PHYSIOLOGY OF RESPIRATION

Exchange and Transport of Respiratory Gases
Respiratory Exchange Ratio
Aviation, Space and Deep Sea Diving

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Exchange and Transport of O_2 and CO_2

- Physical Principles of Gaseous Exchange
- Diffusion of Gases through the respiratory membrane
- Transport of Oxygen in the Blood
- Transport of Carbon Dioxide

Physical Principles of Gaseous Exchange

- Mass and Temperature
  - if remain constant in a chamber- pressure→ volume of ga al with pressure (Boyle's Law)

$$\text{Pressure} \times \text{volume} = \text{constant}; \quad V = \frac{K}{P}$$

Physical Principles of Gaseous Exchange

- Pressure
  - remain constant- temperature varied; volume directly
    emp (Gay Lussac's Law) (Charles Law)

$$\frac{\text{Volume}}{\text{Temperatur e}} = \text{Constant}$$

$$V = TK$$

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Physical Principles of Gaseous Exchange

- Gas Law
  - Combining Boyle's Law and Gay Lussac's Law
  - **PV=nRT**

    P= pressure

    V= volume

    n= quantity of gas

    R= constant depending on the units of measure

    T= temperature

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Physical Principles of Gaseous Exchange

- Vapor Pressure of Water
  - indirect contact with water
  - saturated with water vapor
  - Vaporization mass, pressure
    - vapor pressure of water depends temp of water and gas.
    - the higher the temp:
      - the greater the activity of molecules
      - the greater the likelihood to escape from surface of water to gaseous phase
    - vapor pressure at 37C= 47mmHg

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Physical Principles of Gaseous Exchange

- Solution of Gases in Water
  - Influence by Two Factors
    - 1. The pressure of the gas surrounding the water
    - 2. The solubility coefficient of the gas in water at the temperature of water

    Volume= Pressure X Solubility coefficient
- When volume is expressed in volume of gas dissolved in each volume of water at 0C, pressure in atmosphere,

  solubility coefficient gases at body temp are the following:
    - O2----------0.024
    - CO2--------0.57
    - N------------0.012
    - He----------0.008

Physical Principles of Gaseous Exchange

- Partial pressure of Gases
  - Gas mixture----pressure exerted by each gas is in proportion to the conc. of molecules, w/o regard to the conc. of the other component gases.
  - Total pressure= sum of all partial pressure of component gases (Oxygen 20% of atmosphere, 760mmHg atmospheric pressure: partial pressure__?

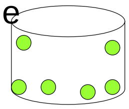
Partial Pressure (mmHg)

	Oxygen	Carbon Dioxide
Atmospheric air	152	0.304
Alveolar air	105	40.0
Arterial Blood	100	40.0
Venous Blood	40	46.0
Tissues	30	50.0

Physical Principles of Gaseous Exchange

- Gas is Independent
  - ability to dissolve in liquid
    - CO_2 dissolve in the blood does not physically affect the quantity of oxygen that can be dissolve in the fluid

Physical Principles of Gaseous Exchange



- Diffusion of Gases
  - kinetic energy of matter
  - move from area of higher conc. towards lower conc. hence the gases always diffuse from area of high pressure to areas of low pressure.
  - Net Flow is proportional to the pressure difference (pressure gradient or diffusion gradient)

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DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Exchange of gas—Diffusion
- interchange of gases--- thin membrane (1/2 to 4 microns thick)
- respiratory exchange– rapidly because thinness and wide surface area (50-100 square meter)
- Diffusion through tissues is described by FICK'S LAW
  - rate of transfer of gas through a sheet of tissue is
    - proportional to the tissue area and the difference in partial pressures of the gas between the two sides
    - inversely proportional to the tissue thickness

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DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Factors Influencing Gaseous Diffusion Through the Pulmonary Membrane
- Diffusing Capacity of the Respiratory Membrane
- Oxygen Diffusion
- Carbon Dioxide Diffusion

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DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Factors Influencing Gaseous Diffusion Through the Pulmonary Membrane
  - Thickness of the membrane
    - inversely proportional
    - edema, fibrosis
  - Surface area of the respiratory membrane
    - removal of the lung, cancer, pneumonia, PTB
    - 1/3, ¼ impedes the exchange
  - The Diffusion Coefficient
    - depends on the solubility of the gas and its molecular weight
    - CO_2 **20x** O_2 **2x** Nitrogen
  - The Pressure Gradient
    - difference between the partial pressure in the alveoli and blood

