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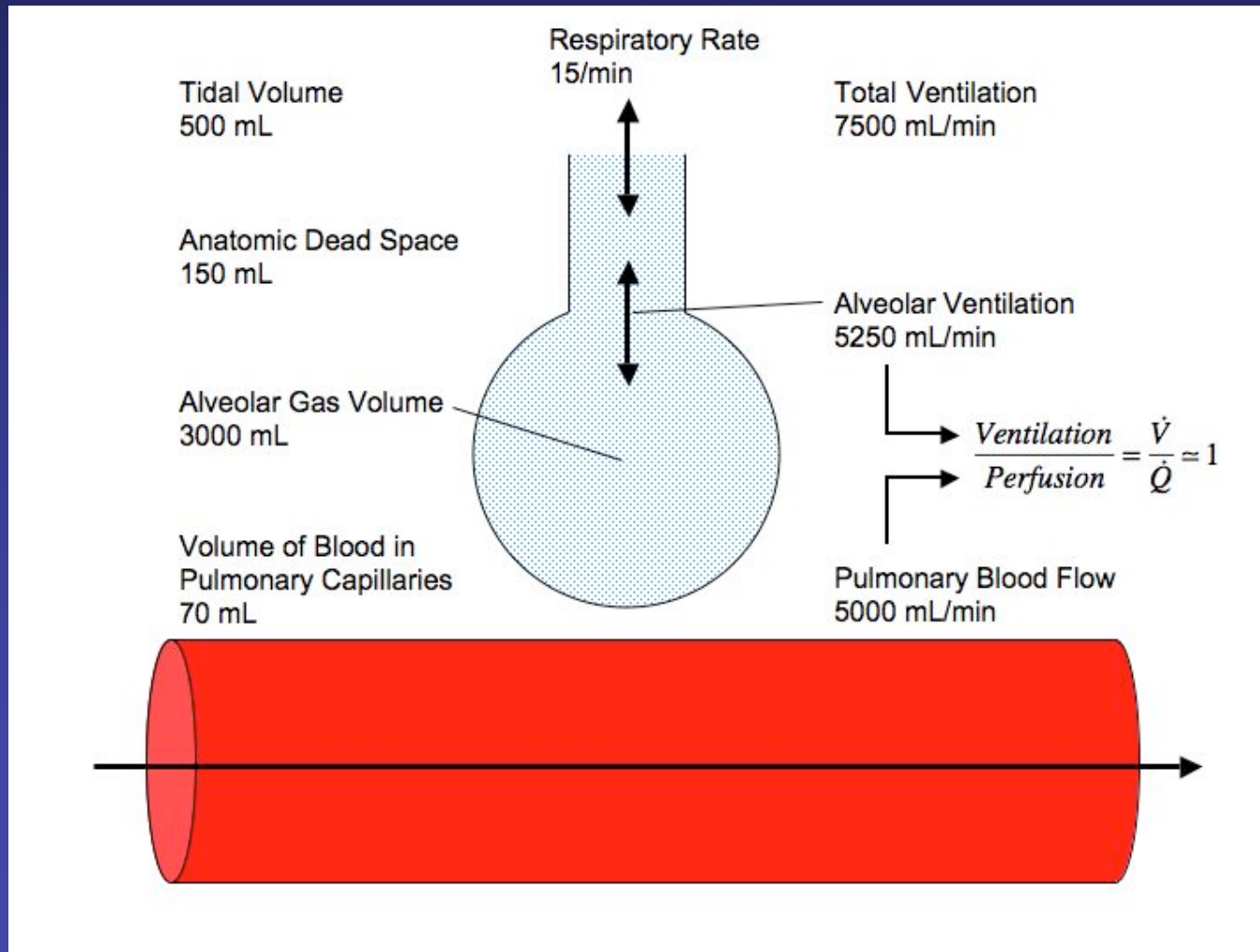
# **Ventilation/Perfusion Matching**

Thomas H. Sisson, M.D.

# 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

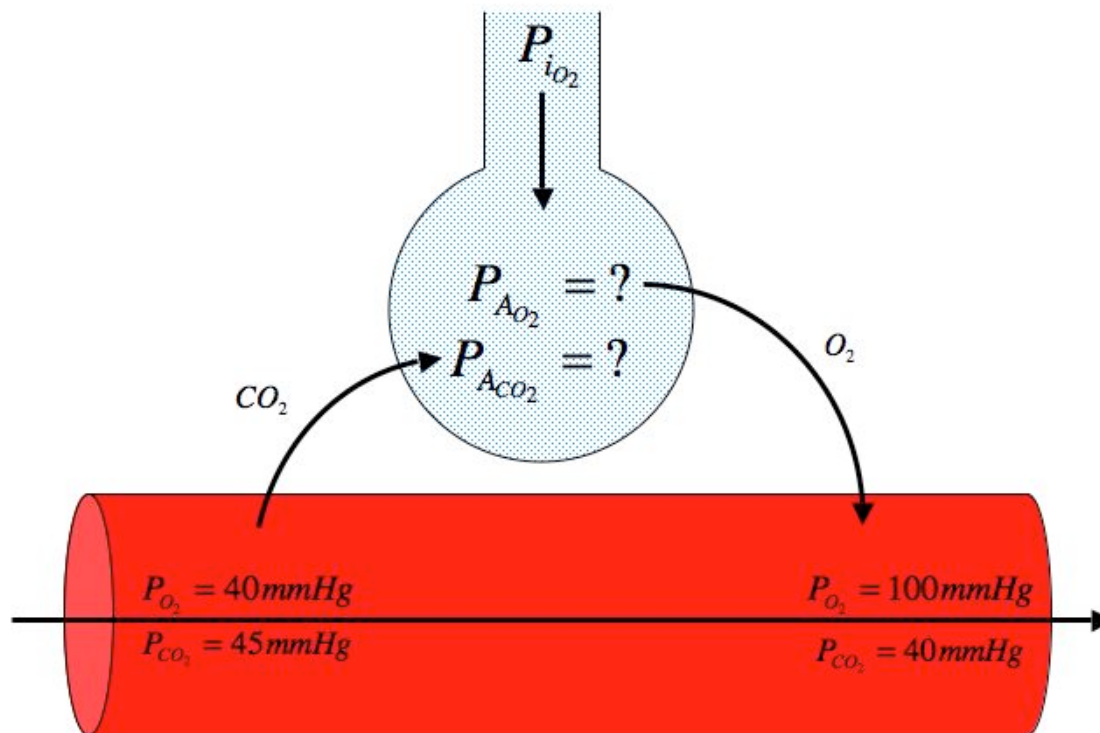
# Ventilation and Perfusion at the Level of the Whole Lung



# Gas Composition in the Alveolar Space

Trachea: partial pressure of CO<sub>2</sub> is approximately 0

$$\begin{aligned} P_{iO_2} &= (\text{barometric pressure} - \text{H}_2\text{O vapor pressure}) \times F_{iO_2} \\ &= (760 - 47) \times 0.21 = 150 \text{ mmHg} \end{aligned}$$



In the alveolar space, oxygen diffuses into the blood and CO<sub>2</sub> 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 ( $VCO_2/VO_2$ ) = 0.8

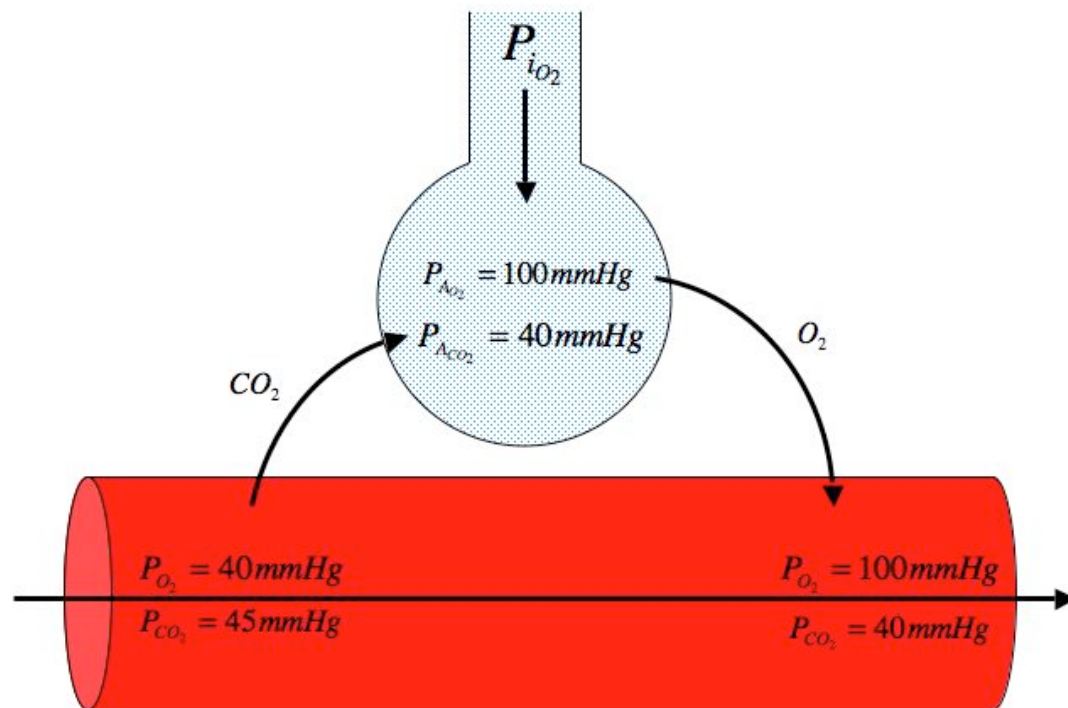
In a normal individual breathing room air:

