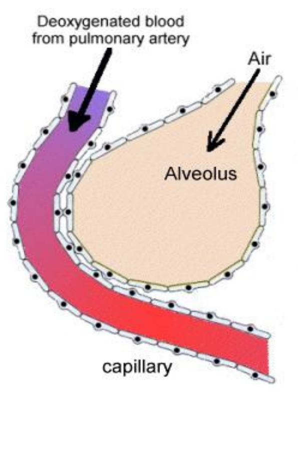
AN INTRODUCTION TO GAS EXCHANGE

Objectives

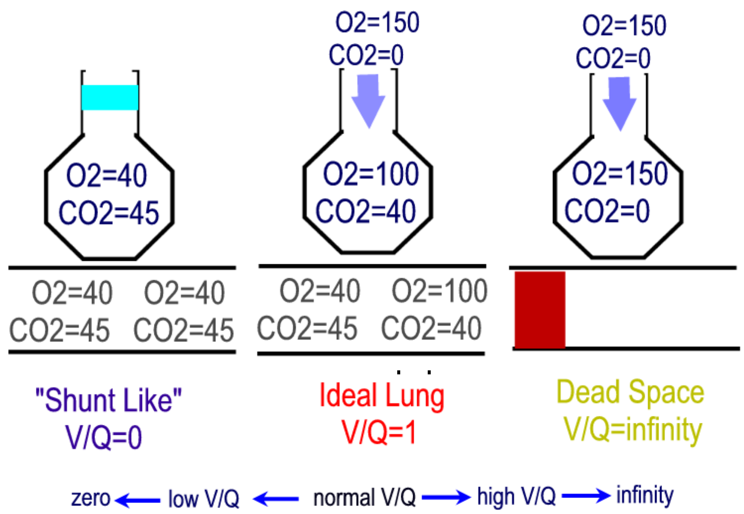
1. Define the partial pressure of a gas and explain why PO_2 in is reduced as atmospheric air enters the airways and reaches the alveoli.
2. Compare the PO_2 & PCO_2 the blood in the pulmonary artery entering (mixed venous blood) entering the pulmonary capillaries the PO_2 & PCO_2 the arterial blood in the pulmonary veins leaving the pulmonary capillaries.
3. Describe the factors that affect the rate of exchange of O_2 & CO_2 across the alveolar-capillary membrane and give examples of disease states where these are altered.
4. Discover the partial pressure gradients that drive the diffusion of O_2 & CO_2 across the systemic capillaries and specify how they vary depending on the metabolic activity of the cells.

PARTIAL PRESSURE OF ALVEOLAR GASES IS REFLECTED IN THE ARTERIAL BLOOD

Gas exchange results in end capillary blood gases that are in equilibrium with the partial pressure of gases in the alveoli

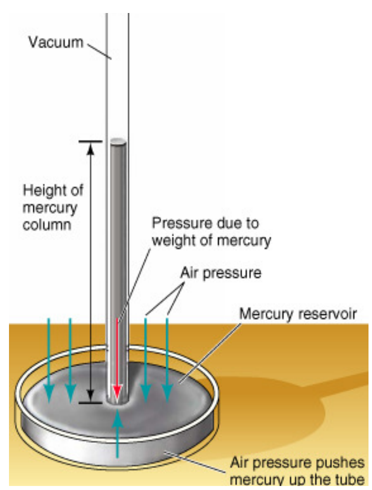


VENTILATION PERFUSION MISMATCH AFFECTS ARTERIAL BLOOD GAS VALUES



ATMOSPHERIC or BAROMETRIC PRESSURE [PB]

