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Ventilation/Perfusion Matching

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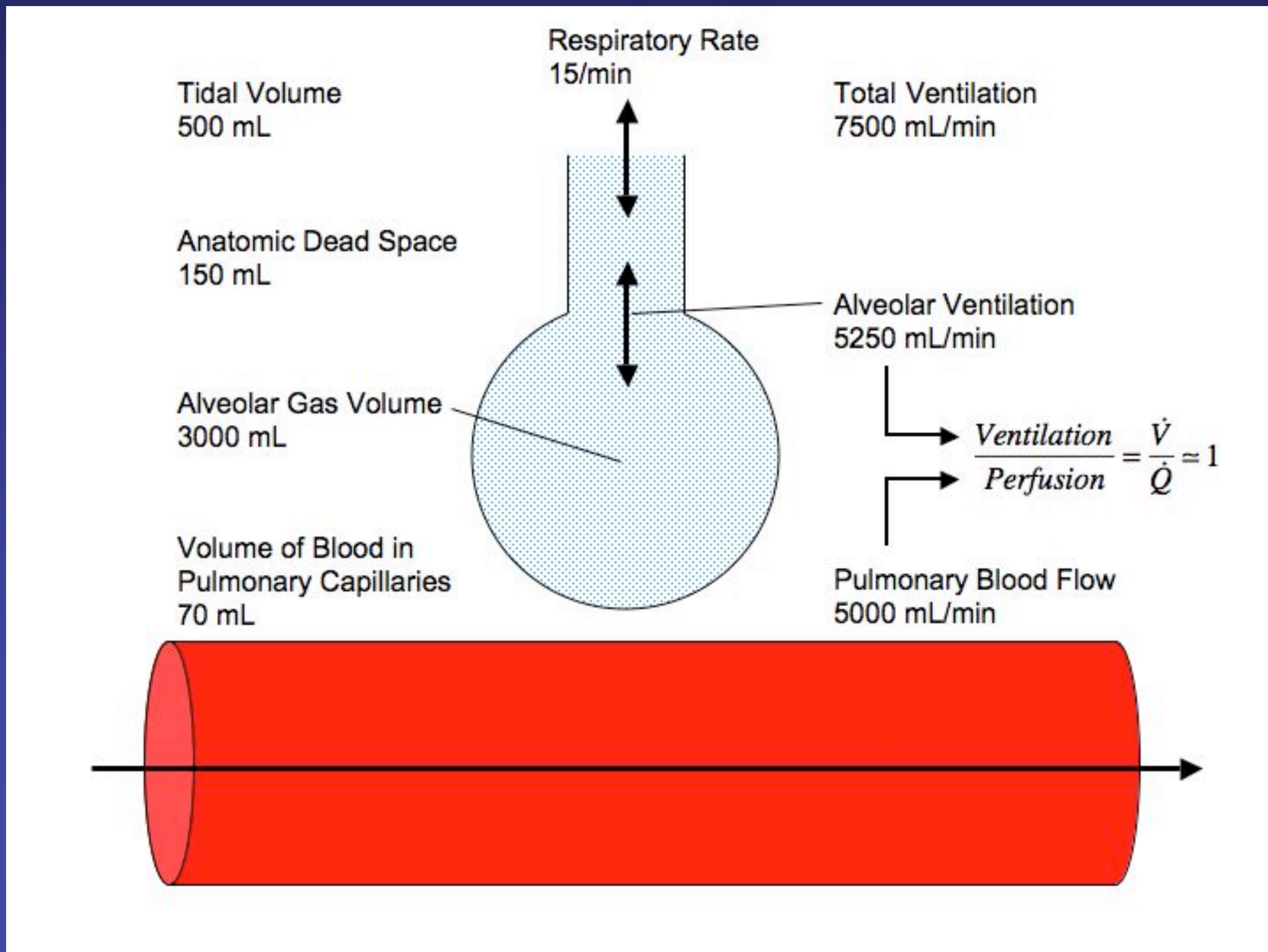
Objectives

- 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

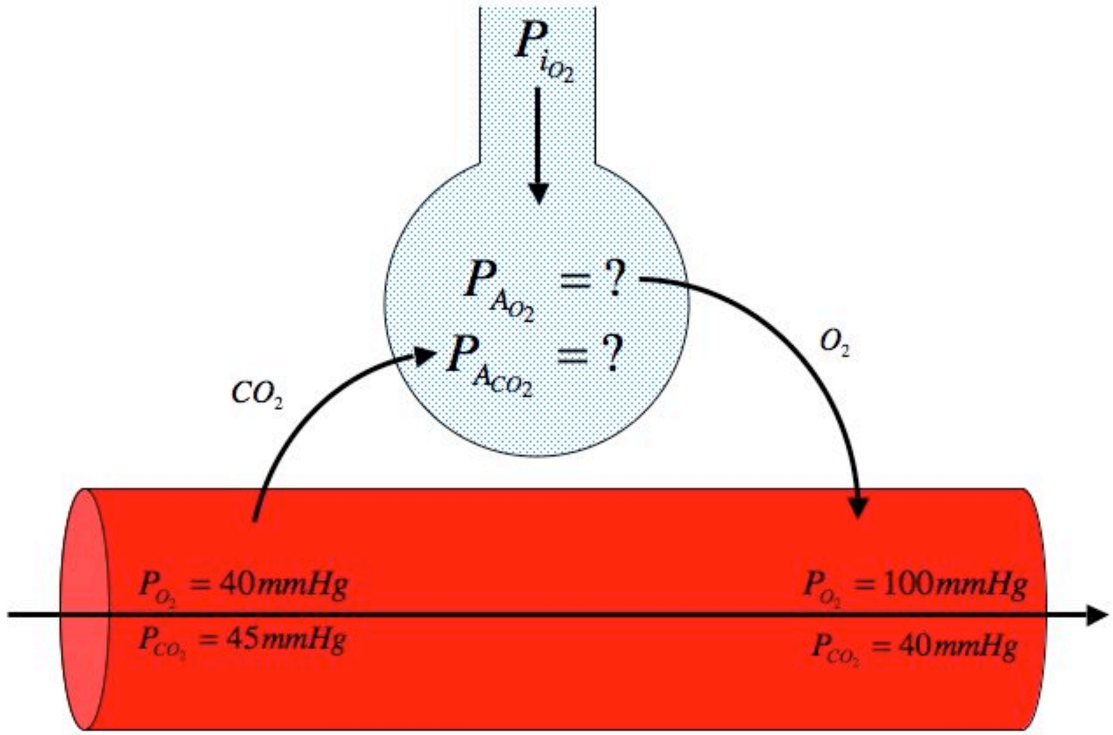
Ventilation and Perfusion at the Level of the Whole Lung



Gas Composition in the Alveolar Space

Trachea: partial pressure of CO2 is approximately 0

PiO2 = (barometric pressure-H2O vapor pressure)xFiO2
= (760 – 47) x 0.21 =150 mmHg



In the alveolar space, oxygen diffuses into the blood and CO2 diffuses into the alveolus from the blood.

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:

