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Ventilation/Perfusion Matching

M1 – Cardiovascular/Respiratory Sequence

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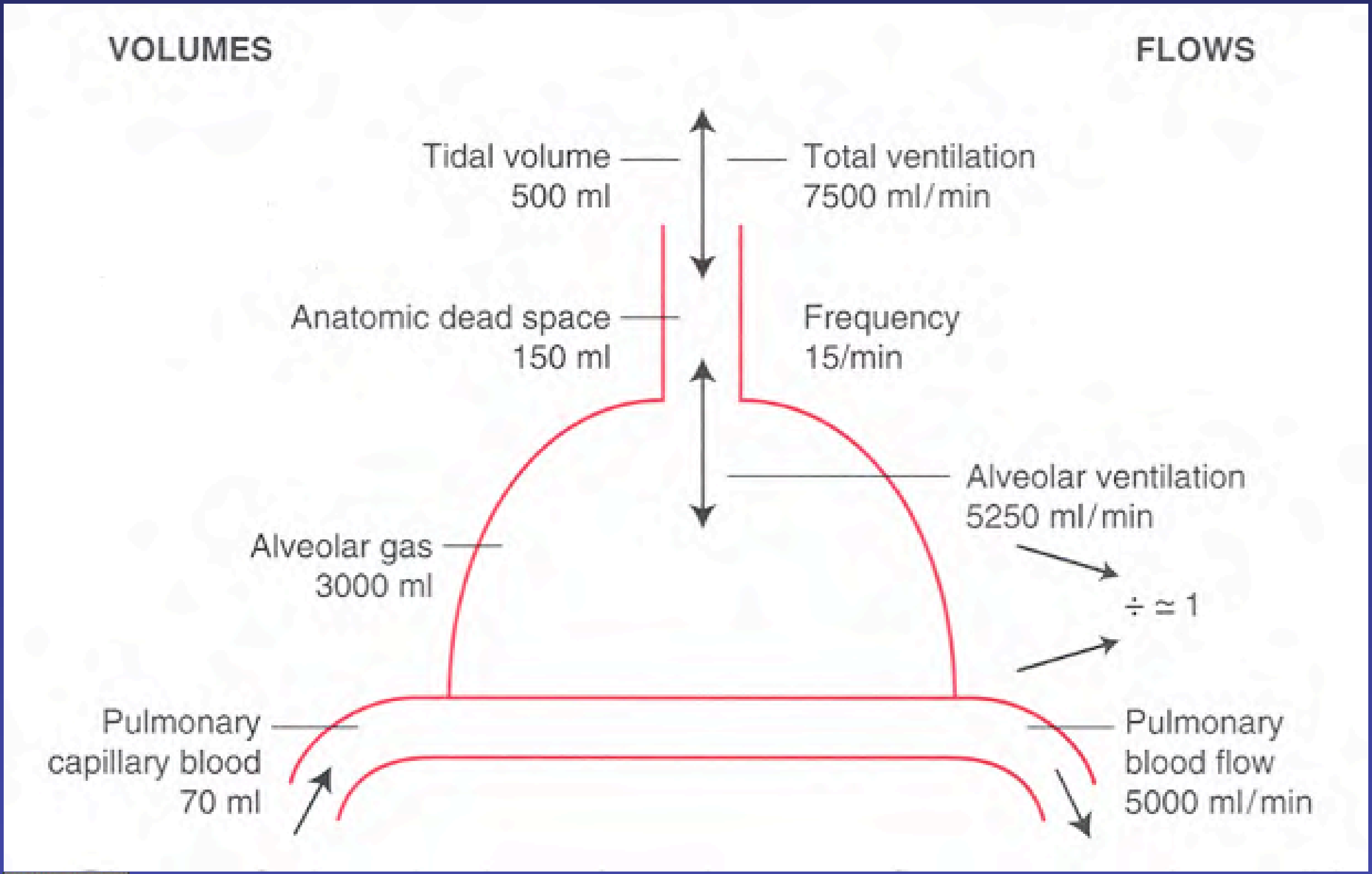
Fall 2008

Objectives

- To recognize the importance of matching ventilation and perfusion
  - To explain the consequences of mismatched ventilation and perfusion
  - To define shunt and dead space physiology
  - To be able to determine the alveolar pO_2
  - To be able to determine the A-a O_2 gradient and understand the implications of an increased gradient
  - To explain and understand the consequences of regional differences in ventilation and perfusion due to effects of gravity

Ventilation and Perfusion at the Level of the Whole Lung



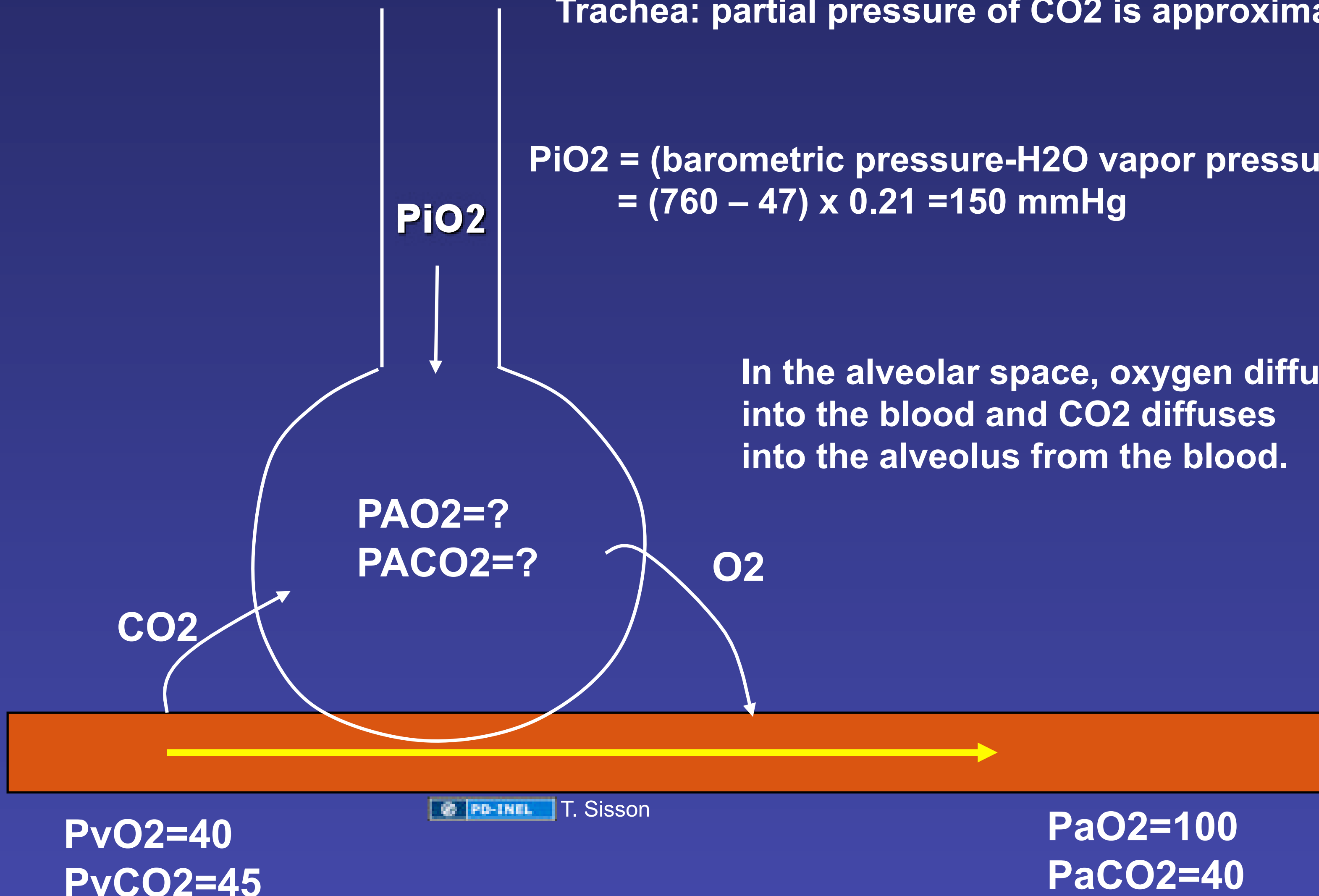
West. Respiratory Physiology: The Essentials 8th ed. Lippincott Williams & Wilkins. 2008

Gas Composition in the Alveolar Space

Trachea: partial pressure of CO_2 is approximately 0

PiO_2 = (barometric pressure-H_2O vapor pressure)xFiO_2
= (760 – 47) x 0.21 =150 mmHg

In the alveolar space, oxygen diffuses into the blood and CO_2 diffuses into the alveolus from the blood.



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Alveolar Gas Equation

$PAO_2 = (PiO_2) – (PaCO_2/R)$.

