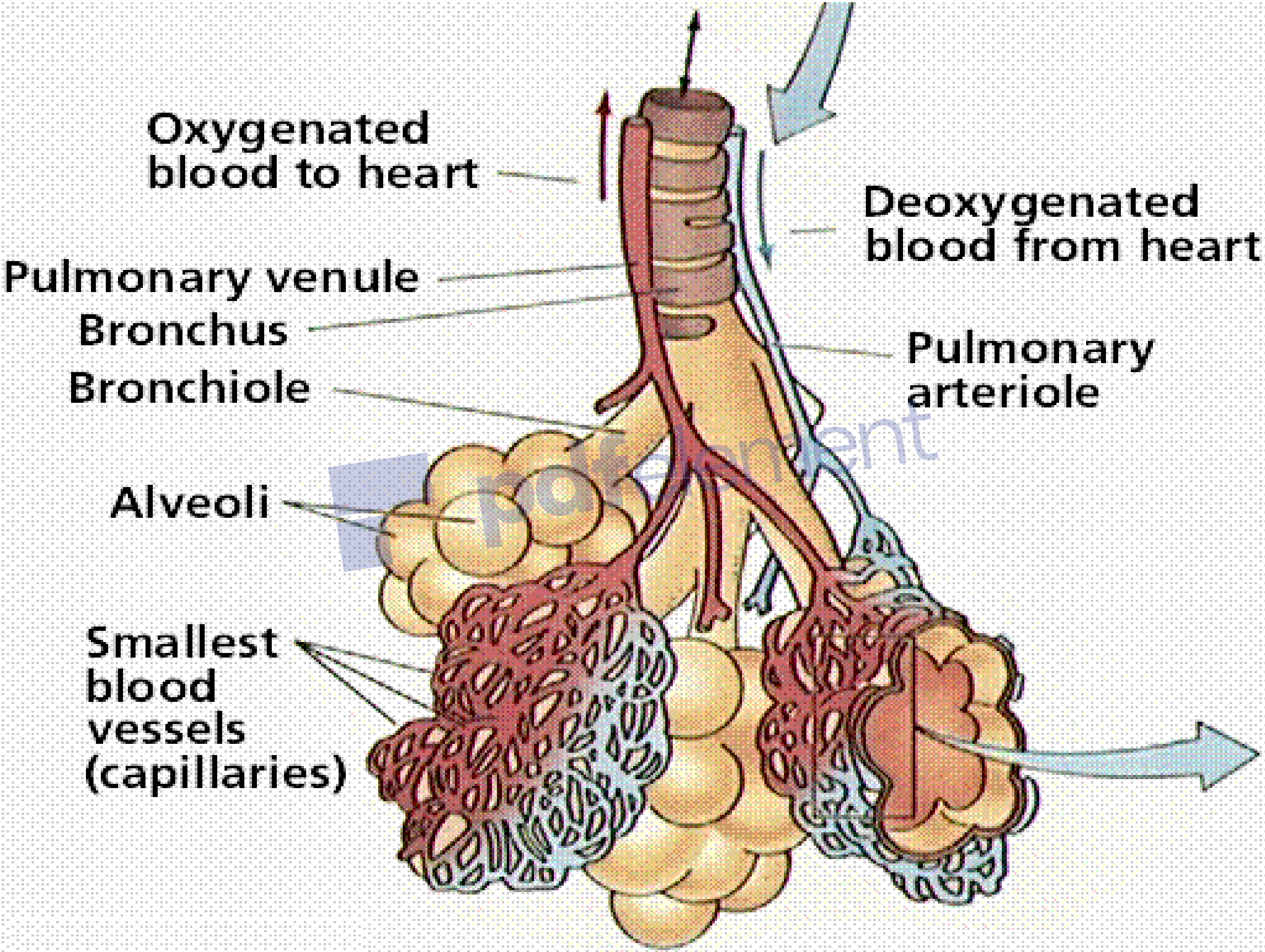

larynx
trachea
sinuses
nasal cavity
mouth
pharynx
epiglottis
larynx
larynx
trachea
bronchus
bronchioles
bronchiole
alveoli
larynx
trachea
lungs
1
2
3
1
2


Bronchioles
Bronchi
Trachea
Rings of
cartilage
Pleural
membrane
Pleural
cavity
Diaphragm

Lungs



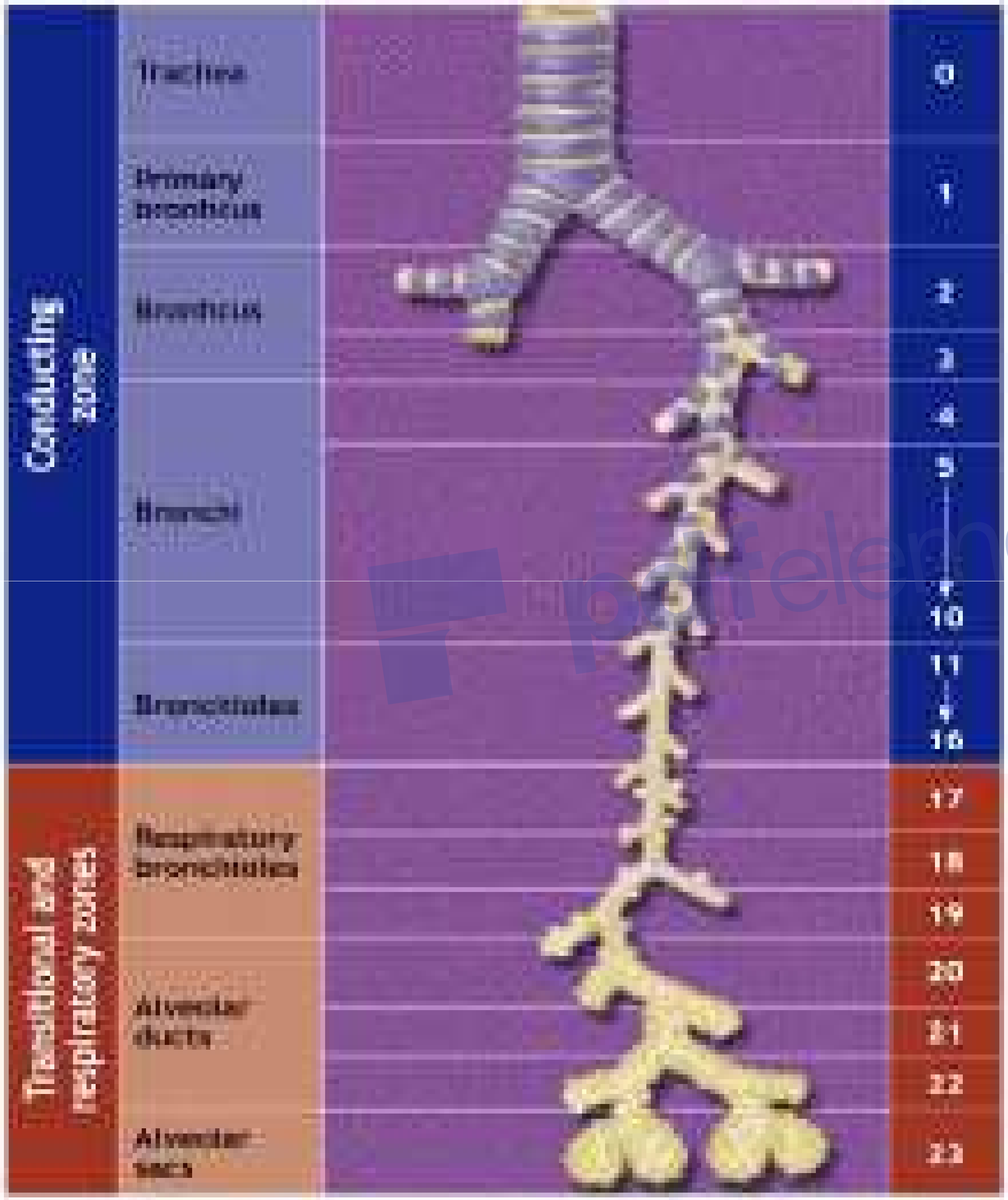
Right main stem bronchus
Right lobes
Trachea
Left main stem bronchus
bronchi
Bronchioles
Left lobes
Pleura
Pleural fluid
Diaphragm
Alveoli
adam.com



Oxygenated blood to heart
Deoxygenated blood from heart
Pulmonary venule
Bronchus
Bronchiole
Pulmonary arteriole
Alveoli
Smallest blood vessels (capillaries)

Respiratory System

- Divided into 2 functional zones:
- 1. Conducting Zone
- 2. Respiratory Zone


Conducting zone
Trachea
Primary bronchus
Bronchus
Bronchi
Bronchioles
Transitional and respiratory zones
Respiratory bronchioles
Alveolar ducts
Alveolar sacs
0
1
2
3
4
5
10
11
16
17
18
19
20
21
22
23

Conducting Zone

- Includes all anatomical structures that air passes through to reach the respiratory zone:
  - trachea
  - bronchial tree
  - bronchioles

Cont'd

- Generally humans breathe through the nose until ventilation is increased to ~ 20-30 L/min at which time the mouth becomes the primary passageway for air.

Function of Conducting Zone

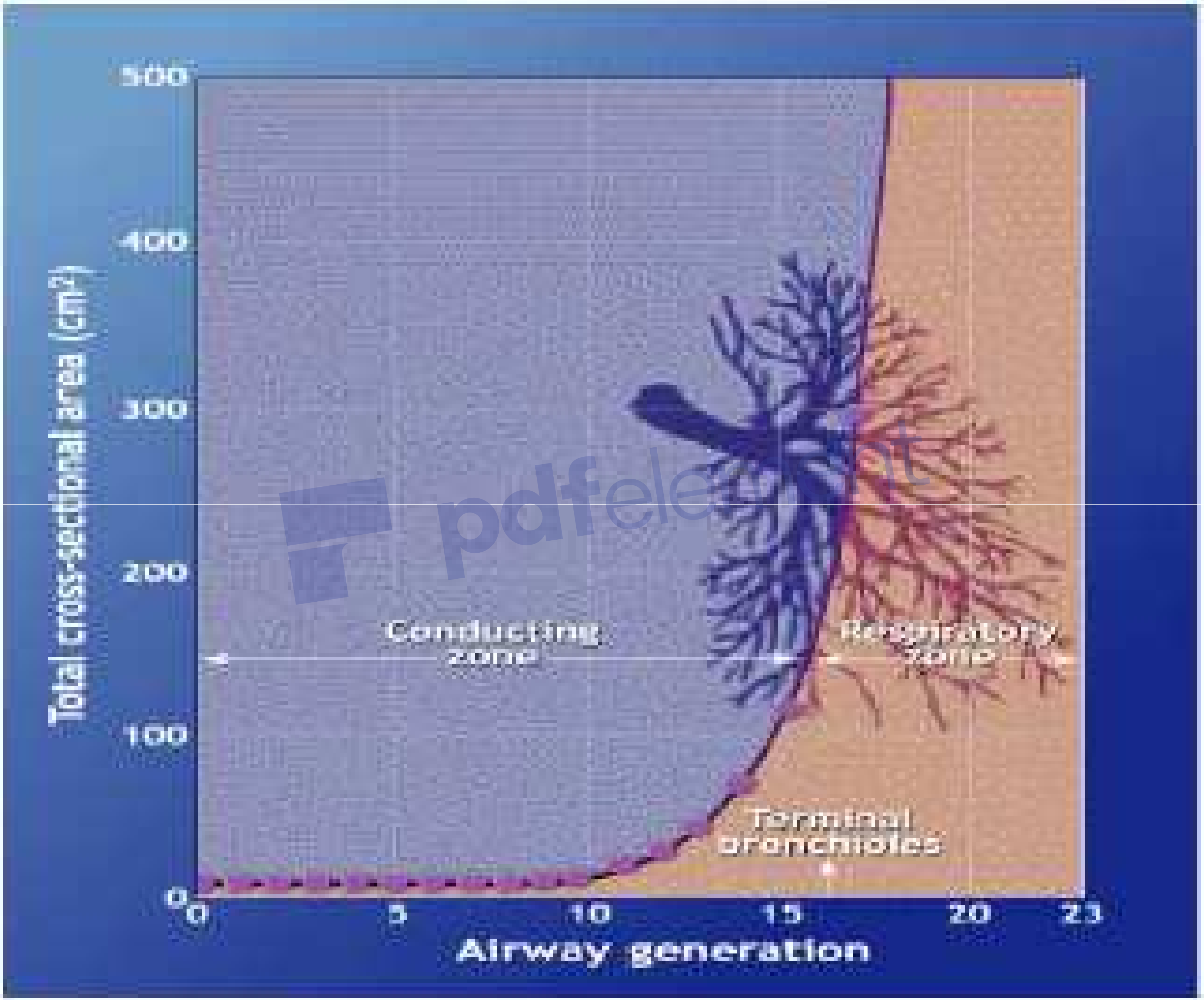
- Humidify
- Saturate
- Characteristic of air reaching the lung
- Importance
  - delicate lung tissue
  - inhalation of damaging particles

Filtration in the Conducting Zone

- 1. Mucus, secreted by cells of the conducting zone trap small inhaled particles. Mucus moved towards the oral cavity via cilia. The mucus can then be swallowed or expelled.
- 2. Macrophages = cells that reside in the alveoli. Function = engulf particles that reach the alveoli.
- Effect of smoking and pollution

Respiratory Zone

- Respiratory bronchioles, alveolar ducts, alveoli
- Primary function
- Relation to lung volume
- Velocity of air movement



Total cross-sectional area (cm2)
500
400
300
200
100
0
0
5
10
15
20
23
Airway generation
Conducting zone
Respiratory zone
Terminal bronchioles

Respiratory Zone

- Gas exchange in the lung occurs across ~ 300 million alveoli
  - function of large #
  - size of total surface area available for gas exchange
  - diffusion distance of blood-gas barrier
    - importance