$PAO_2 = 150 – 40/0.8 = 100$ mmHg

Gas Composition in the Normal Alveolar Space

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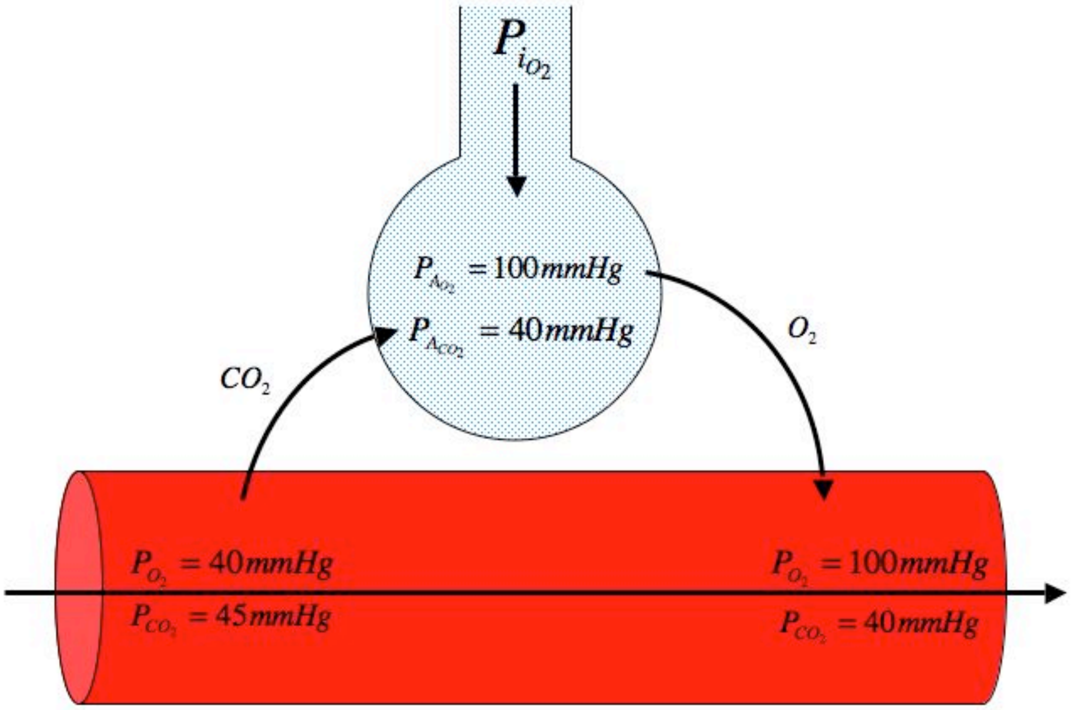
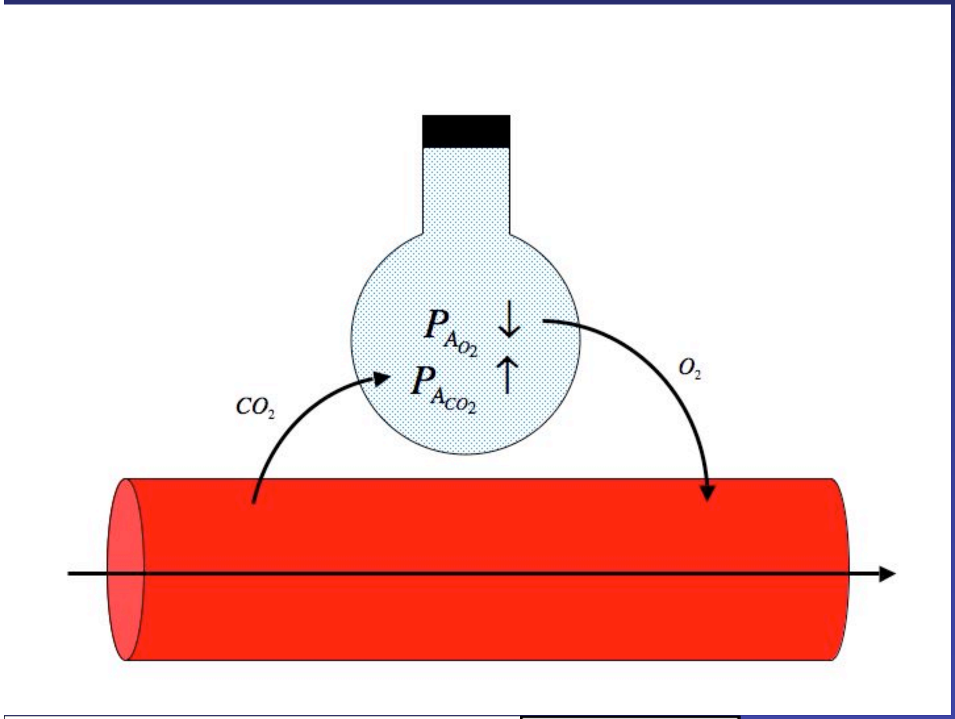
= (760 – 47) x 0.21 =150 mmHg



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

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

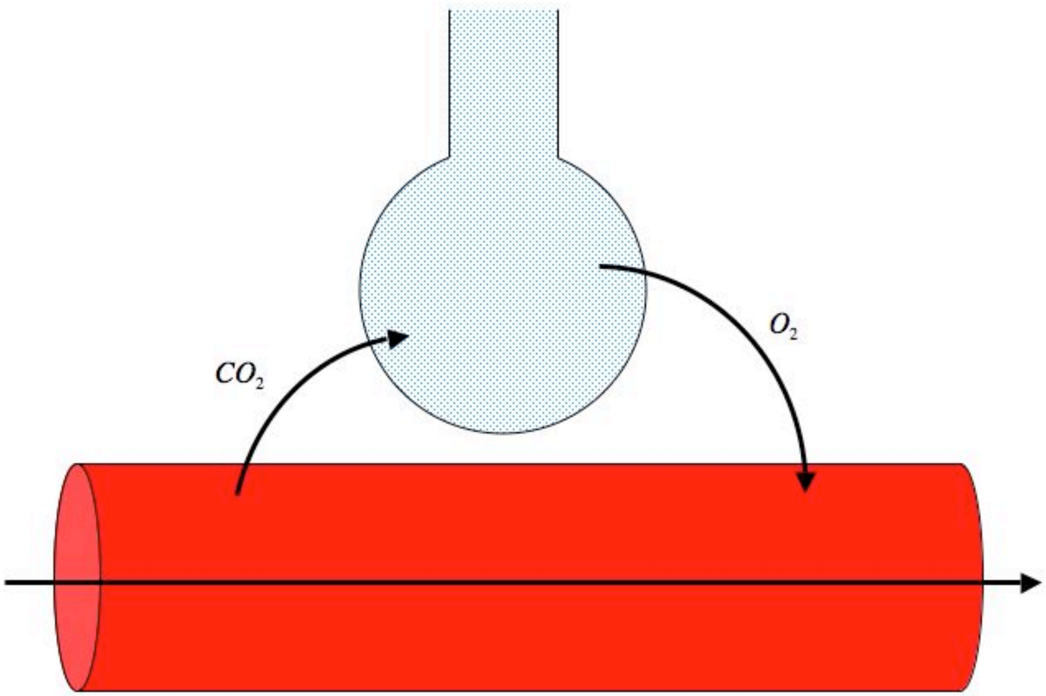
- PaCO2 is:
  - directly related to CO2 production (tissue metabolism).
  - Inversely related to alveolar ventilation.
- Increased PaCO2 (hypercarbia) is always a reflection of inadequate alveolar ventilation (VA).

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

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.

V/Q Matching

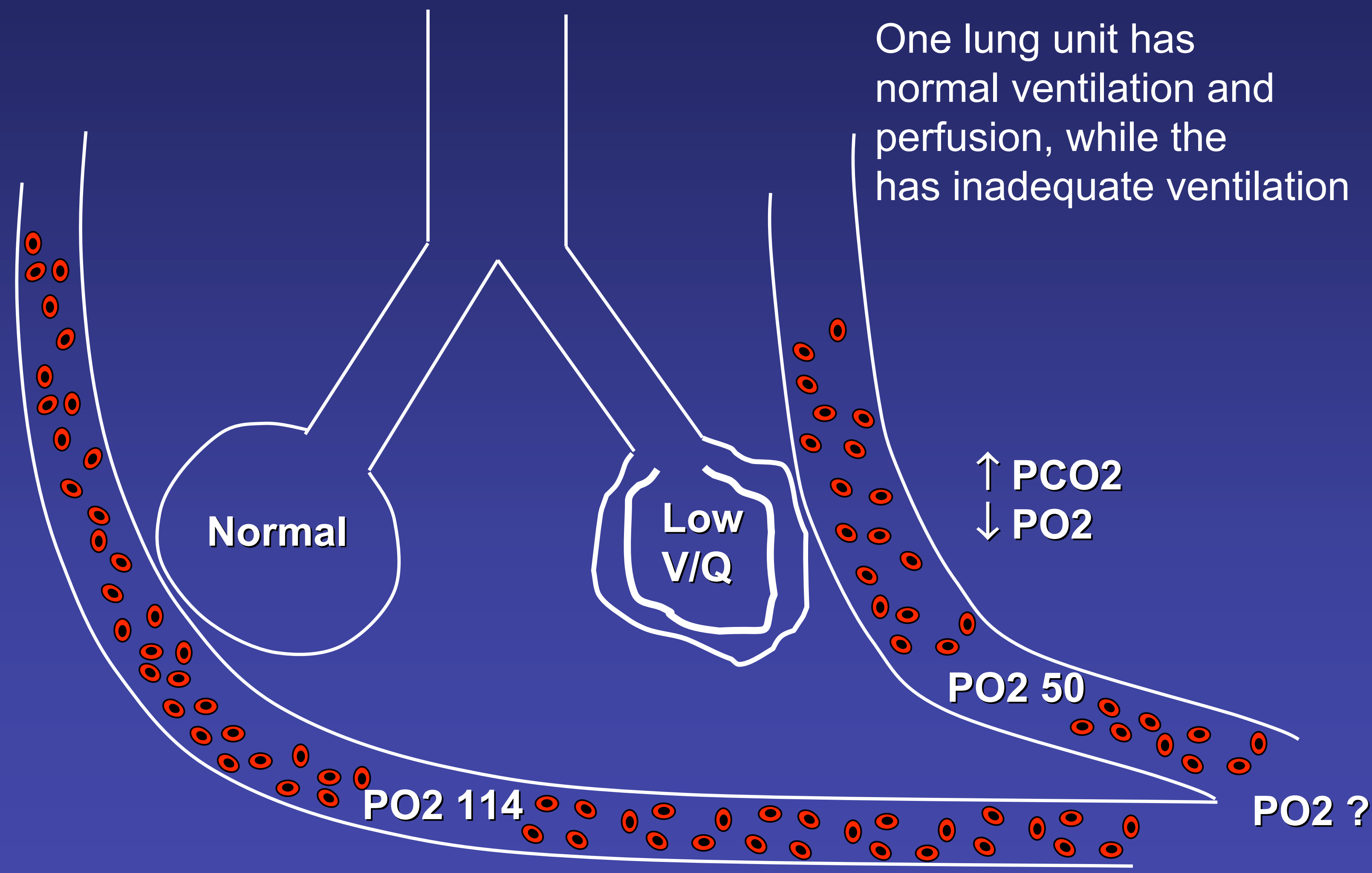
- 300 million alveoli.
- Different alveoli may have widely differing amounts of ventilation and of perfusion.
- Key for normal gas exchange is to have matching of ventilation and perfusion for each alveolar unit
  - Alveoli with increased perfusion also have increased ventilation
  - Alveoli with decreased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