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

# Gas Composition in the Normal Alveolar Space

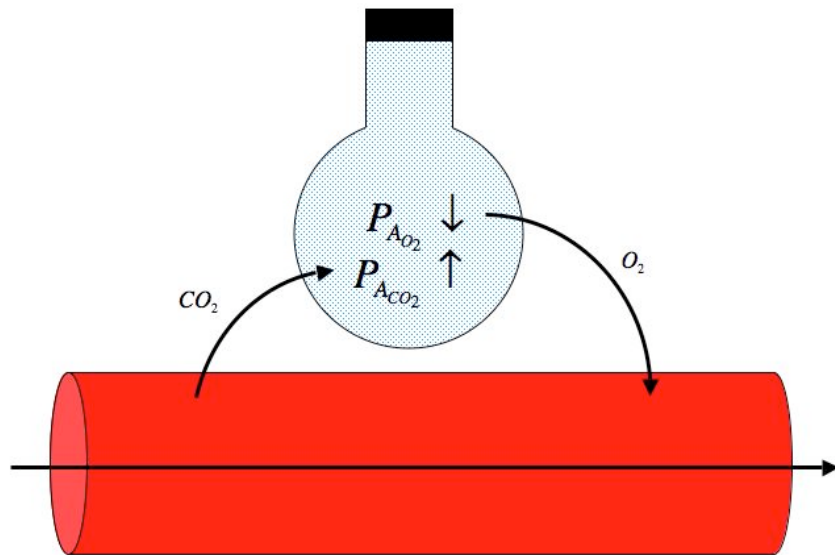
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In the alveolar space, oxygen diffuses into the blood and CO<sub>2</sub> diffuses into the alveolus from the blood.

# Consequences of Inadequate Ventilation



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- Apnea:
  - $PACO_2$  rises
  - $PAO_2$  falls until there is no gradient for diffusion into the blood
- Hypoventilation:
  - Inadequate ventilation for perfusion
  - $PACO_2$  rises
  - $PAO_2$  falls, but diffusion continues

**How Can We Tell if Alveolar  
Ventilation is Adequate?**

# PaCO<sub>2</sub> and Alveolar Ventilation

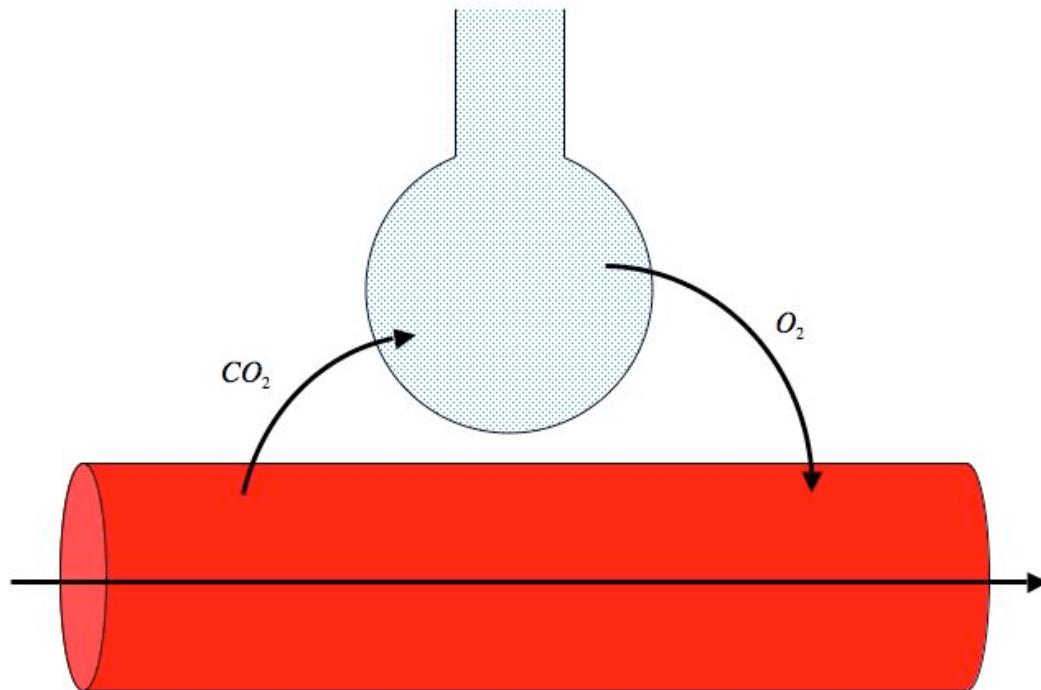
- PaCO<sub>2</sub> is:
  - directly related to CO<sub>2</sub> production (tissue metabolism).
  - Inversely related to alveolar ventilation.
- Increased PaCO<sub>2</sub> (hypercarbia) is always a reflection of inadequate alveolar ventilation (VA).

$$PaCO_2 \approx \frac{VCO_2}{VA}$$

# Alveolar Hypoventilation

Suppose a patient hypoventilates, so that the PCO<sub>2</sub> rises to 80 mmHg. We can estimate the PAO<sub>2</sub> based on the alveolar gas equation.

$$PAO_2 = 150 - 80/0.8 = 50 \text{ mmHg}$$



Thus even with perfectly efficient lungs, the PaO<sub>2</sub> would be 50, and the patient would be severely hypoxemic. Therefore, hypoventilation results in hypoxemia.

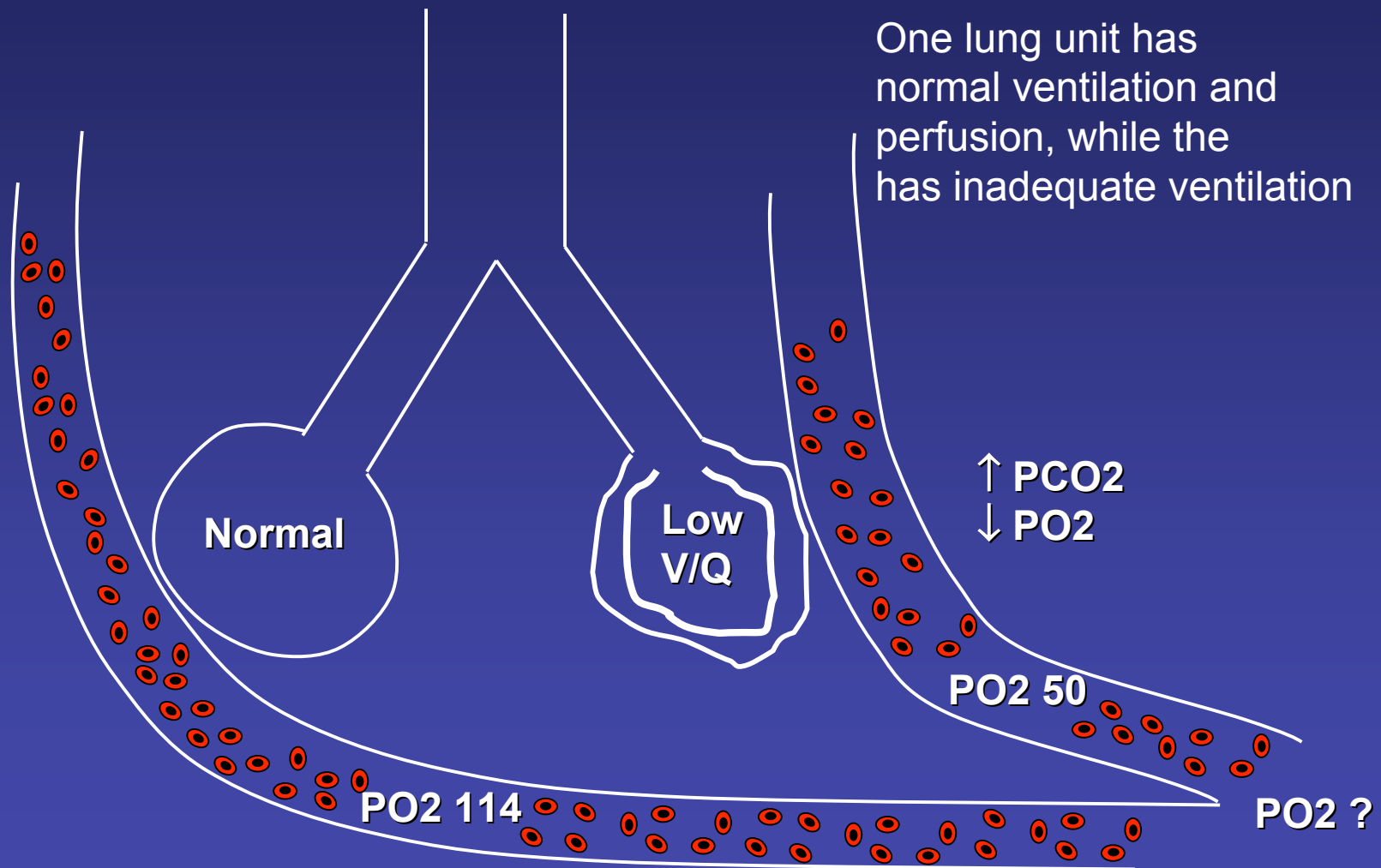
# V/Q Matching

- 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 alveolar unit).