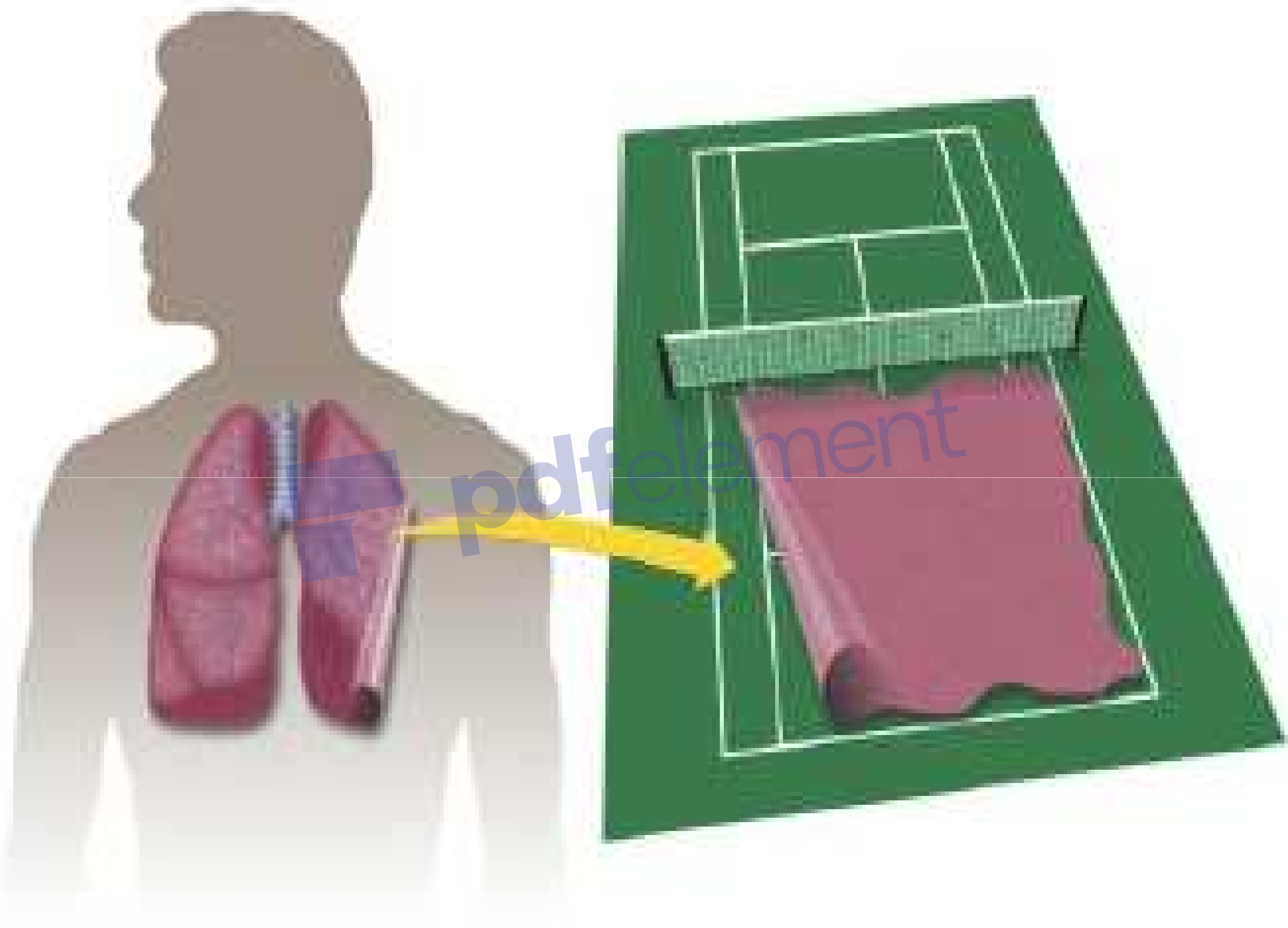


Figure 12.2. The lungs provide an exceptionally large surface for gas exchange.

Cont'd

- Fragility of alveolar sacs due to surface tension of liquid lining the alveoli
  - Effect of large forces on alveoli
- Role of Type II alveolar cells
  - surfactant

Role of Pulmonary Surfactant

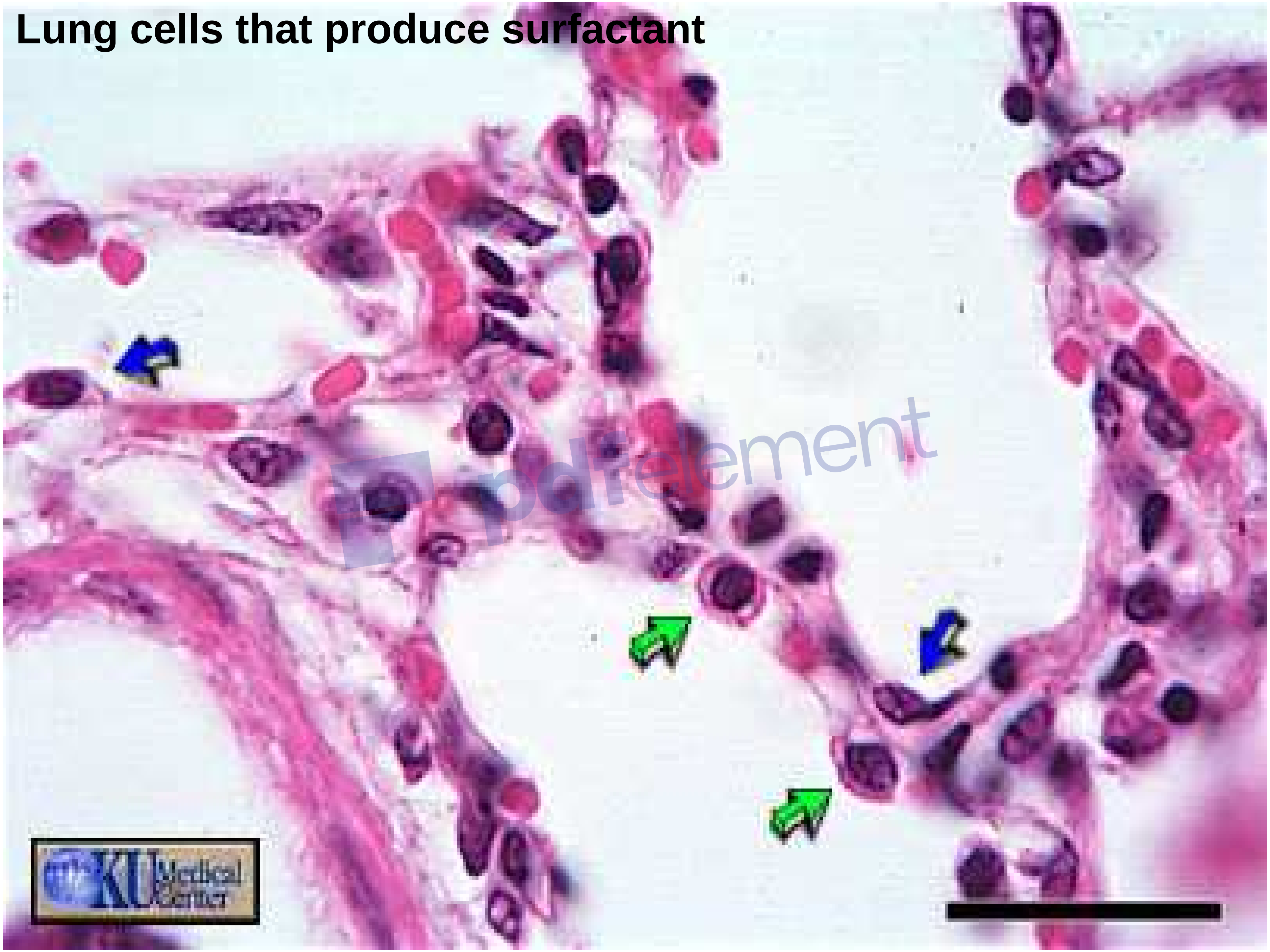
- Surfactant decreases surface tension which:
  - increases pulmonary compliance (reducing the effort needed to expand the lungs)
  - reduces tendency for alveoli to collapse

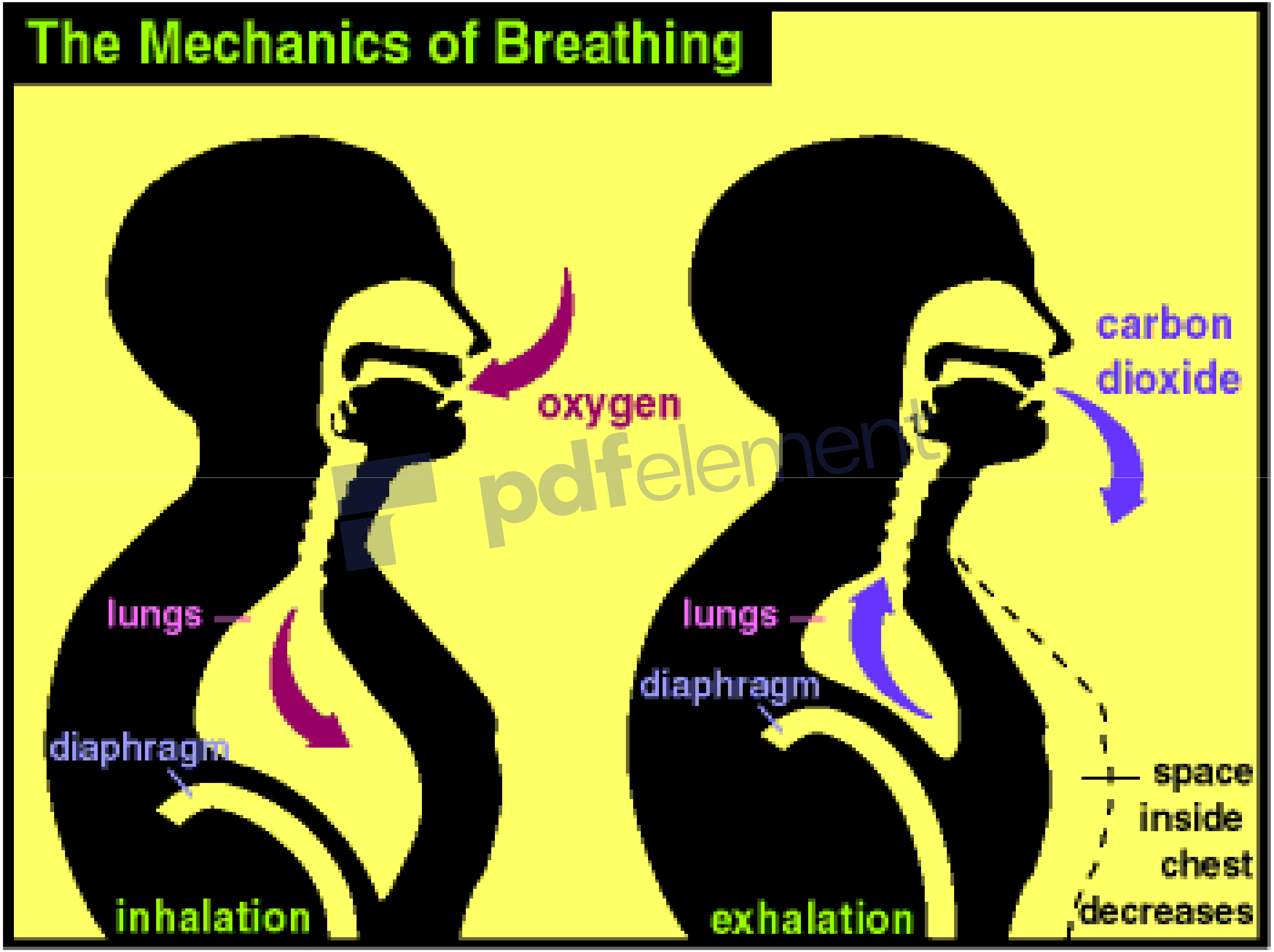
- **The walls of alveoli** are coated with a thin film of water & this creates a potential problem.
- Water molecules, including those on the alveolar walls, are more attracted to each other than to air, and this attraction creates a force called surface tension.
- This surface tension increases as water molecules come closer together, which is what happens when we exhale & our alveoli become smaller (like air leaving a balloon).
- Potentially, surface tension could cause alveoli to collapse and, in addition, would make it more difficult to 're-expand' the alveoli (when you inhaled).
- Both of these would represent serious problems: if alveoli collapsed they'd contain no air & no oxygen to diffuse into the blood &, if 're-expansion' was more difficult, inhalation would be very, very difficult if not impossible.
- Fortunately, our alveoli do not collapse & inhalation is relatively easy because the lungs produce a substance called surfactant that reduces surface tension.

Surfactant

- Lipoprotein mixture
  - Phospholipids
  - Proteins
  - Calcium
- Site of production
- Mechanism of action
  - Mixes with fluid surrounding the alveoli → reduction in alveolar membrane surface tension
  - Result