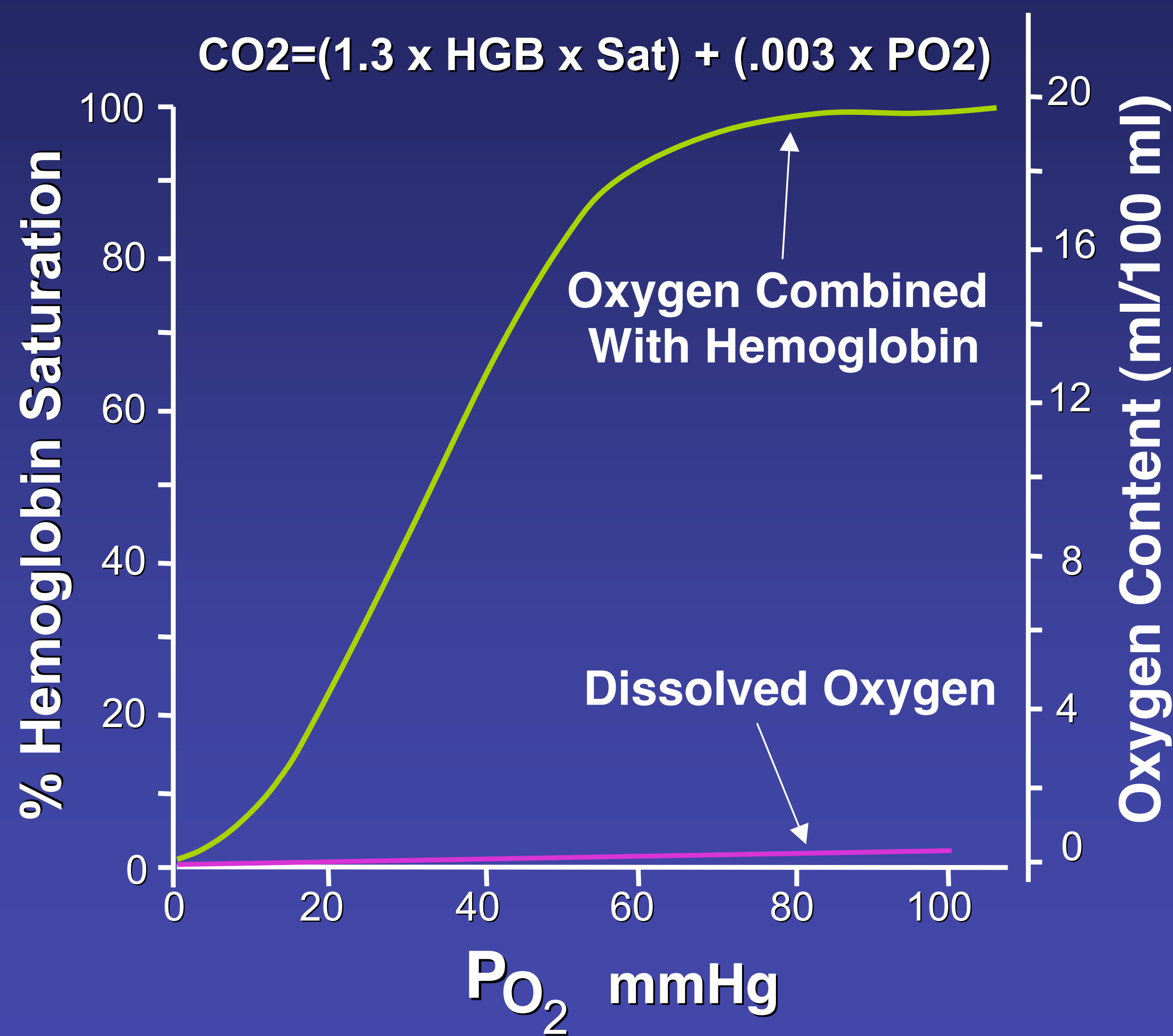
One lung unit has normal ventilation and perfusion, while the has inadequate ventilation



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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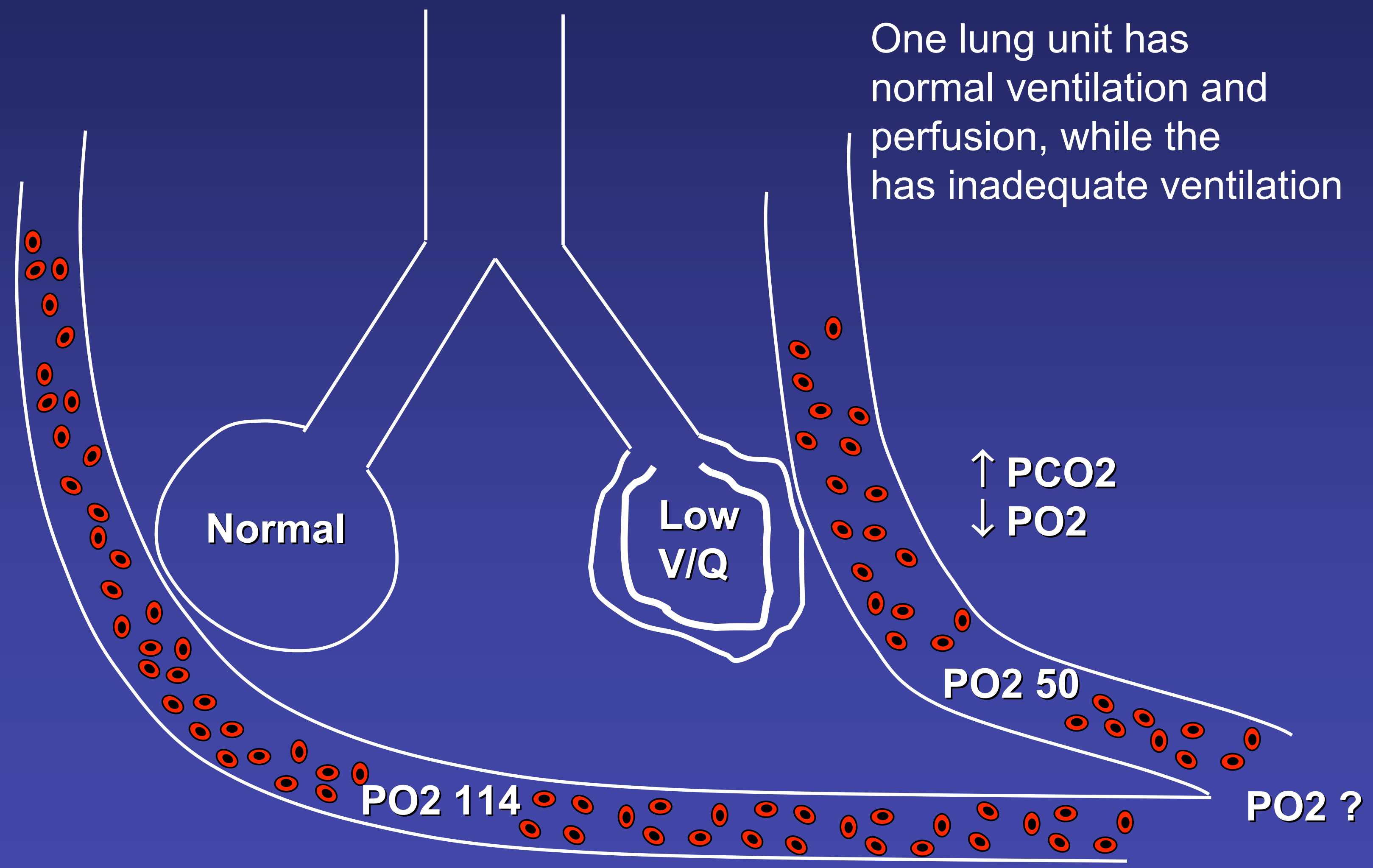
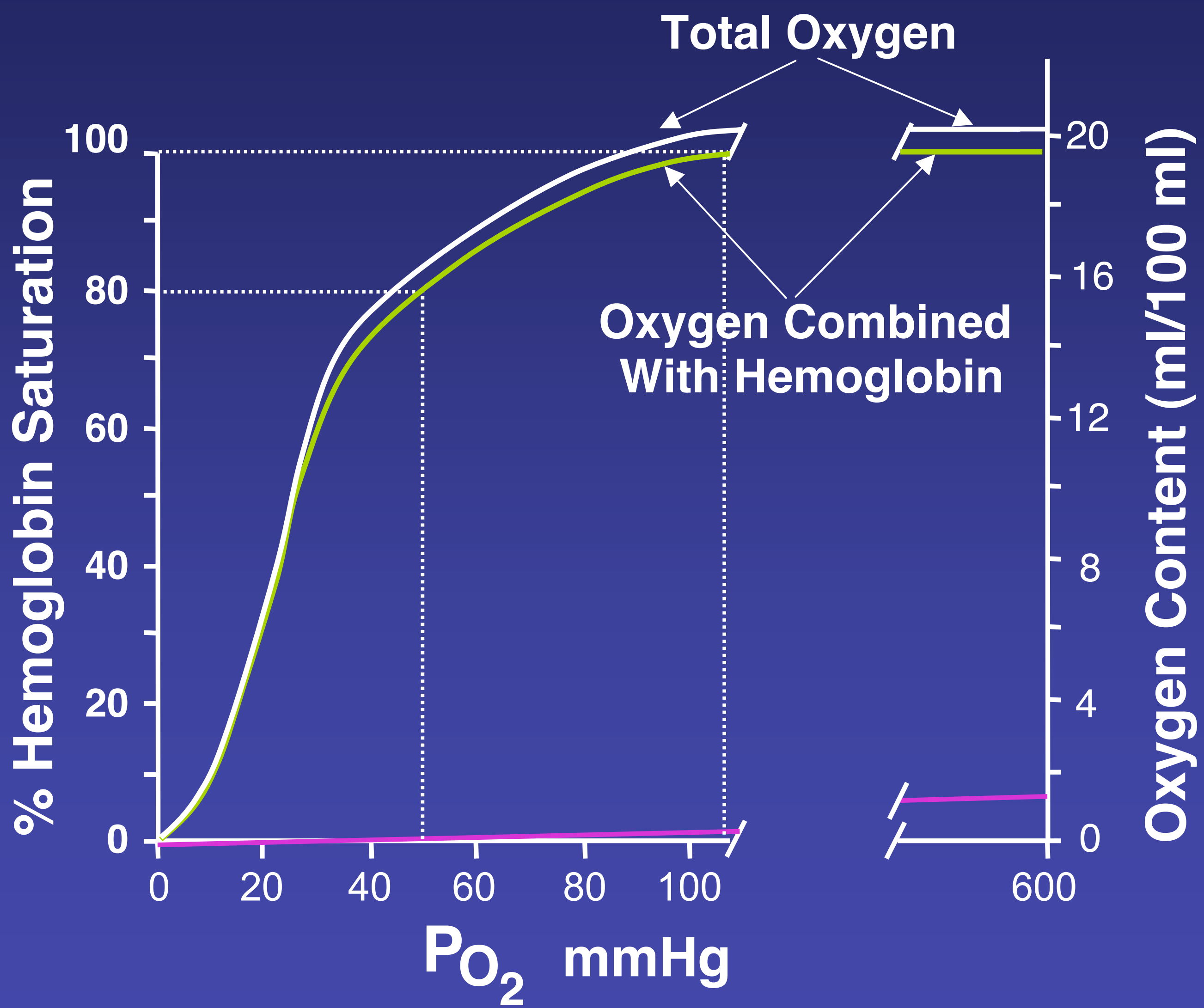