$PaCO_2$ approximates $PACO_2$ due to the rapid diffusion of CO_2

R = Respiratory Quotient (VCO2/V02) = 0.8

In a normal individual breathing room air:

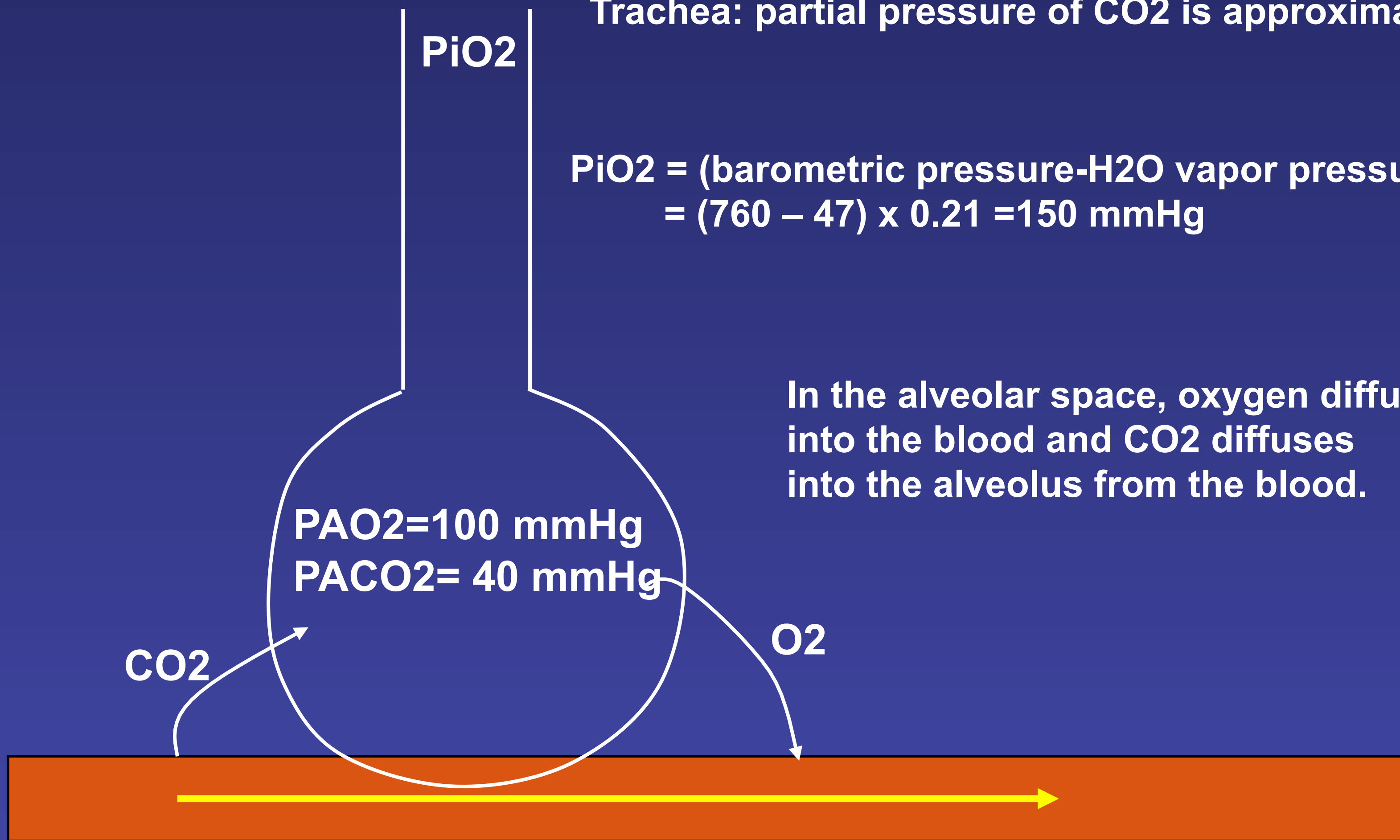
$$PAO_2 = 150 – 40/0.8 = 100 \text{ mmHg}$$

Gas Composition in the Normal Alveolar Space

Trachea: partial pressure of CO_2 is approximately 0

PiO_2 = (barometric pressure-H_2O vapor pressure)xFiO_2
= (760 – 47) x 0.21 =150 mmHg

In the alveolar space, oxygen diffuses into the blood and CO_2 diffuses into the alveolus from the blood.



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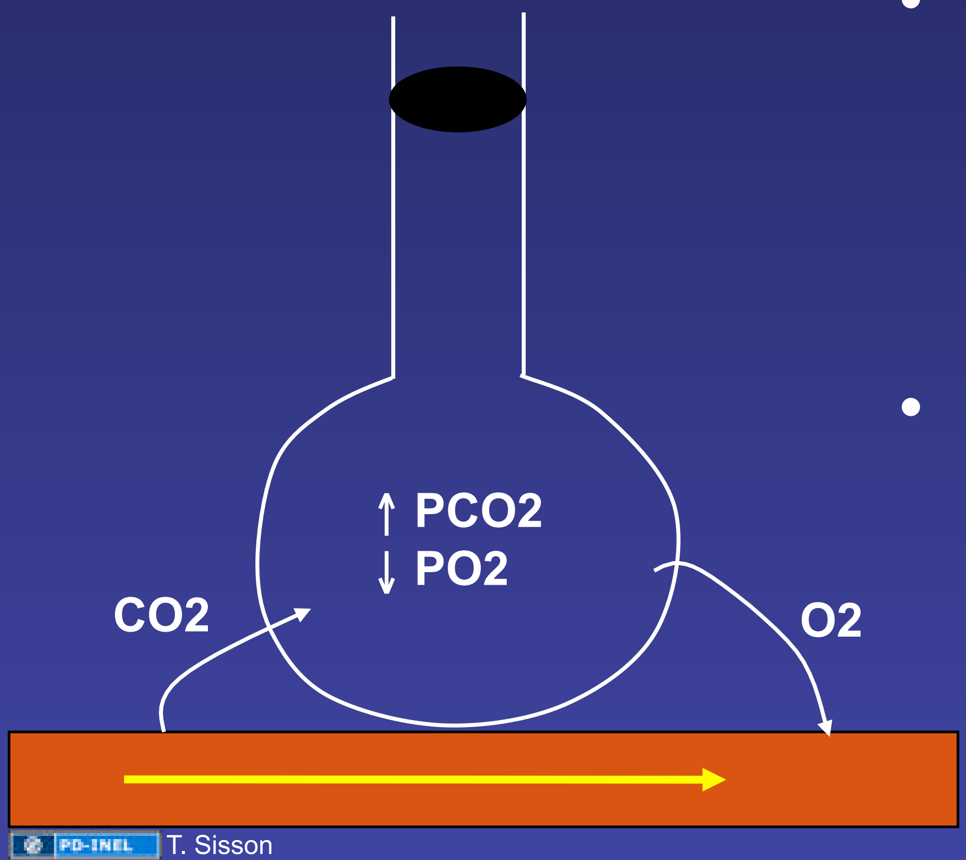
PvO2=40
PvCO2=45

PO2=100
PCO2=40

Consequences of Inadequate Ventilation



- Apnea:
  - PACO2 rises
  - PAO2 falls until there is no gradient for diffusion into the blood
- Hypoventilation:
  - Inadequate ventilation for perfusion
  - PACO2 rises
  - PAO2 falls, but diffusion continues

How Can We Tell if Alveolar Ventilation is Adequate?

PaCO2 and Alveolar Ventilation

- PaCO2 is:
  - directly related to CO2 production (tissue metabolism).
  - Inversely related to alveolar ventilation.

$$PaCO2 \approx \frac{VCO2}{VA}$$

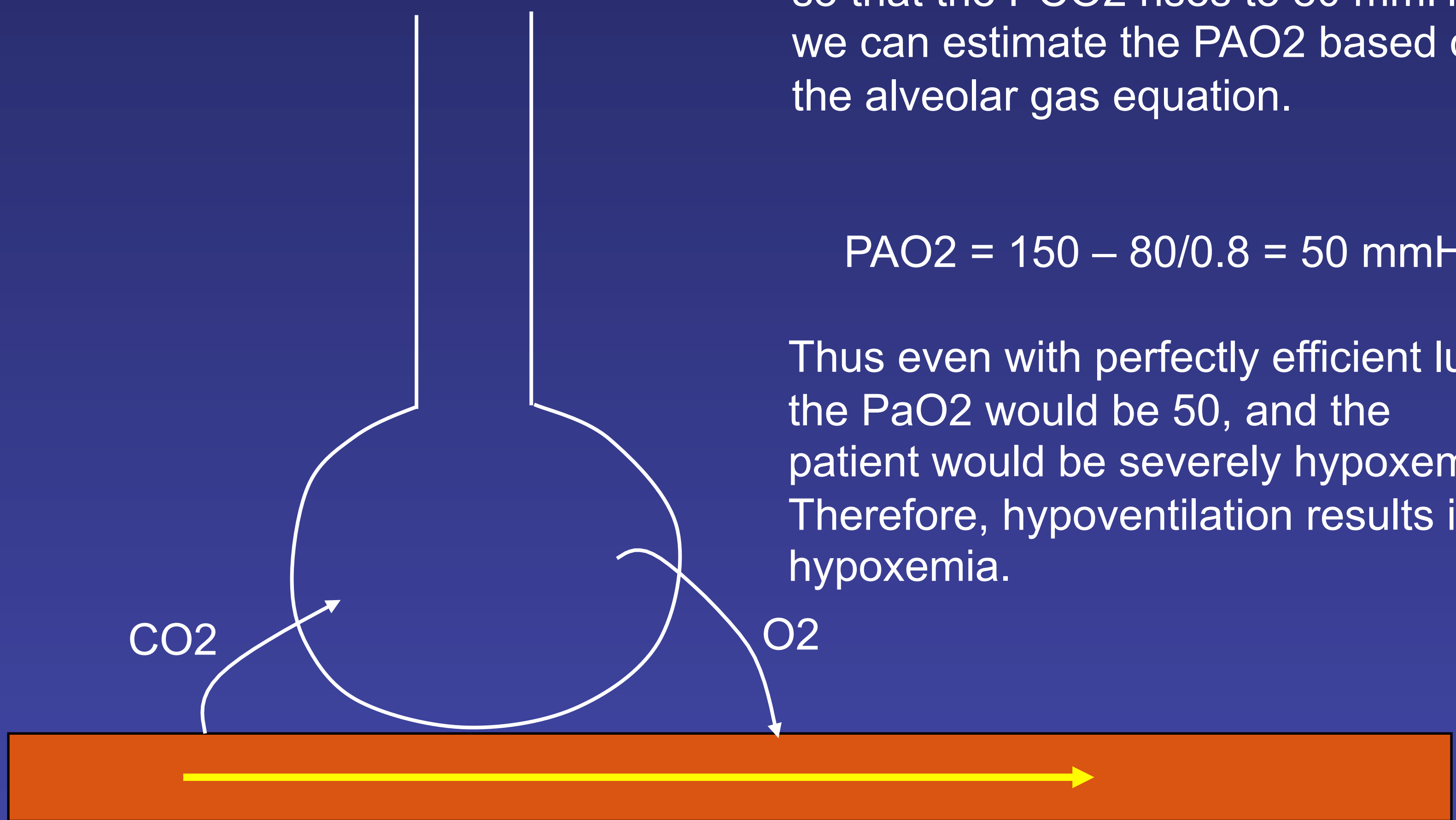
- Increased PaCO2 (hypercarbia) is always a reflection of inadequate alveolar ventilation (VA).