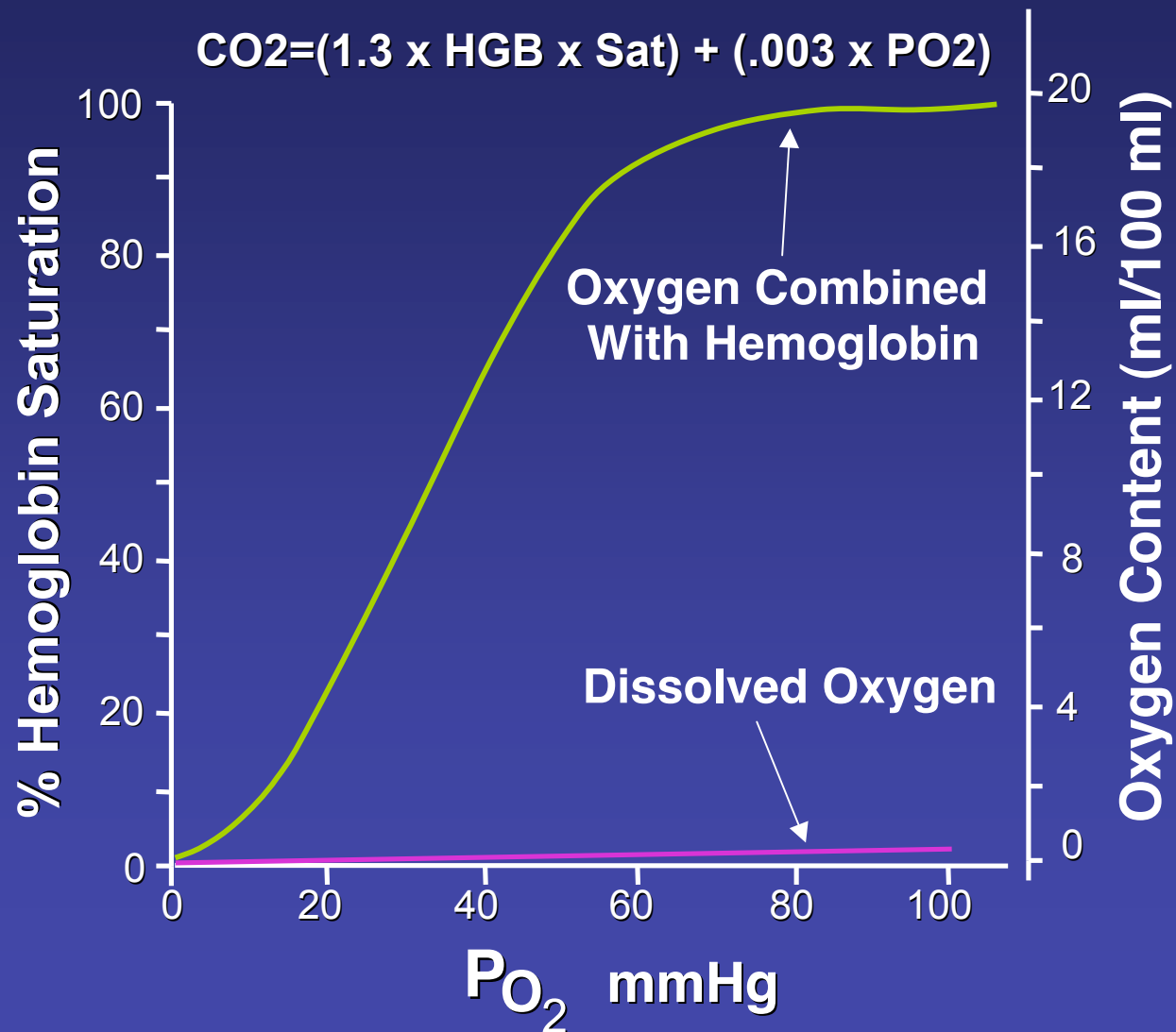
# Low V/Q Effect on Oxygenation



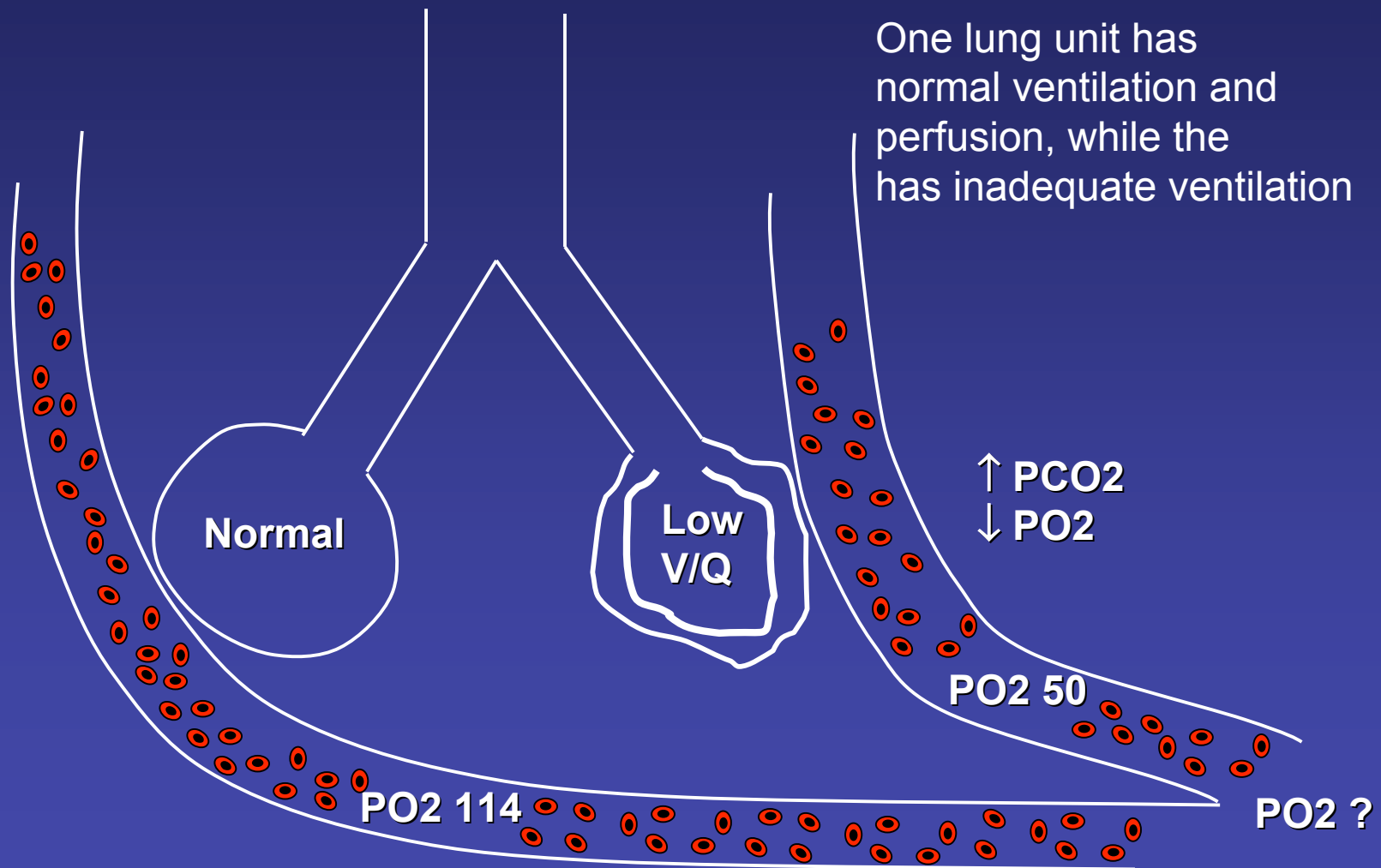
# Mixing Blood

- What is the  $PO_2$  of a mixture of two volumes of blood with different initial  $PO_2$ ?
- Determined by interaction of oxygen with hemoglobin.
  - the partition of oxygen between plasma (and thus the  $pO_2$ ) and bound to hemoglobin is determined by the oxyhemoglobin dissociation curve.

