# Oxygenation:

## From atmosphere to veins


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# Oxygenation Outline

- Physiology
- Assessment of oxygenation
- Oxygen Flux equations
- Examples

# Physiology

Physiology

# Outline

- Commonly used terms
  - Oxygen Partial Pressure
  - Oxygen Saturation
  - Oxygen Content
- Oxygen Carriage in blood
- Relationship of $SaO_2$ to $PaO_2$
- Oxygen Cascade
- Examples

# Definitions and Common Terms

Physiology

# Oxygen Partial Pressure

- The pressure of the oxygen component of a gas or liquid

  - Oxygen in air:  21%
  - Total atmospheric pressure:  760 mmHg
  - Pressure of $O_2$ in atmosphere: 159 mmHg

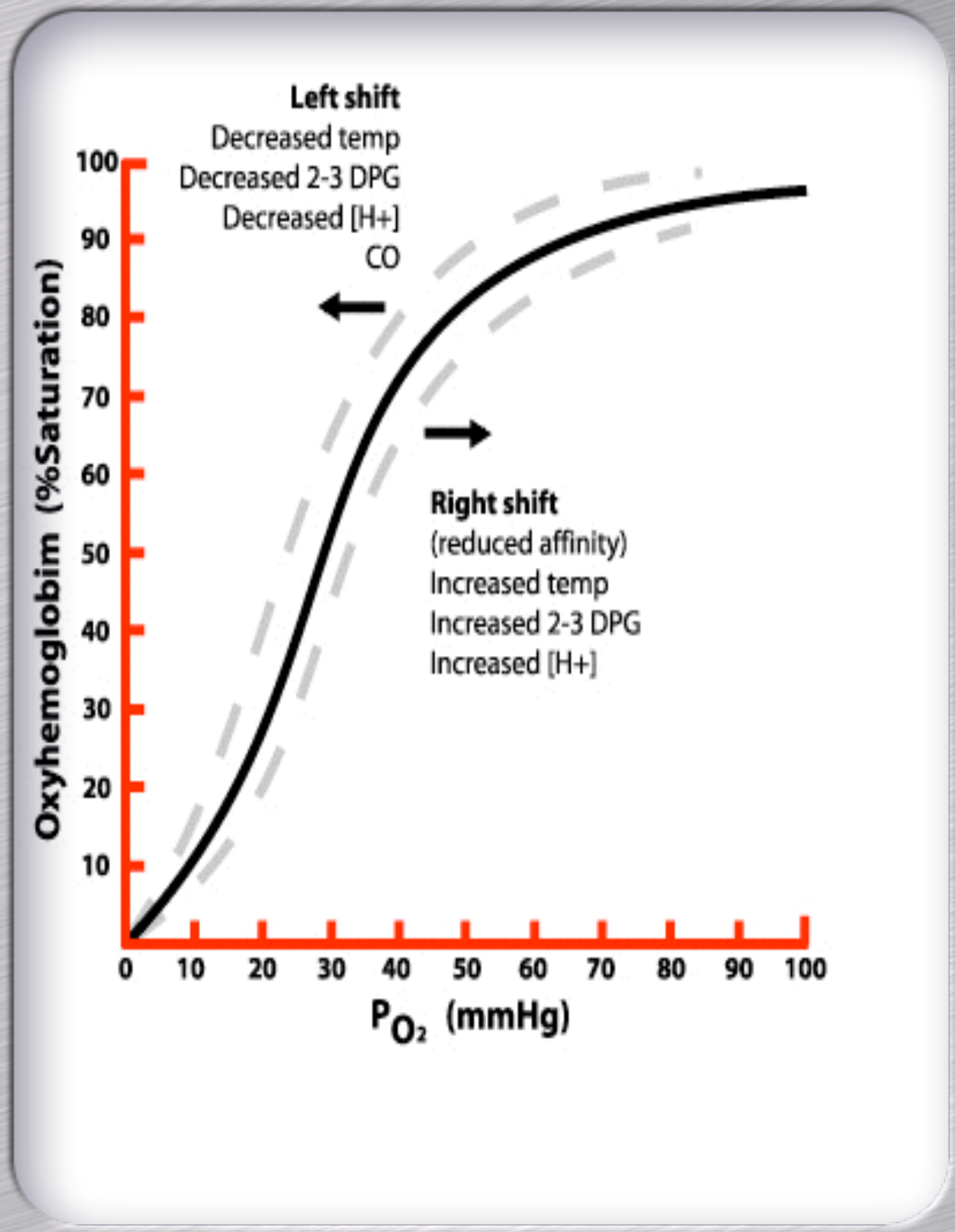
Physiology

# Oxygen Saturation

- This is the percentage of haemaglobin that carries oxygen
  - Normally quite high (> 95%)
- Difference between an ABG and an oximeter
  - $SaO_2$ – From a blood gas machine
  - $SpO_2$ – From an oximeter

# Dissociation curve

- Changes with:
  - ↑ Acidosis
  - ↑ Warmth
  - ↑ Carbon dioxide
- Chronically with:
  - ↑ 2,3 DPG levels



