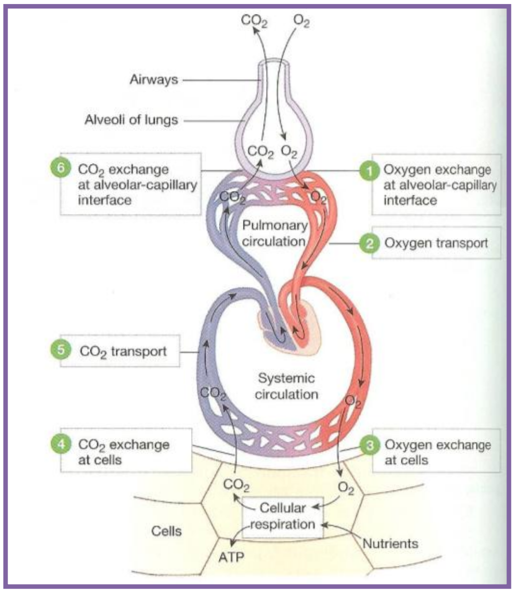
Chapter 18 Gas Exchange and Transport



I. DIFFUSION and SOLBUILITY of GASES

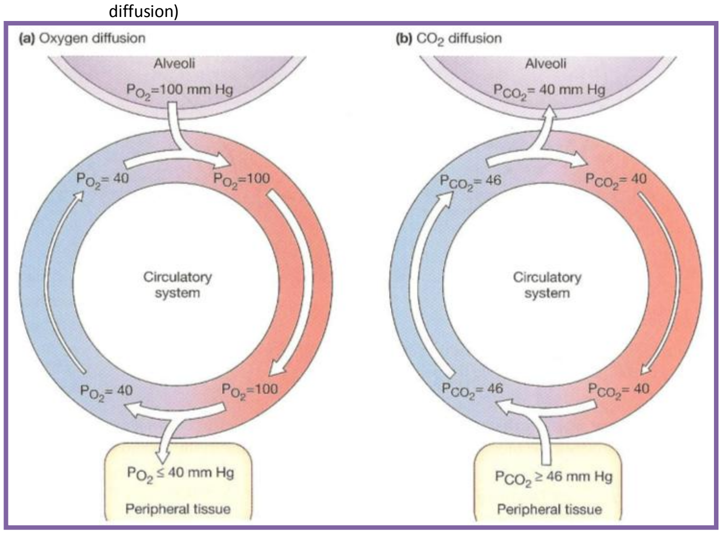
a. FOUR factors that influence diffusion in the lungs

i. Surface Area: Rate of diffusion is directly proportional to available surface area (increased surface area = increased diffusion)

ii. Concentration Gradient: Rate of diffusion is directly proportional to concentration gradient (increase gradient = more diffusion of substances)

iii. Membrane Thickness: Indirectly proportional to diffusion rate (Increase thickness = decrease diffusion)

iv. Diffusion Distance: Directly proportional (short distance = quick diffusion/long distance = slow diffusion)

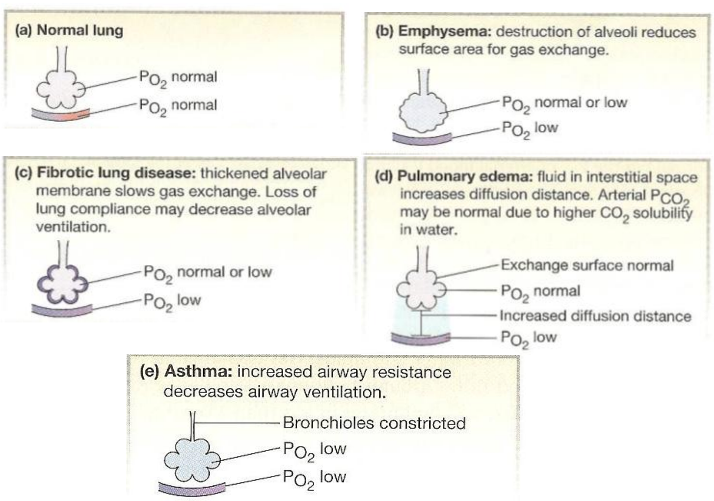


b. Gas Exchange in Lungs and Tissue
   i. Normal ARTERIAL Alveolar PO_2 =100mmHg
   ii. Normal VENOUS Systemic PO_2 = 40mmHg
   iii. Normal ARTERIAL Alveolar PCO_2 = 40mmHg
   iv. Normal VENOUS System PCO_2 = 46mmHg
      1. O_2 100→40 moving down its concentration gradient from alveolar to capillaries
      2. CO_2 is higher in tissues than in systemic capillary blood because carbon dioxide is produced during metabolism
      3. Hypoxia: State of too little oxygen
      4. Hypercapnia: Elevated concentrations of carbon dioxide