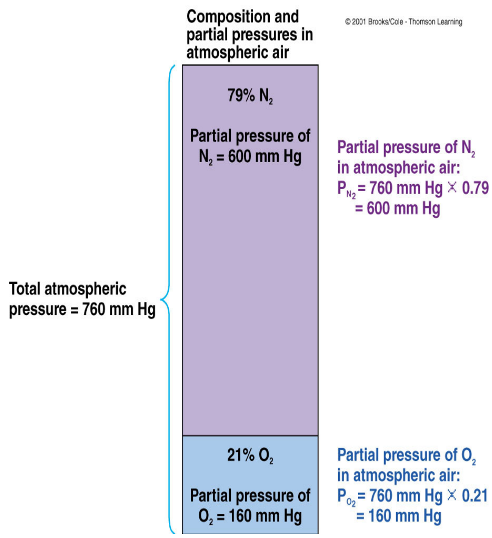
- Dry air is composed of a mixture of gases.
- Each gas exerts a **partial pressure** which is the pressure it would exert if it alone occupied a given volume.
- Barometric pressure [P_B] is the total pressure exerted by this mixture of gases = 760 mmHg at sea level



COMPOSITION OF GASES IN ATMOSPHERIC AIR
Determining Their Partial Pressure

Nitrogen	78.08
Oxygen	20.94
Argon	0.93
Carbon Dioxide	0.03

and trace amounts of--
Neon
Methane
Helium
Krypton
Hydrogen
Xenon



DETERMINING THE PARTIAL PRESSURE OF A GAS
in a mixture of gases & water vapour

$P_{gas} = P_B \times FI_{gas}$

<u>In dry air at sea level</u>

PO_2 = 760 mmHg X 0.21= 160 mmHg

Inspired air is heated to 37ºC, humidified & saturated with water vapour P_{H_2O} = 47 mmHg

<u>During inspiration in the conducting airways</u>

PO_2 = [760 – 47 mmHg) X 0.21 = 150 mmHg

THE PARITAL PRESSURE OF OXYGEN DECREASES AS INSPIRED AIR COURSES THROUGH THE AIRWAYS

PO_2 = 160 mmHg
PCO_2 = 0
P_{H2O} = 0

DRY AIR AT SEA LEVEL

PO_2 = 150
PCO_2 = 0
P_{H2O} = 47

CONDUCTING AIRWAYS
(HEATED & HUMIDIFIED)

PO_2 = 100
PCO_2 = 40
P_{H2O} = 47

ALVEOLI
(MIXED IN A RESERVOIR OF AIR--FRC)

DETERMINE THE PARTIAL PRESSURE OF OXYGEN AT HIGH ALTITUDE

At the summit of Mount Everest at 18,000 ft, barometric pressure is half of its value at sea level.

What happens to the partial pressure of inspired oxygen?
How about the PO2 at the level of carina?

At the summit:

PO_2 = [760/2]X 0.21 = 380X0.21 = 80 mmHg

In the carina:

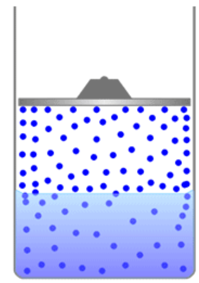
PIO2 = [380-47]X 0.21 = 333X0.21 = 70 mmHg

In the alveoli ?

PARTIAL PRESSURE OF GASES DISSOLVED IN SOLUTION

At equilibrium, the tension of gas in solution = the partial pressure of gas in the pocket above it.

- Gases flow from a region of higher partial pressure to one of lower pressure.
- Gases dissolve, diffuse, and react according to their partial pressures and not according to their concentration in solution



note that the concentration of gas in solution is not the same as its partial pressure as solubility of gas affects its concentration

A Key Factor In The Amount Of Gas Exchange Is The Partial Pressure Difference Across The Gas Exchange Barrier

a.k.a. the driving pressure

Across pulmonary capillaries

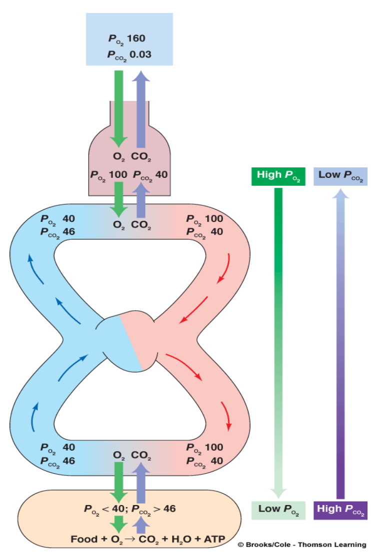
O_2 partial pressure gradient from alveoli to blood = 60 mm Hg (100 -> 40)