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DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Diffusing Capacity of the Respiratory Membrane
  - Diffusing capacity for oxygen
    - average young adult 21ml/min
  - Diffusing capacity for carbon dioxide
    - not measured yet
    - 400-500ml/min under resting condition

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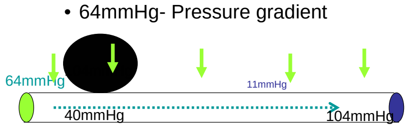
DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Oxygen Diffusion
  - Uptake of Oxygen
    - 40mmHg- venous blood entering pulmonary capillary
    - 104mmHg- alveolus
    - 64mmHg- Pressure gradient



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DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Oxygen Diffusion
  - Uptake of Oxygen
    - small amount of blood (1 to 2 % CO) fails to pass through the pulmonary capillaries– shunted through the non-aerated vessels
    - Venous admixture
    - capillaries of the lung 104mmHg pO2
    - arterial tree 95mmHg pO2

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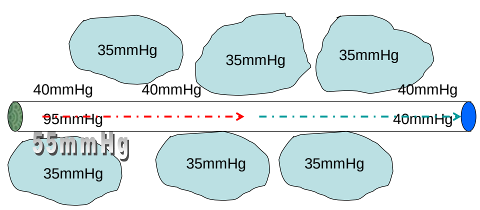
- Oxygen Diffusion
  - Diffusion of Oxygen from the Capillaries into the cells of the Tissues



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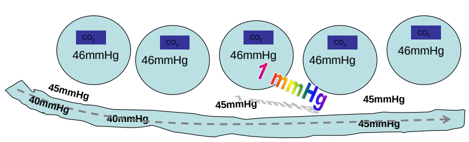
DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Carbon Dioxide Diffusion
  - Removal of Carbon Dioxide



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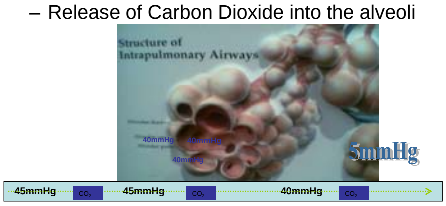
DIFFUSION OF GASES THROUGH THE RESPIRATORY MEMBRANE

- Carbon Dioxide Diffusion
  - Release of Carbon Dioxide into the alveoli



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TRANSPORT OF OXYGEN IN THE BLOOD

Oxygen is present in the blood in two forms

a. physically- plasma

b. chemically- hgb

- Transport of Oxygen in the Dissolved State
  - 1-3 liters or 1.5%
- Transport of Oxygen in Combination with hemoglobin
  - 14-15grams hgb per 100ml blood
  - 1gram hgb per 1.34ml oxygen
  - 98.5%

When the blood fully saturated with oxygen (20 vol percent of oxygen are present as *oxyhemoglobin*)

$$Hb + O_2 \longleftrightarrow HbO_2$$

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$$Hb + O_2 \longleftrightarrow HbO_2$$

- Reversible
- Shift to the RIGHT
- Shift to the LEFT
- Oxygen dissociation curve

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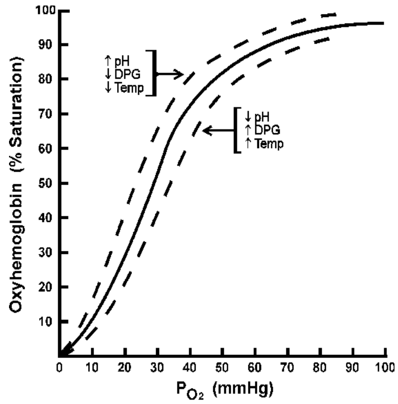

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TRANSPORT OF OXYGEN IN THE BLOOD

- The combination of Oxygen with Hemoglobin (the oxygen-dissociation curve) is influenced by:
  - Partial pressures of oxygen
  - Hydrogen ion concentration or pH
    - pH shift to the right (Bohr Effect)
    - pH shift to the left
  - Temperature
    - temp favors the release of O_2
  - ↑ 2-3 DPG in the red blood cells (2-3 bisphosphoglycerate)
    - release of oxygen