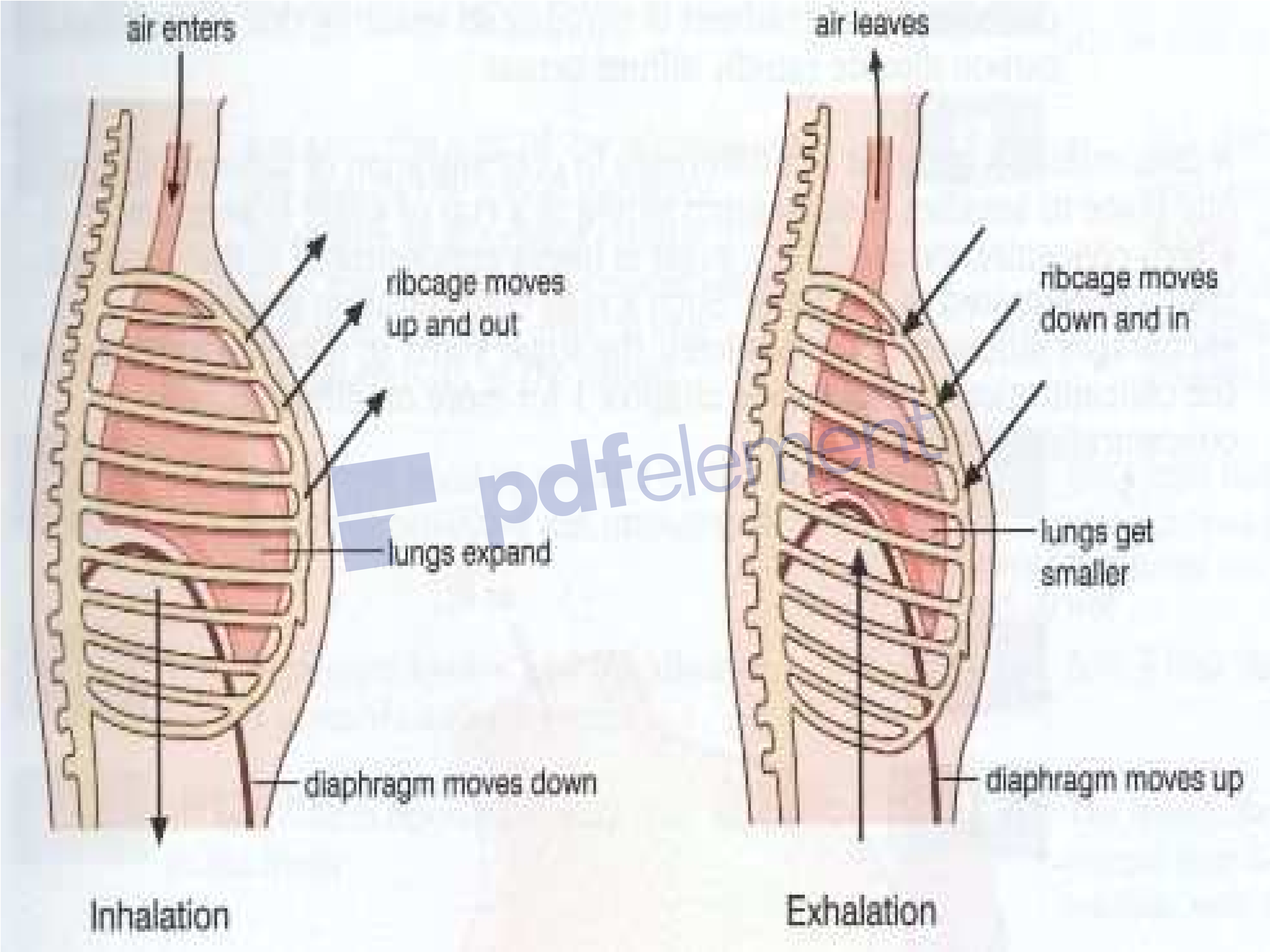
Lung cells that produce surfactant



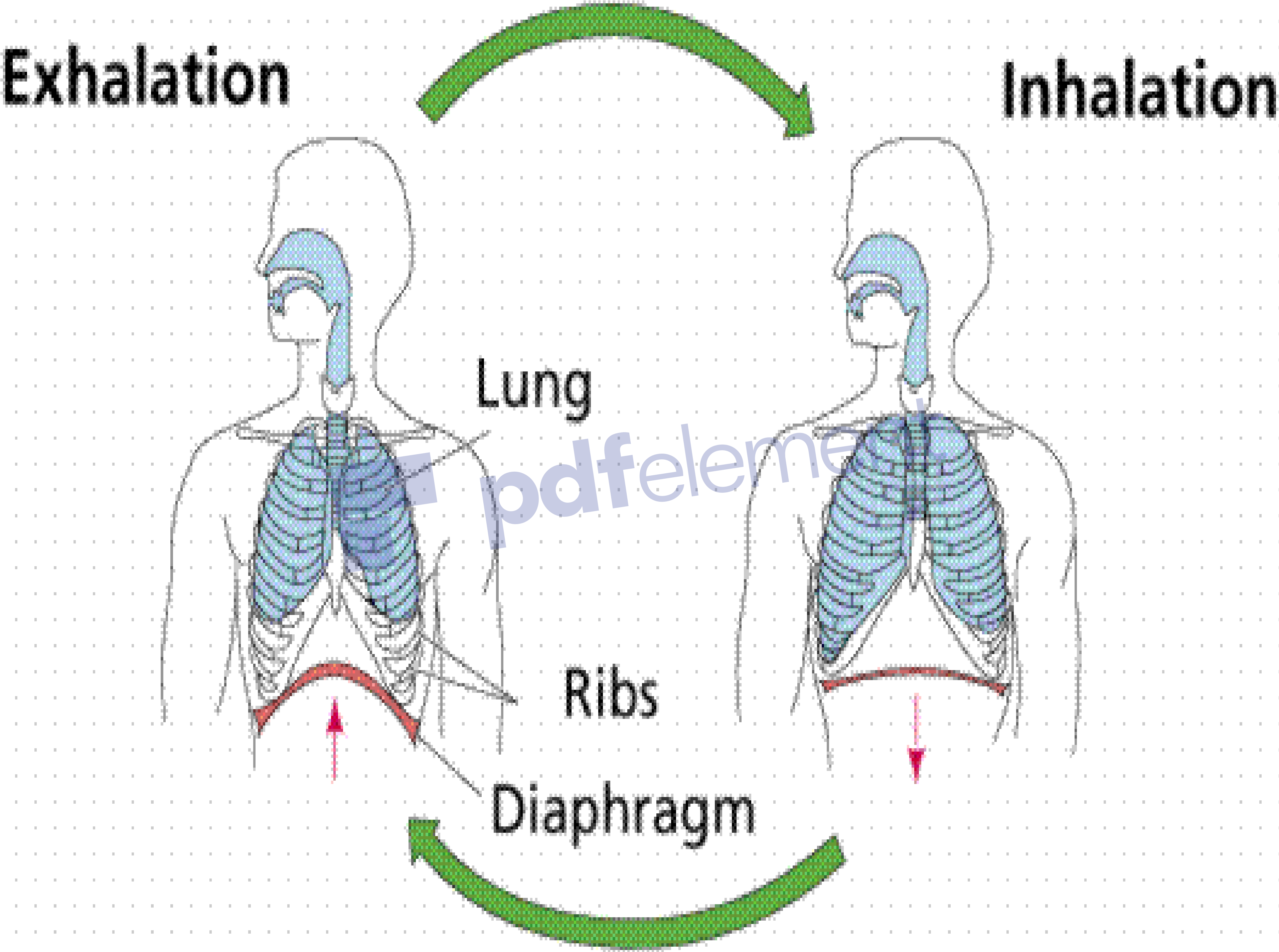


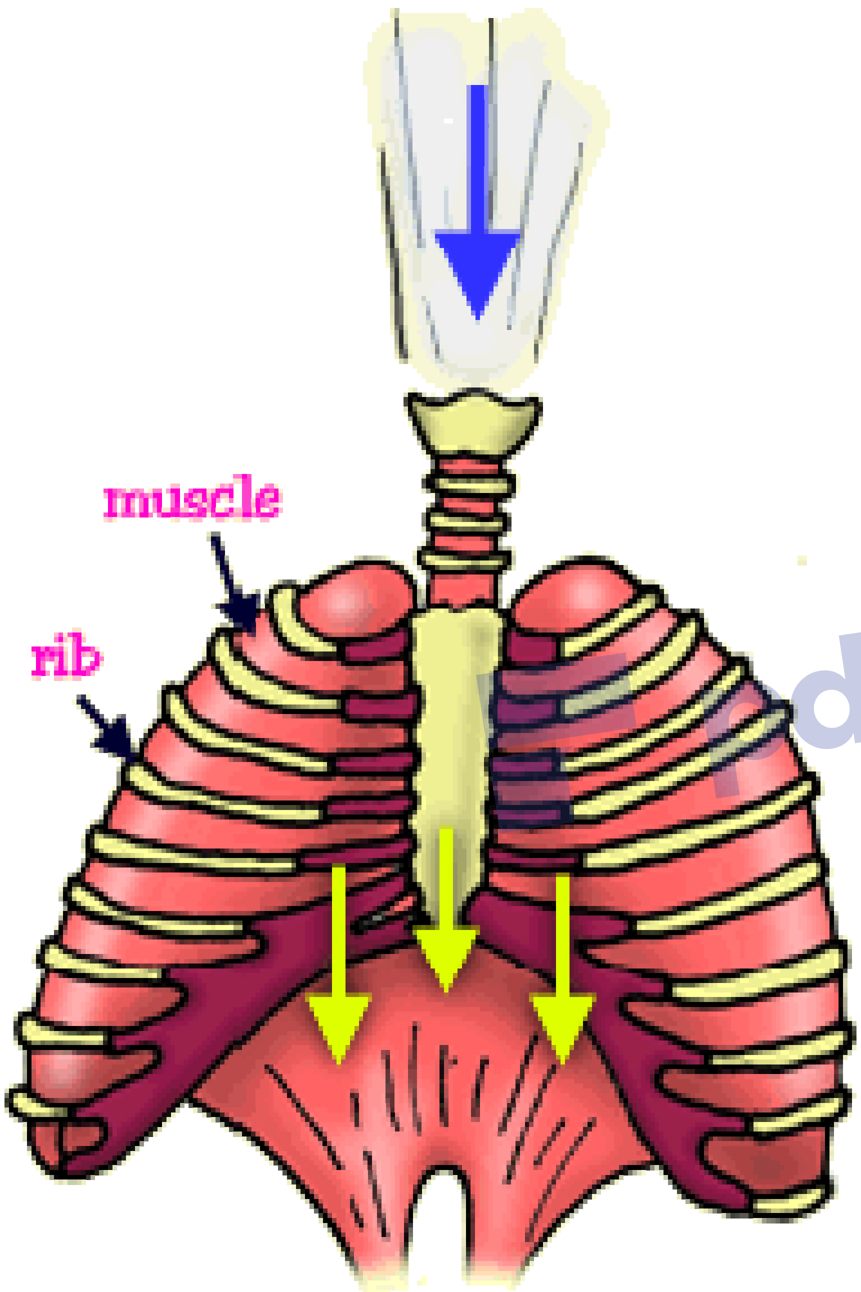
The Mechanics of Breathing
oxygen
lungs
diaphragm
inhalation
carbon dioxide
lungs
diaphragm
exhalation
space inside chest decreases

- Breathing is an active process - requiring the contraction of skeletal muscles.
- The primary muscles of respiration include the external intercostals muscles (located between the ribs) and the diaphragm (a sheet of muscle located between the thoracic & abdominal cavities
- **The external intercostals plus the diaphragm contract to bring about inspiration:**
- **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:

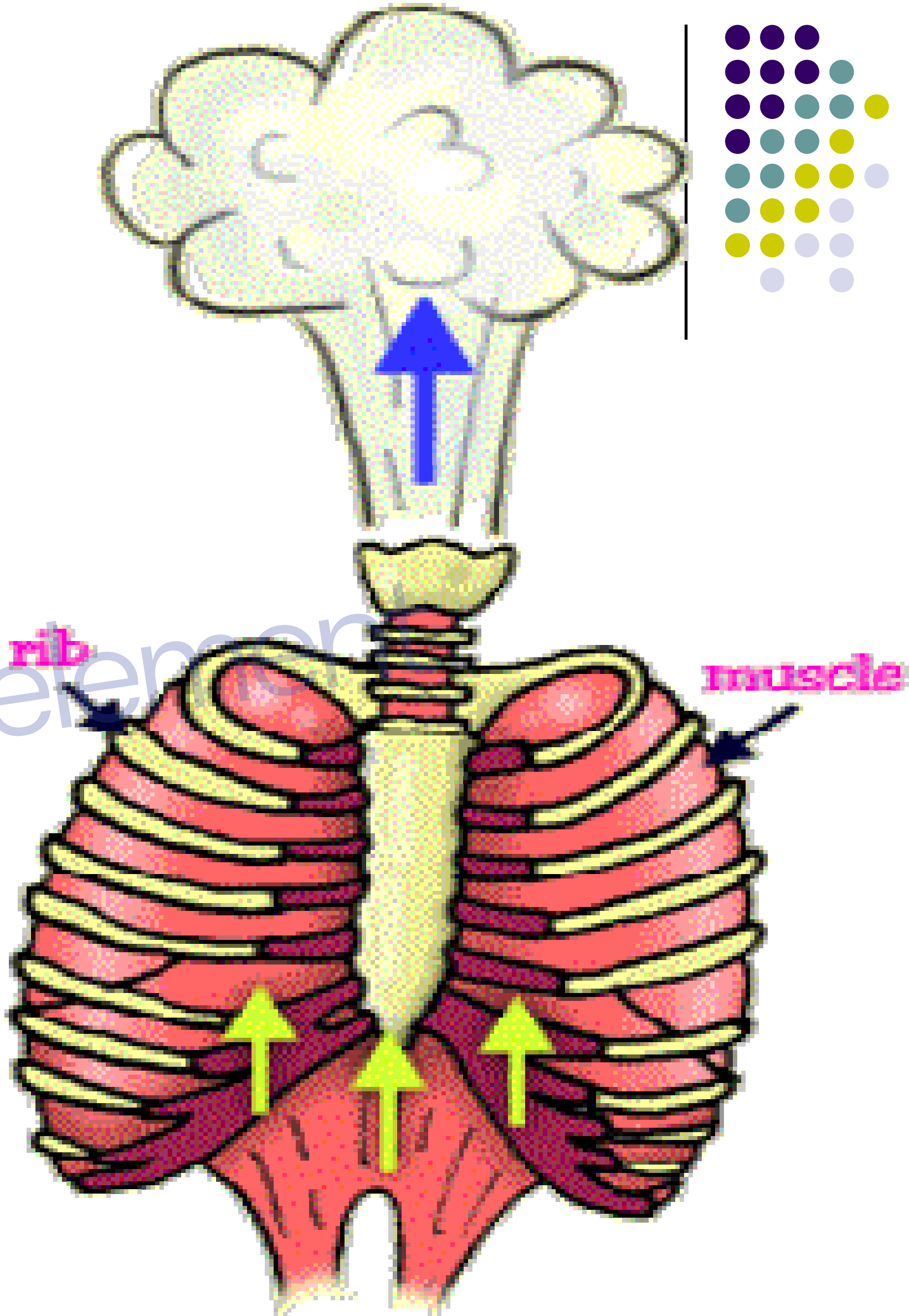


air enters
ribcage moves up and out
lungs expand
diaphragm moves down
Inhalation
air leaves
ribcage moves down and in
lungs get smaller
diaphragm moves up
Exhalation