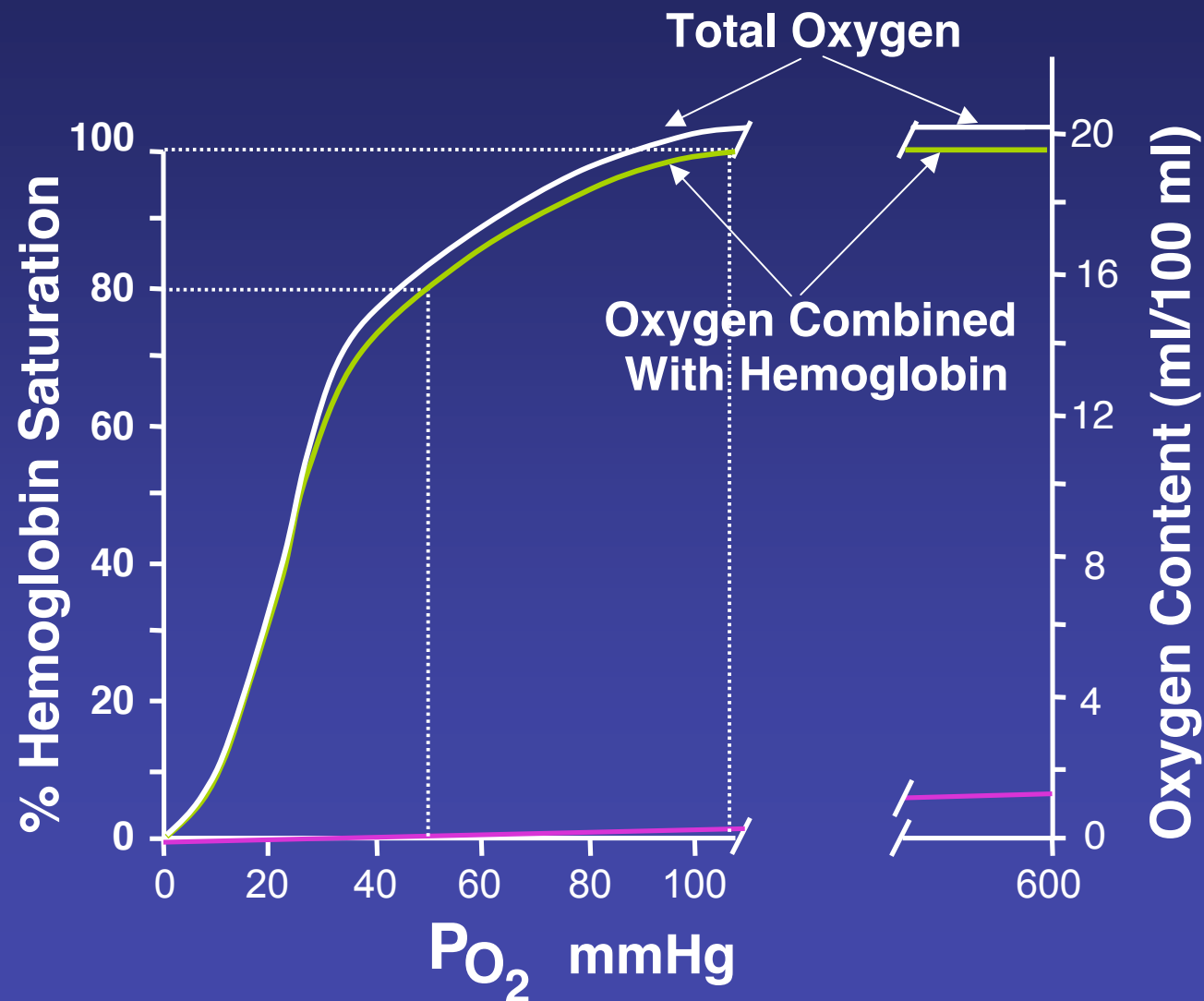
# Oxyhemoglobin Dissociation Curve



# Low V/Q Effect on Oxygenation

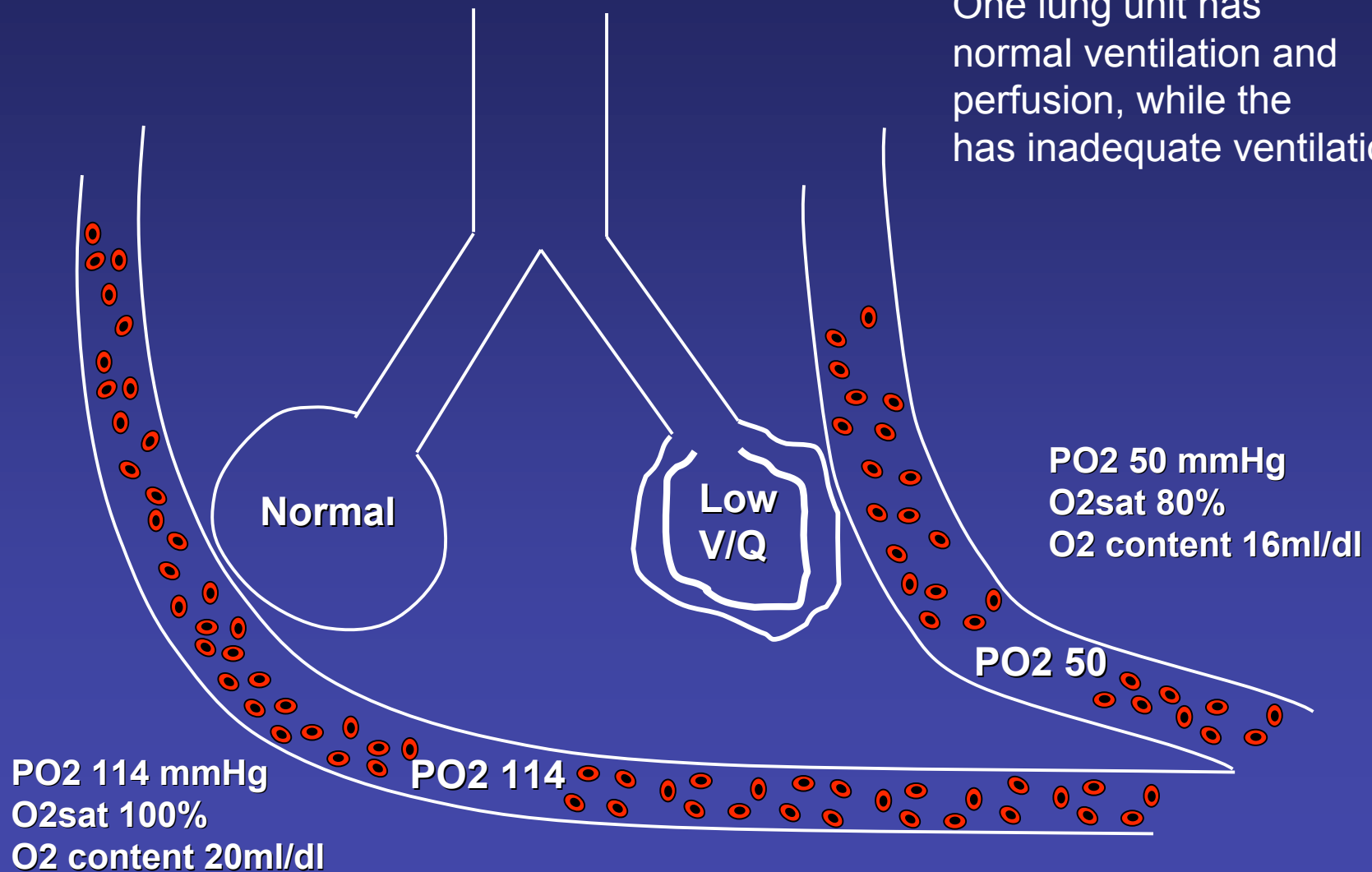


# Oxyhemoglobin Dissociation Curve and O<sub>2</sub> Content

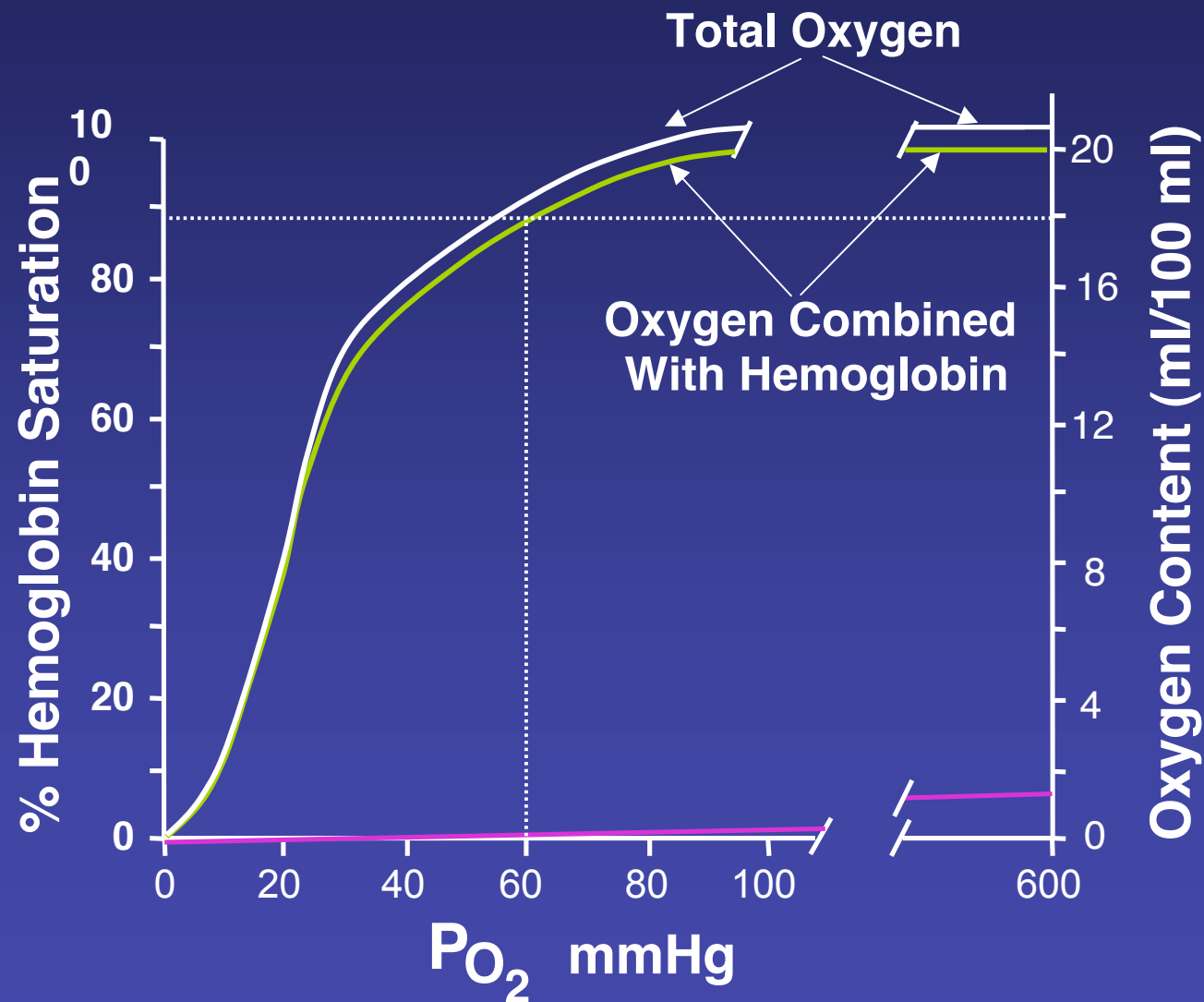


# Low V/Q Effect on Oxygenation

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