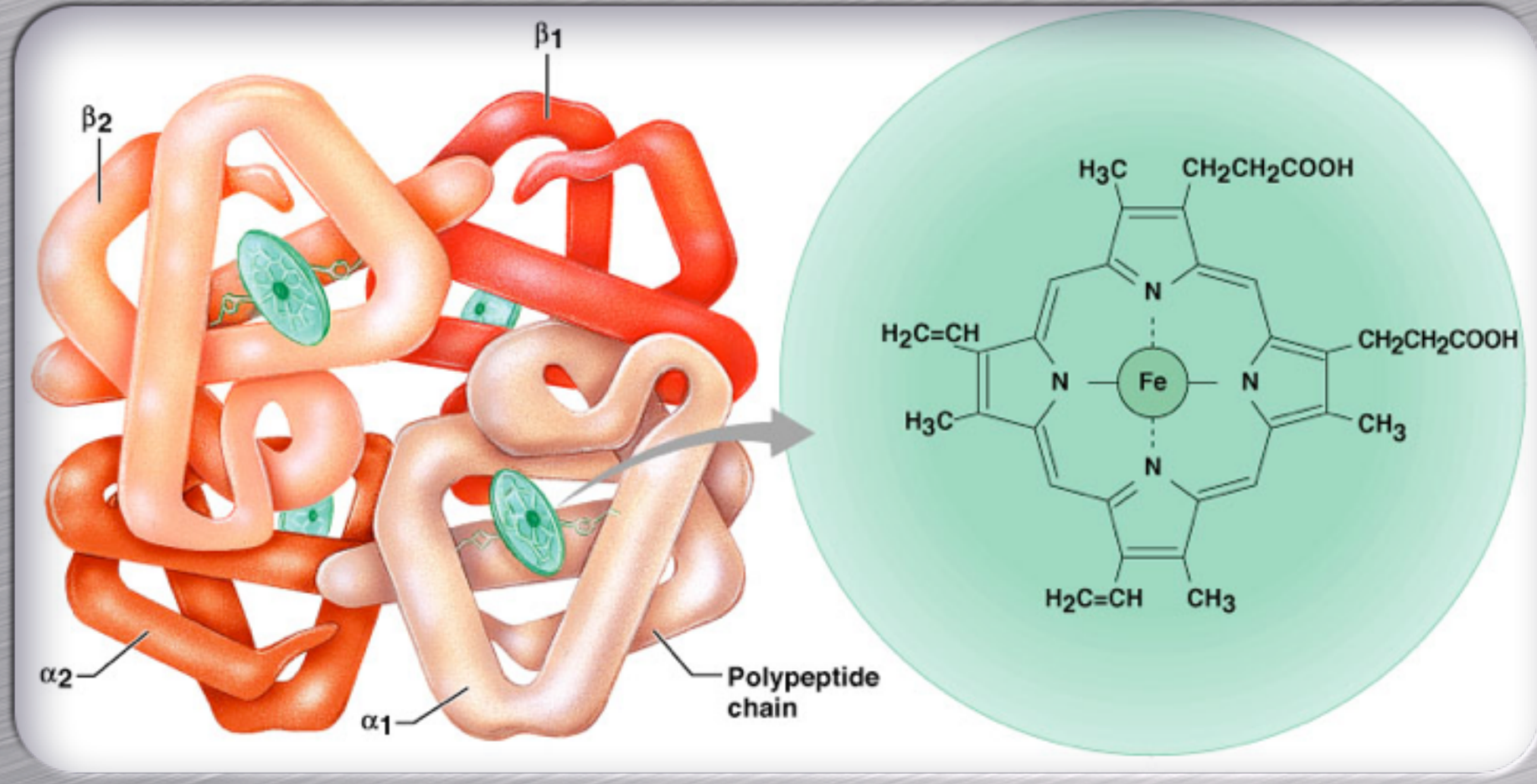
# Oxygen Carriage

Physiology

# Oxygen Content

- Where is oxygen stored in the blood?
  - Directly in blood as a gas in solution
  - On Haemoglobin

- $CaO_2$ is the oxygen content of blood
  - Expressed in ml oxygen per litre blood