Alveolar Hypoventilation

Suppose a patient hypoventilates, so that the PCO2 rises to 80 mmHg. we can estimate the PAO2 based on the alveolar gas equation.

$$PAO2 = 150 – 80/0.8 = 50 \text{ mmHg}$$

Thus even with perfectly efficient lungs, the PaO2 would be 50, and the patient would be severely hypoxemic. Therefore, hypoventilation results in hypoxemia.



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V/Q Matching

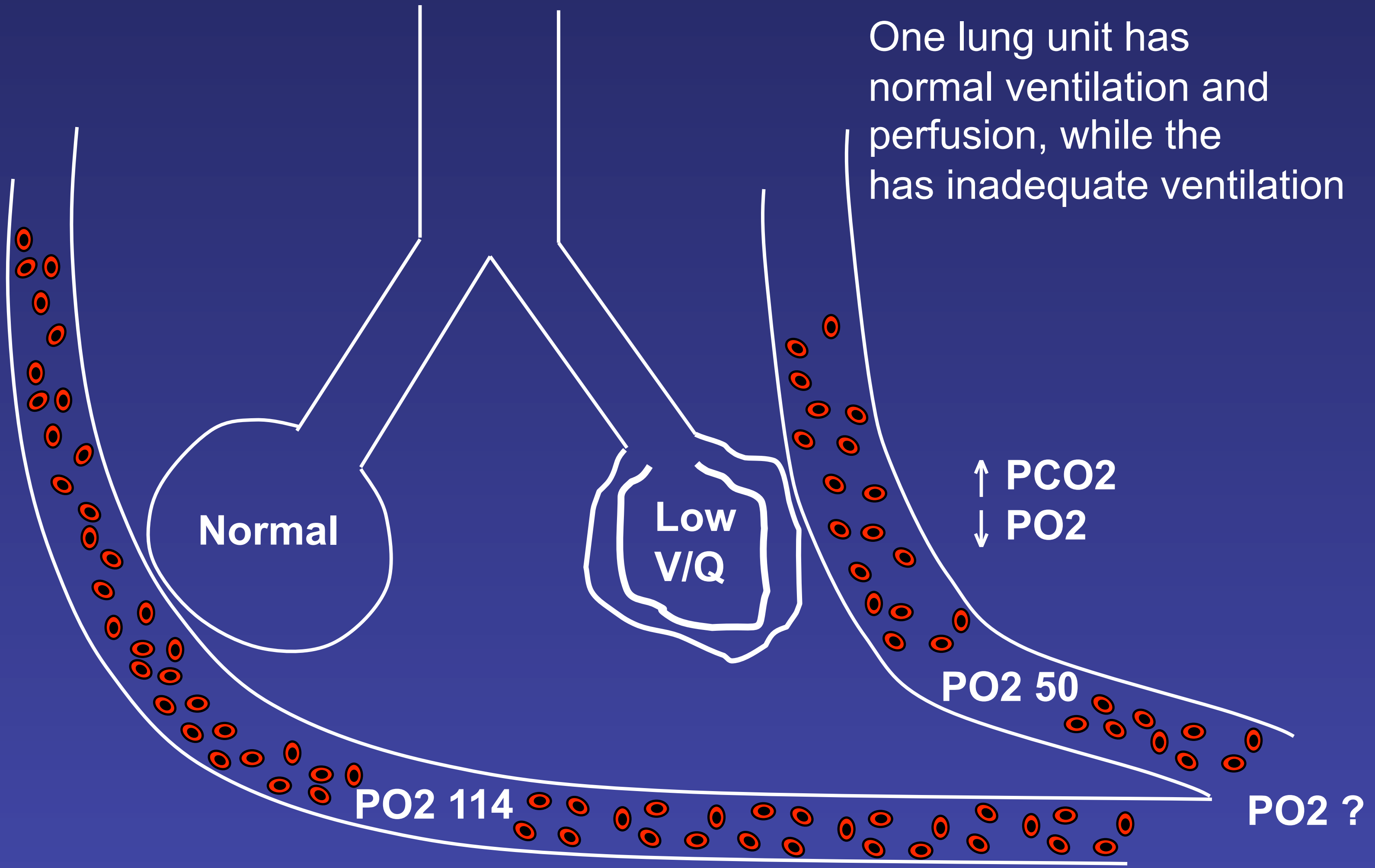
- 300 million alveoli.
- Different alveoli may have widely differing amounts of ventilation and of perfusion.
- Key for normal gas exchange is to have matching of ventilation and perfusion for each alveolar unit
  - Alveoli with increased perfusion also have increased ventilation
  - Alveoli with decreased perfusion also have decreased ventilation
  - V/Q ratio = 1.0

Two Lungs, Not One

- Suppose the left lung is ventilated but not perfused (dead space).
- Suppose the right lung is perfused but not ventilated (shunt).
- Total V/Q = 1, but there is no gas exchange (V/Q must be matched at level of alveoalr unit).

Low V/Q Effect on Oxygenation

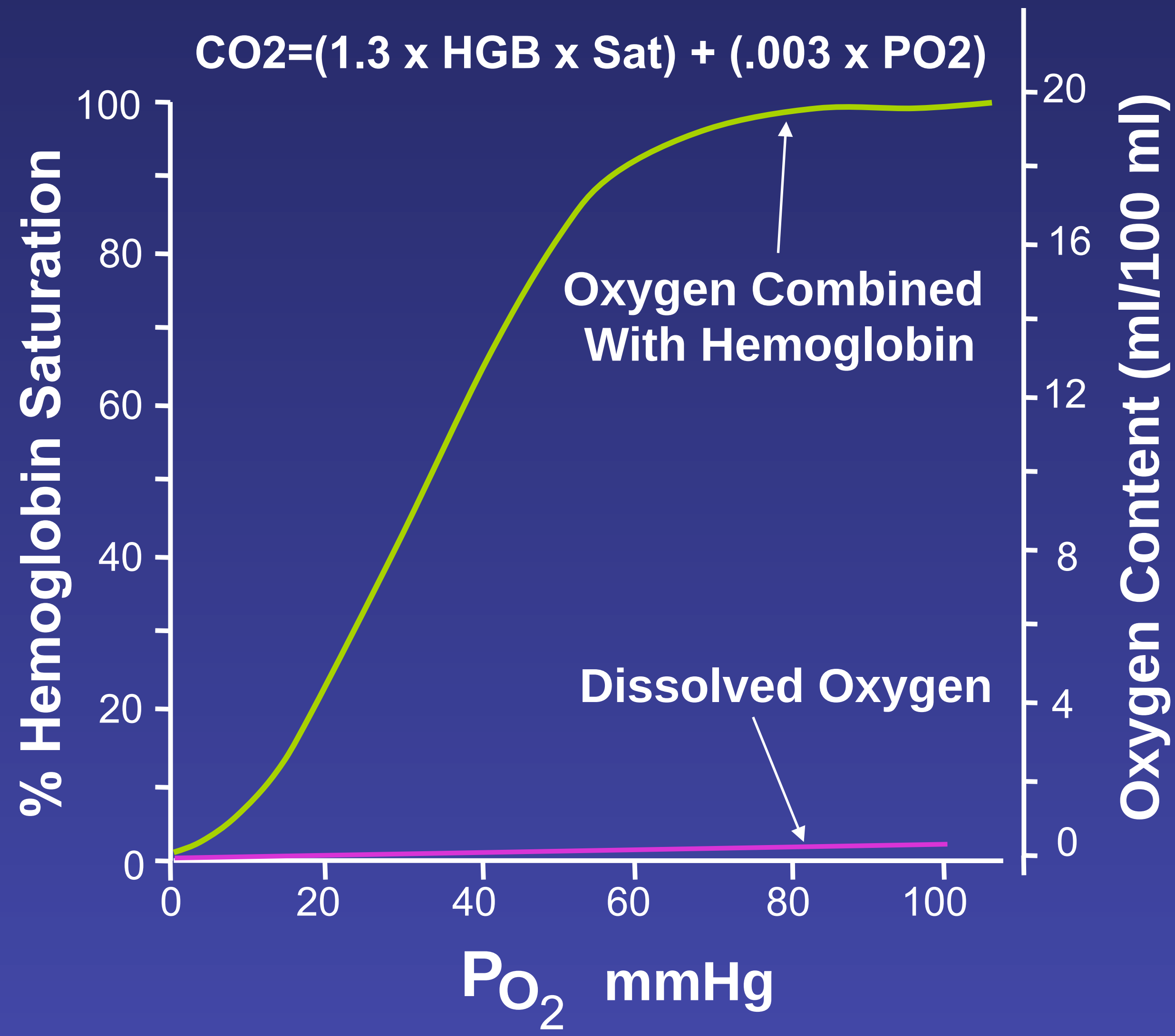
One lung unit has normal ventilation and perfusion, while the has inadequate ventilation



Mixing Blood

- What is the PO2 of a mixture of two volumes of blood with different initial PO2?
- Determined by interaction of oxygen with hemoglobin.
  - the partition of oxygen between plasma (and thus the pO2) and bound to hemoglobin is determined by the oxyhemoglobin dissociation curve.