Oxyhemoglobin Dissociation Curve and O2 Content



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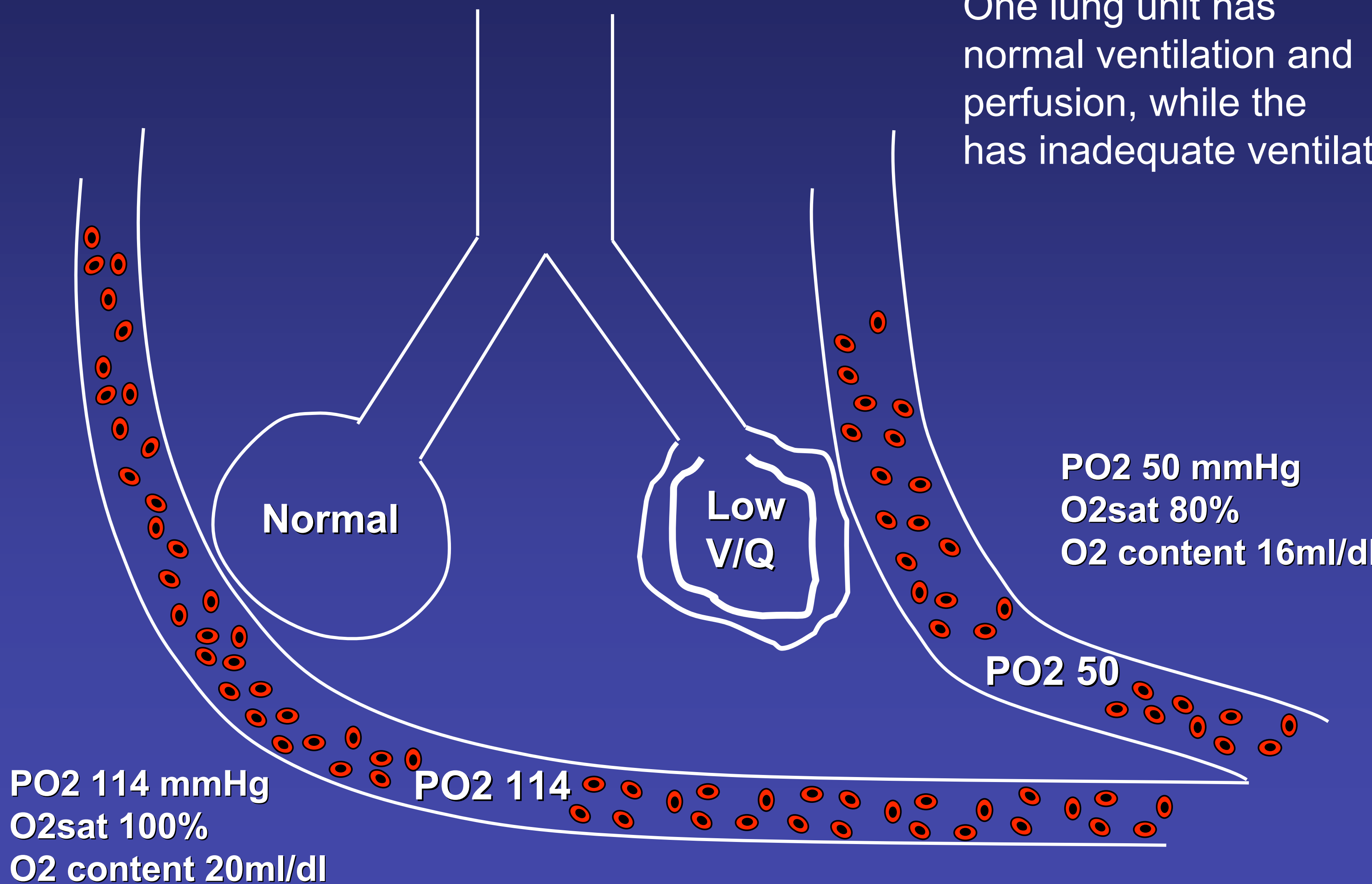