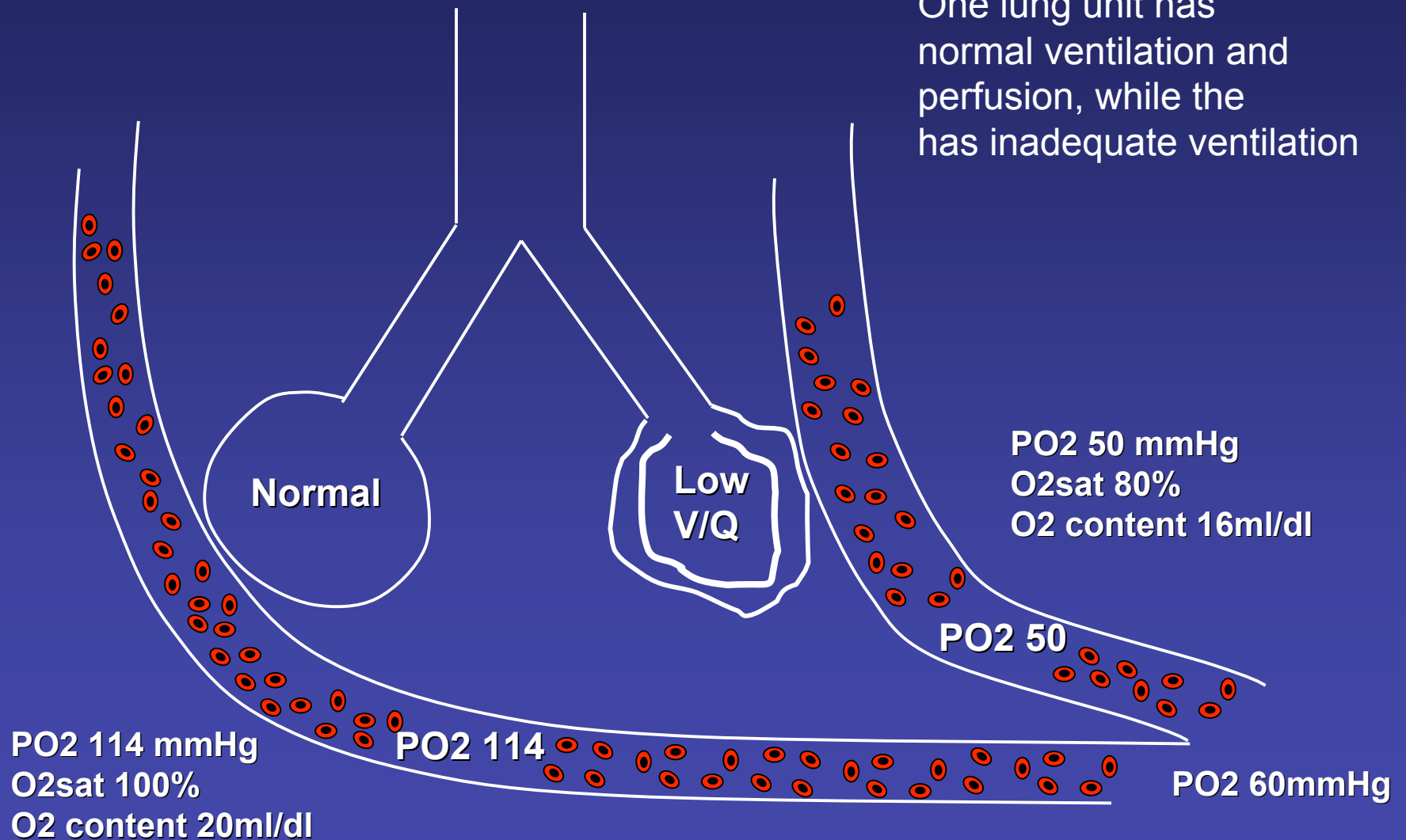


# Oxyhemoglobin Dissociation Curve and O<sub>2</sub> Content



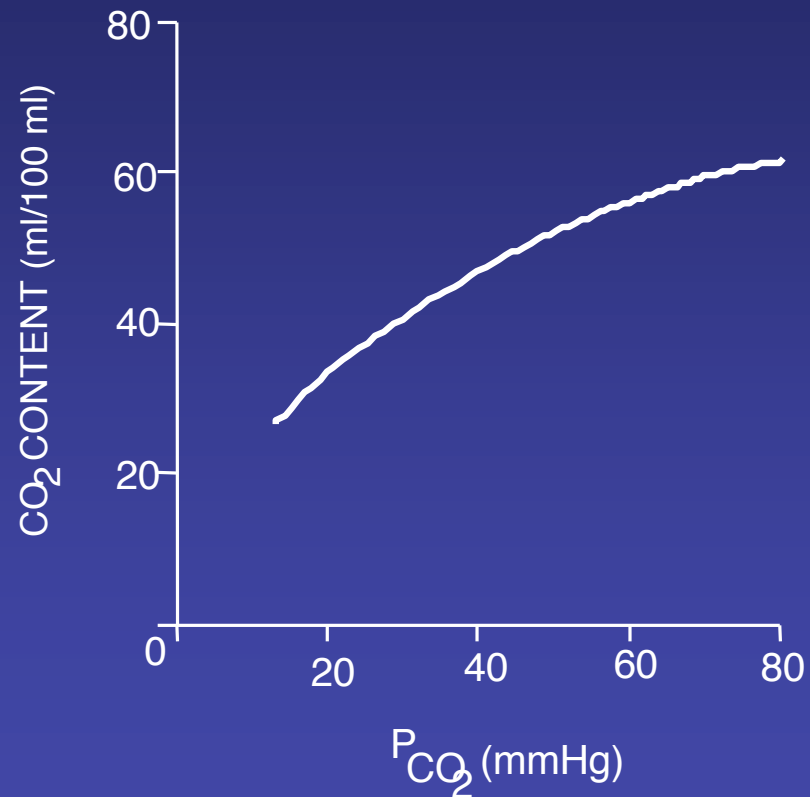
# Low V/Q Effect on Oxygenation

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



# PCO<sub>2</sub> in V/Q Mismatch

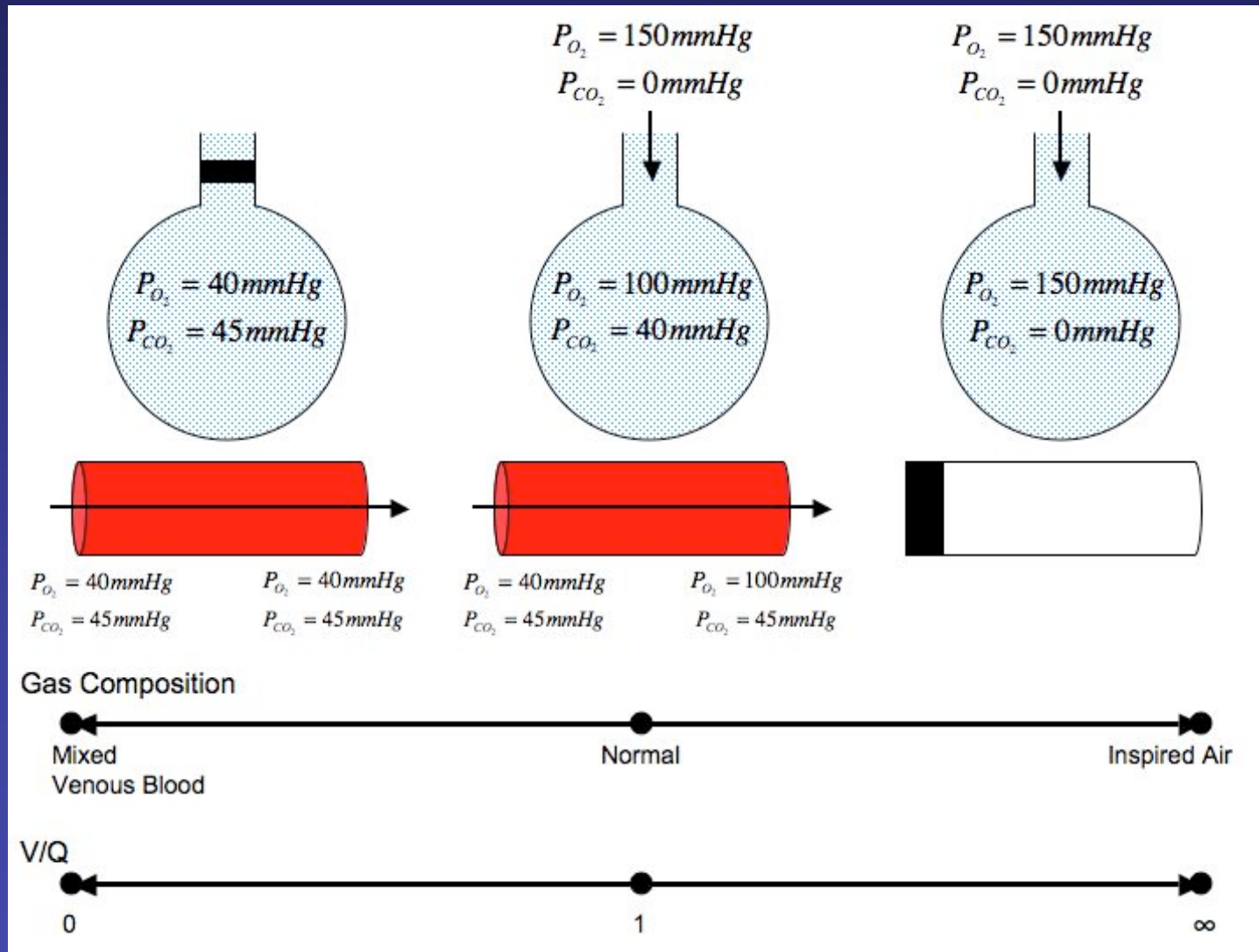