Oxyhemoglobin Dissociation Curve



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Low V/Q Effect on Oxygenation

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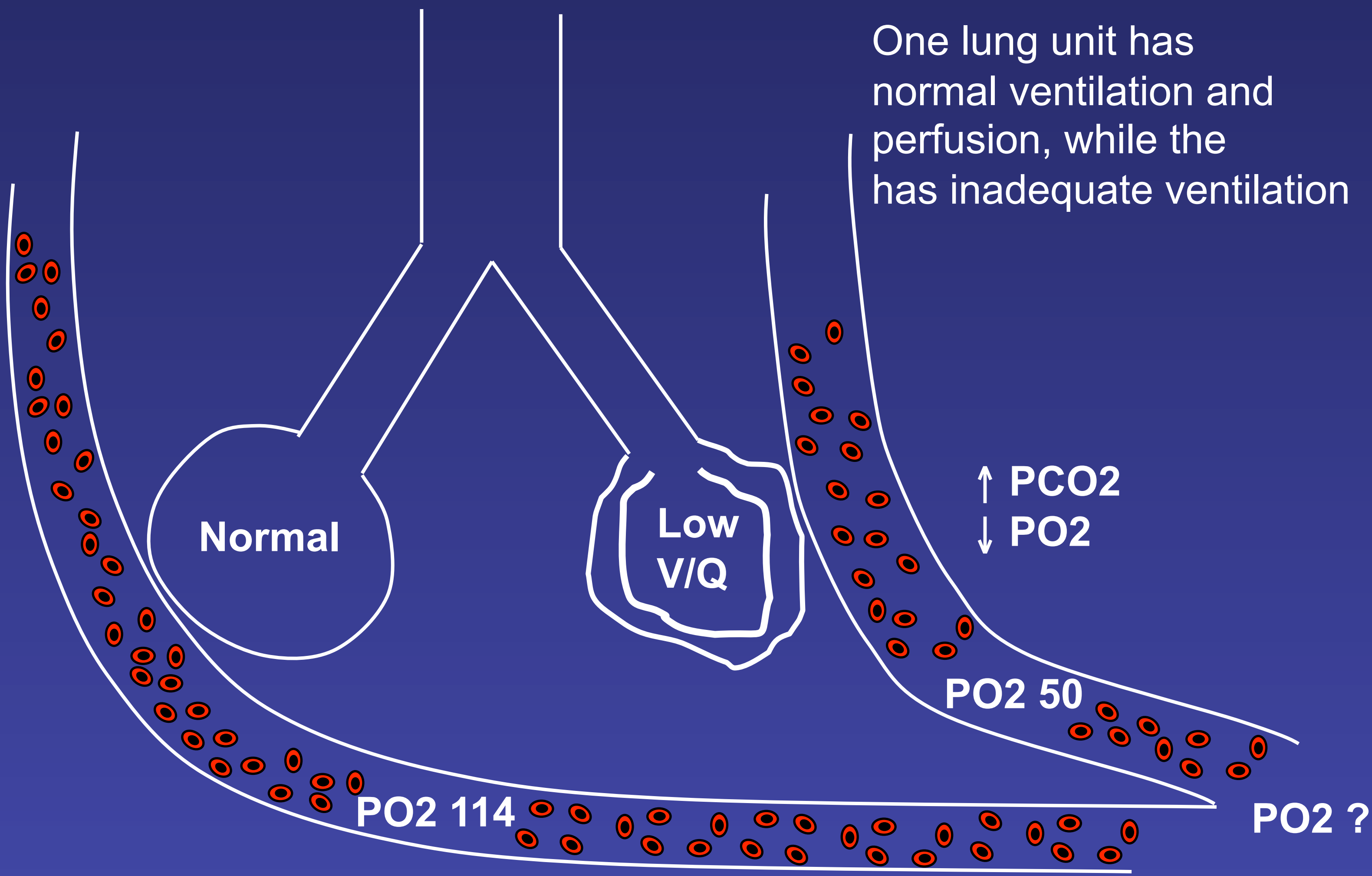
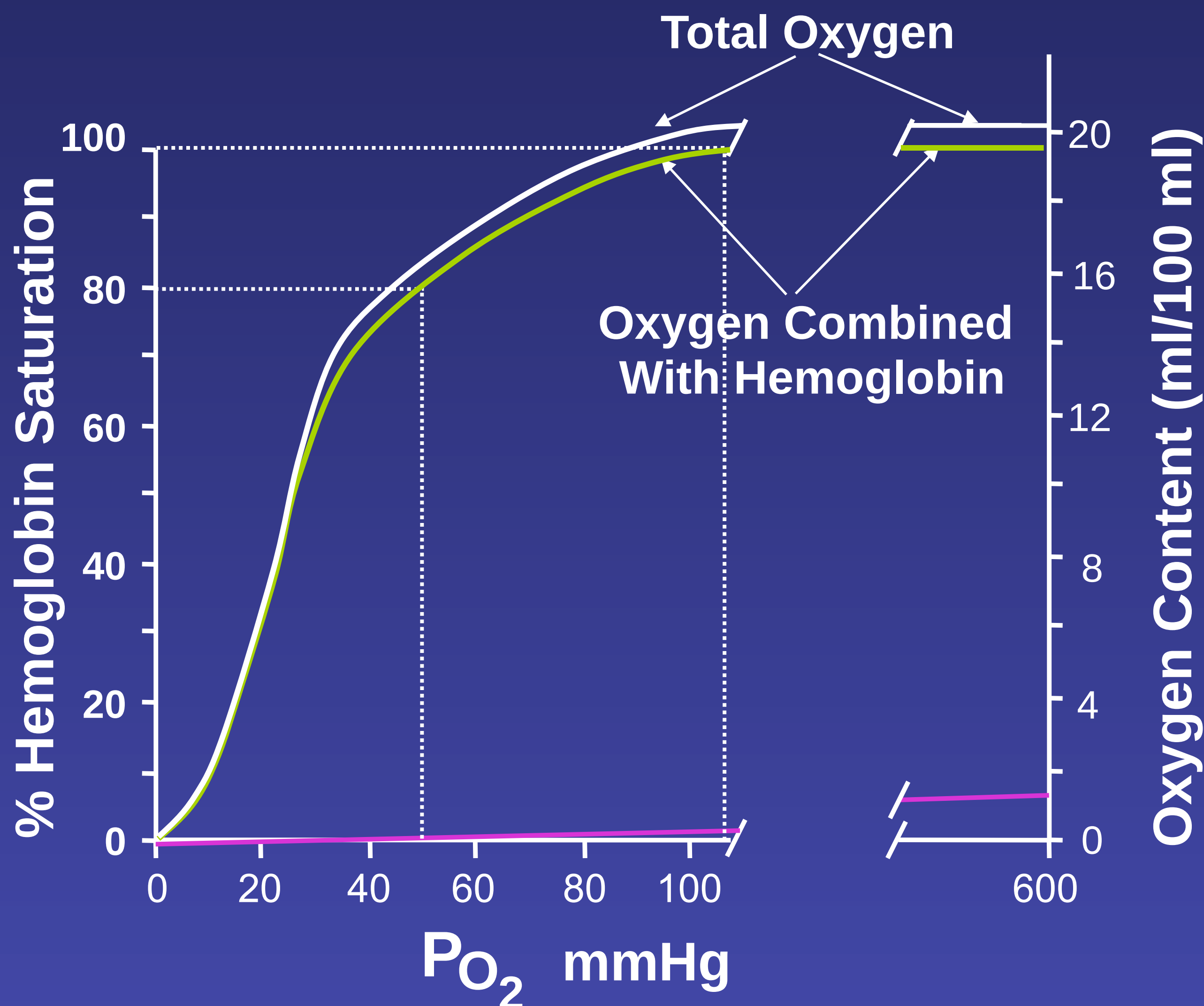