# On Haemaglobin

# Directly in Plasma

- Small amount stored on plasma.
- $PaO_2$ * 0.03

Physiology

# Oxygen Storage

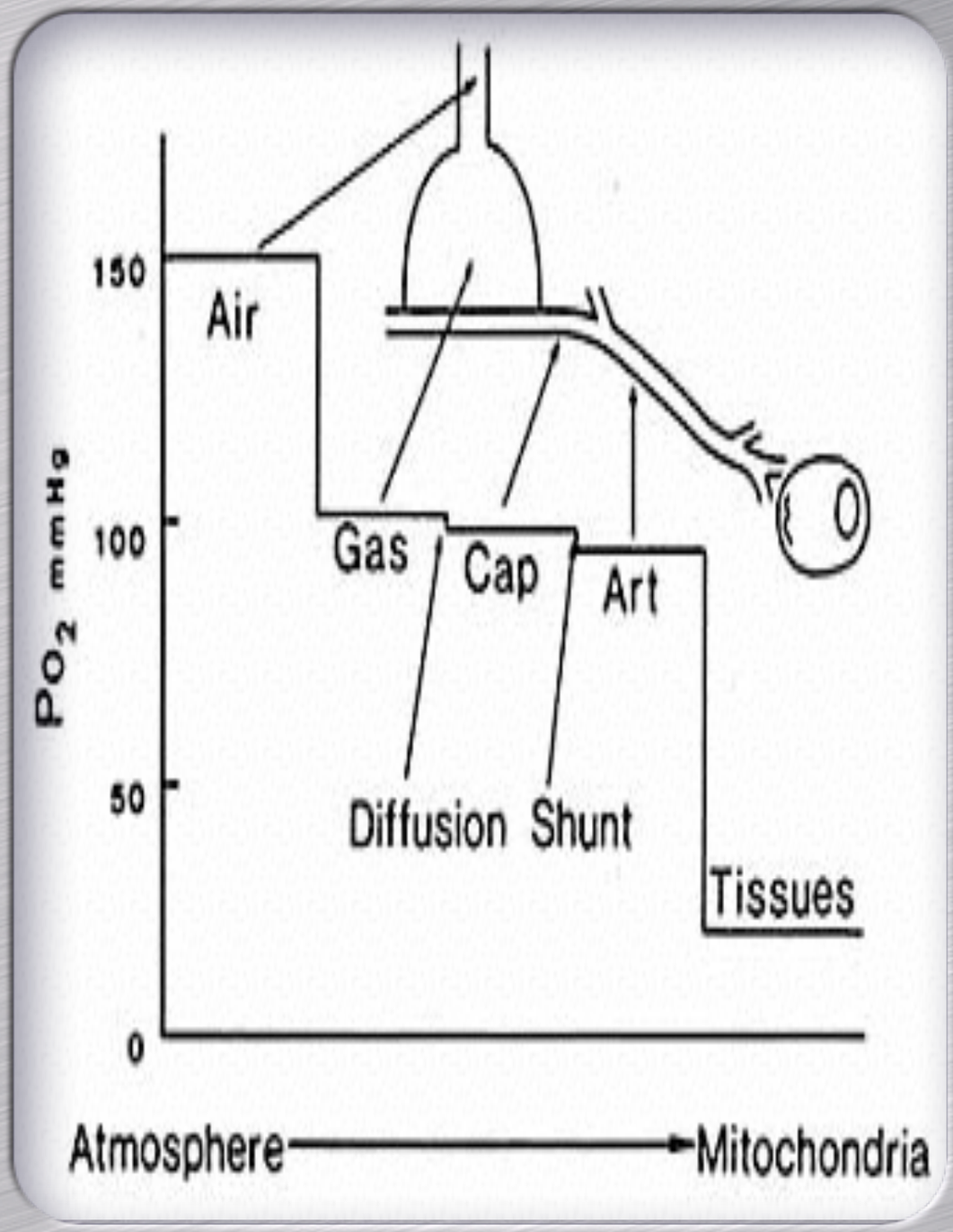
- Oxygen storage in blood equals
  - Oxygen stored on Hb
  - PLUS
  - Oxygen dissolved in blood