CO_2 partial pressure gradient from blood to alveoli = 6 mm Hg (46 -> 40)

Across tissue capillaries

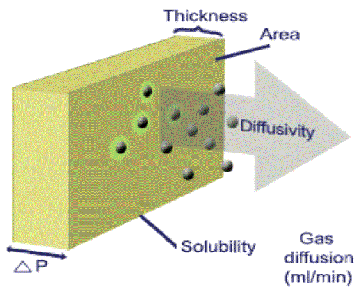
O_2 partial pressure gradient from blood to tissue= 60 mm Hg (100 -> 40)

CO_2 partial pressure gradient from tissue cell to blood = 6 mm Hg (46 -> 40)



FACTORS THAT AFFECT DIFFUSION OF GASES ACROSS BARRIERS

Fick's Law Of Diffusion



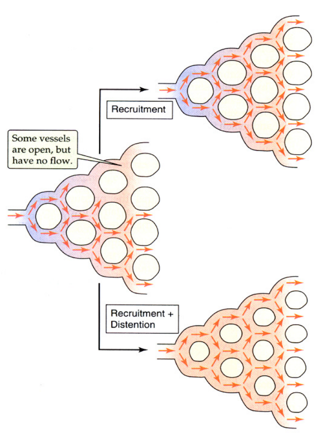
$$\dot{V}_{GAS} \; \alpha \; \frac{A \, D \, [\Delta P]}{T}$$

D = "DIFFUSIVITY" or "DIFFUSION COEFFICIENT" α SOLUBILITY/ $\sqrt{\textbf{MW}}$

Compare D & ΔP of O2 and CO2 and explain equal time for end capillary equilibration of these gases in the lungs.