Oxyhemoglobin Dissociation Curve and O2 Content



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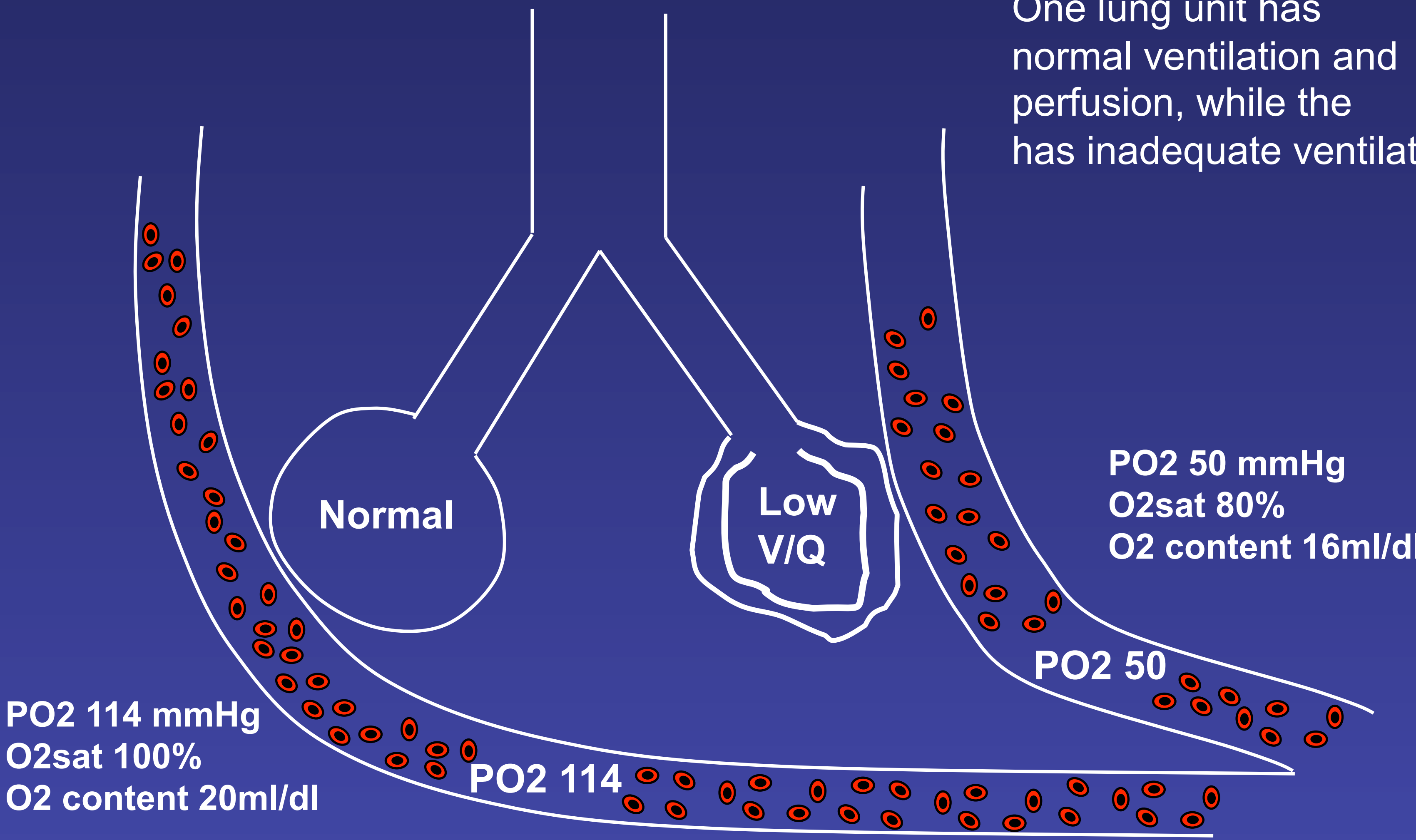

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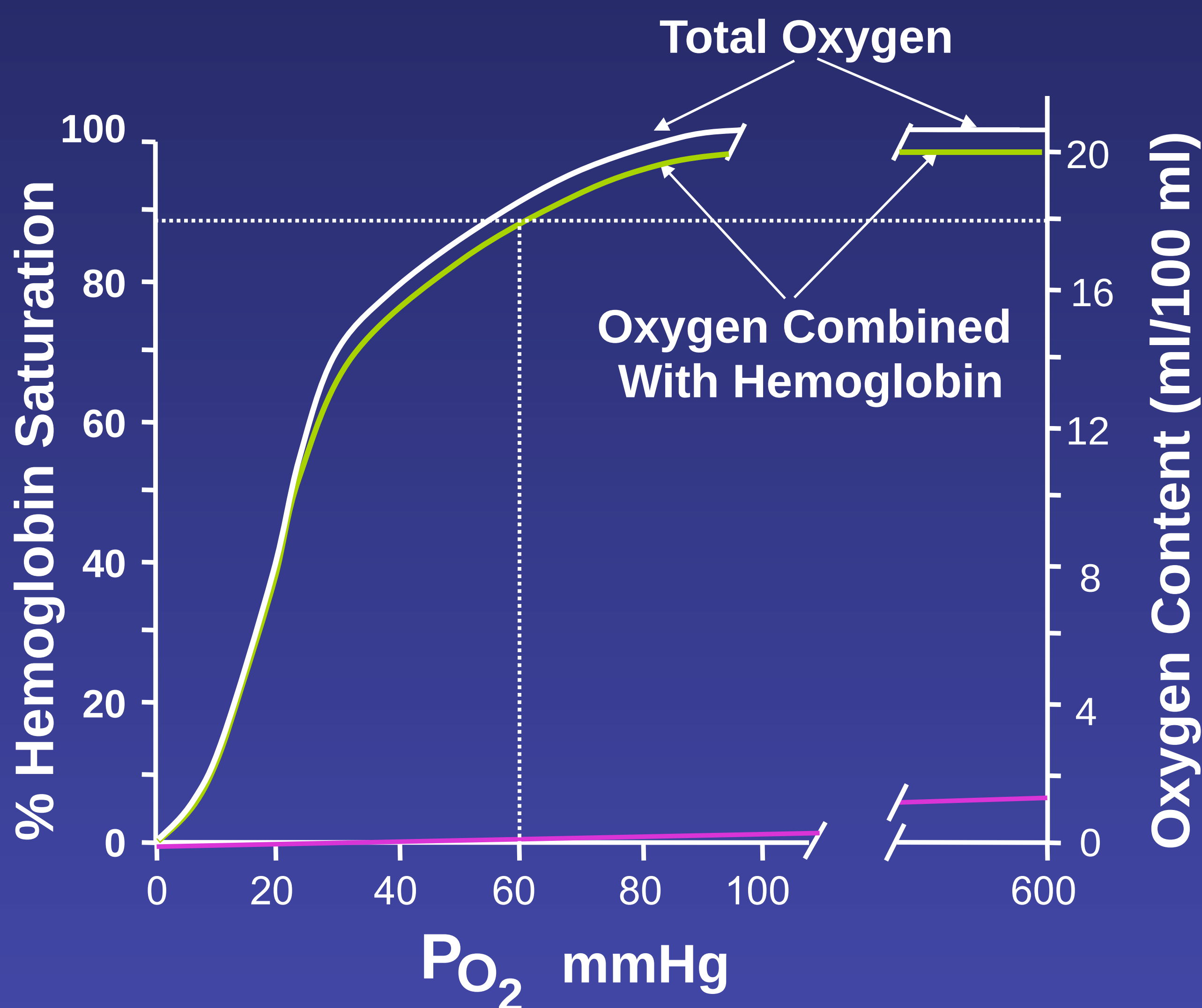
Oxyhemoglobin Dissociation Curve and O2 Content



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Low V/Q Effect on Oxygenation

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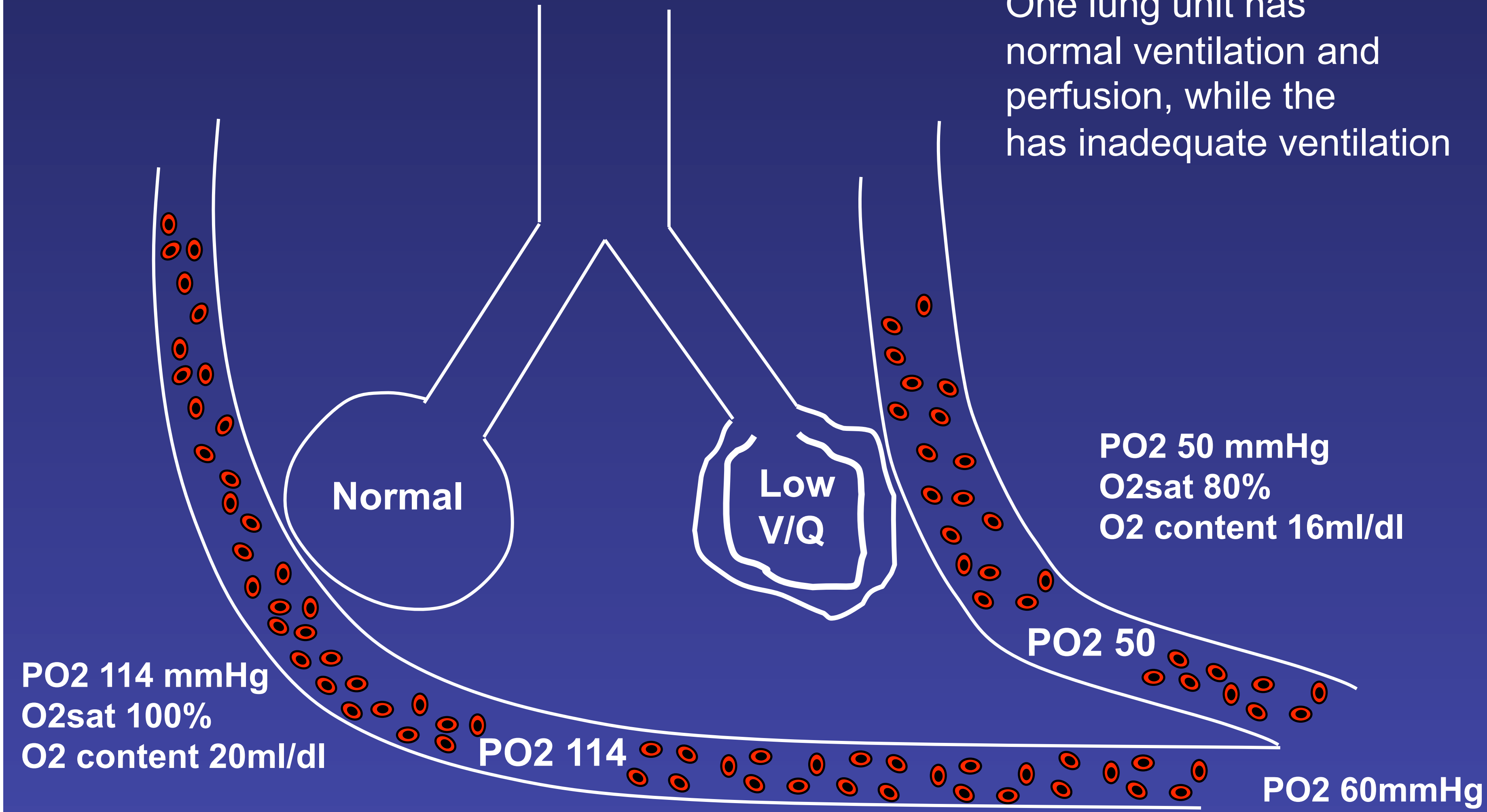
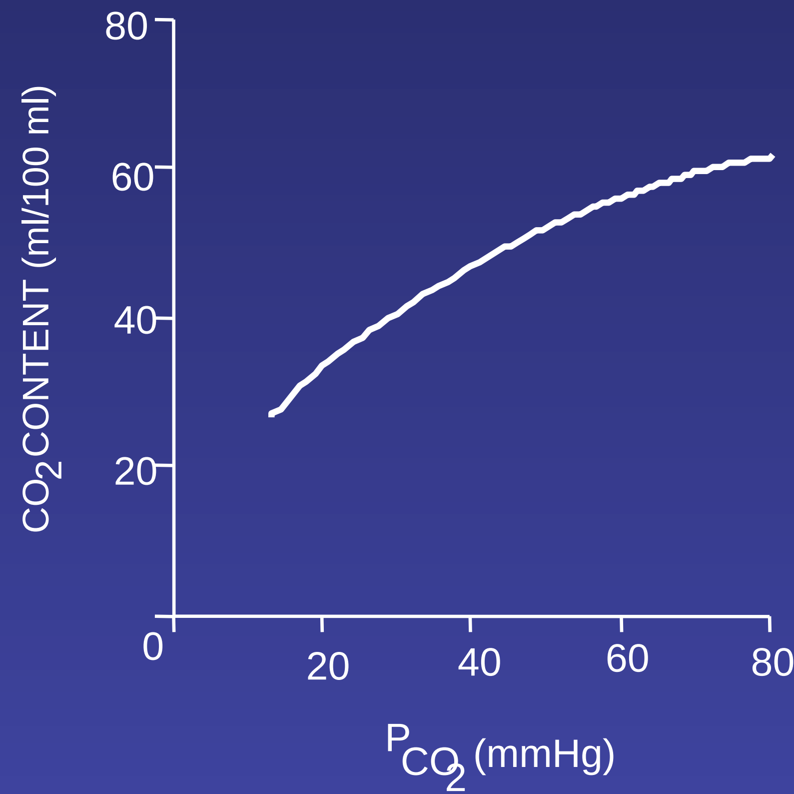