$$SaO_2 \cdot Hb \cdot 1.34 \quad + \quad PaO_2 \cdot 0.03$$

# Oxygen Cascade

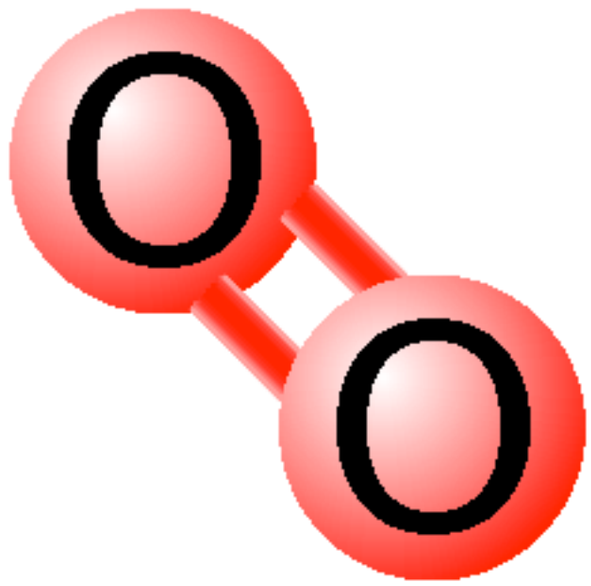
# Oxygen Cascade

- Normal inspired Oxygen is 160 mmHg
- Pressure falls by:
  - Humidification
  - Mixing with $CO_2$
  - Diffusion
  - Shunt
- Before entering tissues