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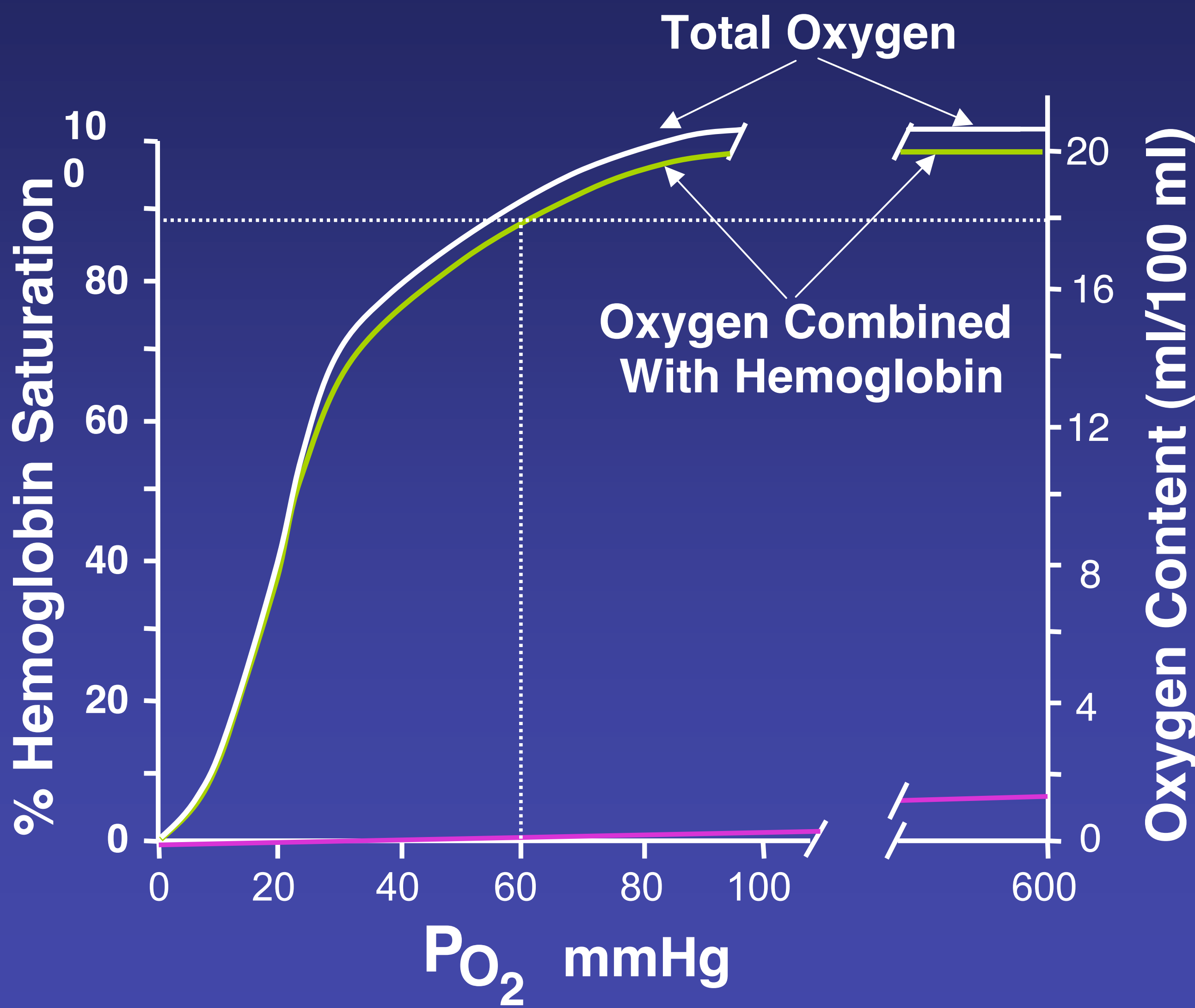

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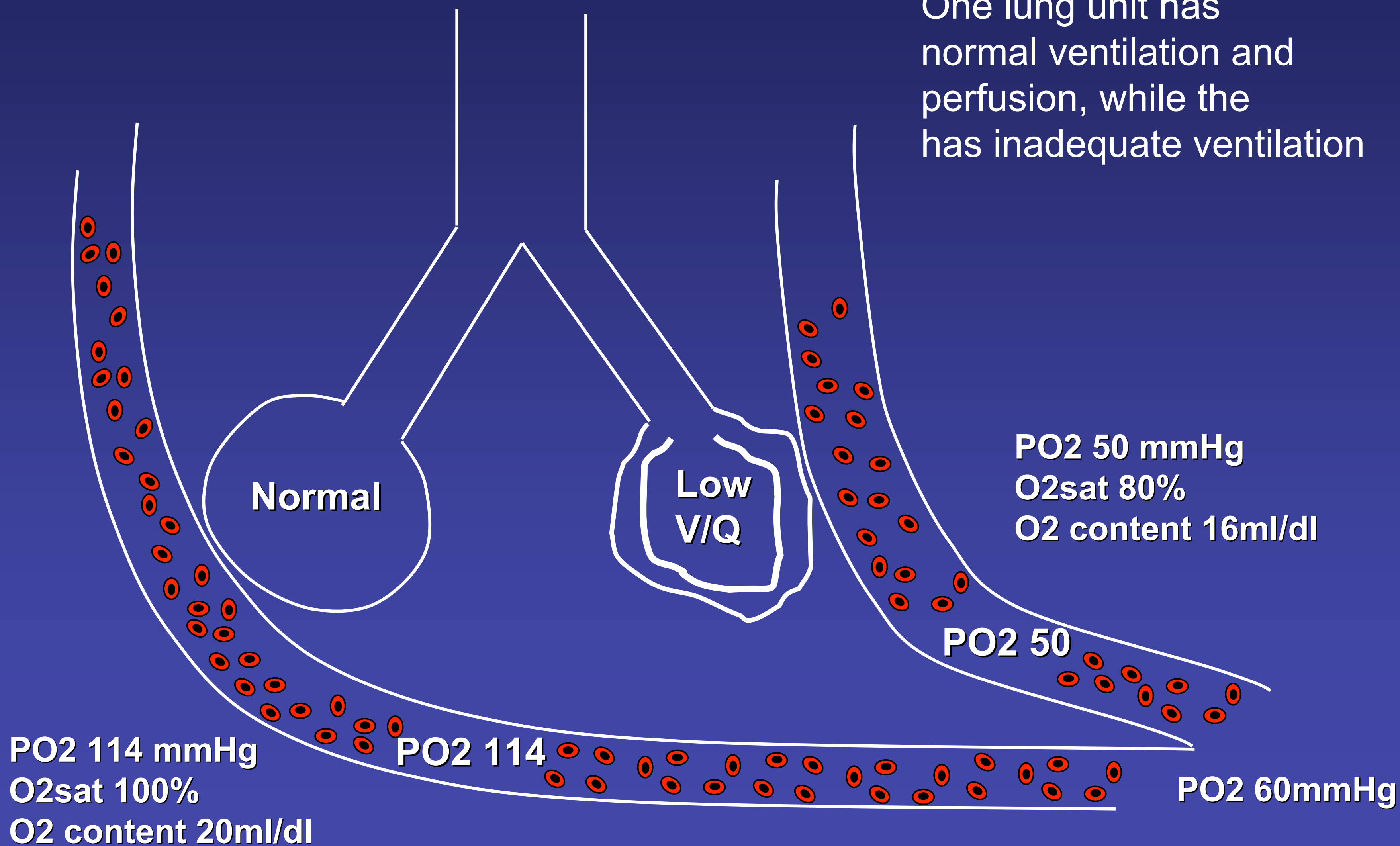
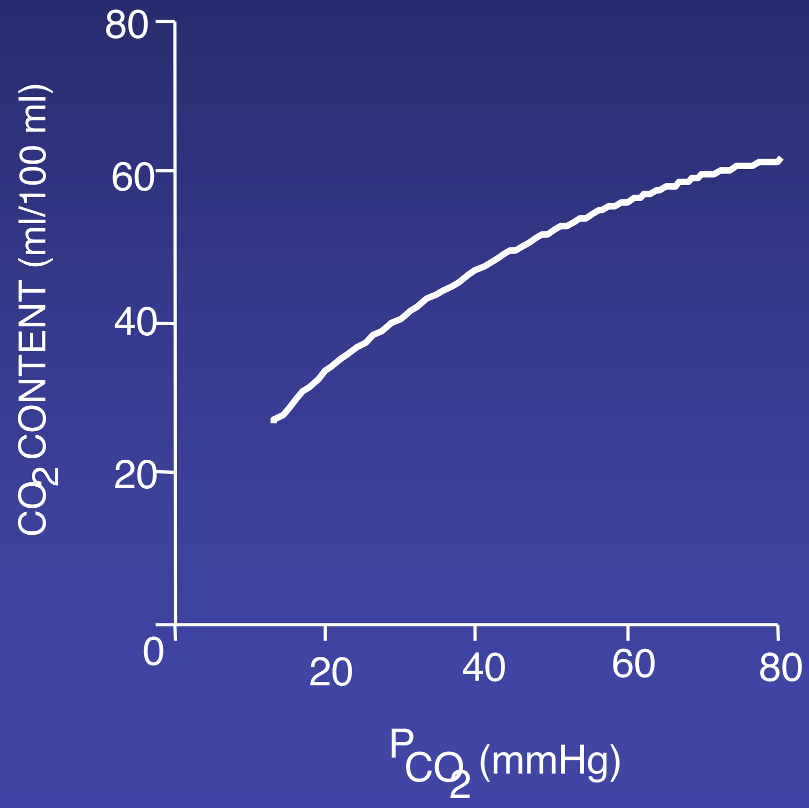