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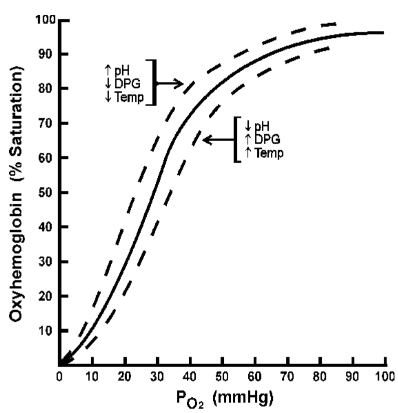

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CARBON DIOXIDE TRANSPORT (Three Ways)

- **Dissolved CO_2:**
  - CO_2 solubility is ~ 25-fold more than O_2, so about 10% (7%) of the CO_2 unloaded in the lung derives from dissolved CO_2.
- **Hydrated CO_2:**
  - This reaction only occurs to an appreciable extent in the red cell containing the enzyme, carbonic anhydrase.
    - The permeability of red cells to anions is high so HCO_3^- diffuses into the plasma, with Cl^- diffusing inward to maintain electrical neutrality (Chloride shift).
    - The H^+ ions are buffered, mainly by the imidazole groups of hemoglobin- histidine, so there is only a slight pH drop.
  - About 60%(70%) of the CO_2 eliminated in the lungs is transported as HCO_3^-.
- **Formation of carbamino compounds:**
  - The H^+ produced is buffered by Hb.
  - About 30% (23%) of the CO_2 eliminated is transported as $HbBHCOO^-$.

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Chloride Shift

- As HCO_3 is formed it diffuses out of the red cell.
- Cl- diffuses into the red cell to maintain electroneutrality. This is the Chloride Shift or Hamburger Shift.
  - 1. The chloride shift is rapid and is complete before the cells exit the capillary.
  - 2.The osmotic effect of the extra HCO_3 and Cl- in venous red cells causes the venous RBC volume to increase slightly. <u>For this reason venous hematocrit slightly exceeds arterial hematocrit.</u>

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TRANSPORT OF CARBON DIOXIDE

- Forms in which carbon dioxide is transported
  - Dissolve carbon dioxide
  - Carbon dioxide combined with water to form carbonic acid in the plasma
  - Bicarbonate ions resulting from dissociation of the carbonic acid within the red cells
  - Carbamino compounds resulting mainly from combination of carbon dioxide with hemoglobin

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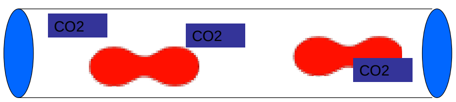
TRANSPORT OF CARBON DIOXIDE

- Forms in which carbon dioxide is transported
  - Dissolve carbon dioxide
    - some remains in the blood in the dissolve state→ transported to the lungs
    - 0.2ml carbon dioxide/100ml blood
    - 10%



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TRANSPORT OF CARBON DIOXIDE

Bicarbonate ions resulting from dissociation of the carbonic acid within the red cells

Carbonic anhydrase

- $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO^3 + H^+$
- The dissociative products of carbonic acid accounts for the transport of approximately 60% of all the CO_2 (3ml/100ml of blood)

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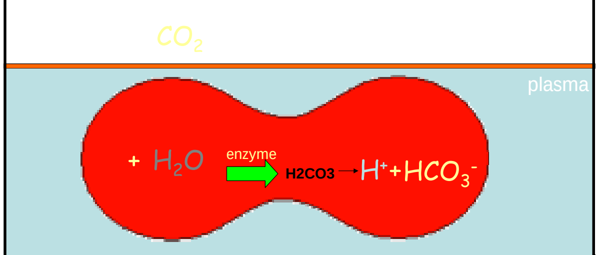
Transport of carbon dioxide

- In tissue :



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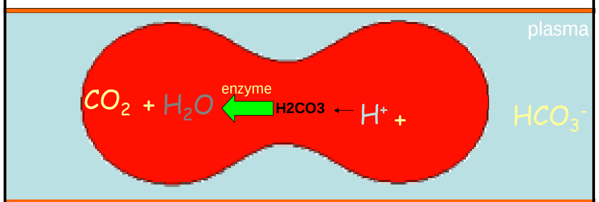
Transport of carbon dioxide

- In lungs:



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TRANSPORT OF CARBON DIOXIDE

- Carbamino compounds resulting mainly from combination of carbon dioxide with hemoglobin
- CO2 + hgb ⟷ Carbamino hgb
  - Reversible
  - 30% of total quantity transported (1.5ml/100ml of blood)

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Define

- Bohr Effect
  - When carbon dioxide is bound with hemoglobin, slightly less oxygen can combine with the same hemoglobin solution for a given pO2.
- Haldane Effect
  - When oxygen binds with hemoglobin, this causes hemoglobin to bind very poorly with carbon dioxide.