Comment [HAW1]: Starts high → gets low because cells have low concentration of oxygen

Comment [HAW2]: Starts low → gets high because cells release CO_2 during ATP/energy production

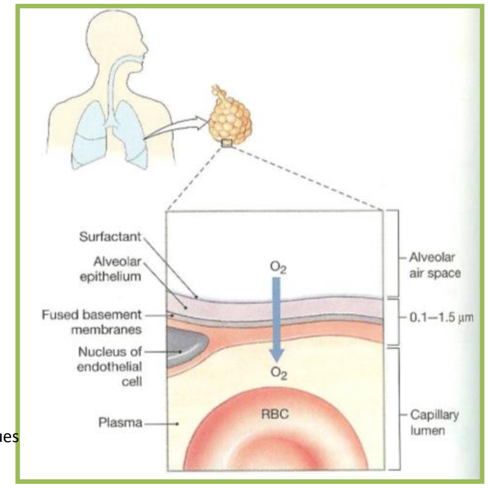
c. A decrease in Alveolar PO_2 Decreases Oxygen Uptake at the Lungs
   i. First requirement for adequate oxygen delivery to the tissues is to have adequate oxygen intake from the atmosphere (levels of elevation)
   ii. Main factor that affects oxygen content of inspired air is altitude
   iii. Normal Atmospheric Level 760mmHg (sea level) 160 mmHg O_2
   iv. High altitude Level (Denver) 628mmHg = 132 mmHg O_2
   v. If Alveolar PO_2 is low but the composition of inspired air is normal the problem lies with alveolar ventilation
      1. Low alveolar ventilation – hypoventilation (lower than normal volumes of fresh air entering the alveoli)
         a. Emphysema
         b. Fibrotic lung disease
         c. Pulmonary edema
         d. Asthma



II. Changes in the Alveolar Membrane Alter Gas Exchange
   a. Transfer of oxygen from alveoli to blood requires diffusion across the barrier created by type I alveolar cells
   b. Gas exchange in the lungs is rapid, blood flow through pulmonary capillaries is slow, and diffusion reaches equilibrium in less then 1 second
   c. Pathological changes that effect gas exchange
      i. Decrease in the amount of alveolar surface area available for gas exchange (EMPHYSEMA)
      ii. Increase in the thickness of the alveolar membrane (FIBROTIC LUNG DISEASE)
      iii. Increase in the diffusion distance between alveoli and blood (PULMONARY EMEDA)

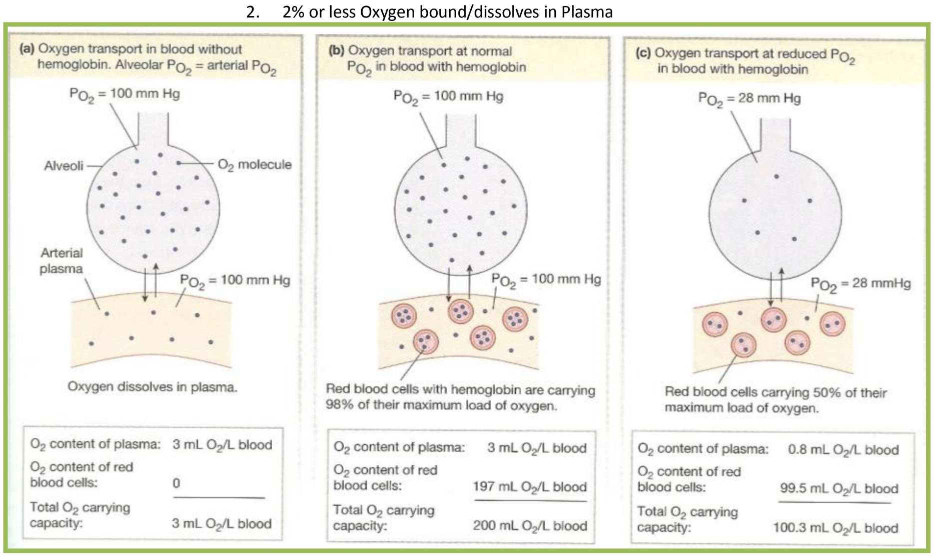
Comment [HAW3]: Elastic Disorder; Lose of elasticity; Trouble during exhalation