- Increased ventilation can compensate for low V/Q units.
  - Shape of CO<sub>2</sub> curve
- Total ventilation (VE) must increase for this compensation.



# 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

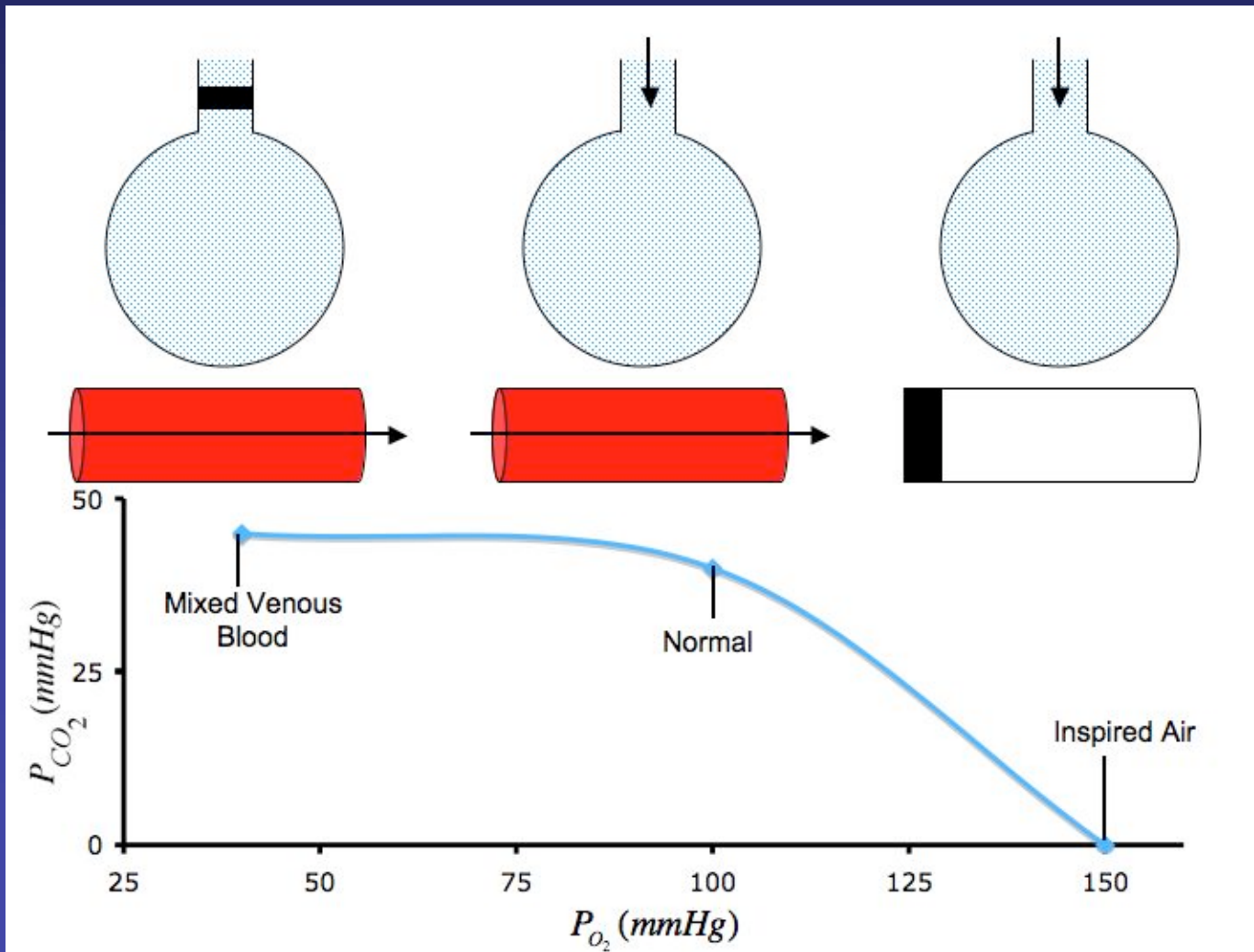
# Effect of Changing V/Q Ratio on Alveolar PO<sub>2</sub> and PCO<sub>2</sub>