Exhalation
Inhalation
Lung
Ribs
Diaphragm



Diaphragm Lowers

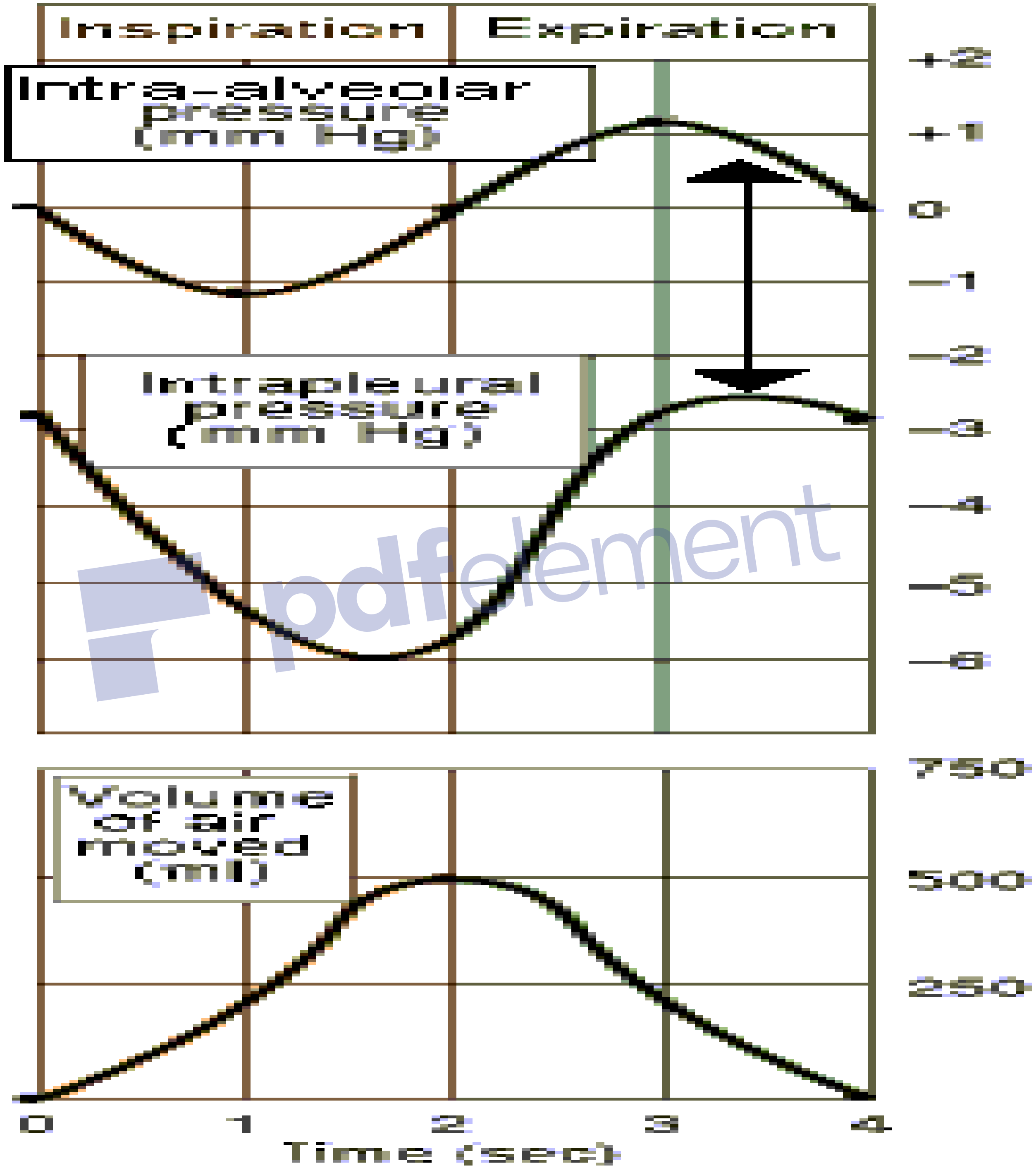


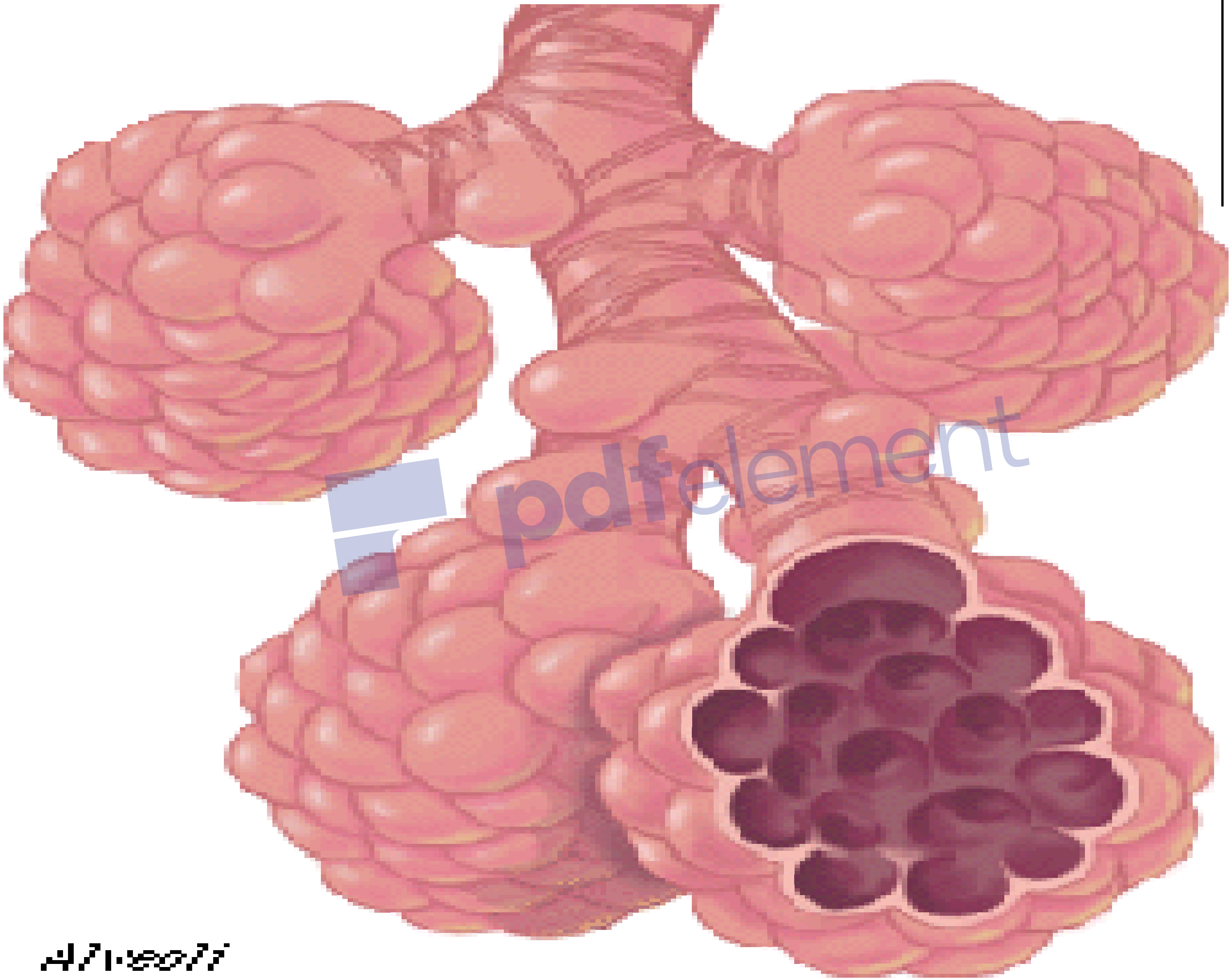
Diaphragm Elevates

- 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

Intra-alveolar pressure during inspiration & expiration

- As the external intercostals & diaphragm contract, the lungs expand.
- The expansion of the lungs causes the pressure in the lungs (and alveoli) to become slightly negative relative to atmospheric pressure.
- As a result, air moves from an area of higher pressure (the air) to an area of lower pressure (our lungs & alveoli).
- During expiration, the respiration muscles relax & lung volume decreases. This causes pressure in the lungs (and alveoli) to become slight positive relative to atmospheric pressure. As a result, air leaves the lungs.


Inspiration
Expiration
Intra-alveolar pressure (mm Hg)
Intrapleural pressure (mm Hg)
+2
+1
0
−1
−2
−3
−4
−5
−6
Volume of air moved (ml)
750
500
250
0
1
2
3
4
Time (sec)



Alveoli

Exchange of gases:

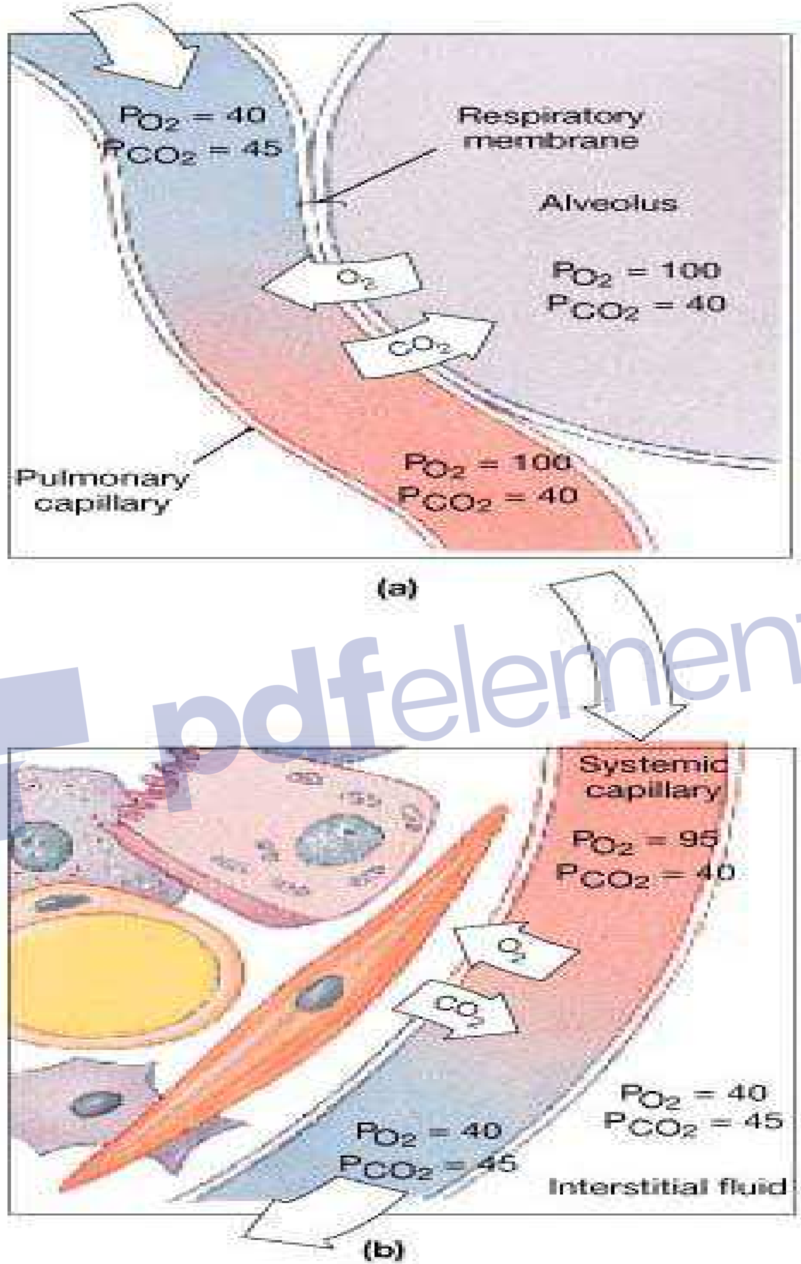
- External respiration:
  - exchange of O_2 & CO_2 between external environment & the cells of the body
  - efficient because alveoli and capillaries have very thin walls & are very abundant (your lungs have about 300 million alveoli with a total surface area of about 75 square meters)
- Internal respiration - intracellular use of O_2 to make ATP
- occurs by simple diffusion along partial pressure gradients

What is Partial Pressure?:

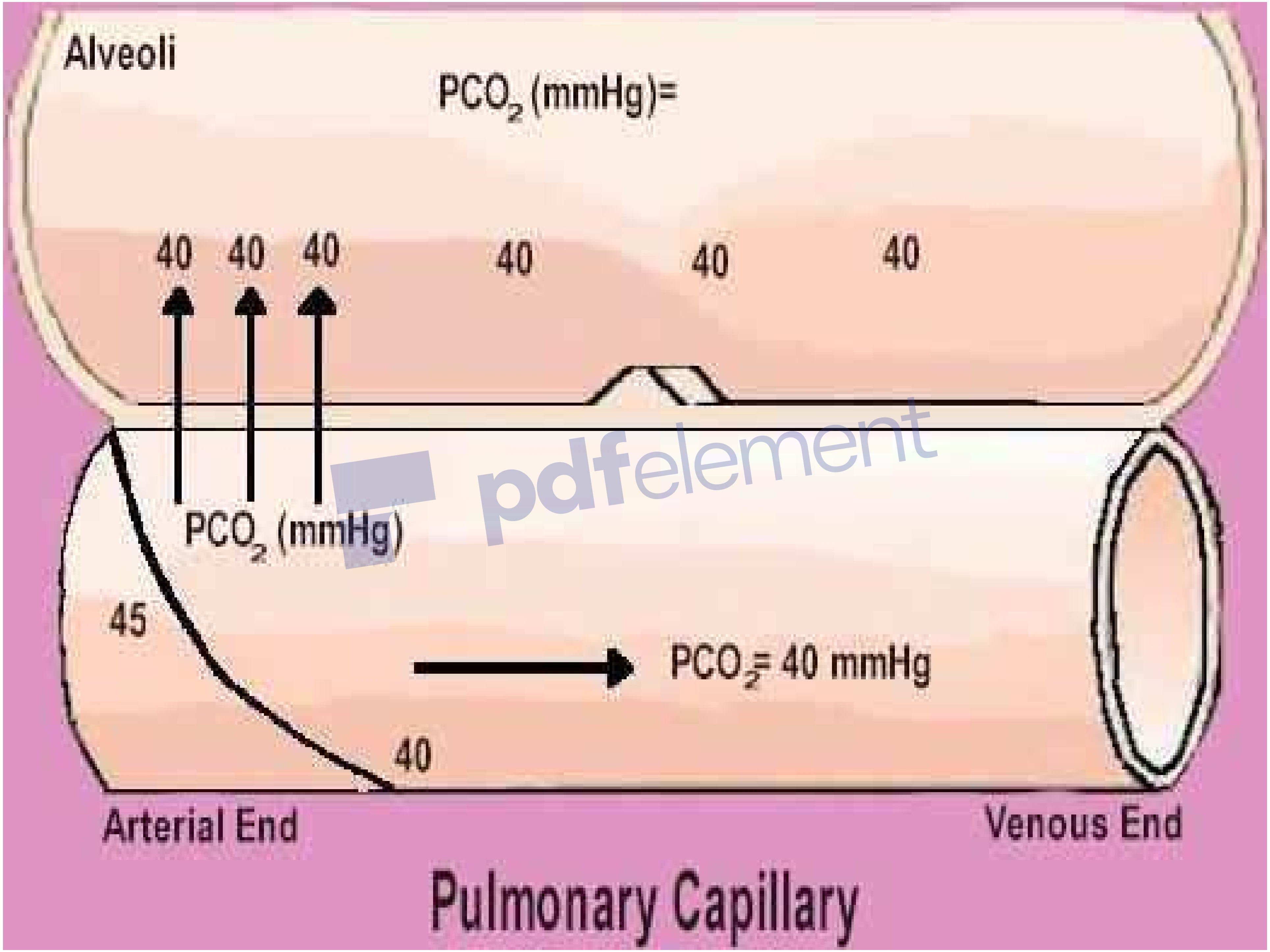
- it's the individual pressure exerted independently by a particular gas within a mixture of gasses.
- The air we breath is a mixture of gasses: primarily nitrogen, oxygen, & carbon dioxide.
- However, the total pressure generated by the air is due in part to nitrogen, in part to oxygen, & in part to carbon dioxide.
- That part of the total pressure generated by oxygen is the 'partial pressure' of oxygen, while that generated by carbon dioxide is the 'partial pressure' of carbon dioxide.
- A gas's partial pressure, therefore, is a measure of how much of that gas is present (e.g., in the blood or alveoli).
- The partial pressure exerted by each gas in a mixture equals the total pressure times the fractional composition of the gas in the mixture.
- So, given that total atmospheric pressure (at sea level) is about 760 mm Hg and, further, that air is about 21% oxygen, then the partial pressure of oxygen in the air is 0.21 times 760 mm Hg or 160 mm Hg.