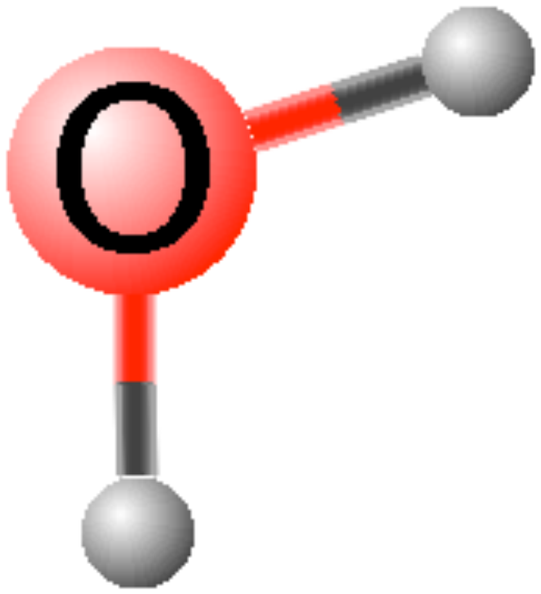


# Air

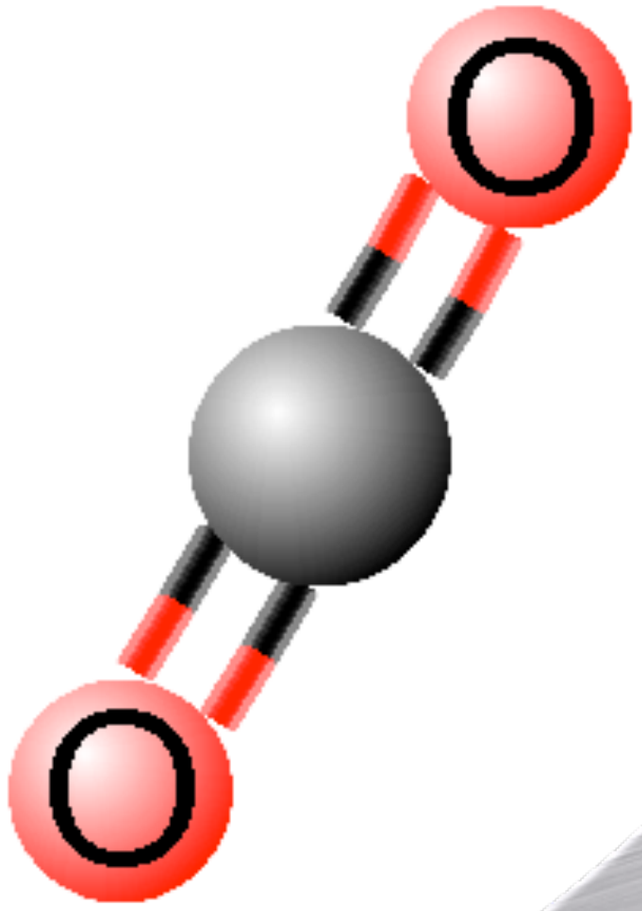
- Atmospheric pressure is 760 mmHg
- 21% of this is $O_2$
  - $PO_2$ = 160 mmHg



# Humidification



- Air is warmed and humidified in airways.
- $P_{Water}$ at body temperature is 47 mmHg
  - $PO_2$ = 150 mmHg