PCO2 in V/Q Mismatch

- Increased ventilation can compensate for low V/Q units.
  - Shape of CO2 curve
- Total ventilation (VE) must increase for this compensation.



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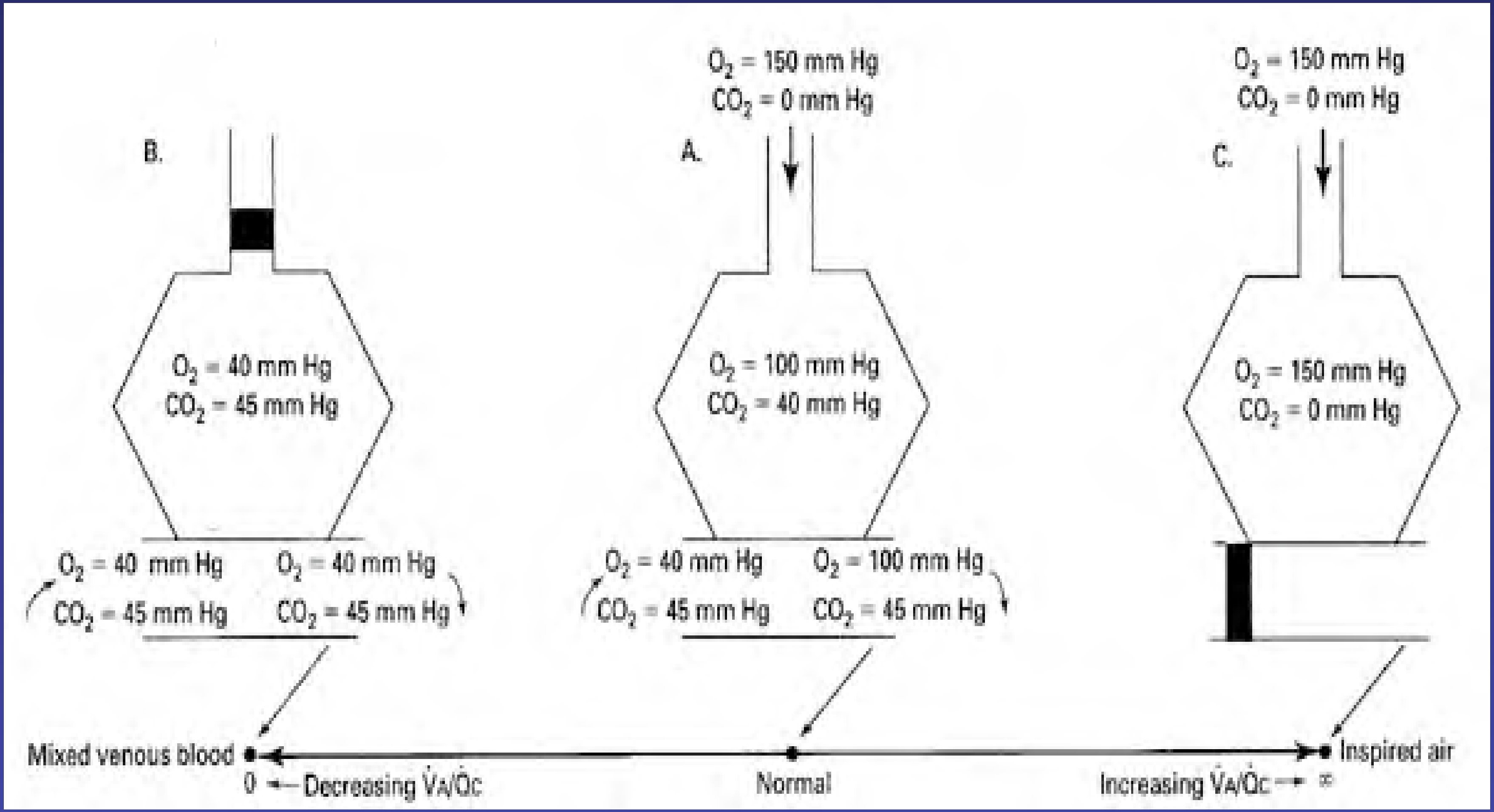
Extremes of V/Q Inequality

- Shunt
  - Perfusion of lung units without ventilation
    - Unoxygenated blood enters the systemic circulation
    - V/Q = 0
- Dead space
  - Ventilation of lung units without perfusion
    - Gas enters and leaves lung units without contacting blood
    - Wasted ventilation
    - V/Q is infinite

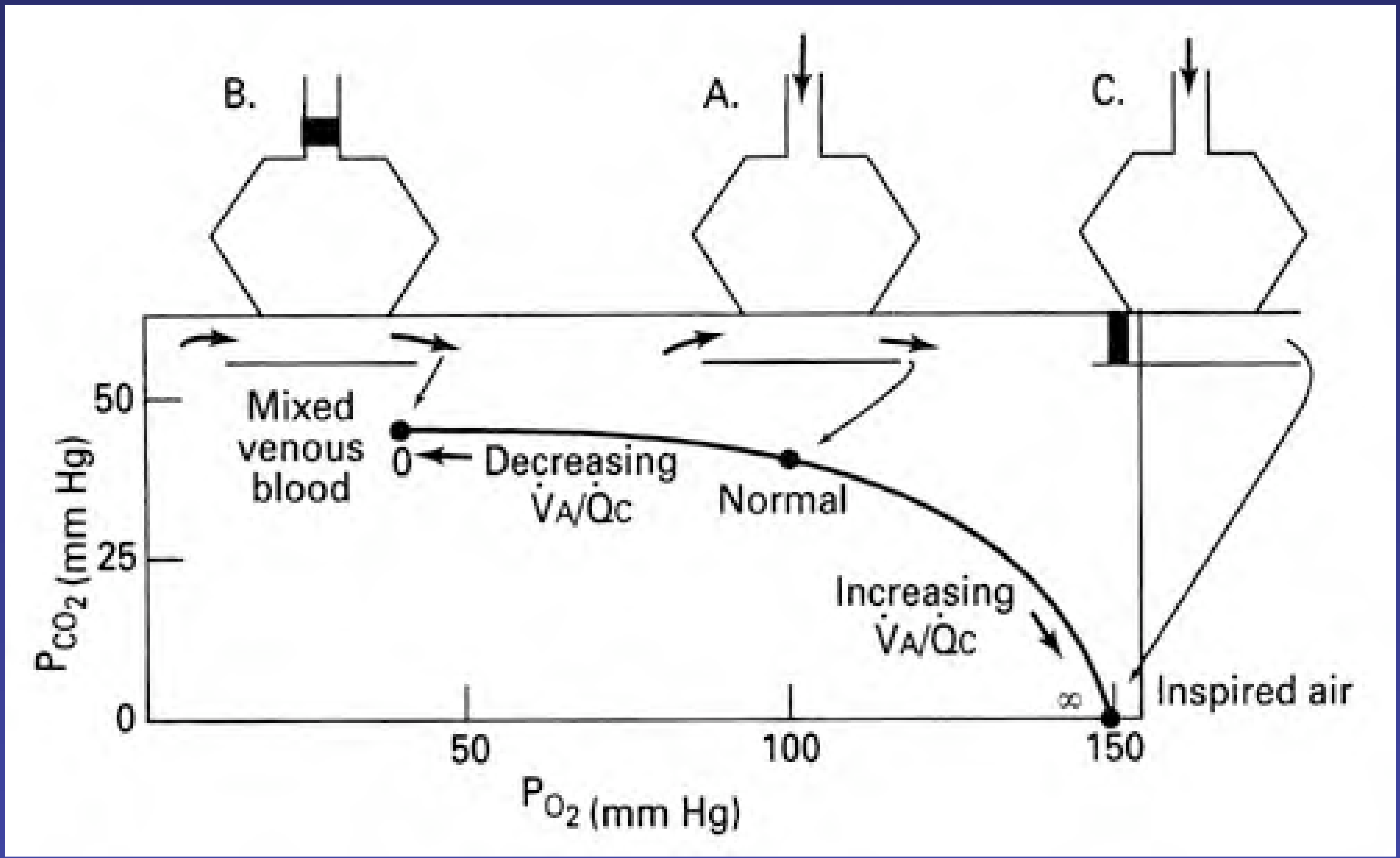
Effect of Changing V/Q Ratio on Alveolar PO2 and PCO2