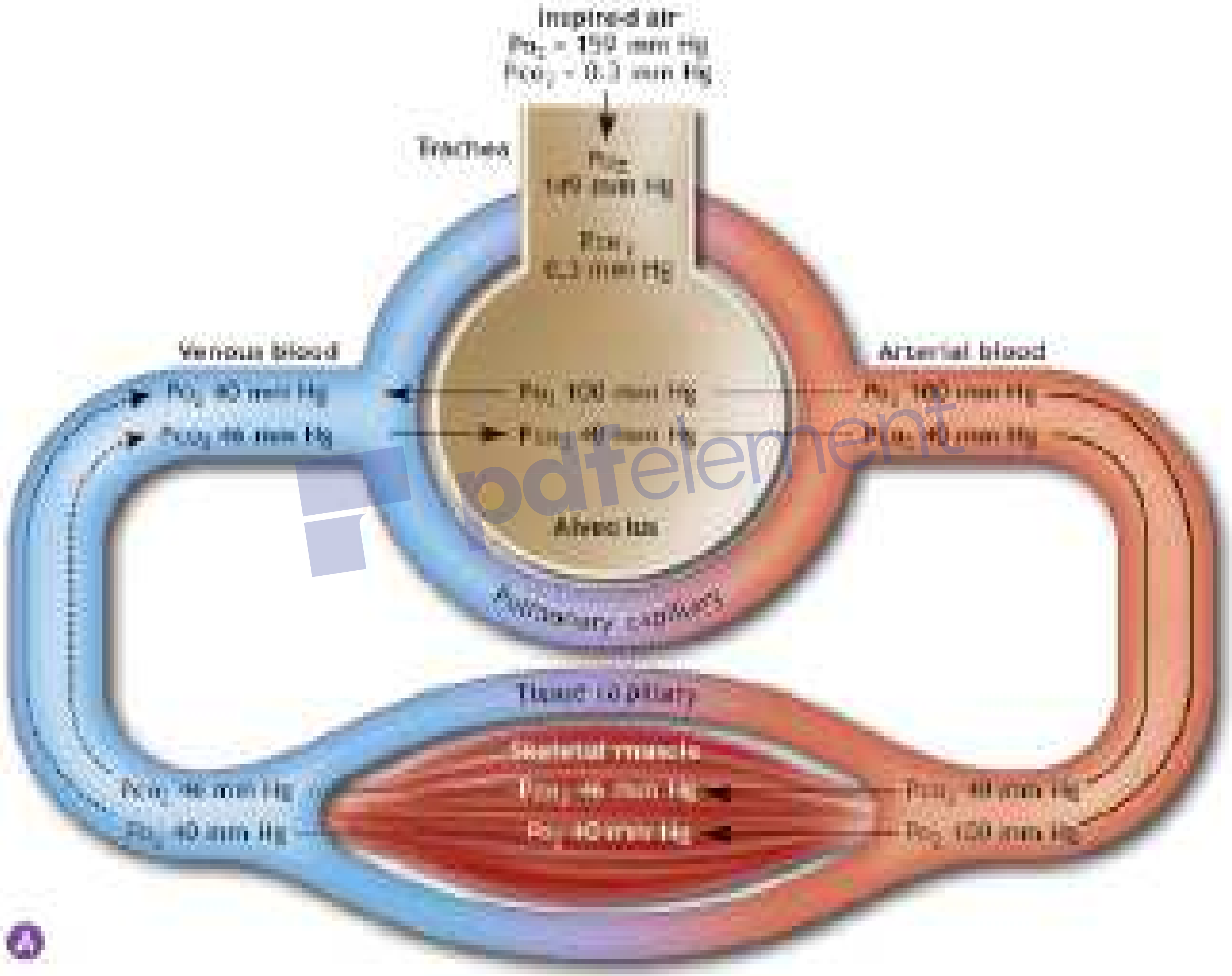
Partial Pressures of O2 and CO2 in the body

- (normal, resting conditions):
- Alveoli
  - PO_2 = 100 mm Hg
  - PCO_2 = 40 mm Hg
- Alveolar capillaries
  - Entering the alveolar capillaries
    - PO_2 = 40 mm Hg (relatively low because this blood has just returned from the systemic circulation & has lost much of its oxygen)
    - PCO_2 = 45 mm Hg (relatively high because the blood returning from the systemic circulation has picked up carbon dioxide)



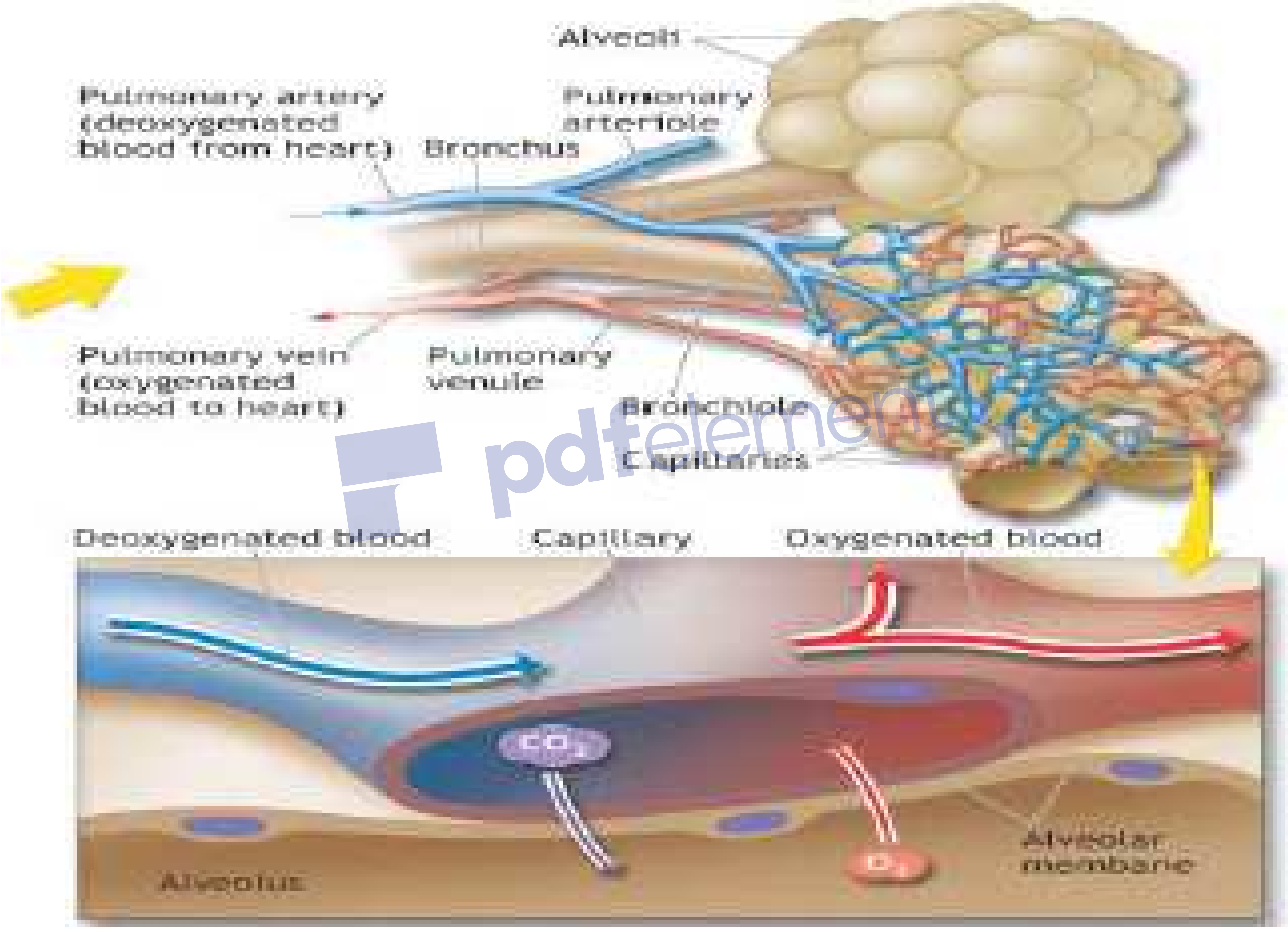
• ***FIGURE 23-20*** **An Overview of Respiratory Processes and Partial Pressures in Respiration.** **(a)** Partial pressures and diffusion at the respiratory membrane. **(b)** Partial pressures and diffusion in other tissues.


Alveoli
PCO2 (mmHg)=
40
40
40
40
40
40
PCO2 (mmHg)
45
PCO2= 40 mmHg
40
Arterial End
Venous End
Pulmonary Capillary


Inspired air
Trachea
Venous blood
Arterial blood
Alveolus
Pulmonary capillary
Tissue capillary
Skeletal muscle

- While in the alveolar capillaries, the diffusion of gasses occurs: oxygen diffuses from the alveoli into the blood & carbon dioxide from the blood into the alveoli.
  - Leaving the alveolar capillaries
    - PO_2 = 100 mm Hg
    - PCO_2 = 40 mm Hg

- Blood leaving the alveolar capillaries returns to the left atrium & is pumped by the left ventricle into the systemic circulation. This blood travels through arteries & arterioles and into the systemic, or body, capillaries. As blood travels through arteries & arterioles, no gas exchange occurs.
  - Entering the systemic capillaries
    - PO_2 = 100 mm Hg
    - PCO_2 = 40 mm Hg
  - Body cells (resting conditions)
    - PO_2 = 40 mm Hg
    - PCO_2 = 45 mm Hg


Alveoli
Pulmonary artery (deoxygenated blood from heart)
Pulmonary arteriole
Bronchus
Pulmonary vein (oxygenated blood to heart)
Pulmonary venule
Bronchiole
Capillaries
Deoxygenated blood
Capillary
Oxygenated blood
CO_2
O_2
Alveolar membrane
Alveolus

Respiration

- Pulmonary Respiration
  - Ventilation (breathing) and the exchange of gases (O_2 and CO_2)
- Cellular Respiration
  - Relates to O_2 utilization and CO_2 production by tissues

Function of the Lung

- Primary purpose of respiration = provide a means of gas exchange between the external environment and the body

- Exchange of O_2 and CO_2 due to:
  - 1. ventilation
  - 2. diffusion

Cont'd

- Ventilation = mechanical process of moving air into and out of the lungs
- Diffusion = random movement of molecules from an area of high concentration to an area of low concentration
  - Area of high [O_2], area of low [O_2]
  - Area of high [CO_2], area of low [CO_2]

Cont'd

- Speed of diffusion in respiratory system
  - Role of surface area in lungs
  - Role of diffusion distance between lungs and blood

Cont'd

- Pleura = set of membranes that enclose the lung
  - Visceral pleura – adheres to the outer surface of the lung
  - Parietal pleura – lines the thoracic walls and the diaphragm.
    - Separated by a thin layer of fluid that acts as a lubricant, allowing a gliding action of one pleura over another

Pleural Pressure

- The pressure within the pleural cavity (intrapleural pressure) < atmospheric pressure

  - Effect of inspiration
  - Importance

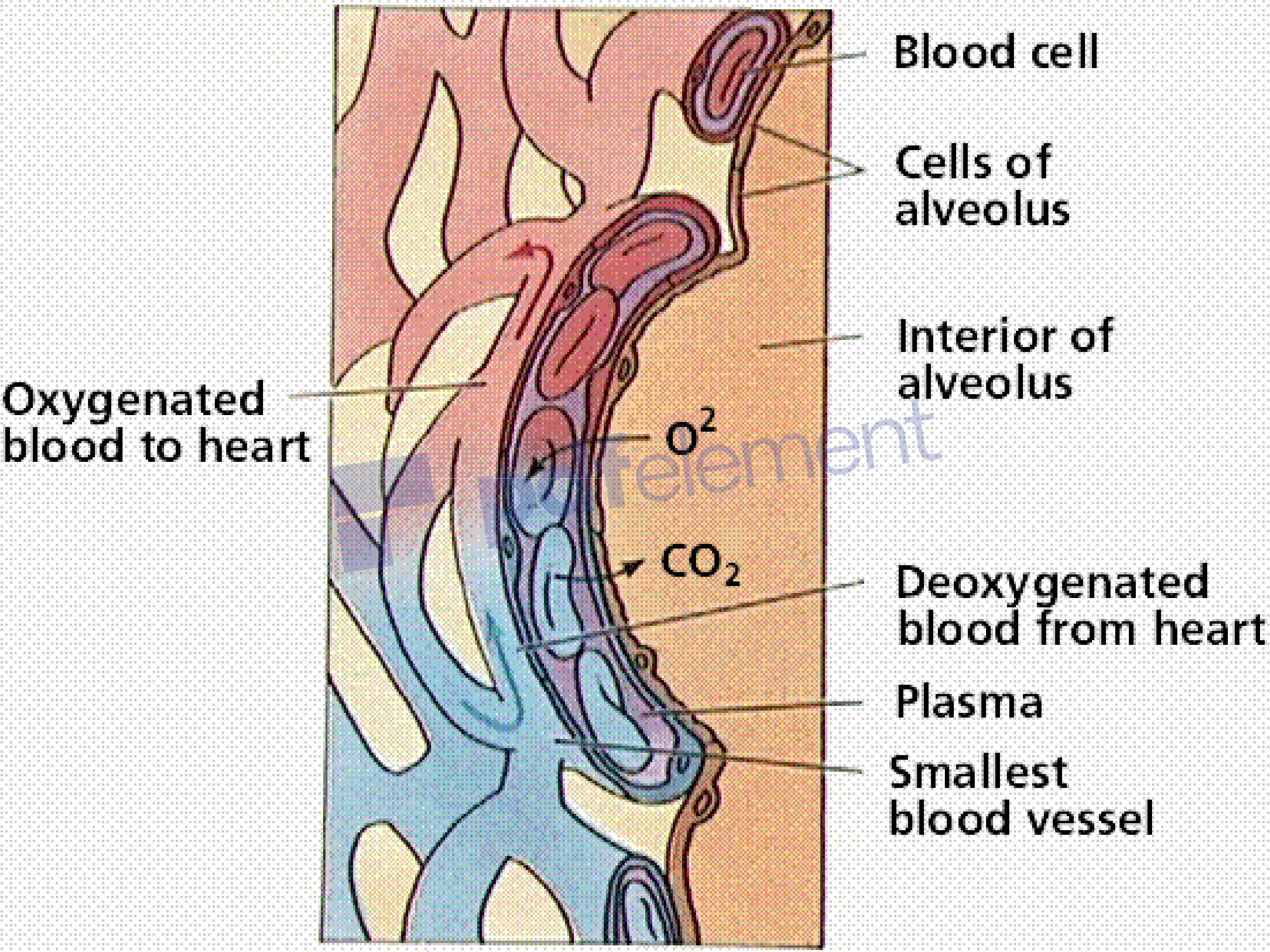
- Because of the differences in partial pressures of oxygen & carbon dioxide in the systemic capillaries & the body cells, oxygen diffuses from the blood & into the cells, while carbon dioxide diffuses from the cells into the blood.
  - Leaving the systemic capillaries
    - PO_2 = 40 mm Hg
    - PCO_2 = 45 mm Hg