PCO2 in V/Q Mismatch

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



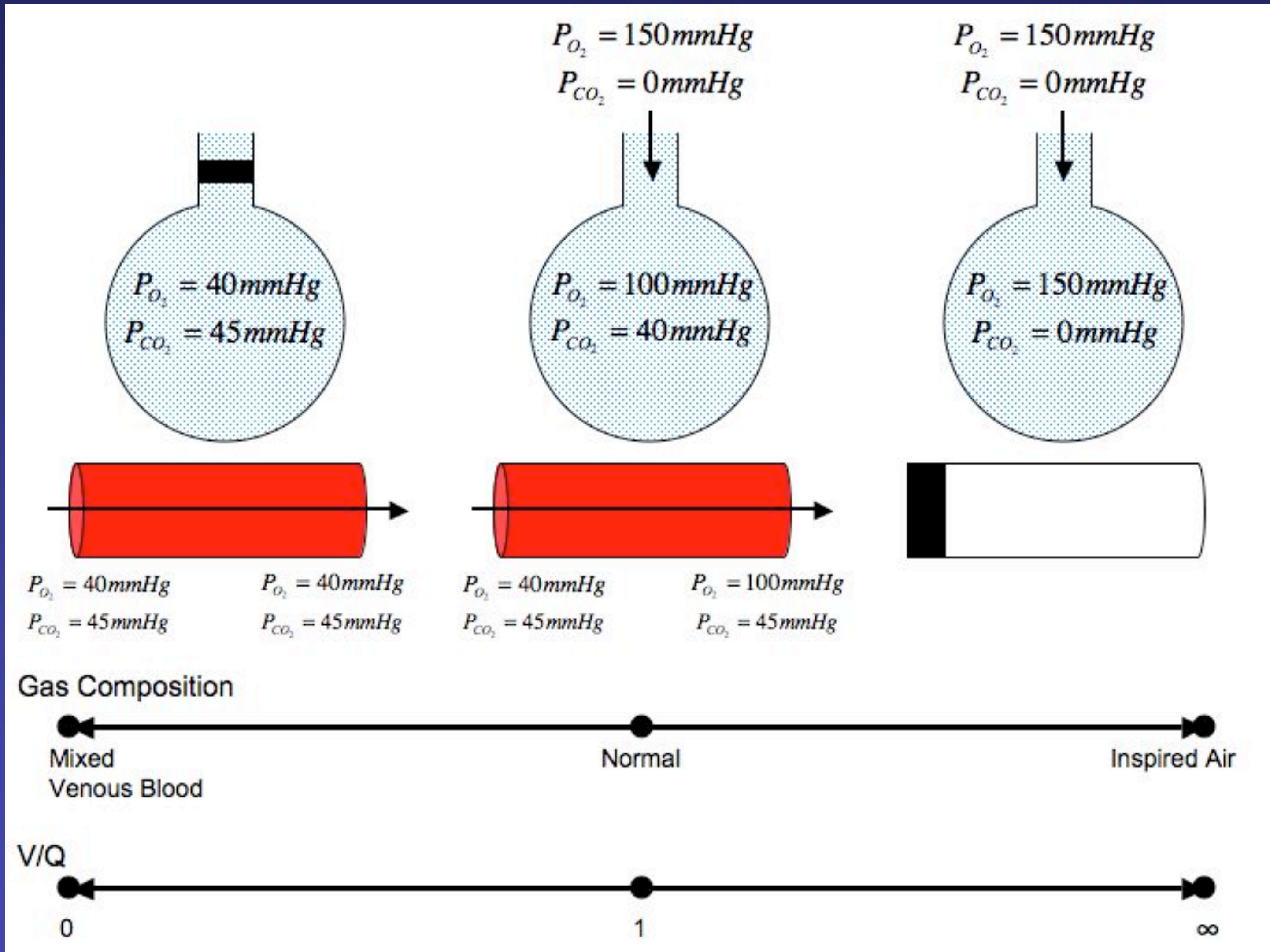
Extremes of V/Q Inequality

- 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

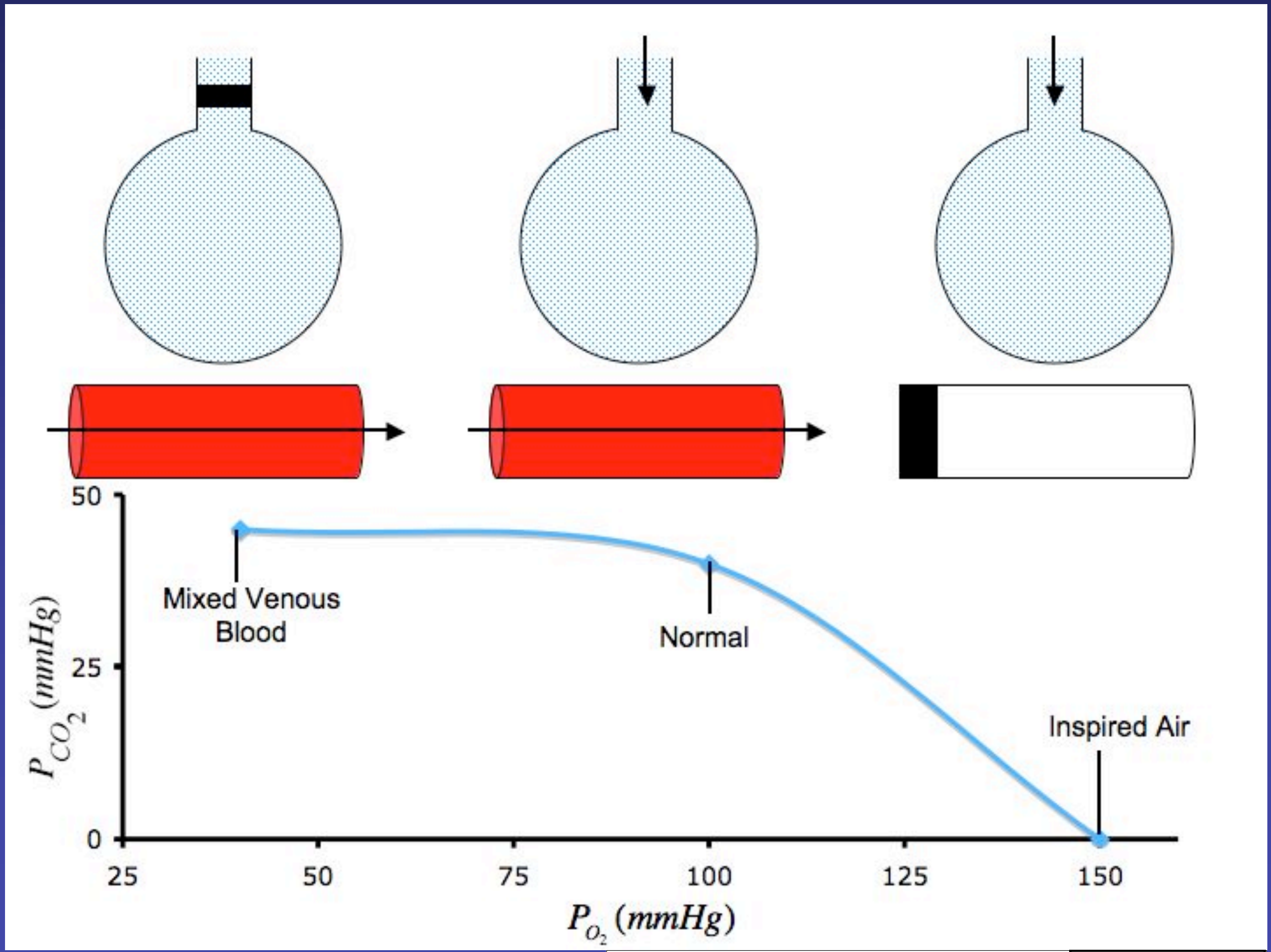
Effect of Changing V/Q Ratio on Alveolar PO2 and PCO2