Comment [HAW4]: Compliance Disorder; Lose of stretch; Trouble during Inhalation



GAS TRANSPORTED IN THE BLOOD

I. Hemoglobin transports most Oxygen to the Tissues
    a. Oxygen is transported in two ways
        i. Dissolved in plasma
        ii. Bound to Hemoglobin (Hb)
    b. Pulmonary Capillaries and places with high concentration of O_2; Hemoglobin has a high affinity for oxygen
    c. At cells where oxygen is being used and plasma PO_2 levels are low; hemoglobin has a low affinity for oxygen
        1. 98% of Oxygen in given volume of blood is bound to hemoglobin
        2. 2% or less Oxygen bound/dissolves in Plasma



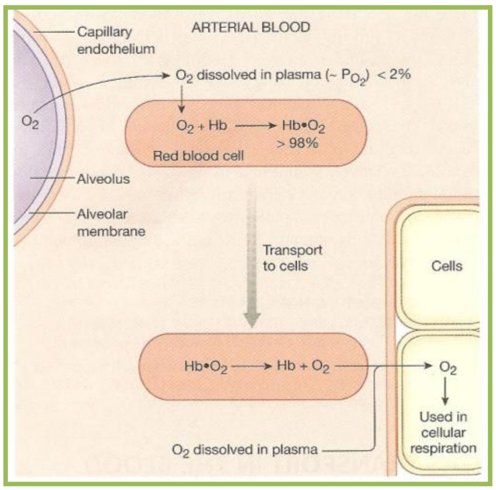
    d. Hemoglobin's binding ability to oxygen depends on two factors
        i. PO_2 in the plasma surrounding the RBC
        ii. Number of potential binding sites available in the red blood cells
            1. PO_2 is the primary factor determining how many of the available hemoglobin binding sites are occupied by oxygen

2. Total number of oxygen-binding sites depends on the number of hemoglobin molecules in the RBC

II. One Hemoglobin Molecule Binds Up to Four Oxygen Molecules
  a. Hemoglobin is a complex protein whose quaternary structure has four globular protein chains
  b. Each chain is wrapped around a iron-containing *heme group*
  c. Four *heme groups* in hemoglobin are identical
  d. The iron-oxygen interaction is a weak bond that can be easily broken without altering either the hemoglobin or oxygen

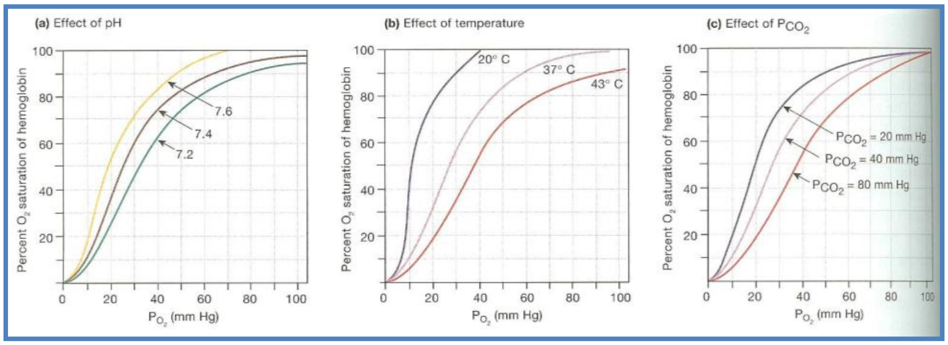
III. Oxygen-Hemoglobin Binding Obeys the law of Mass Action
  a. Hemoglobin bound to oxygen is known as oxyhemoglobin (HbO_2)
  b. If oxygen concentration ↑ the oxygen-hemoglobin binding reactions shifts to the right and more oxygen binds to hemoglobin
  c. If oxygen concentration ↓ the oxygen-hemoglobin binding reaction shifts to the left and less oxygen binds to hemoglobin