Shunt **Dead Space**

Levitzky. Pulmonary Physiology, 6th ed. McGraw-Hill. 2003

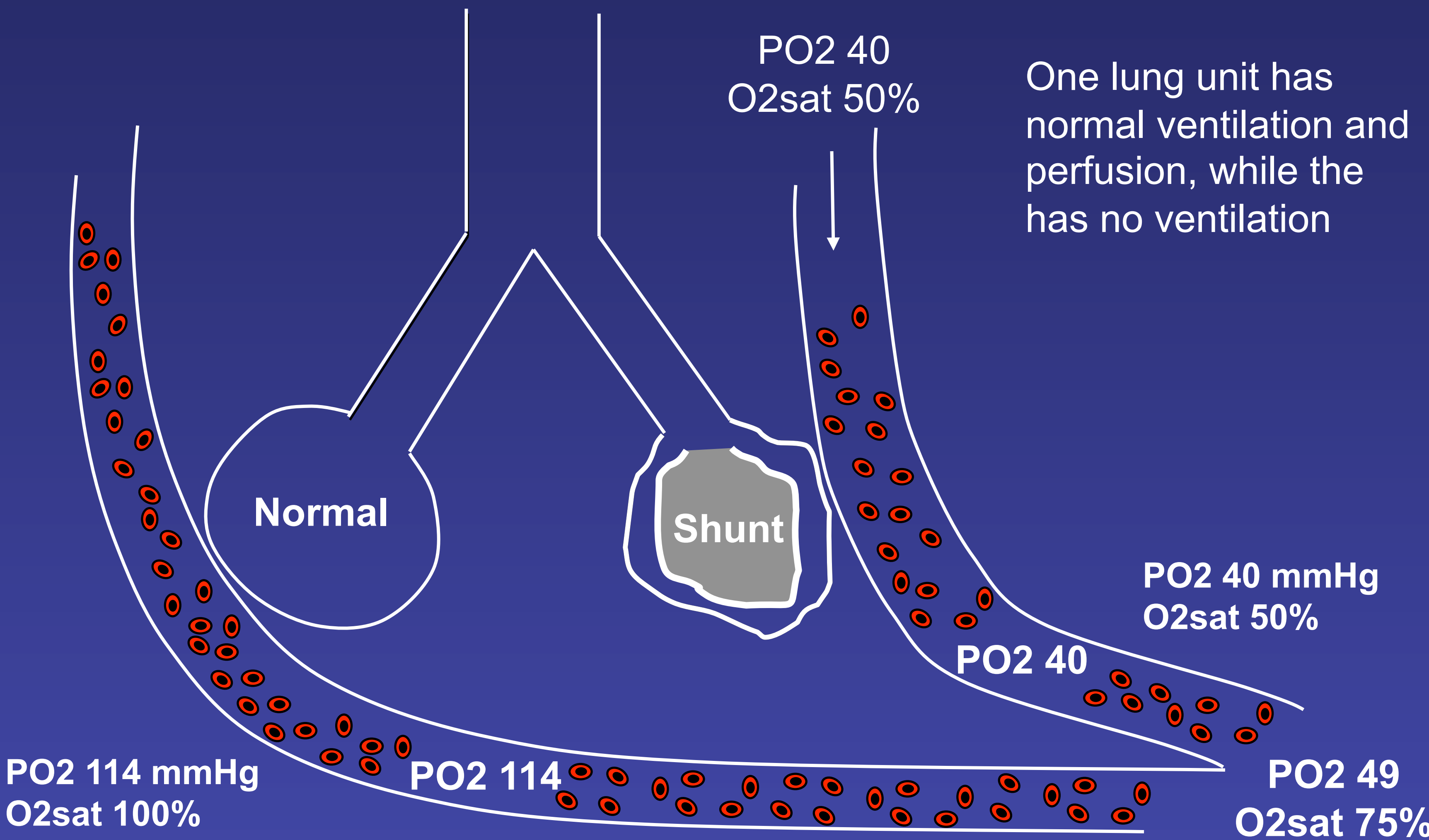
Effects of V/Q Relationships on Alveolar PO2 and PCO2



Levitzky. Pulmonary Physiology, 6th ed. McGraw-Hill. 2003

Shunt Physiology

One lung unit has normal ventilation and perfusion, while the has no ventilation



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Response to Breathing 100% Oxygen

- Alveolar hypoventilation or V/Q mismatch responds to 100% oxygen breathing.
- Nitrogen will be washed out of low ventilation lung units over time.
- PaO2 will rise to > 550 mmHg.
- Limited response to oxygen in shunt.
- Use this characteristic to diagnose shunt.

Shunt Calculation

- Qt x CaO2 = total volume of oxygen per time entering systemic arteries
  - Qt = total perfusion
  - Qs = shunt perfusion
  - CaO2, Cc'O2, CvO2 are oxygen contents of arterial, capillary and venous blood
- (Qt-Qs) x Cc'O2 = oxygen coming from normally functioning lung units
- Qs x CvO2 = oxygen coming from shunt blood flow

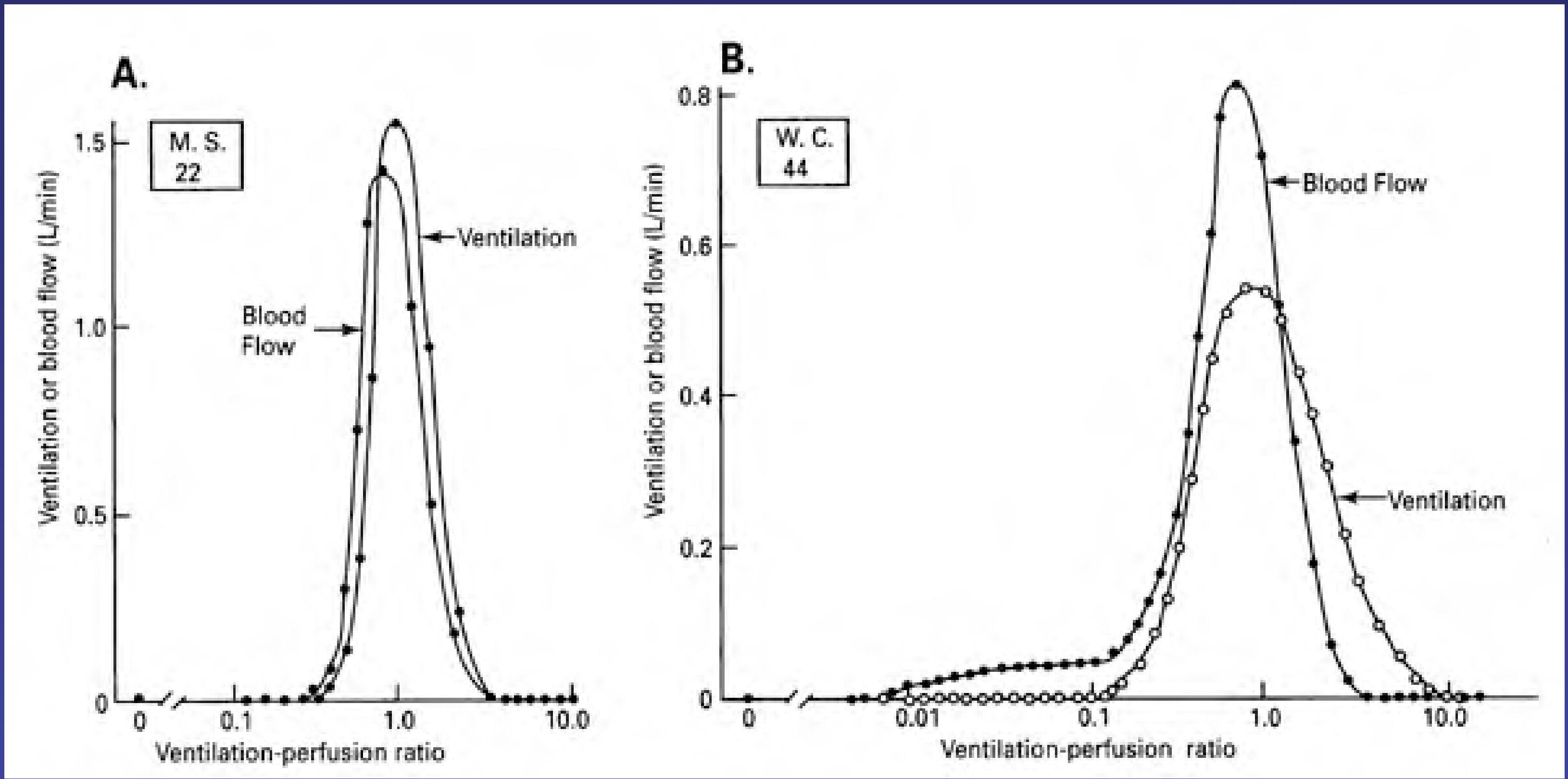
Causes of Shunt

- Physiologic shunts:
  - Bronchial veins, pleural veins
- Pathologic shunts:
  - Intracardiac
  - Intrapulmonary
    - Vascular malformations
    - Unventilated or collapsed alveoli

Detecting V/Q Mismatching and Shunt

- Radiotracer assessments of regional ventilation and perfusion.
- Multiple inert gas elimination.
  - Takes advantage of the fact that rate of elimination of a gas at any given V/Q ratio varies with its solubility.
- A-aO2 Gradient.