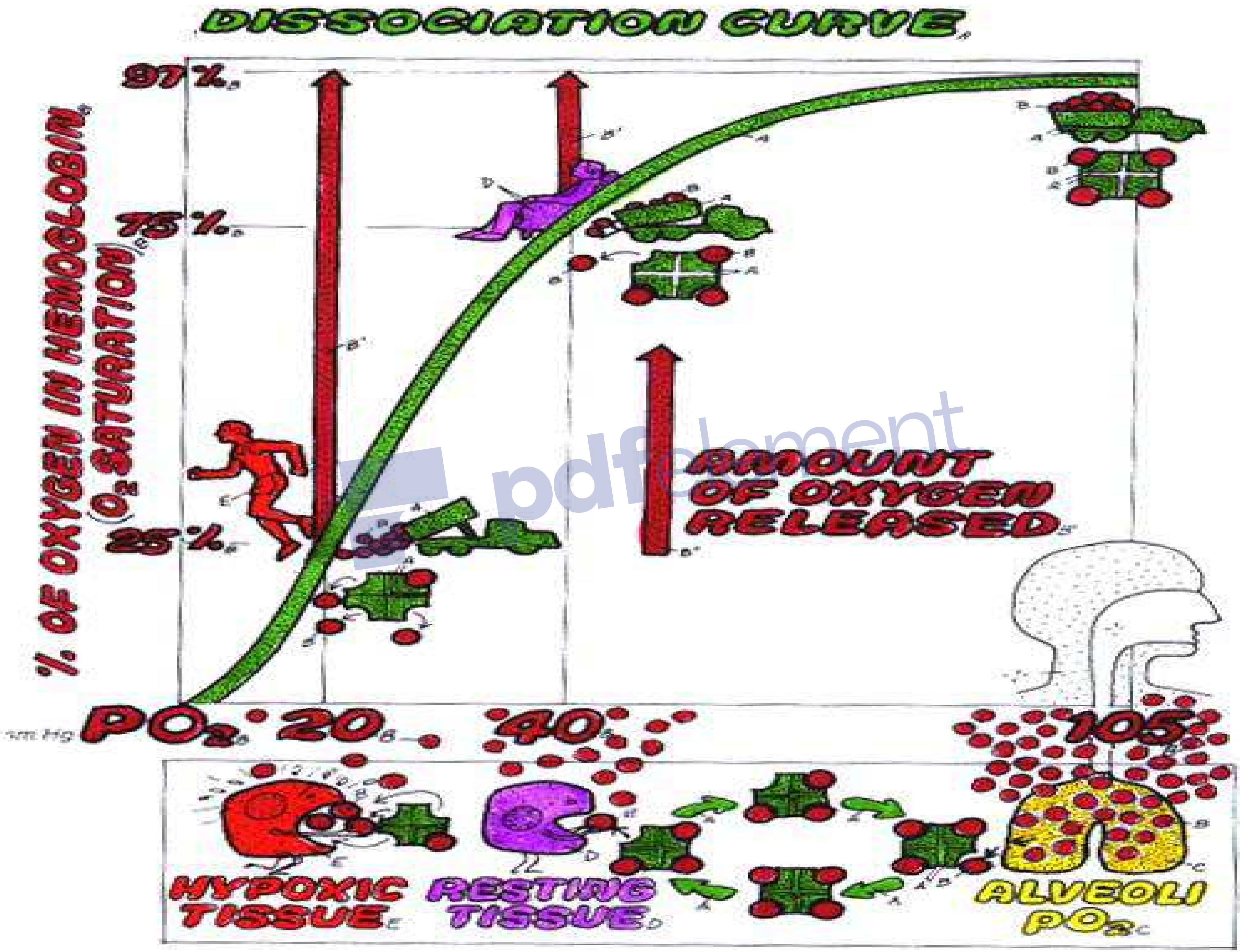
- Blood leaving the systemic capillaries returns to the heart (right atrium) via venules & veins (and no gas exchange occurs while blood is in venules & veins). This blood is then pumped to the lungs (and the alveolar capillaries) by the right ventricle.

How are oxygen & carbon dioxide transported in the blood?

- Oxygen is carried in blood:
- 1 - bound to hemoglobin (98.5% of all oxygen in the blood)
- 2 - dissolved in the plasma (1.5%)

- Because almost all oxygen in the blood is transported by hemoglobin, the relationship between the concentration (partial pressure) of oxygen and hemoglobin saturation (the % of hemoglobin molecules carrying oxygen) is an important one.

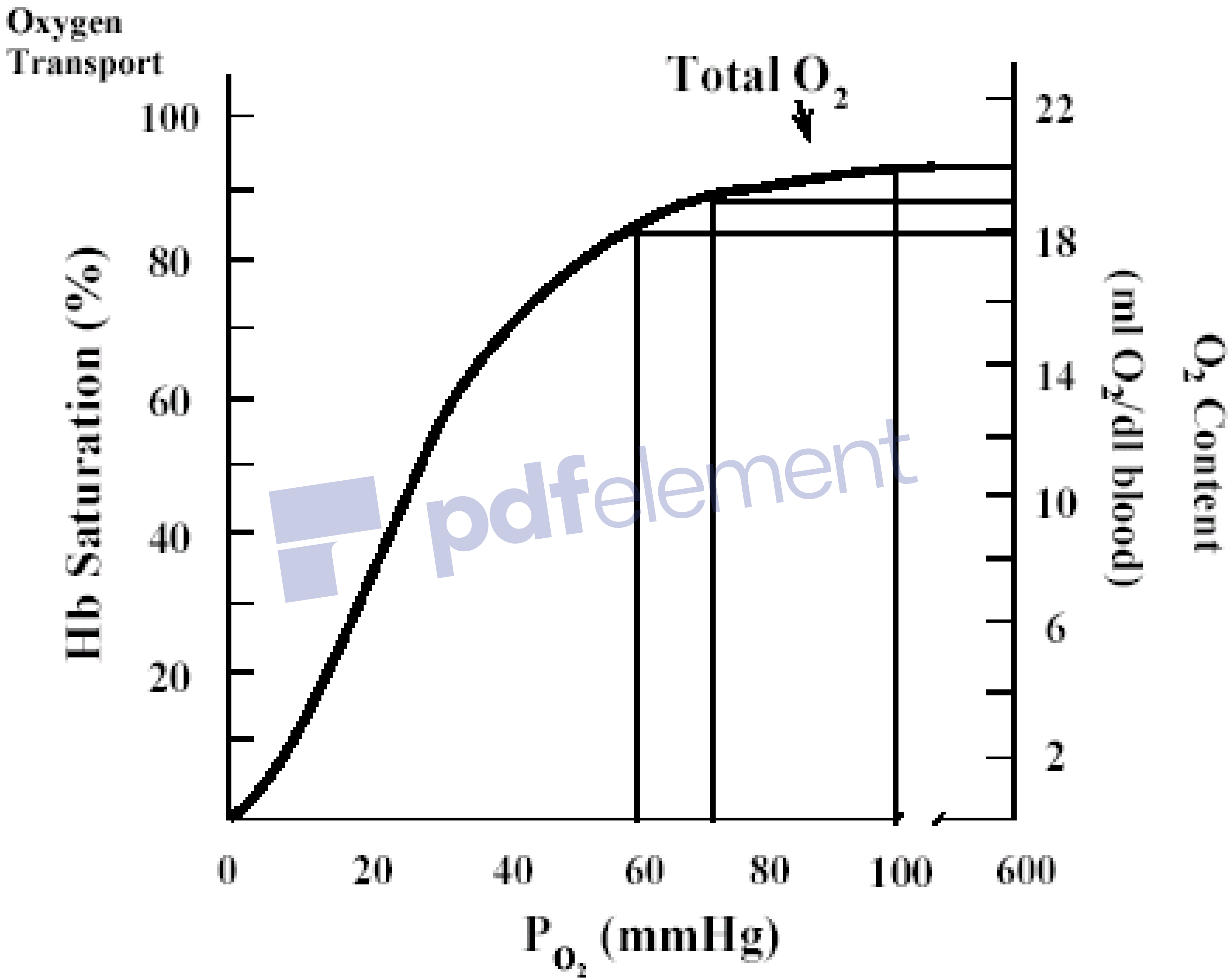

Blood cell
Cells of alveolus
Interior of alveolus
Oxygenated blood to heart
O^2
CO_2
Deoxygenated blood from heart
Plasma
Smallest blood vessel


DISSOCIATION CURVE
97 %
75 %
25 %
% OF OXYGEN IN HEMOGLOBIN
(O_2 SATURATION)
AMOUNT OF OXYGEN RELEASED
mm Hg
PO₂
20
40
105
HYPOXIC TISSUE
RESTING TISSUE
ALVEOLI PO₂

Hemoglobin saturation:

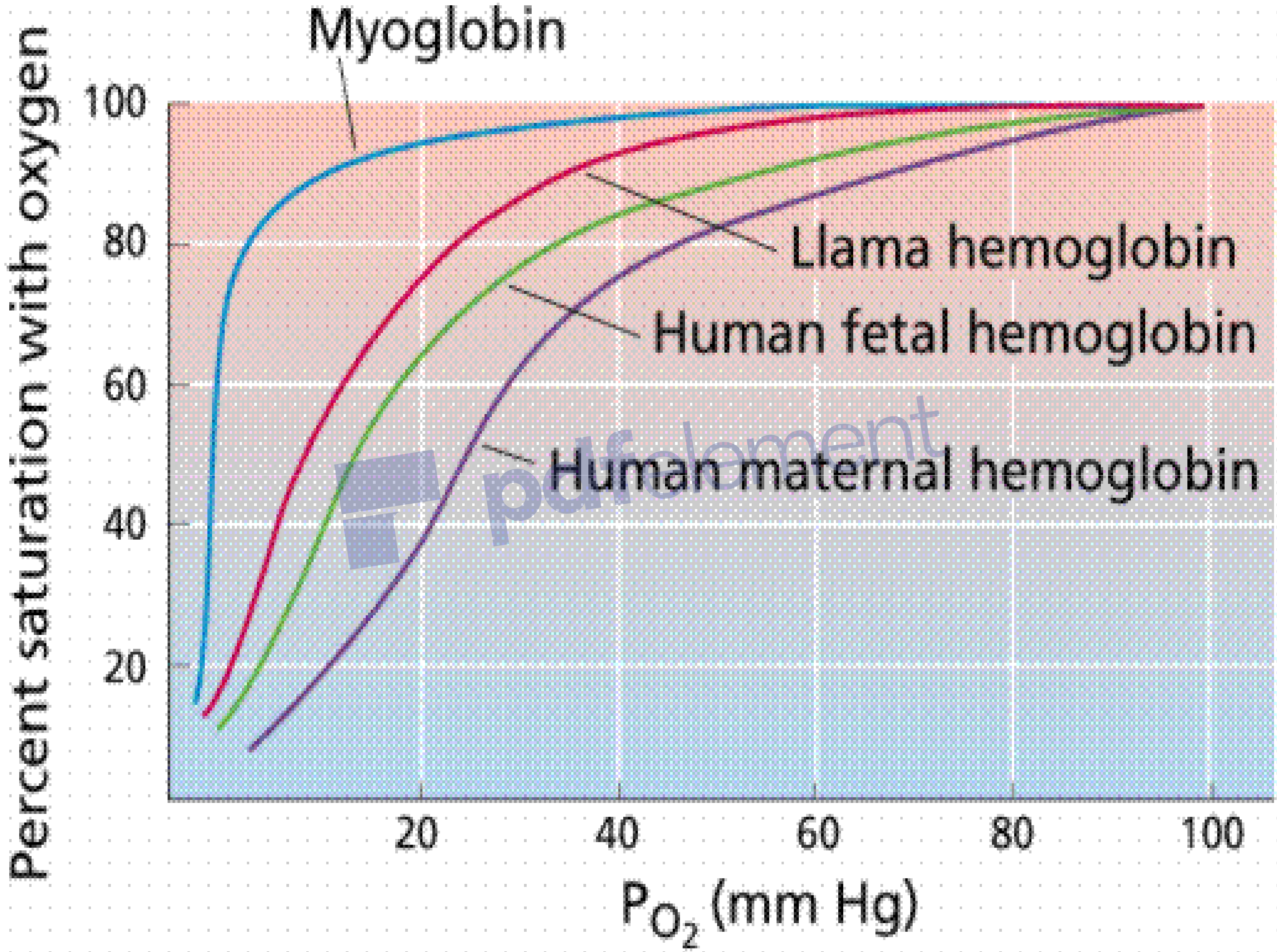
extent to which the hemoglobin in blood is combined with O_2