IV. PO_2 Determines Oxygen-Hemoglobin Binding
  a. Amount of oxygen bound to hemoglobin depends primary on the PO_2 of plasma surrounding the RBC



  b. In pulmonary capillaries O_2 dissolved in the plasma diffuses into RBC where it binds to hemoglobin
  c. This removes dissolved O_2 from the plasma causing more oxygen to diffuse in from the alveoli
  d. The PO_2 of tissue cells determines how much oxygen unloads from hemoglobin
    i. As cells increase their metabolic activity, their PO_2 decrease, and hemoglobin releases more oxygen to them

V. TEMP/pH/Metabolites Affect Oxygen-Hemoglobin Binding
  a. Physiological changes in plasma pH, PCO_2, and temperature all alter oxygen-binding affinity of hemoglobin
  b. ↑ Temperature= Decrease affinity of hemoglobin for oxygen/shift curve to the right
  c. ↑PCO_2 = Decrease affinity of hemoglobin for oxygen/shift curve to the right
  d. ↓ pH = Decrease affinity of hemoglobin for oxygen/shift curve to the right
    i. pH
      1. Anaerobic metabolism in exercising muscle fibers produces lactic acid which releases H^+ into E.C.F. and cytoplasm
      2. More oxygen is released at the tissues as the blood becomes more acidic
      3. Borh Effect



e. DPG

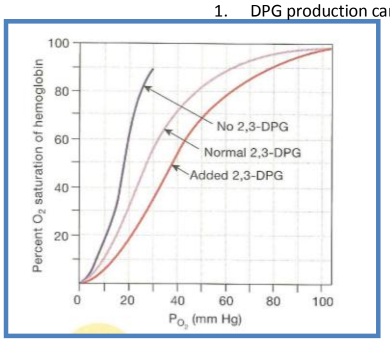
i. 2,3 Diphosphoglycerate

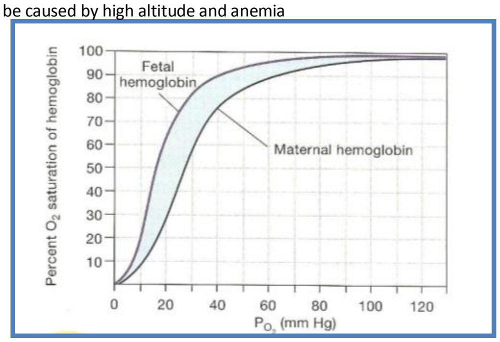
ii. Compound made from an intermediate of glycolysis pathway

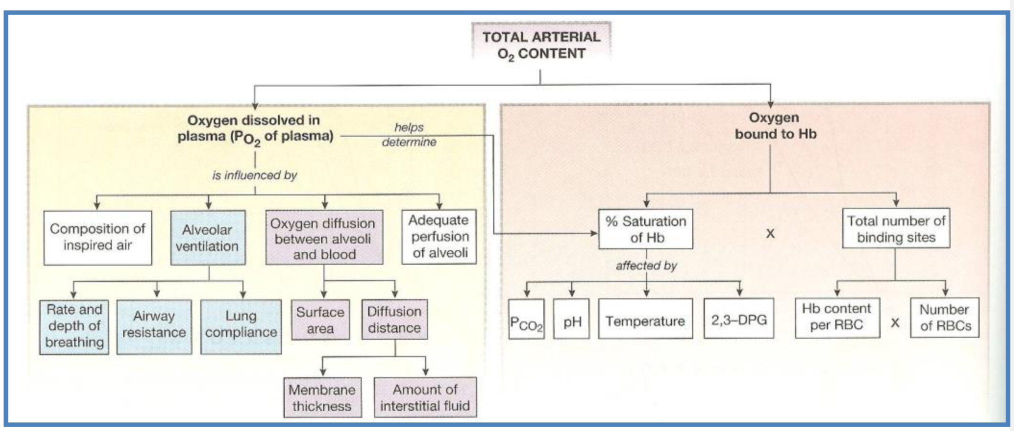
iii. Triggered by *Chronic Hypoxia,* increases production of DPG in RBC