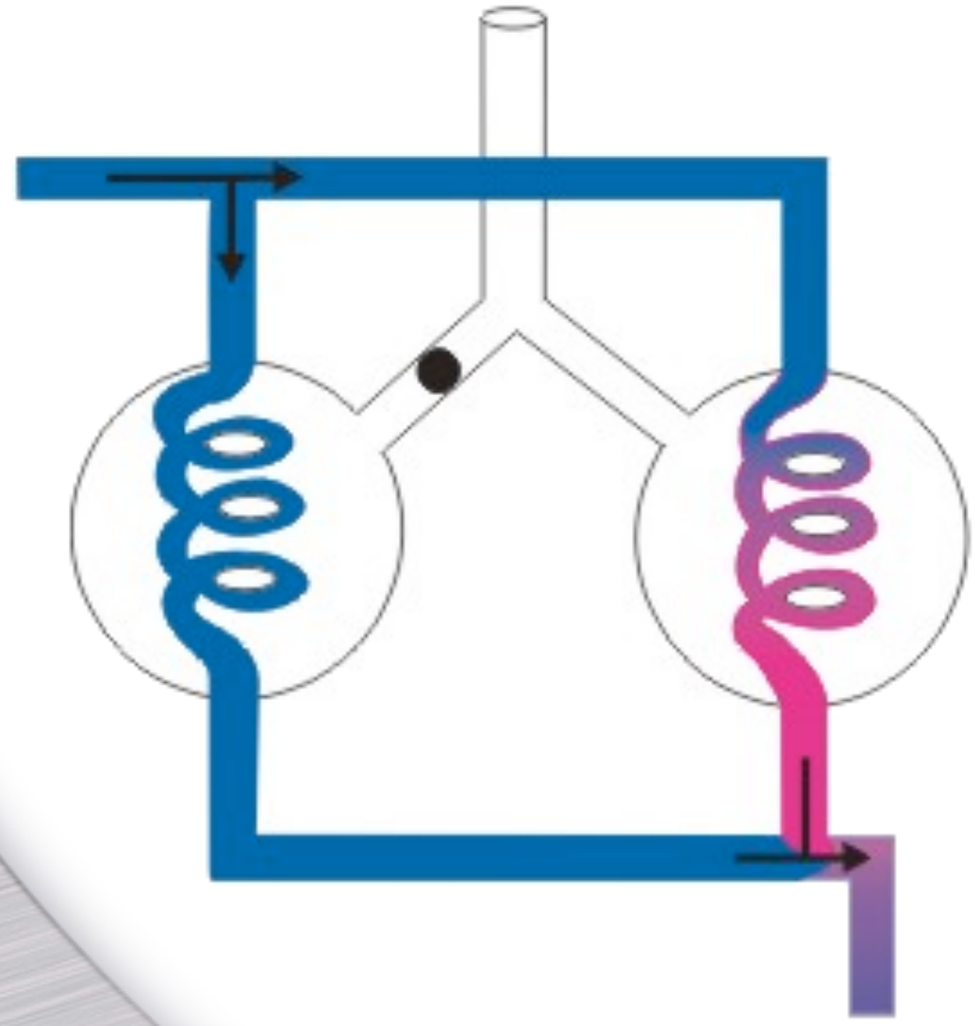



# Mixing of $CO_2$

- The humidified air then mixes with carbon dioxide in the alveoli
- $PO_2$ = 100 mmHg