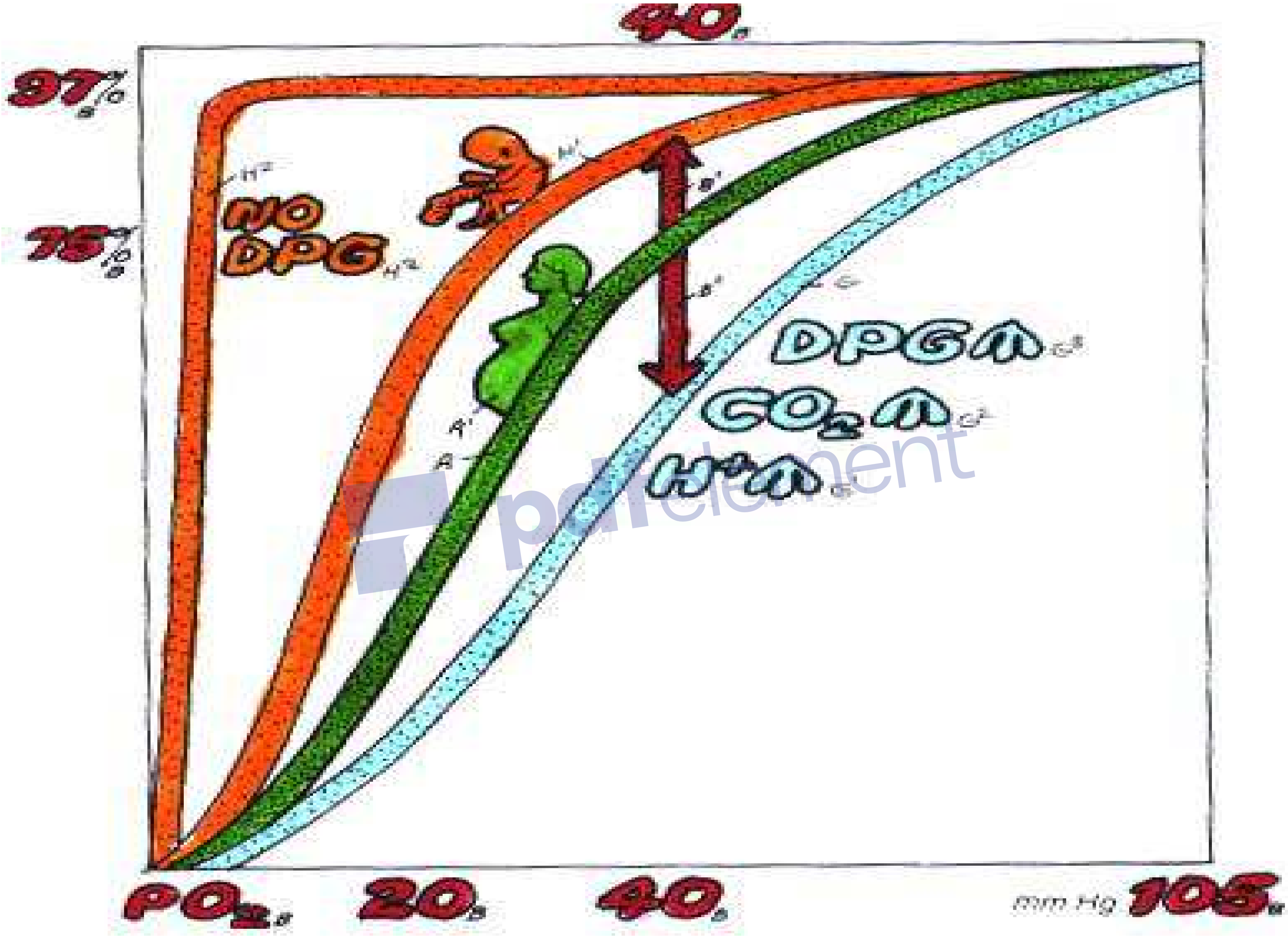
- depends on PO_2 of the blood: The relationship between oxygen levels and hemoglobin saturation is indicated by the **oxygen-hemoglobin dissociation (saturation) curve.**
- It can be seen that at high partial pressures of O_2 (above about 40 mm Hg), hemoglobin saturation remains rather high (typically about 75 - 80%).
- This rather flat section of the oxygen-hemoglobin dissociation curve is called the 'plateau.'



Oxygen
Transport
Total O_2
Hb Saturation (%)
100
80
60
40
20
0
20
40
60
80
100
600
P_{O_2} (mmHg)
22
18
14
10
6
2
O_2 Content
(ml O_2/dl blood)

- Recall that 40 mm Hg is the typical partial pressure of oxygen in the cells of the body.
- Examination of the oxygen-hemoglobin dissociation curve reveals that, under resting conditions, only about 20 - 25% of hemoglobin molecules give up oxygen in the systemic capillaries.
- This is significant (in other words, the 'plateau' is significant) because it means that you have a substantial reserve of oxygen. In other words, if you become more active, & your cells need more oxygen, the blood (hemoglobin molecules) has lots of oxygen to provide
- When you do become more active, partial pressures of oxygen in your (active) cells may drop well below 40 mm Hg.
- A look at the oxygen-hemoglobin dissociation curve reveals that as oxygen levels decline, hemoglobin saturation also declines - and declines precipitously. This means that the blood (hemoglobin) 'unloads' lots of oxygen to active cells - cells that, of course, need more oxygen.


Myoglobin
Llama hemoglobin
Human fetal hemoglobin
Human maternal hemoglobin
Percent saturation with oxygen
100
80
60
40
20
20
40
60
80
100
P_{O_2} (mm Hg)



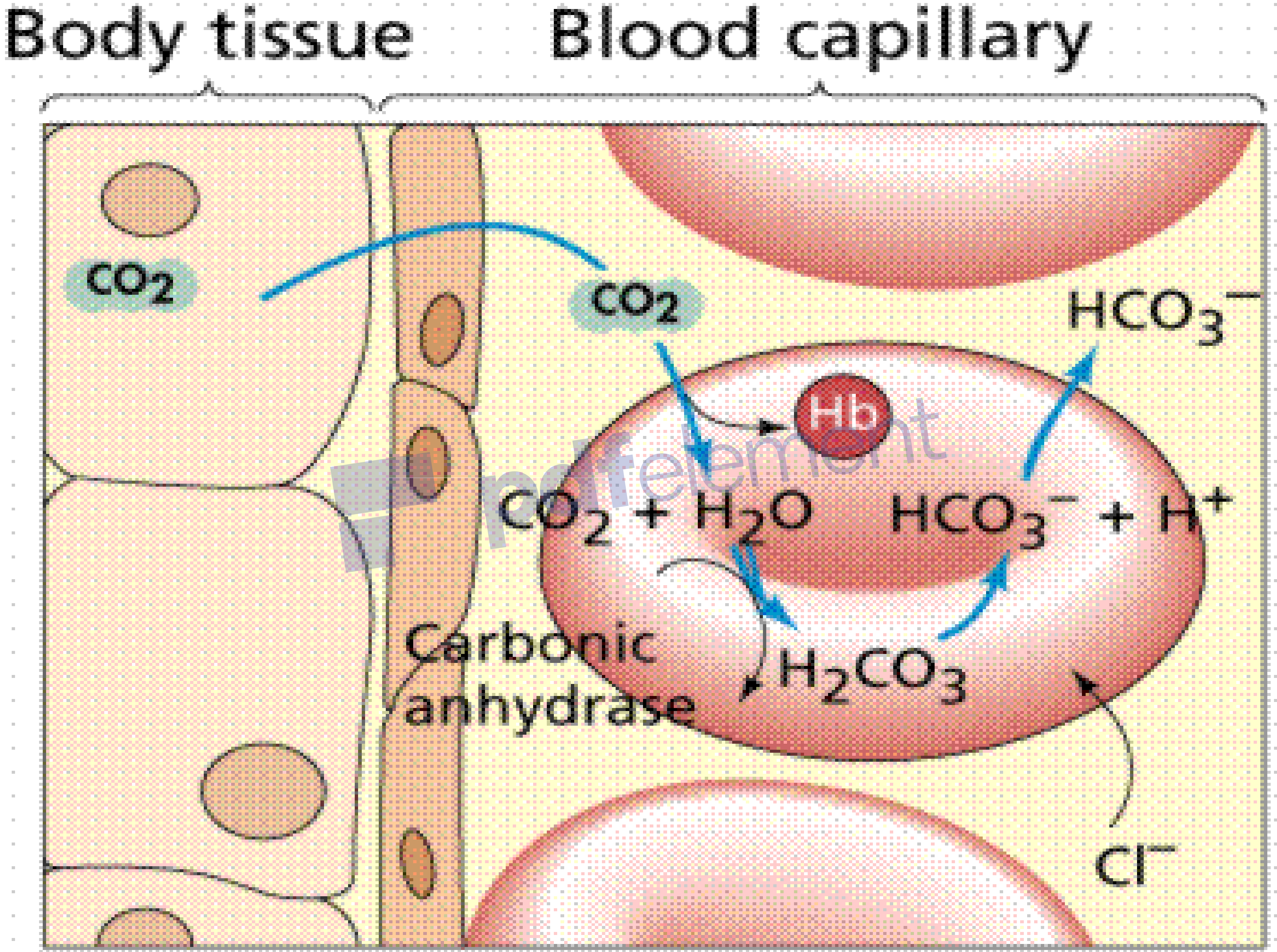
90
97%
75%
NO DPG
DPG ↑
CO2 ↑
H+ ↑
PO2
20
40
mm Hg 105

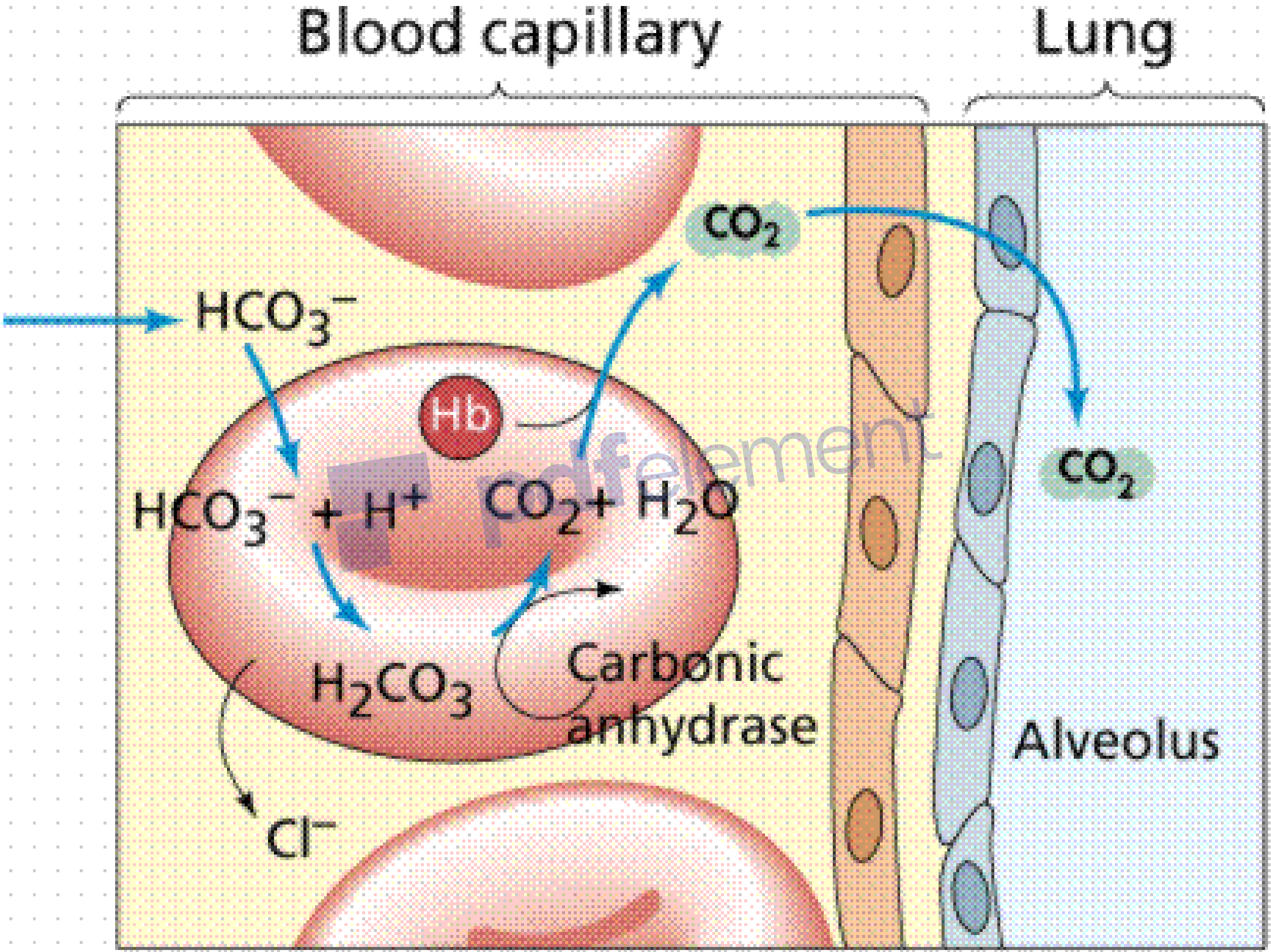
Factors that affect the Oxygen-Hemoglobin Dissociation Curve:

- The oxygen-hemoglobin dissociation curve 'shifts' under certain conditions. These factors can cause such a shift:
- lower pH
- increased temperature
- more 2,3-diphosphoglycerate
- increased levels of CO_2

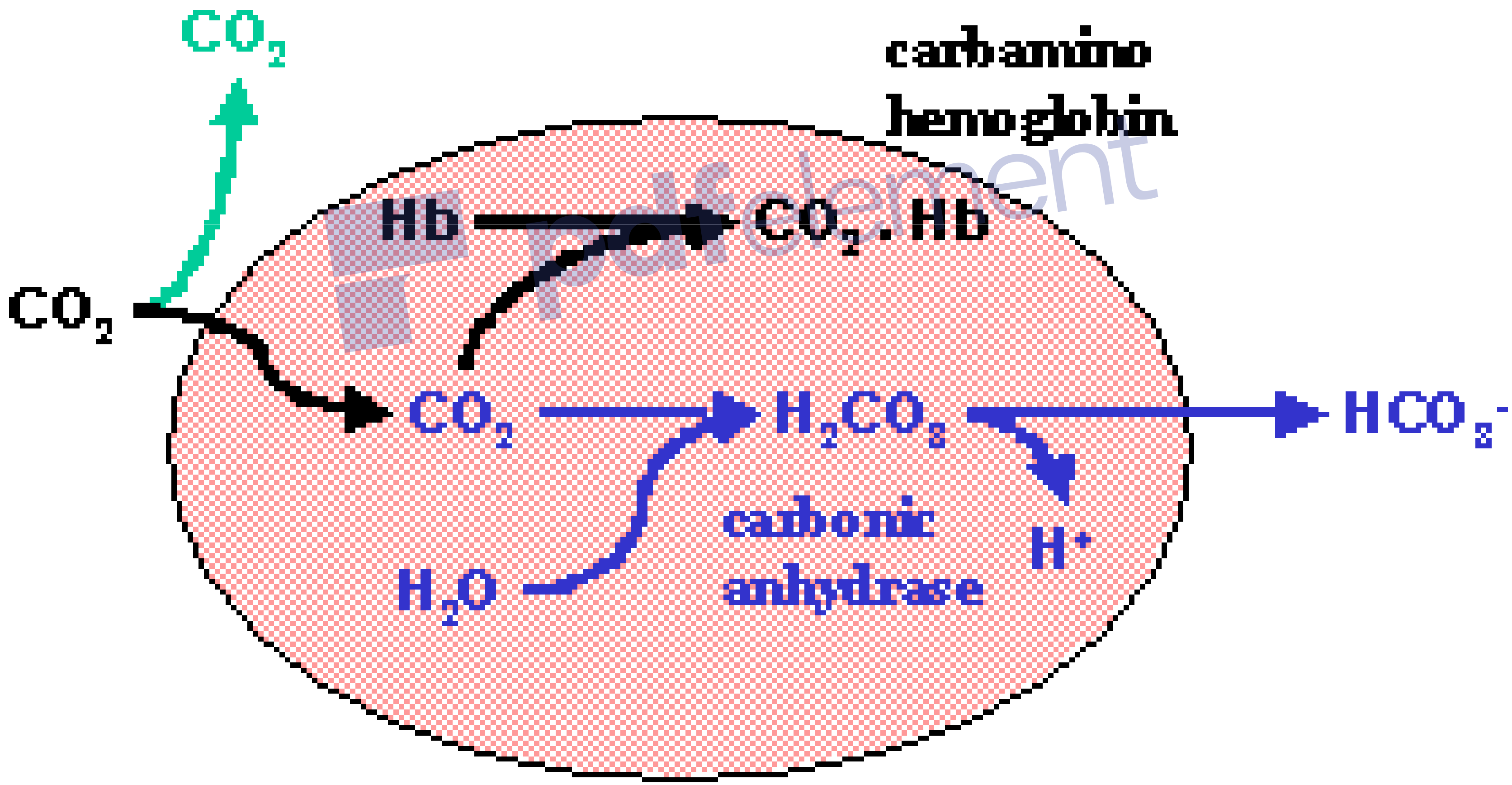
- These factors change when tissues become more active.
- For example, when a skeletal muscle starts contracting, the cells in that muscle use more oxygen, make more ATP, & produce more waste products (CO_2).
- Making more ATP means releasing more heat; so the temperature in active tissues increases.
- More CO_2 translates into a lower pH.
- That is so because this reaction occurs when CO_2 is released:
- CO2 + H20 -----> H2CO3 -----> HCO3- + H+