V/Q Relationships



Levitzky. Pulmonary Physiology, 6th ed. McGraw-Hill. 2003

Multiple Inert Gas Elimination

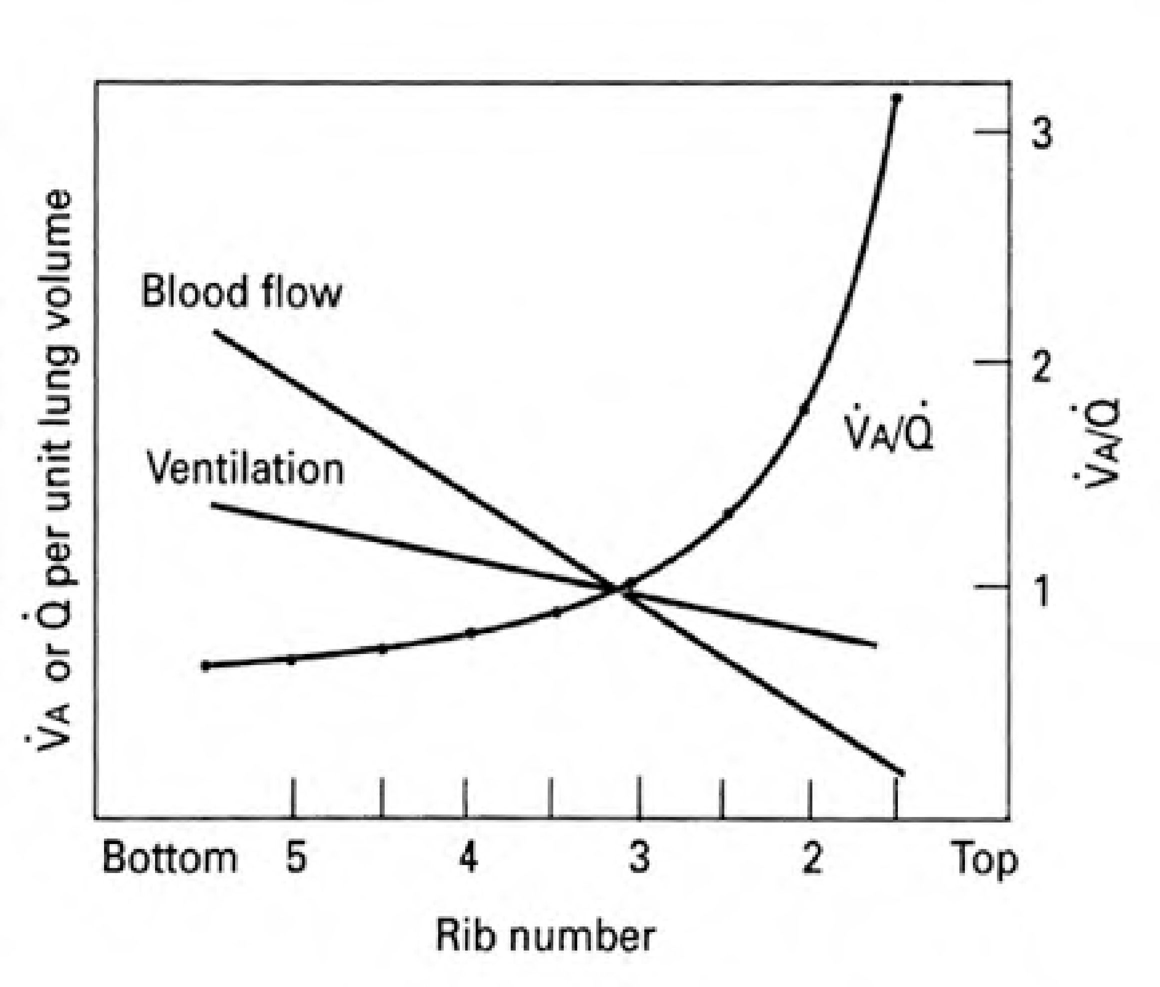
A-a O2 gradient

- In a totally efficient lung unit with matched V/Q, alveolar and capillary PO2 would be equal.
- Admixture of venous blood (or of blood from low V/Q lung units) will decrease the arterial PaO2, without effecting alveolar O2 (PAO2).
- Calculate the PAO2 using the alveolar gas equation, then subtract the arterial PaO2: $[(PiO_2) – (PaCO_2/R)]$ – PaO2.
- The A-a O2 gradient (or difference) is < 10-15 mmHg in normal subjects
  - Why is it not 0?

Apical and Basilar Alveoli in the Upright Posture

- Elastic recoil of the individual alveoli is similar throughout the normal lung.
- At end expiration (FRC) apical alveoli see more negative pressure and are larger than basilar alveoli.
- During inspiration, basilar alveoli undergo larger volume increase than apical alveoli.
- Thus at rest there is more ventilation at the base than the apex.
- Also More Perfusion to Lung Bases Due to Gravity.

Effects of Gravity on Ventilation and Perfusion



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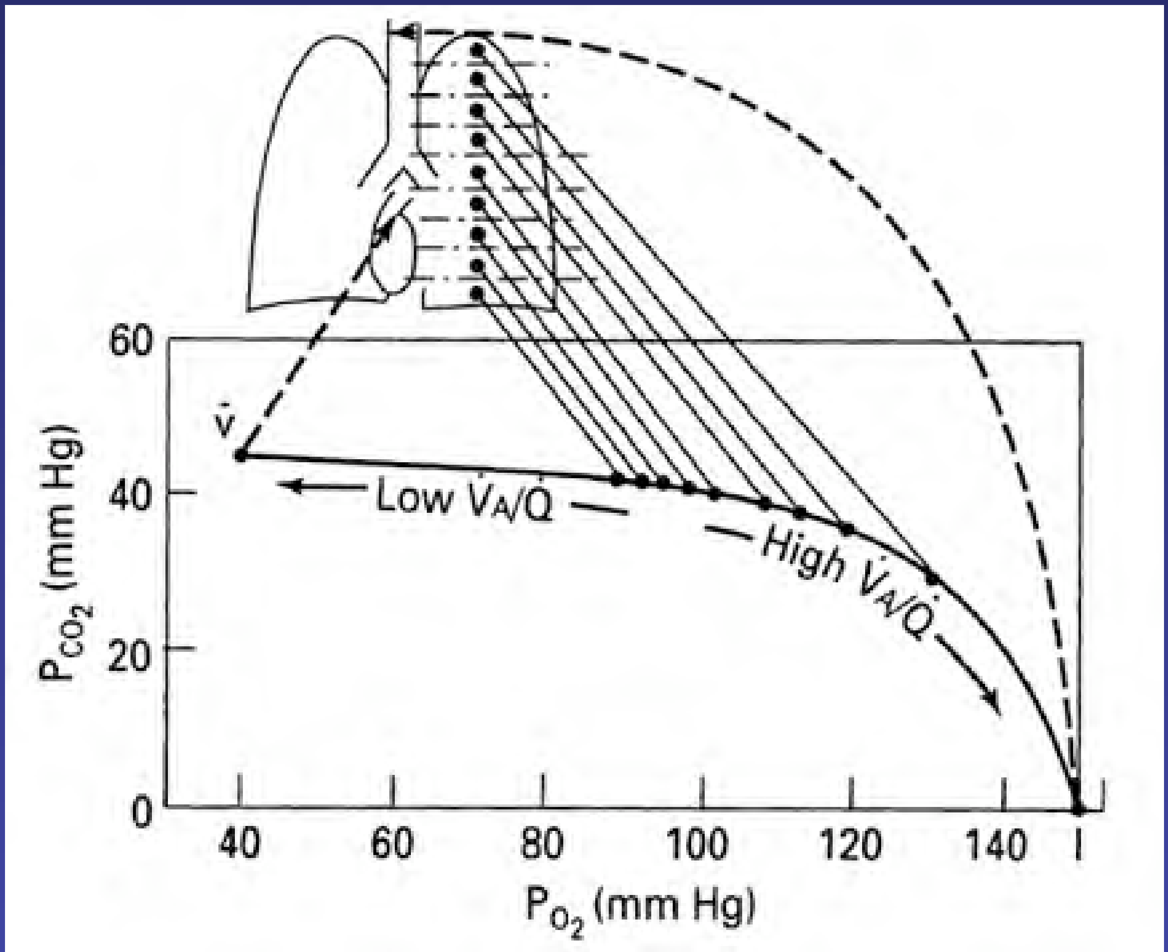
Effects of Gravity on Ventilation and Perfusion Matching



PD-INEL Levitzky. Pulmonary Physiology, 6th ed. McGraw-Hill. 2003

Causes of Abnormal Oxygenation

- Hypoventilation
- V/Q mismatch
- Shunt
- Diffusion block

Key Concepts:

- Ventilation and Perfusion must be matched at the alveolar capillary level.
- V/Q ratios close to 1.0 result in alveolar PO2 close to 100 mmHg and PCO2 close to 40 mmHg.
- V/Q greater than 1.0 increase PO2 and Decrease PCO2. V/Q less than 1.0 decrease PO2 and Increase PCO2.
- Shunt and Dead Space are Extremes of V/Q mismatching.
- A-a Gradient of 10-15 Results from gravitational effects on V/Q and Physiologic Shunt.

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