iv. Increase in DPG levels lower hemoglobin's binding affinity

1. DPG production can be caused by high altitude and anemia

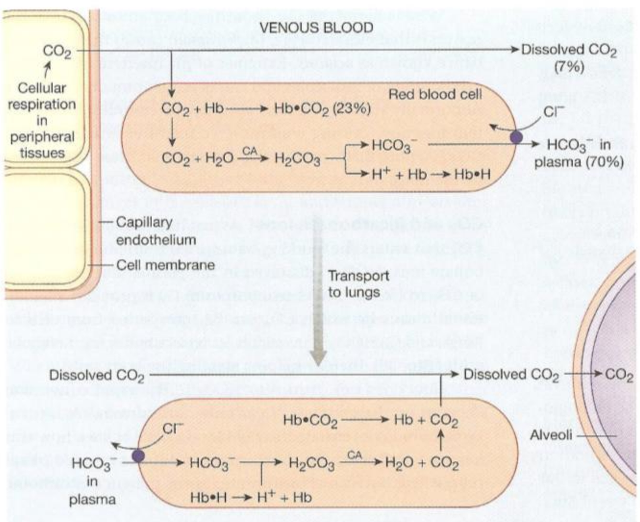






CARBON DIOXIDE

I. Carbon Dioxide is Transported in Three Ways
   a. Gas transport in blood includes CO_2 removal
   b. CO_2 is byproduct of cellular respiration
   c. Cells product more CO_2 then plasma can dissolve (7% CO_2 dissolved by venous blood)
   d. 93% of CO_2 is dissolved in RBC where
      i. 70% of CO_2 in RBC is converted to *Bicarbonate Ions*
      ii. 23% of CO_2 in RBC gets bound to hemoglobin (Hb-CO_2)



   e. Removing CO_2 from the blood is important because elevated PCO_2 (hypercapnia) cause
      i. a decrease in pH, *acidosis*
      ii. Denature proteins
      iii. Depress N.S. functions
      iv. Confusion
      v. Coma
      vi. Death

Comment [HAW5]: CO_2 is a potentially toxic waste product that must be removed by the lungs

II. CO_2 and Bicarbonate Ions
   a. 70% of CO_2 that enters RBC is converted into Bicarbonate Ions (HCO_3^-) that travels to the lungs dissolved in plasma

$CO_2 + H_2O \leftrightarrow H_2CO_3 H^+ + HCO_3^-$

$\underline{CO_2 + H_2O \leftrightarrow H^+ + HCO_3^-}$

Comment [HAW6]: Carbonic Acid; Product of carbonic anhydrase (CA) enzyme that converts carbon dioxide and water into carbonic acid; Carbonic Acid then dissociates into hydrogen and bicarbonate

   b. Conversion takes place because
      i. Provides an additional means by which CO_2 can be transported from cells to the lungs
      ii. HCO_3^- can act as a buffer for metabolic acids helping to stabilize body pH
   c. To keep conversion of CO_2 to hydrogen and bicarbonate it must be removed from cytoplasm of RBC

III. Hemoglobin and H^+
   a. If PCO_2 is elevated hemoglobin cannot bind with H^+ produced from the reaction of CO_2 and H_2O

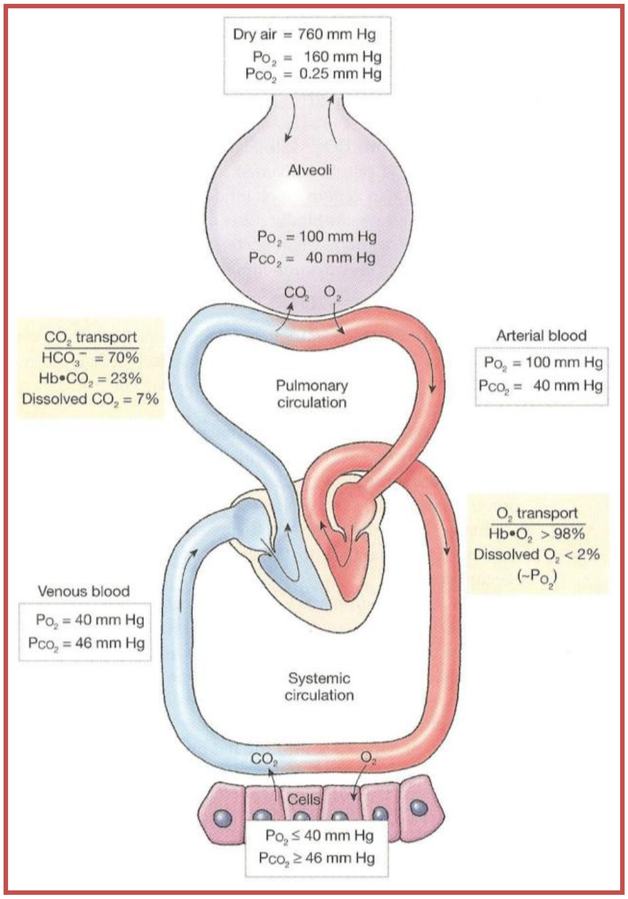
b. Excess H^+ accumulates in the plasma causing *respiratory acidosis*