Shunt



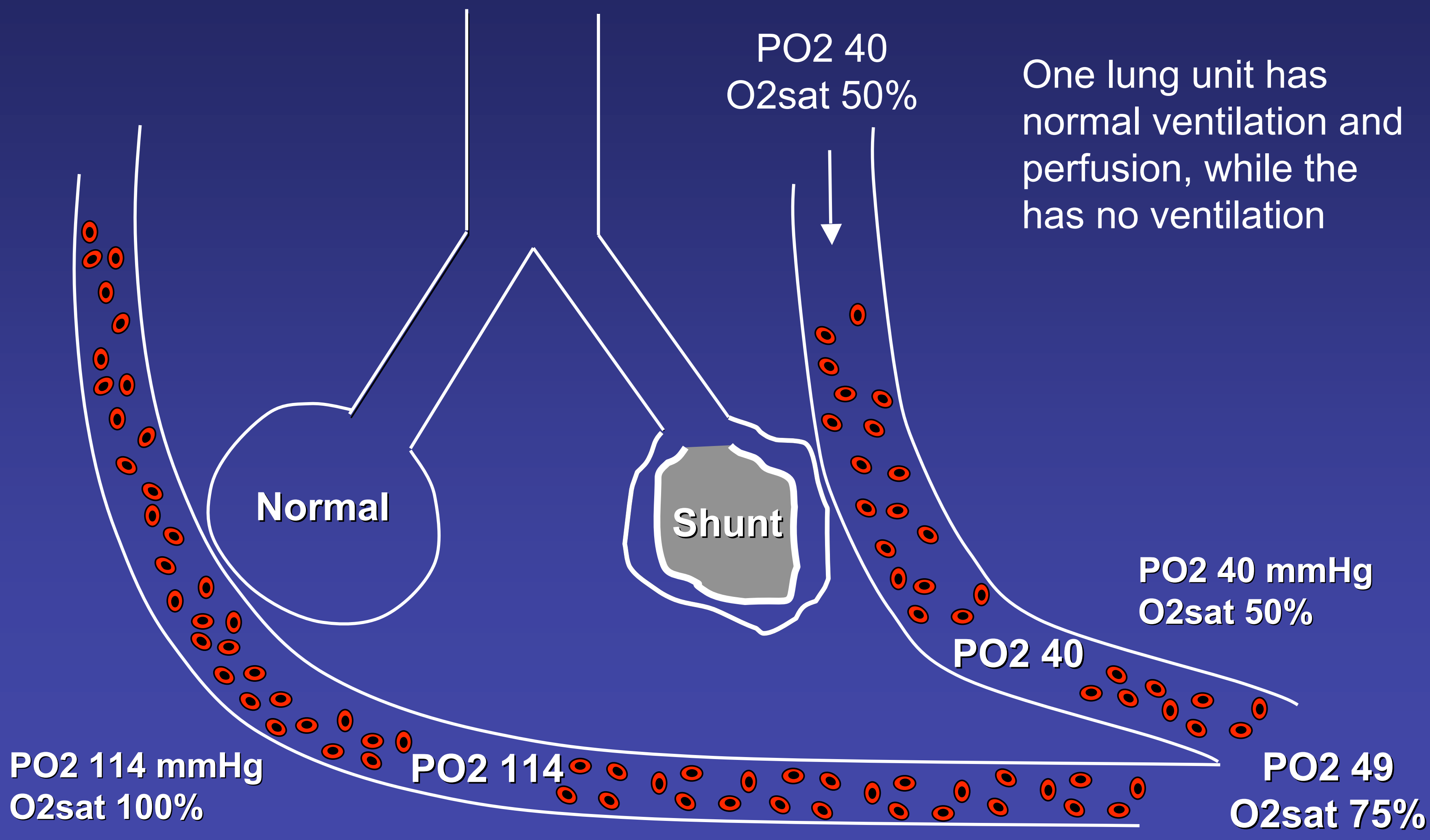
Dead Space

Effects of V/Q Relationships on Alveolar PO2 and PCO2



Shunt Physiology

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



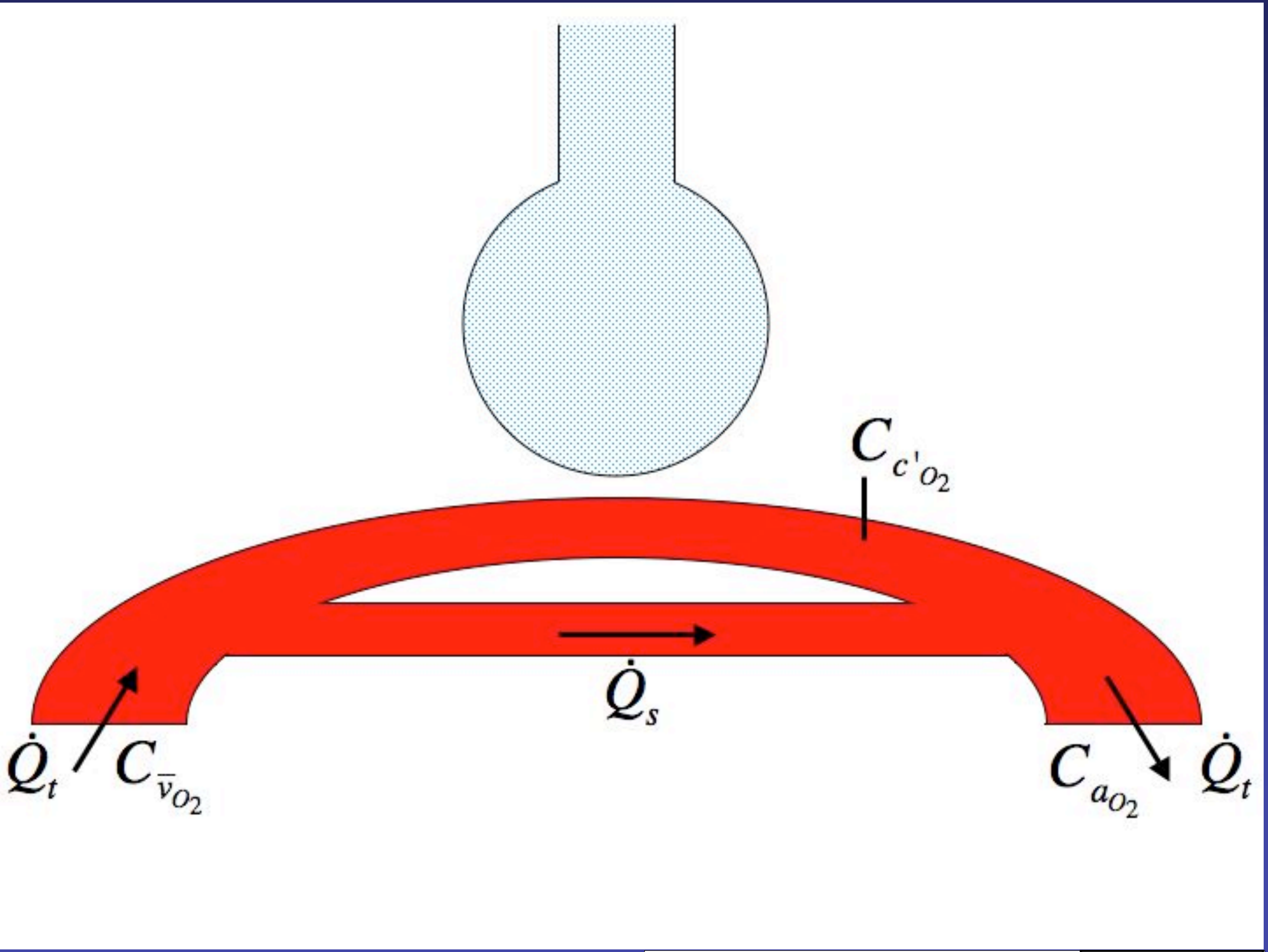
Response to Breathing 100% Oxygen

- 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

- $Qt \times CaO2$ = 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
- $(Qt-Qs) \times Cc'O2$ = oxygen coming from normally functioning lung units
- $Qs \times CvO2$ = oxygen coming from shunt blood flow

Shunt



Shunt Equation

Qt* x *CaO2 = [(Qt – Qs)* x *CcO2] + [Qs x CvO2]