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THE RESPIRATORY EXCHANGE RATIO

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Oxygen

- lungs→ tissue
- each diciliter of blood= 5ml O_2
- 5ml/dl

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Carbon Dioxide

- tissue→ LUNGS
- each diciliter of blood= 4ml CO_2
- 4ml/dl

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$$\textcircled{R} = \frac{\text{Rate of carbon dioxide output}}{\text{Rate of oxygen uptake}}$$

- Respiratory Exchange Ratio
- 80%
- Carbohydrates for body metabolism→ R=1.00
  - 1 molecule of CO_2 for each O_2 molecule consumed
- Fats for body metabolism→ R=0.7
  - when oxygen reacts with fats→ O_2 combines with hydrogen atoms from the fats to form water instead of CO_2
- Normal Diet (CHO,CHON, Fats)→ R= 0.825

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PHYSIOLOGY OF AVIATION AND SPACE

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EFFECTS OF LOW OXYGEN PRESSURE ON THE BODY

- Alveolar PO_2 at Different Elevations
- Effects of Breathing Pure Oxygen on Alveolar PO_2 at Different Altitudes
- Acclimatization to low PO_2

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EFFECTS OF LOW OXYGEN PRESSURE ON THE BODY

- Alveolar PO2 at Different Elevations
  - Carbon Dioxide and Water Vapor Decrease the Alveolar Oxygen
  - Alveolar PO2 at Different Altitudes
  - Saturation of Hemoglobin with Oxygen at Different Altitudes

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Table 43–1 EFFECTS OF ACUTE EXPOSURE TO LOW ATOMOSPHERIC PRESSURES ON ALVEOLAR GAS CONCENTRATIONS AND ARTERIAL OXYGEN SATURATION*

			Breathing Air			Breathing Pure Oxygen		
Altitude (ft)	Barometric Pressure (mm Hg)	Po_2 in Air (mm Hg)	*Pco_2 in Alveoli (mm Hg)*	*Po_2 in Alveoli (mm Hg)*	*Arterial Oxygen Saturation (%)*	*Pco_2 in Alevoli (mm Hg)*	*Po_2 in Alveoli (mm Hg)*	*Arterial Oxygen Saturation (%)*
0	760	159	40 (40)	104 (104)	97 (97)	40	673	100
10,000	523	110	36 (23)	67 (77)	90 (92)	40	436	100
20,000	349	73	24 (10)	40 (53)	73 (85)	40	262	100
30,000	226	47	24 (7)	18 (30)	24 (38)	40	139	99
40,000	141	29				36	58	84
50,000	87	18				24	16	15

* Numbers in parentheses are acclimatized values.

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- Carbon Dioxide and Water Vapor Decrease the Alveolar Oxygen
  - CO_2 continually excreted, water vaporizes→ dilute the oxygen in the alveoli→ reduce oxygen concentration
  - Water Vapor 47mmHg
  - high ALTITUDES→ CO_2 falls from 40mmHg
  - Mount Everest 29,028 feet
    - 253mmHg
      - 47mmHg- Water Vapor
    - 206mmHg
      - 7mmHg CO_2
      - 199mmHg
      - 39.8mmHg or 40mmHg

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EFFECTS OF LOW OXYGEN PRESSURE ON THE BODY

- Alveolar PO2 at Different Elevations
  - Alveolar PO2 at Different Altitudes

Table 43–1 EFFECTS OF ACUTE EXPOSURE TO LOW ATOMOSPHERIC PRESSURES ON ALVEOLAR GAS CONCENTRATIONS AND ARTERIAL OXYGEN SATURATION*

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- Alveolar PO2 at Different Elevations
  - Saturation of Hemoglobin with Oxygen at Different Altitudes

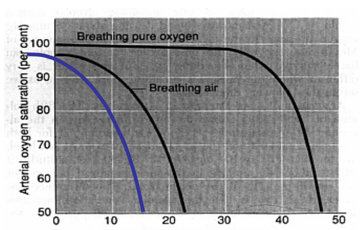

Figure 43–1. Effect of high altitude on arterial oxygen saturation when one is breathing air and when breathing pure oxygen.