IV. Hemoglobin and CO_2

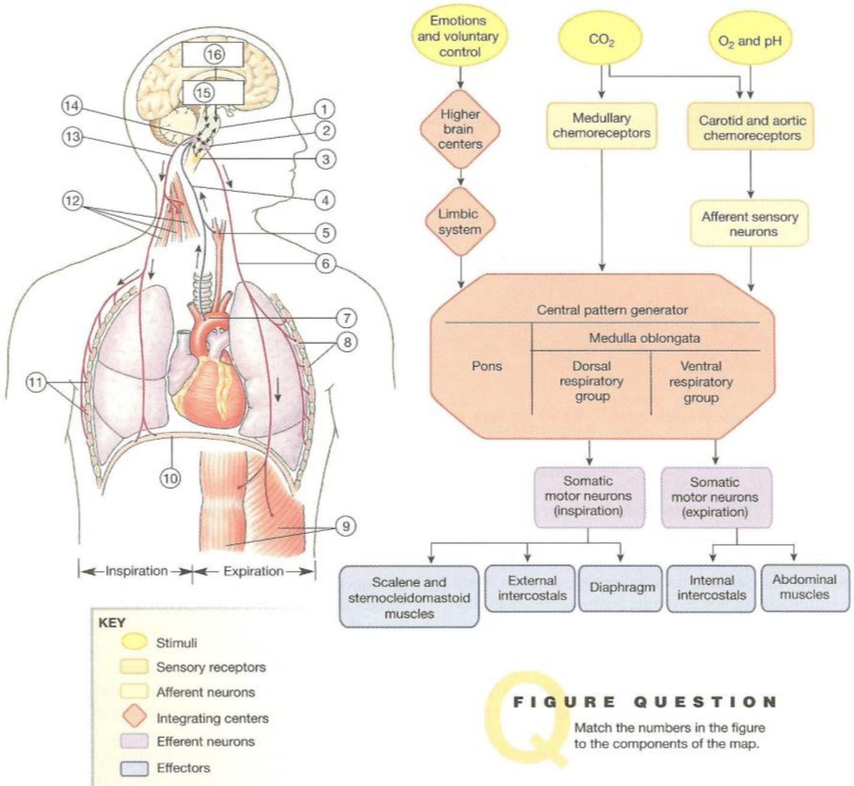
a. 23% of CO_2 in venous blood binds directly to hemoglobin

b. When O_2 leaves its binding sites from hemoglobin CO_2 binds to free binding sites to form *carbaminohemoglobin* ($HbCO_2$)

Comment [HAW7]: Both CO_2 and H^+ presence decreases hemoglobin's binding affinity for oxygen



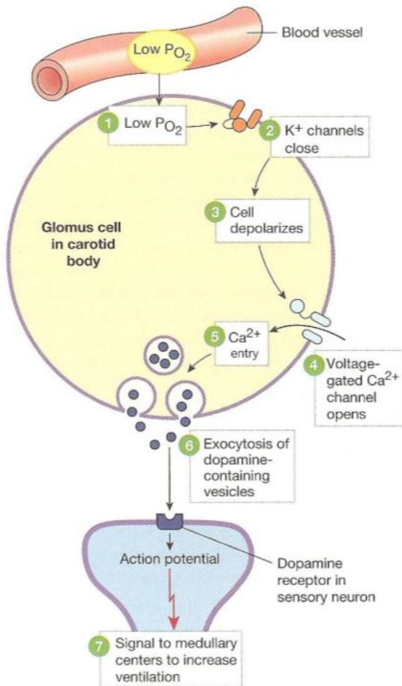
REGULATION OF VENTILATION



I. Carbon dioxide, Oxygen and pH influence Ventilation
   a. Central and peripheral chemoreceptors modify rhythmicity of the central pattern generator
   b. CO_2 is the primary stimulus for changes in ventilation (oxygen and plasma pH play lesser roles)
   c. Chemoreceptors (for O_2 and CO_2) are strategically associated with arterial circulation
      i. ↓ O_2 in arterial blood = Rate and depth of breathing decreases
      ii. If CO_2 production by the cells exceeds rate of CO_2 removal by the lungs, a an ↑ CO_2 in arterial blood = ventilation is intensified (hypernea/tachypnea)