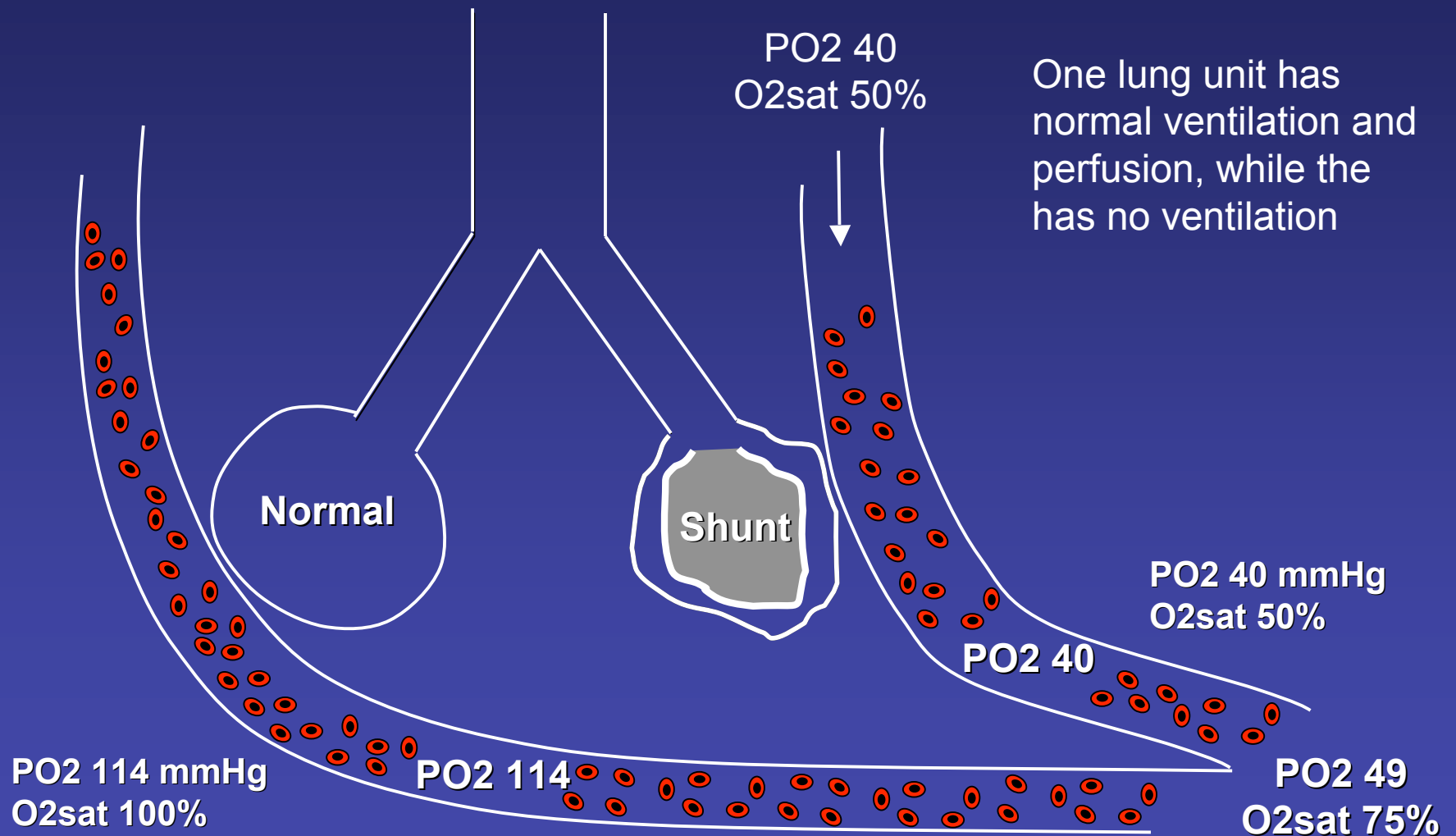
Shunt

Dead Space

# Effects of V/Q Relationships on Alveolar $P_{O_2}$ and $P_{CO_2}$



# Shunt Physiology



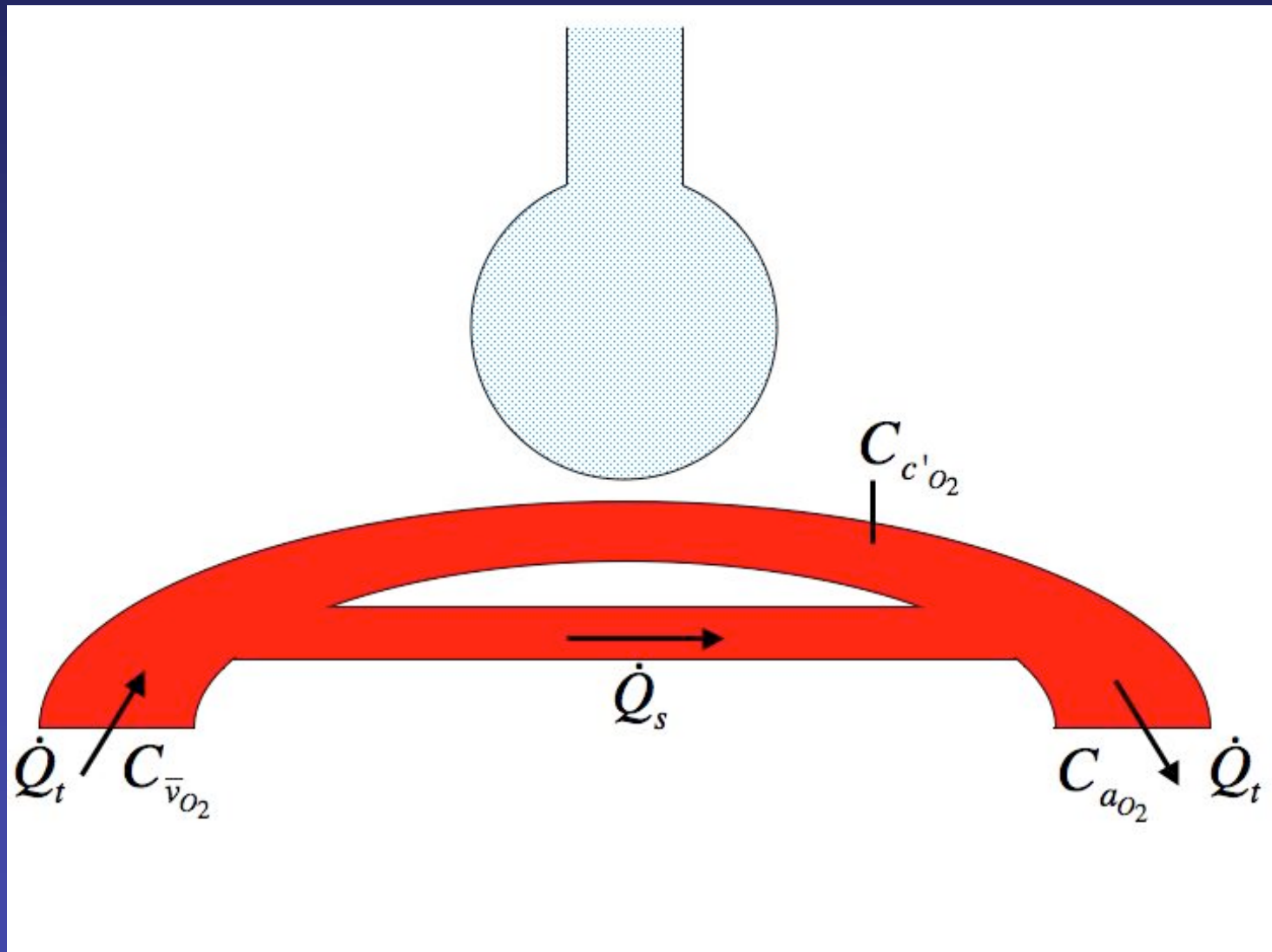
# Response to Breathing 100% Oxygen

- Alveolar hypoventilation or V/Q mismatch responds to 100% oxygen breathing.
- Nitrogen will be washed out of low ventilation lung units over time.
- PaO<sub>2</sub> will rise to > 550 mmHg.
- Limited response to oxygen in shunt.
- Use this characteristic to diagnose shunt.

# Shunt Calculation

- $Q_t \times CaO_2$  = total volume of oxygen per time entering systemic arteries
  - $Q_t$  = total perfusion
  - $Q_s$  = shunt perfusion
  - $CaO_2$ ,  $Cc'O_2$ ,  $CvO_2$  are oxygen contents of arterial, capillary and venous blood
- $(Q_t - Q_s) \times Cc'O_2$  = oxygen coming from normally functioning lung units
- $Q_s \times CvO_2$  = oxygen coming from shunt blood flow

# Shunt



# Shunt Equation

$$Q_t \times CaO_2 = [(Q_t - Q_s) \times CcO_2] + [Q_s \times CvO_2]$$

$$\frac{Q_s}{Q_t} = \frac{Cc'O_2 - CaO_2}{Cc'O_2 - CvO_2}$$

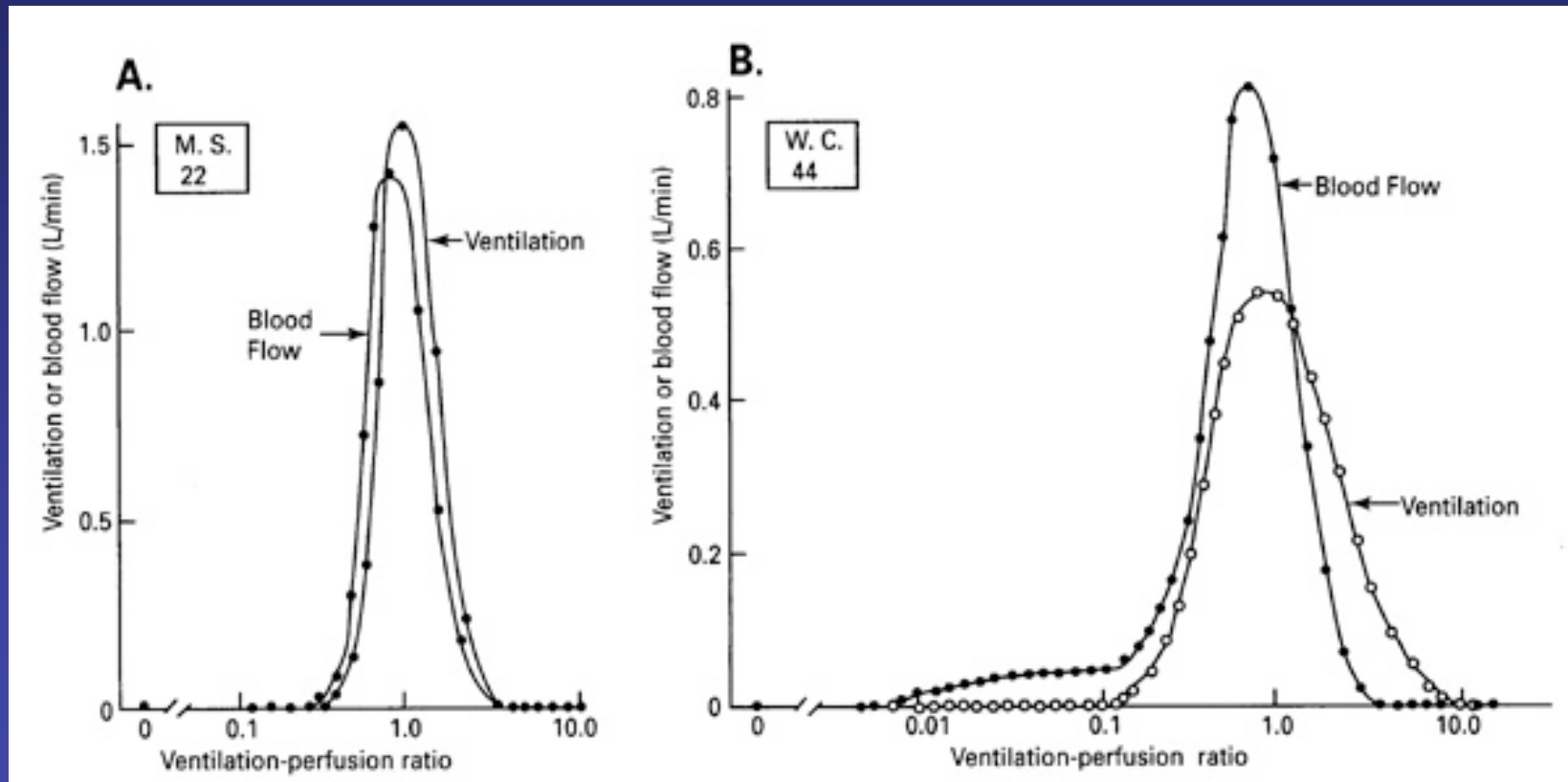
# Causes of Shunt

- 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-aO<sub>2</sub> Gradient.