- & more hydrogen ions = a lower (more acidic) pH. So, in active tissues, there are higher levels of CO_2, a lower pH, and higher temperatures.
- In addition, at lower PO_2 levels, red blood cells increase production of a substance called 2,3-diphosphoglycerate. These changing conditions (more CO_2, lower pH, higher temperature, & more 2,3-diphosphoglycerate) in active tissues cause an alteration in the structure of hemoglobin, which, in turn, causes hemoglobin to give up its oxygen.
- In other words, in active tissues, more hemoglobin molecules give up their oxygen. Another way of saying this is that the oxygen-hemoglobin dissociation curve 'shifts to the right' (as shown with the light blue curve in the graph below).
- This means that at a given partial pressure of oxygen, the percent saturation for hemoglobin with be lower. For example, in the graph below, extrapolate up to the 'normal' curve (green curve) from a PO_2 of 40, then over, & the hemoglobin saturation is about 75%.
- Then, extrapolate up to the 'right-shifted' (light blue) curve from a PO_2 of 40, then over, & the hemoglobin saturation is about 60%. So, a 'shift to the right' in the oxygen-hemoglobin dissociation curve (shown above) means that more oxygen is being released by hemoglobin - just what's needed by the cells in an active tissue!


Body tissue
Blood capillary
CO2
CO2
Hb
HCO3−
CO2 + H2O
HCO3− + H+
Carbonic anhydrase
H2CO3
Cl−


Blood capillary
Lung
CO_2
HCO_3^-
Hb
$HCO_3^- + H^+$
$CO_2 + H_2O$
CO_2
H_2CO_3
Carbonic anhydrase
Alveolus
Cl^-

Carbon dioxide transport

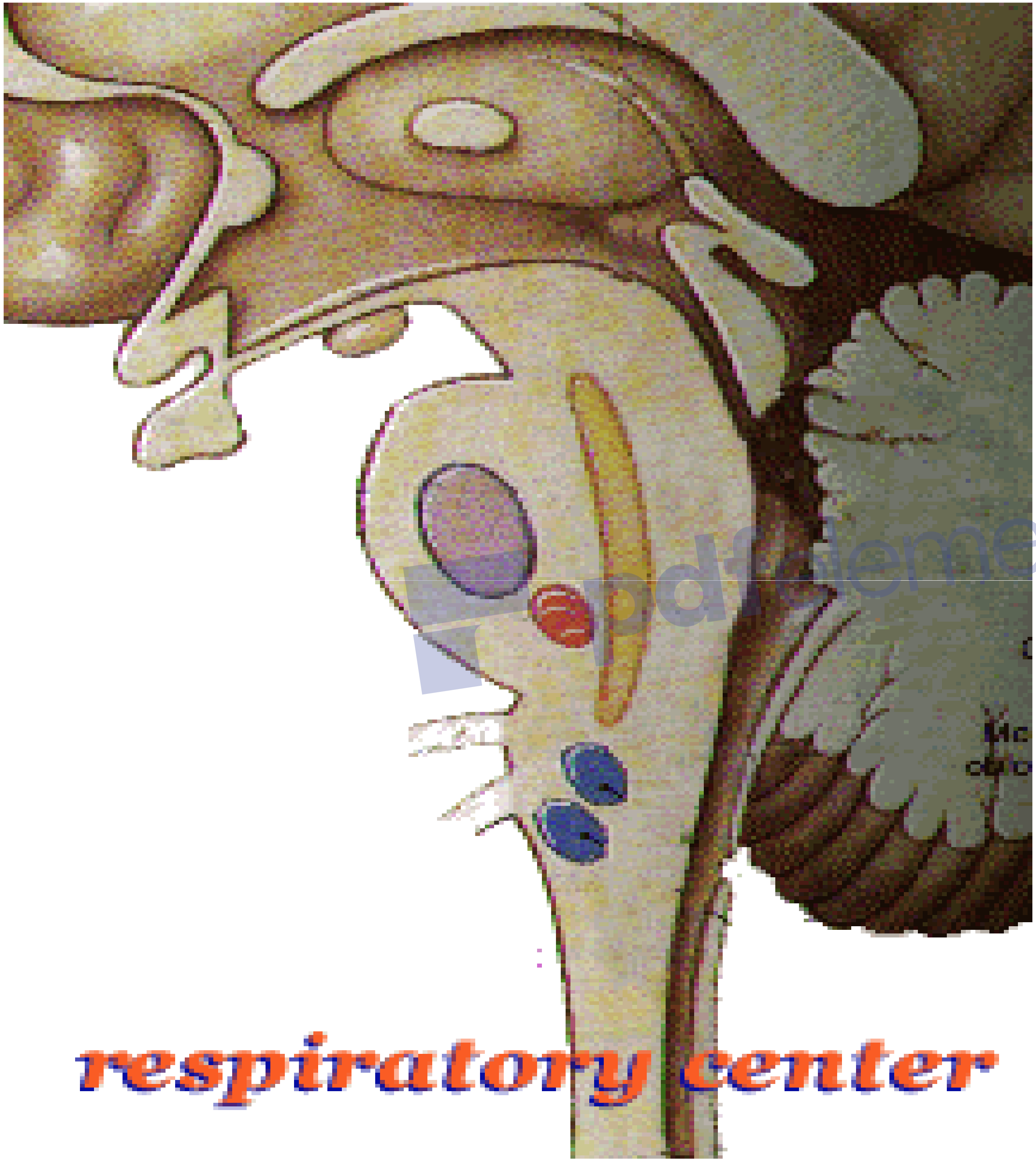


- **Carbon dioxide** - transported from the body cells back to the lungs as:
- 1 - bicarbonate (HCO_3) - 60%
  - formed when CO_2 (released by cells making ATP) combines with H_2O (due to the enzyme in red blood cells called carbonic anhydrase) as shown in the diagram below
- 2 - carbaminohemoglobin - 30%
  - formed when CO_2 combines with hemoglobin (hemoglobin molecules that have given up their oxygen)
- 3 - dissolved in the plasma - 10%

Control of Respiration

- Your respiratory rate changes. When active, for example, your respiratory rate goes up; when less active, or sleeping, the rate goes down.
- Also, even though the respiratory muscles are voluntary, you can't consciously control them when you're sleeping.
- So, how is respiratory rate altered & how is respiration controlled when you're not consciously thinking about respiration?

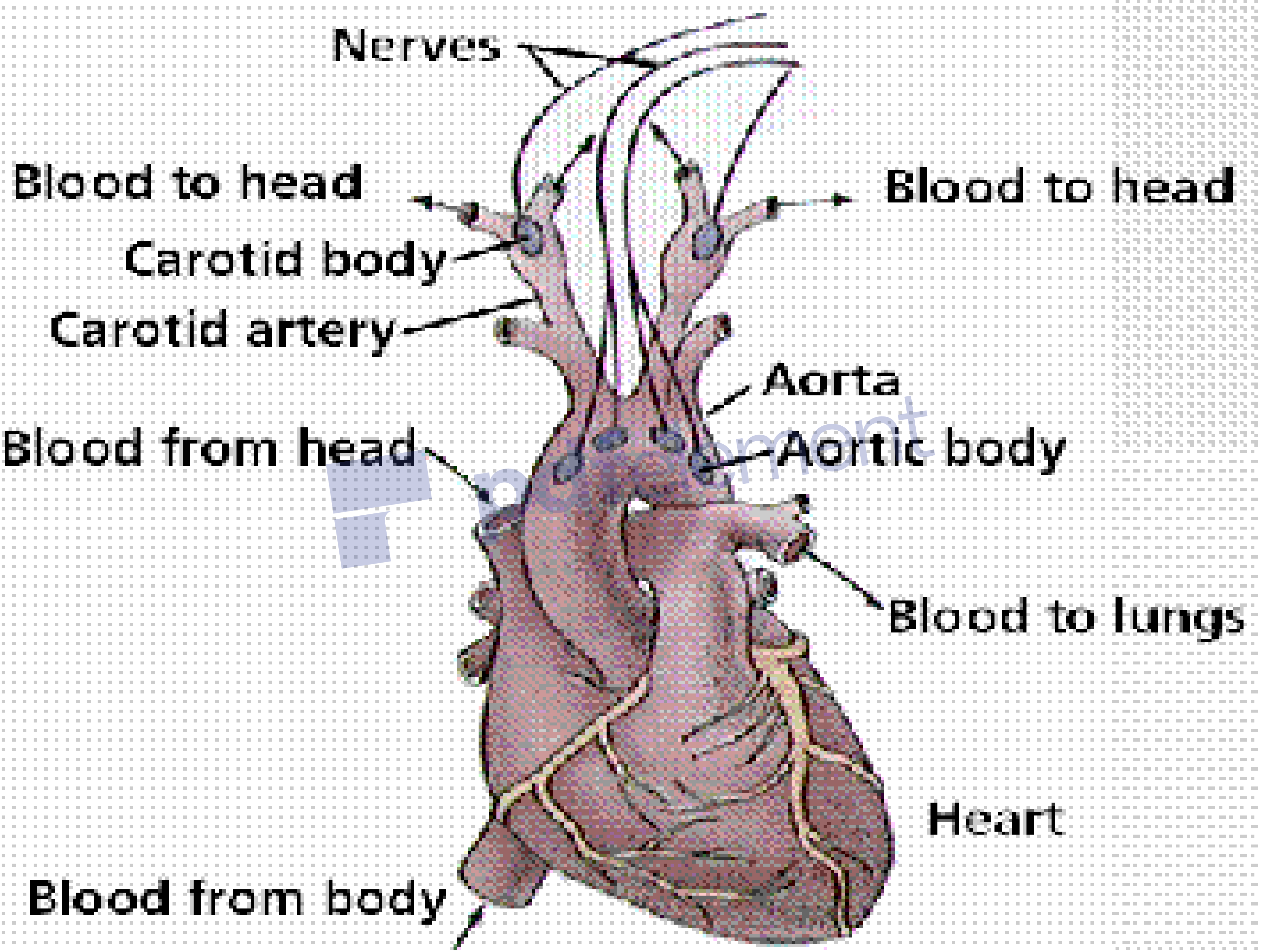
- The rhythmicity center of the medulla:
- controls automatic breathing
- consists of interacting neurons that fire either during inspiration (I neurons) or expiration (E neurons)
  - I neurons - stimulate neurons that innervate respiratory muscles (to bring about inspiration)
  - E neurons - inhibit I neurons (to 'shut down' the I neurons & bring about expiration)
- Apneustic center (located in the pons) - stimulate I neurons (to promote inspiration)
- Pneumotaxic center (also located in the pons) - inhibits apneustic center & inhibits inspiration



respiratory center

Factors involved in increasing respiratory rate

- Chemoreceptors - located in aorta & carotid arteries (peripheral chemoreceptors) & in the medulla (central chemoreceptors)
- Chemoreceptors (stimulated more by increased CO_2 levels than by decreased O_2 levels) > stimulate Rhythmicity Area > Result = increased rate of respiration
- Heavy exercise ==> greatly increases respiratory rate
- Mechanism?
- NOT increased CO_2
- Possible factors:
  - reflexes originating from body movements (proprioceptors)
  - increase in body temperature
  - epinephrine release (during exercise)
- impulses from the cerebral cortex (may simultaneously stimulate rhythmicity area & motor neurons



Nerves
Blood to head
Blood to head
Carotid body
Carotid artery
Aorta
Blood from head
Aortic body
Blood to lungs
Heart
Blood from body

Diseases and disorders of the respiratory tract

- **Hiccups**
  - are spasms of the diaphragm thought to be caused by not enough CO_2 in the body. Thus, hiccups are frequently cured by breathing into a paper bag.
- **Rhinitis**
  - is an inflammation of the mucus membrane in the nose, due to a common cold, allergies, etc.
- **Pharyngitis**
  - is a sore throat, which could be due to a viral infection such as the common cold or flu or a bacteria infection such as *Streptococcus pyogenes*.
- **Laryngitis**
  - is an inflammation of the vocal cords in which the person partially or totally loses his/her voice.
- **Bronchitis**
  - is an inflammation of the bronchi, causing them to over-secrete mucus, which in turn, causes coughing to get it up.
- **Pneumonia** and **tuberculosis**
  - infect the lungs.

- **Empyema**
  - is an infection, similar to pneumonia, in the chest cavity outside of the lungs.
- **Pleurisy**
  - is an infection of the pleural membranes lining the inside of the chest cavity and coating the lungs. Normally these membranes are very slippery, aiding in breathing, but when they become infected, they don't slide over each other as well, and breathing becomes painful.
- **Asthma**
  - is an allergic reaction that causes constriction of the bronchiole muscles, thereby reducing the air passages, thus the amount of air that can get to the alveoli. Interestingly, many of the treatments for asthma are similar to treatments used for **hypoglycemia**. That and the fact that diabetics rarely also have asthma have led some authors to suggest that asthma may be related to hypoglycemia, and that a hypoglycemia diet may aid in alleviation of asthma symptoms.
- **Emphysema**
  - is a progressive loss of elasticity in the lungs due to rupture of some alveolar walls, coalescing of alveoli, and formation of scar tissue.

- **Lung cancer**
  - has been shown to be more common in people who smoke cigarettes and/or who are constantly forced to inhale someone else’s side stream smoke. A number of pamphlets from the American Cancer Society and biology textbooks have featured pictures that show what smoking can do to a person’s lungs. Typically, there is a photograph of a robust, healthy, pink lung next to a photograph of a shrivled, diseased, blackened lung from a smoker. Similarly, people who work around substances like asbestos fibers, coal dust, flour dust, or dry, crumbled, dusty bird droppings for much of their lives, frequently show signs of lung diseases caused by these substances.
- Cystic fibrosis is a genetic defect that causes excessive mucus production that clogs the airways.