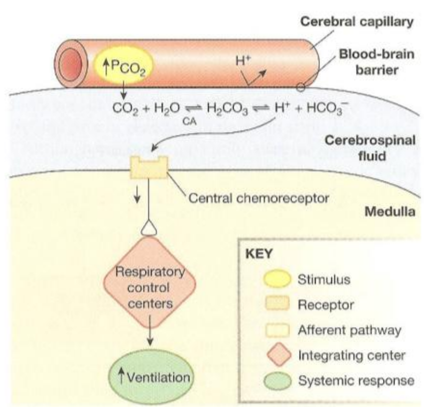
PERIPHERAL CHEMORECEPTORS

a) Located in the carotid and aortic arteries
b) Sense changes in CO_2, O_2, and pH
c) Close to baroreceptors
d) Trigger an INCREASE VENTILATION
e) PO_2 must fall below 60mmHg or a 40% drop must occur



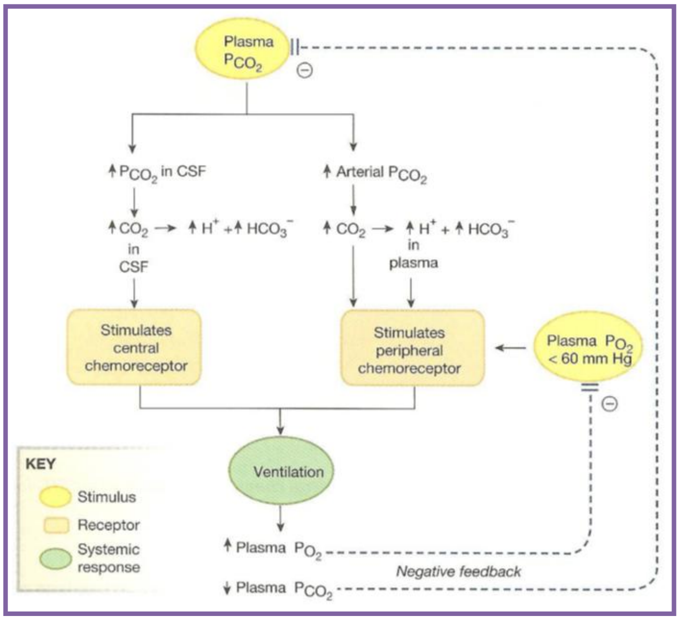
CENTRAL CHEMORECEPTORS

a) Most important chemical controller of ventilation is $CO_{2,}$ mediated through central chemoreceptors in the Medulla
b) When arterial CO_2 increases, it crosses the BBB rapidly and activates the central chemoreceptors
c) Receptors signal an INCREASE VENTILATION
    a. Increase Rate and Depth
    b. Increase Alveolar ventilation
d) If PCO_2 remains elevated over a period of time the ventilation falls back to normal/adaption takes place; HCO_3^- begins to enter CSF and buffer/denaturalize acidic environment
e) Respond to decreased Arterial CO_2 as well as increased
    a. During decreased CO_2 (hyperventilation), central chemoreceptor activity declines, allowing ventilation rate to slow down and allow CO_2 to accumulate



Comment [HAW8]: Blood Brain Barrier

Comment [HAW9]: Although we say it measures CO_2 it really **MEASURES pH** changes in the CSF
-Increase in H^+ from $CO_2 + H_2O \leftrightarrow H^+ + HCO_3^-$ causes acidotic conditions, which activated the central chemoreceptors



f) Chronic Lung Disease
   a. Emphysema
      i. Chronic Hypercapnia
      ii. Chronic Hypoxia
      iii. Their central chemoreceptors adapt to elevated levels of PCO_2 and low O_2
      iv. Their peripheral chemoreceptors though remain intact, and sense low O_2 levels and stimulate ventilation