$$\frac{Qs}{Qt} = \frac{Cc'O2 - CaO2}{Cc'O2 - CvO2}$$

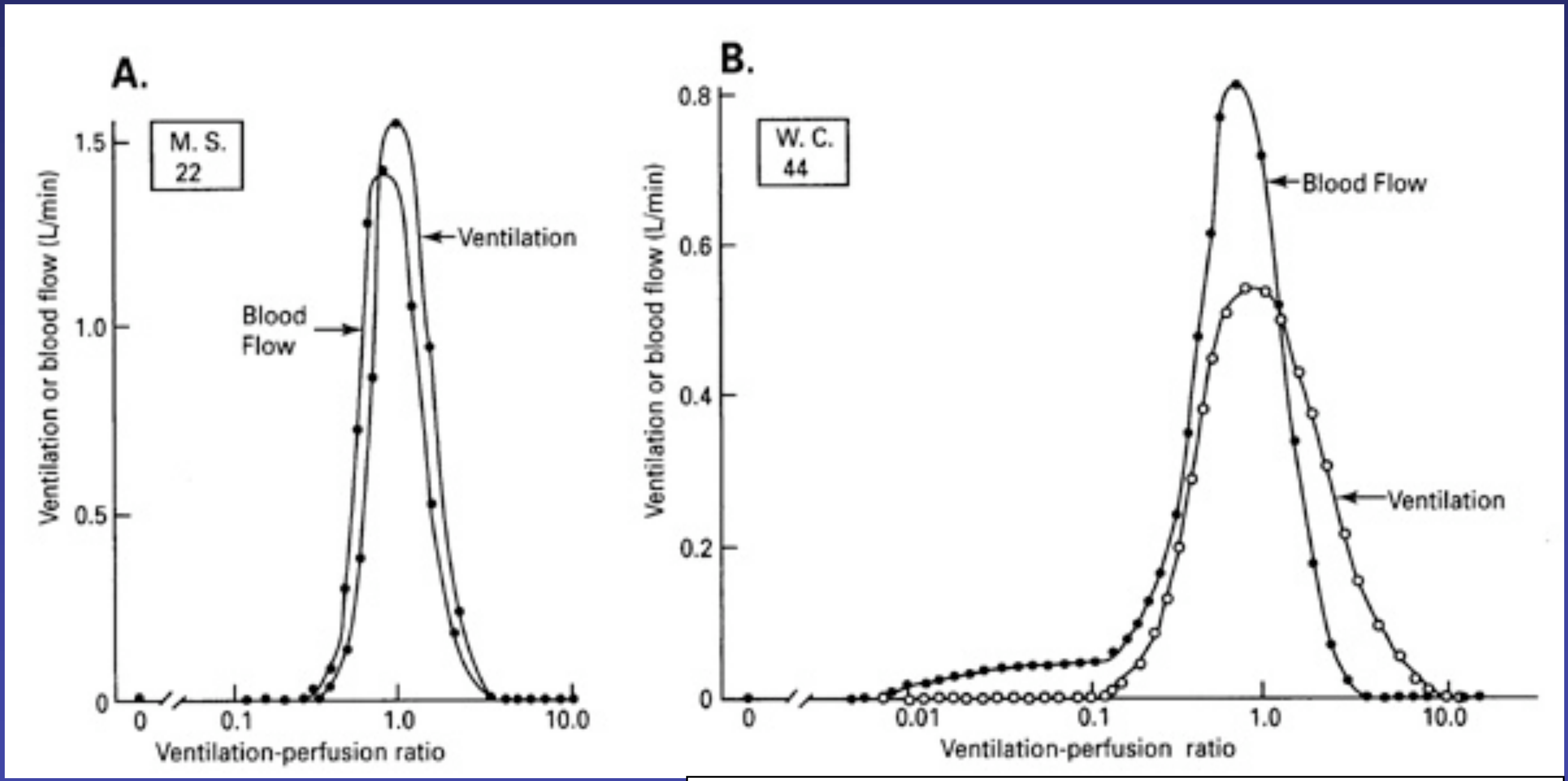
Causes of Shunt

- 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



Source: *Pulmonary Physiology*, The McGraw-Hill Companies, Inc., 2007

Multiple Inert Gas Elimination

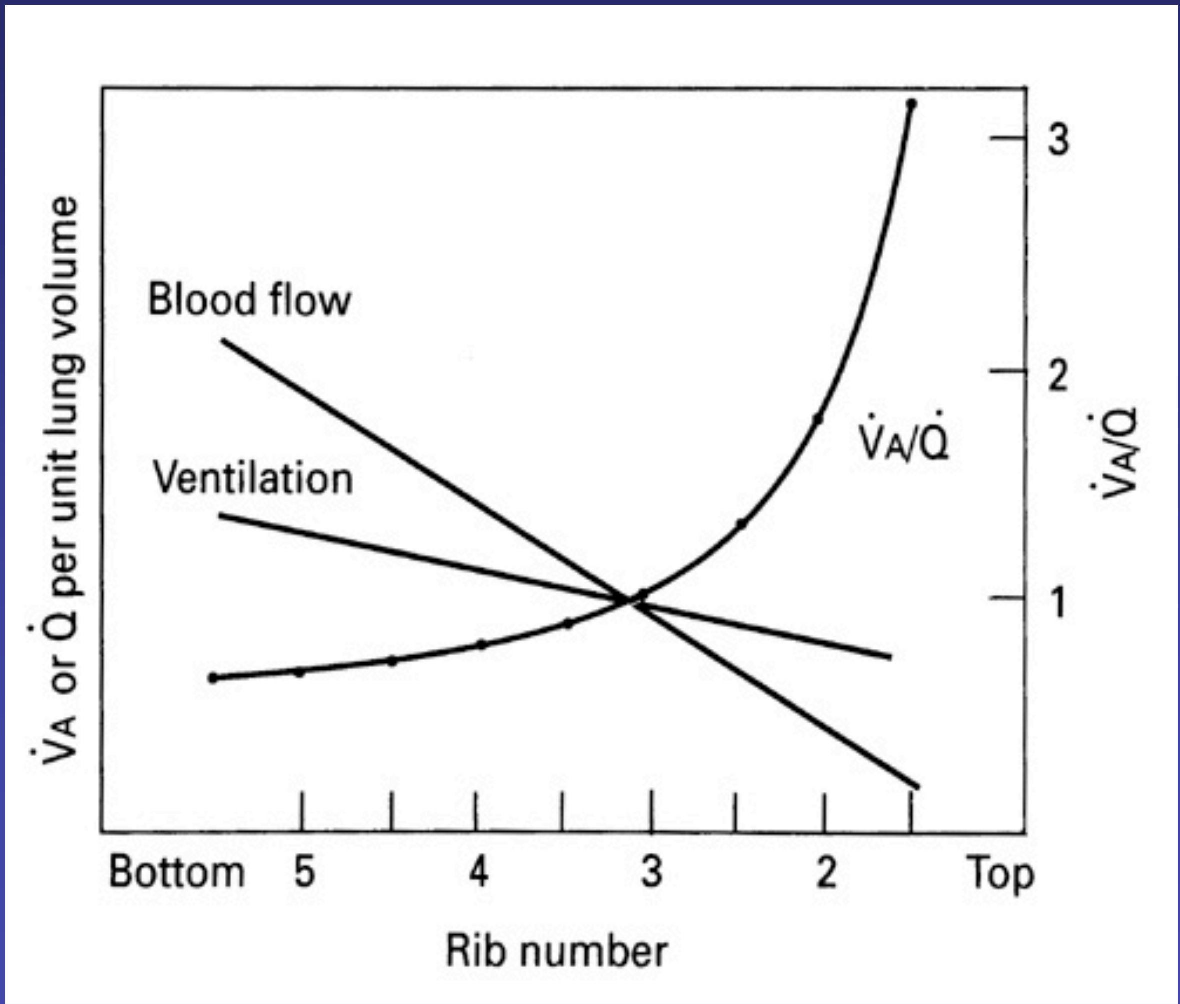
A-a O2 gradient

- 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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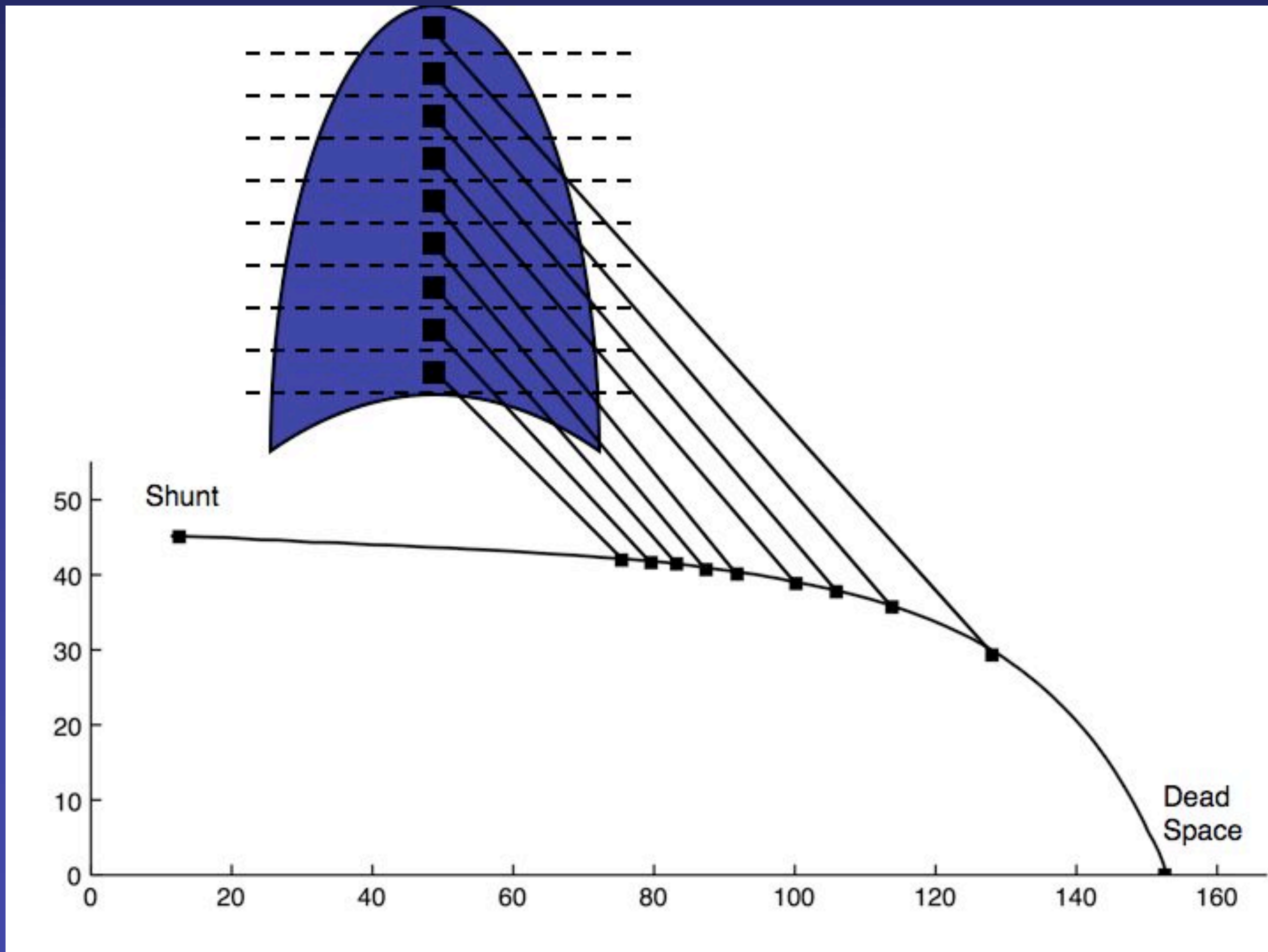
Effects of Gravity on Ventilation and Perfusion Matching



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.