# V/Q Relationships



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

Multiple Inert Gas Elimination

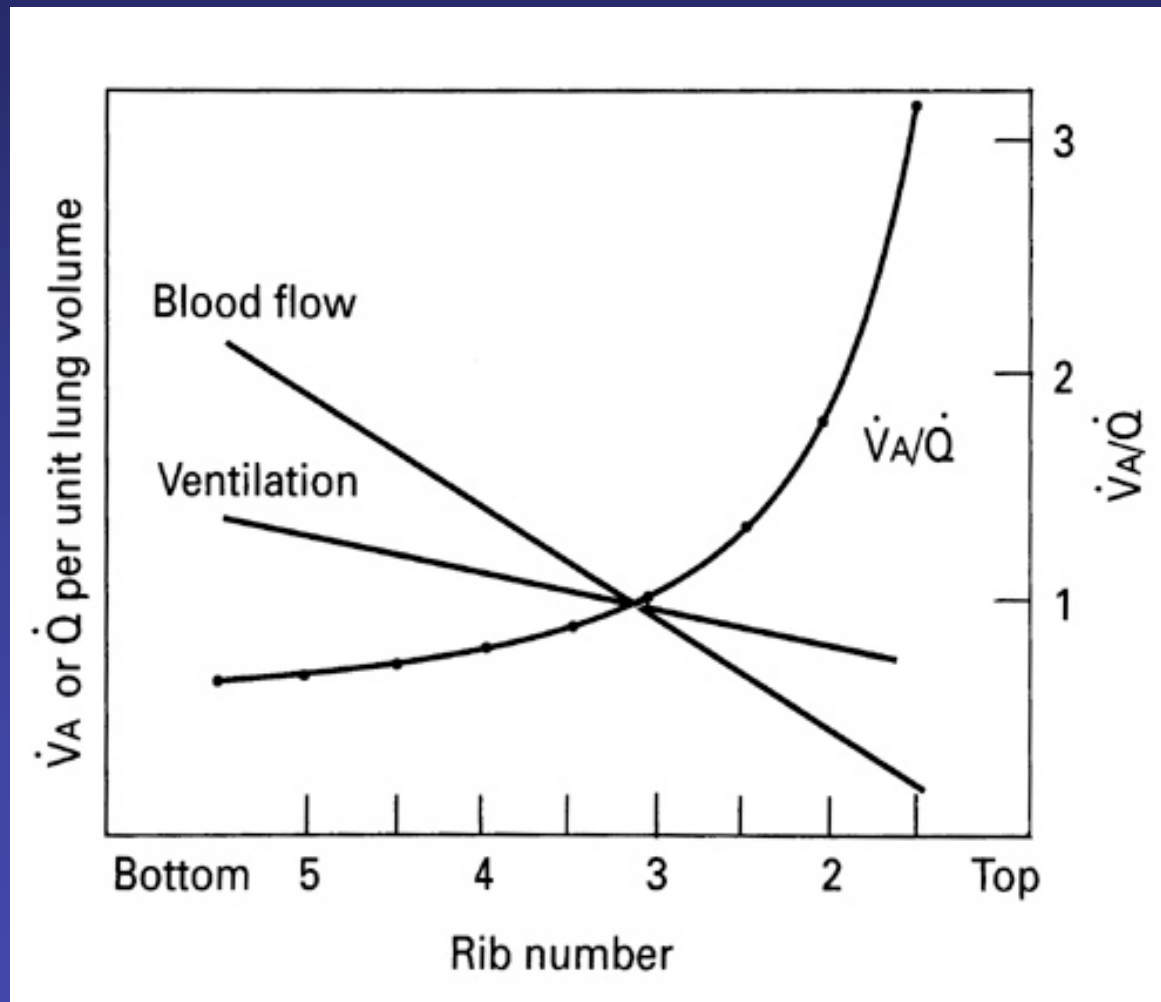
# A-a O<sub>2</sub> gradient

- In a totally efficient lung unit with matched V/Q, alveolar and capillary PO<sub>2</sub> would be equal.
- Admixture of venous blood (or of blood from low V/Q lung units) will decrease the arterial PaO<sub>2</sub>, without effecting alveolar O<sub>2</sub> (PAO<sub>2</sub>).
- Calculate the PAO<sub>2</sub> using the alveolar gas equation, then subtract the arterial PaO<sub>2</sub>:  $[(P_{iO_2}) - (P_{aCO_2}/R)] - PaO_2$ .
- The A-a O<sub>2</sub> gradient (or difference) is < 10-15 mmHg in normal subjects
  - Why is it not 0?

# Apical and Basilar Alveoli in the Upright Posture

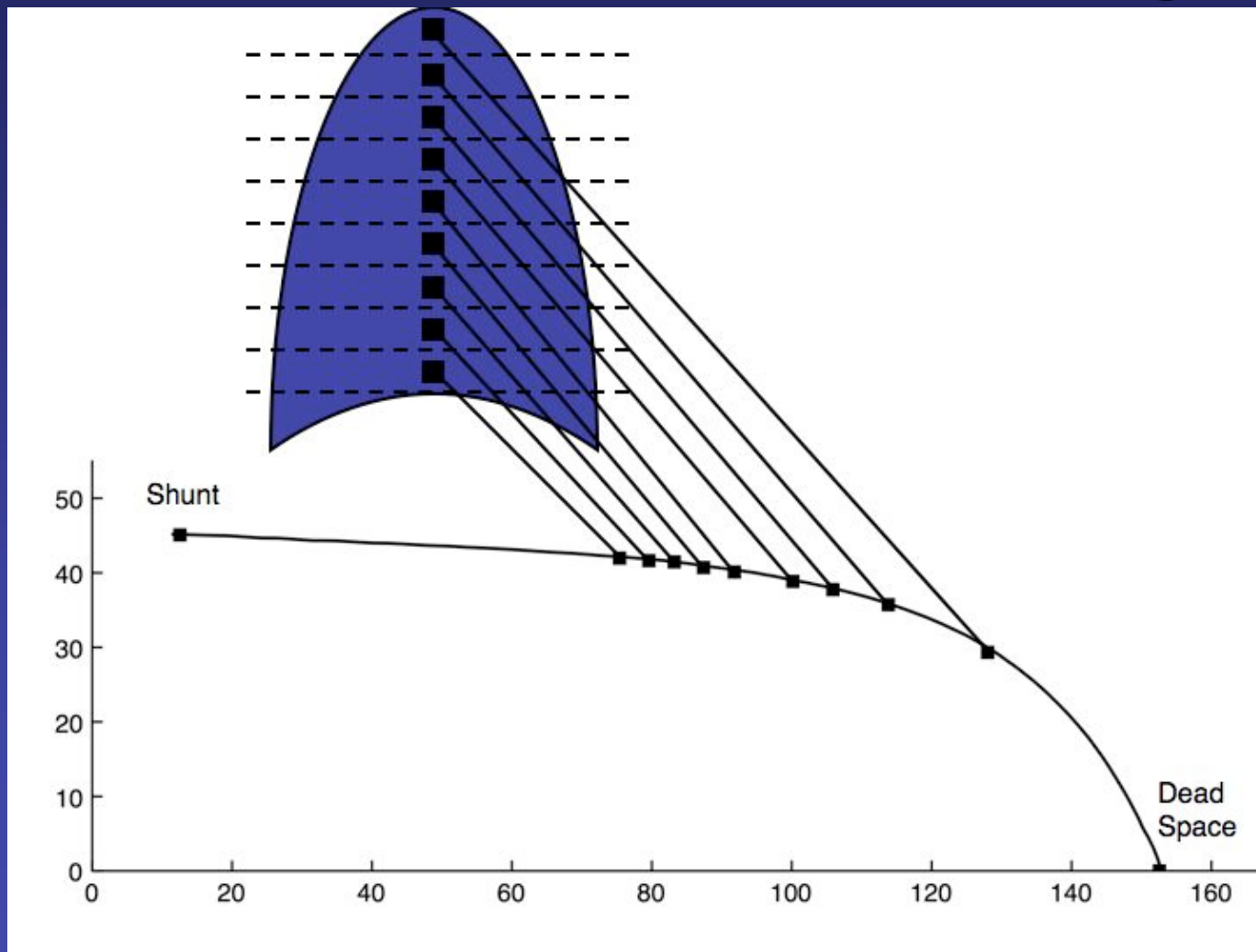
- Elastic recoil of the individual alveoli is similar throughout the normal lung.
- At end expiration (FRC) apical alveoli see more negative pressure and are larger than basilar alveoli.
- During inspiration, basilar alveoli undergo larger volume increase than apical alveoli.
- Thus at rest there is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

# Effects of Gravity on Ventilation and Perfusion



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

# 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 PO<sub>2</sub> close to 100 mmHg and PCO<sub>2</sub> close to 40 mmHg.
- V/Q greater than 1.0 increase PO<sub>2</sub> and Decrease PCO<sub>2</sub>. V/Q less than 1.0 decrease PO<sub>2</sub> and Increase PCO<sub>2</sub>.
- 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.