EFFECT OF SURFACE AREA ON GAS EXCHANGE

Increase in Surface Area



EXERCISE → ↑ TIDAL VOLUME

↓

↑ CARDIAC OUTPUT

↓

↑ PULMONARY VASCULAR PRESSURE

↓

↑ RECRUITMENT & DISTENSION OF PULMONARY CAPILLARIES

↑ SURFACE AREA
↓ ALVEOLAR THICKNESS

↓

↑SURFACE AREA FOR GAS EXCHANGE ←

→ IMPROVE GAS EXCHANGE

EFFECT OF SURFACE AREA ON GAS EXCHANGE

Loss of Surface Area

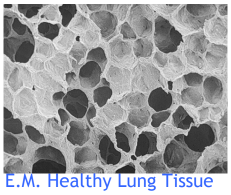
EMPHYSEMA

↓

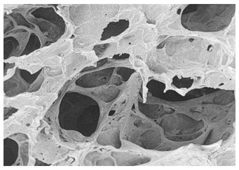
DESTRUCTION OF ALVEOLAR WALLS

↓

↑LUNG COMPLIANCE
MECHANICAL COMPLICATION
&
AREA FOR GAS EXCHANGE
↓GAS EXCHANGE COMPLICATION



E.M. Healthy Lung Tissue



E.M. Emphysematous Lungs

Other

- Athelectasis (Collapse Of Lung Parenchyma)
- Surgical Removal Of Lung Tissue

EFFECT OF THICKNESS ON GAS EXCHANGE

Increased Thickness

PULMONARY FIBROSIS

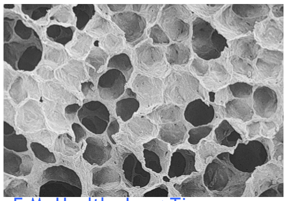
↓

COLLAGEN DEPOSITION & SCAR
FORMATION IN ALVEOLAR WALLS

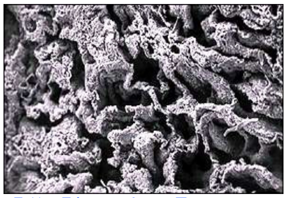
↓

MECHANICAL COMPLICATION
↓ LUNG COMPLIANCE

GAS EXCHANGE COMPLICATION
↑THICKNESS FOR GAS EXCHANGE



E.M. Healthy Lung Tissue



E.M. Fibrotic Lung Tissue

EFFECT OF THICKNESS ON GAS EXCHANGE

Increased Thickness

PULMONARY FIBROSIS (scar formation)
results in response to exposure to--

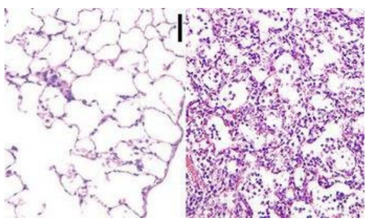
- industrial dust [asbestosis, silicosis]
- spores from moldy hay [Farmers lungs]
- antigens in avian feather/excreta [Bird breeders lung]
- therapeutic drugs, radiation, poisons [weed killer, paraquat]

EFFECT OF THICKNESS ON GAS EXCHANGE

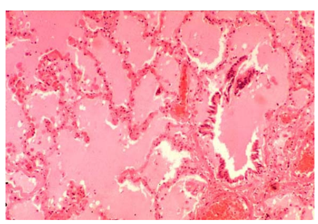
Increased Thickness

- Pneumonia- inflammatory fluid accumulation in & around the alveoli from viral/bacterial (common: *Streptococcal pneumonia- deadly: Severe Acute Respiratory Syndrome (SARS)-the alveolar infection can reach blood—sepsis or the pleural space--empyema)*
  /fungal infections or accidental aspiration of food, vomitus, chemicals or lung injury or indirectly as result of other illness. Pneumonia is the leading cause of death amongst chronically ill elderly

- Pulmonary Edema
  abnormal build up of fluid in the interstitial or alveolar space as a result of direct damage to lung tissue or inability of heart to pump blood --as in left heart failure



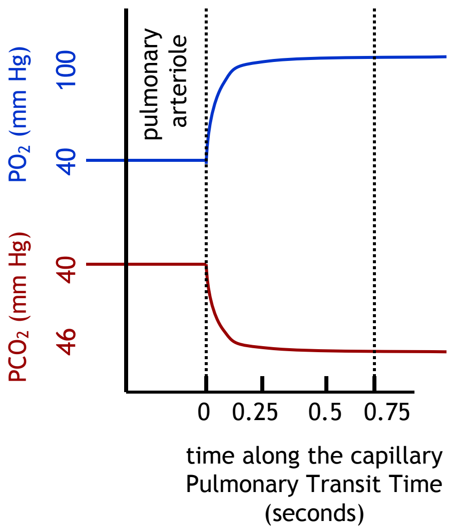
normal pneumonia



pulmonary edema

GAS EXCHANGE ACROSS THE PULMONARY CAPILLARY

Is Complete Within ¼ Second



- <u>at rest</u> pulmonary transit time [¾ second] is more than that required to complete gas exchange [¼ second].
- <u>during exercise</u>, despite increased cardiac output, pulmonary transit time remains > ¼ second & gas exchange is complete.
- <u>in pulmonary fibrosis</u>, reduced gas exchange is often seen in patients during exercise. At rest, the additional time spent in the capillary is sufficient to compensate for the thickened barrier .
- <u>elite athletes</u> with very high cardiac outputs have pulmonary transit times below ¼ second during intense exercise→ inadequate oxygen exchange at the lungs ⟶ low oxygen levels in the blood [arterial hypoxemia]