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EFFECTS OF LOW OXYGEN PRESSURE ON THE BODY

- Effects of Breathing Pure Oxygen on Alveolar PO2 at Different Altitudes
  – space occupied by nitrogen now occupied by oxygen

Table 43–1 EFFECTS OF ACUTE EXPOSURE TO LOW ATOMOSPHERIC PRESSURES ON ALVEOLAR GAS CONCENTRATIONS AND ARTERIAL OXYGEN SATURATION*

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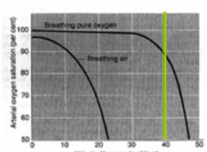

Figure 43–1. Effect of high altitude on arterial oxygen saturation when one is breathing air and when breathing pure oxygen.

EFFECTS OF LOW OXYGEN PRESSURE ON THE BODY

- Acclimatization to low PO2
  – person remain at high altitudes (days, weeks, months, or years)→ fewer deleterious effects, possible for the person to work harder w/o hypoxic effects

  – The FIVE Principal Means by which Acclimatization comes about are:
    - Increased Pulmonary Ventilation
    - Increase in Red Blood Cells and Hemoglobin During Acclimatization
    - Increased Diffucing Capacity After Acclimatization
    - Circulatory System in Acclimatization- Increased Capillarity
    - Cellular Acclimatization

PHYSIOLOGY OF DEEP SEA DIVING

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EFFECTS OF HIGH PARTIAL PRESSURES OF GASES ON THE BODY

- Nitrogen Narcosis at High Nitrogen Pressures
- Oxygen Toxicity at High Pressures
- Carbon Dioxide Toxicity at Great Depths in the Sea
- "Saturation Diving" and Use of Helium-Oxygen Mixtures in Deep Dives

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EFFECTS OF HIGH PARTIAL PRESSURES OF GASES ON THE BODY

- Nitrogen Narcosis at High Nitrogen Pressures
  - 4/5 of the air
  - sea level- no known effect
  - high pressure- narcosis
  - DIVER→ compressed air→120 ft (mild narcosis)→ 150-200 feet (drowsy)→ 250 feet (strength wanes)→ beyond (useless)
  - Nitrogen Narcosis (alcoholic intoxication) "raptures of the depths"
    - MECHANISM same as gas anesthetics- dissolves freely in the fats of the body, dissolves freely in the membrane of the neurons.

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EFFECTS OF HIGH PARTIAL PRESSURES OF GASES ON THE BODY

- Oxygen Toxicity at High Pressures
  - epileptic convulsions→ coma
  - REASON: increase concentration of oxidizing free radicals (O_2^-)→ destroy essential elements of the cell→ damage the metabolic system of the cells.

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EFFECTS OF HIGH PARTIAL PRESSURES OF GASES ON THE BODY

- Carbon Dioxide Toxicity at Great Depths in the Sea
  - depth alone does not increase carbon dioxide partial pressure in the alveoli
  - continues to breathe a normal tidal volume
  - continue to expire the carbon dioxide as it is formed

"Maintain the CO2 Partial Pressure at a normal value of almost 40mmHg"

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EFFECTS OF HIGH PARTIAL PRESSURES OF GASES ON THE BODY

- Carbon Dioxide Toxicity at Great Depths in the Sea
  - Alveolar CO2 beyond 80mmHg→respiratory center depressed→ respiration fail→ respiratory acidosis, lethargy, and narcosis→ Anesthesia

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EFFECTS OF HIGH PARTIAL PRESSURES OF GASES ON THE BODY

- "Saturation Diving" and Use of Helium–Oxygen Mixtures in Deep Dives
  - Very deep dives, HELIUM is usually used in the gas mixture.
    - it has only about 1/5 the narcotic effect of nitrogen
    - only about half as much as volume of helium dissolves in the body tissue as nitrogen
    - the low density of helium (1/7 the density of nitrogen) keeps the airway resistance for breathing at a minimum

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Thank You for not Listening

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