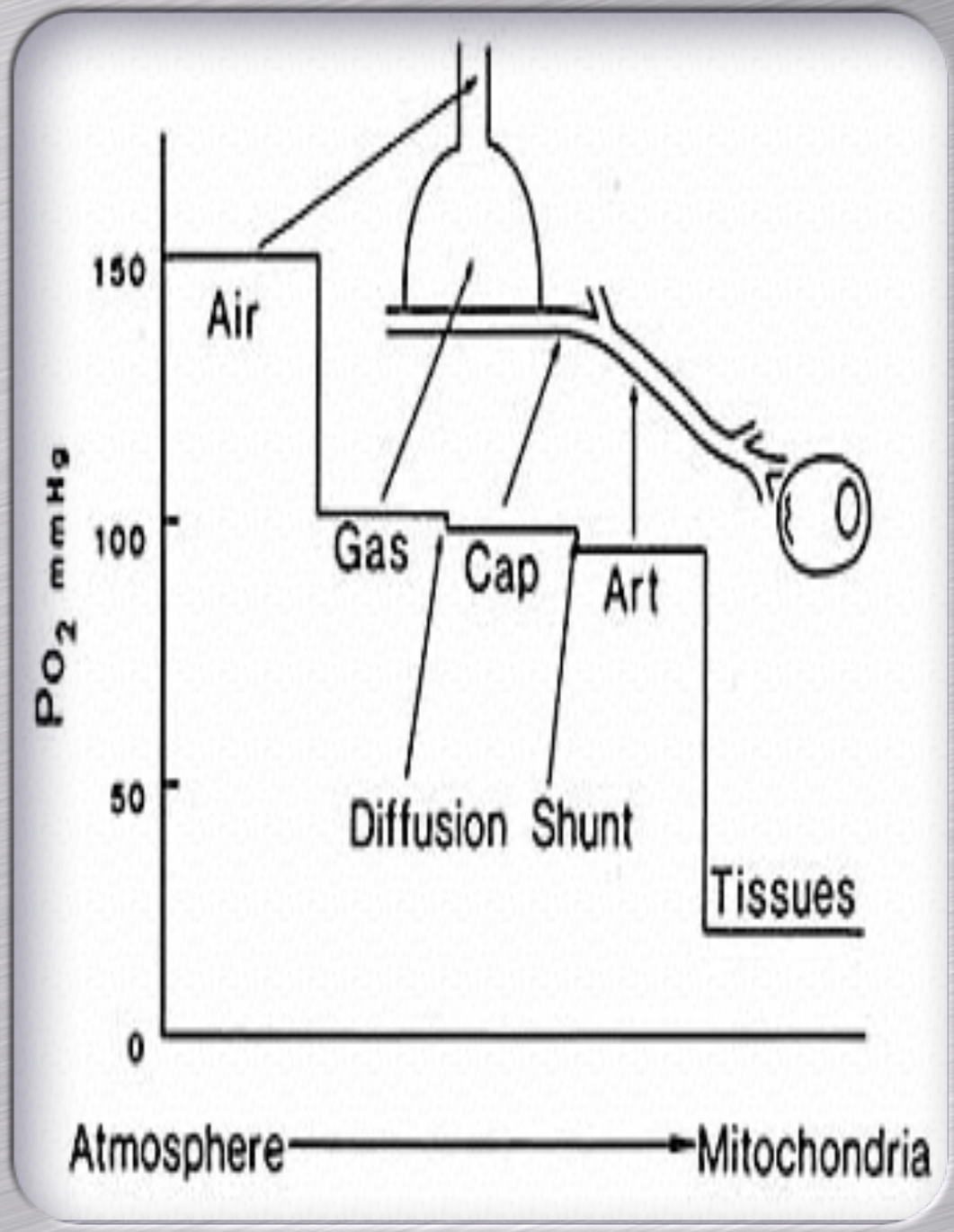
# VQ matching & Shunt

- Not all alveolii are equal - some are better ventilated than others.
- Mixing of shunted blood leads to falls in $O_2$ content



# Oxygen Cascade

- Normal inspired Oxygen is 160 mmHg
- Pressure falls by:
  - Humidification
  - Mixing with CO2
  - Diffusion
  - Shunt
- Normally 100 mmHg in Blood



# Physiology Examples

Maximal Ventilation
Supplimental Oxygen
Changes with Altitude

Physiology

# Maximal Ventilation

- Hyperventilation reduces displacement by carbon dioxide in lungs
- Maximal hyperventilation ($CO_2$ = 15 mmHg)
  - Water 10 mmHg, $CO_2$ 20 mmHg
- Maximum oxygen on air = 120 mmHg

Physiology

# Supplimental Oxygen

- 100 % oxygen gives 760 mmHg partial pressure
- Displacement still occurs
  - Water 47 mmHg  $CO_2$ 50 mmHg
- Maximum $PO_2$ on 100% oxygen
  - 760 – 47 – 50 = 663 mmHg

Physiology

# Mountain Climbing

- $P_{atm}$ halves each 5500m ascent
- At 5500m:
  - Atmostpheric pressure 380 mmHg
  - Partial Pressure Oxygen 80 mmHg
- If SVP $H_2O$ is 47 and $CO_2 = 40$:
  - $PaO_2 = 80 - 10 - 50 = 20$ mmHg
- If SVP $H_2O$ is 47 and $CO_2 = 16$
  - $PaO_2 = 80 - 10 - 20 = 50$ mmHg

Physiology

# Estimating $PaO_2$

- Maximum expected arterial oxygen level
  - About six times the $FiO_2$
- Room air 6* 20 = 120
- 100% oxygen  6* 100 = 600
- Not a perfect rule, but an easy one.

Physiology

# Summary

- Commonly used terms
  - Oxygen Partial Pressure
  - Oxygen Saturation
  - Oxygen Content
- Oxygen Carriage in blood
- Relationship of $SaO_2$ to $PaO_2$
- Oxygen Cascade
- Examples

# Assessment of Oxygenation

Sampling

# What to look at.

- Oxygen Saturation ($SaO_2$)
- Oxygen Partial Pressure ($PaO_2$)
- Oxygen Carrying Capacity (Hb)

Sampling

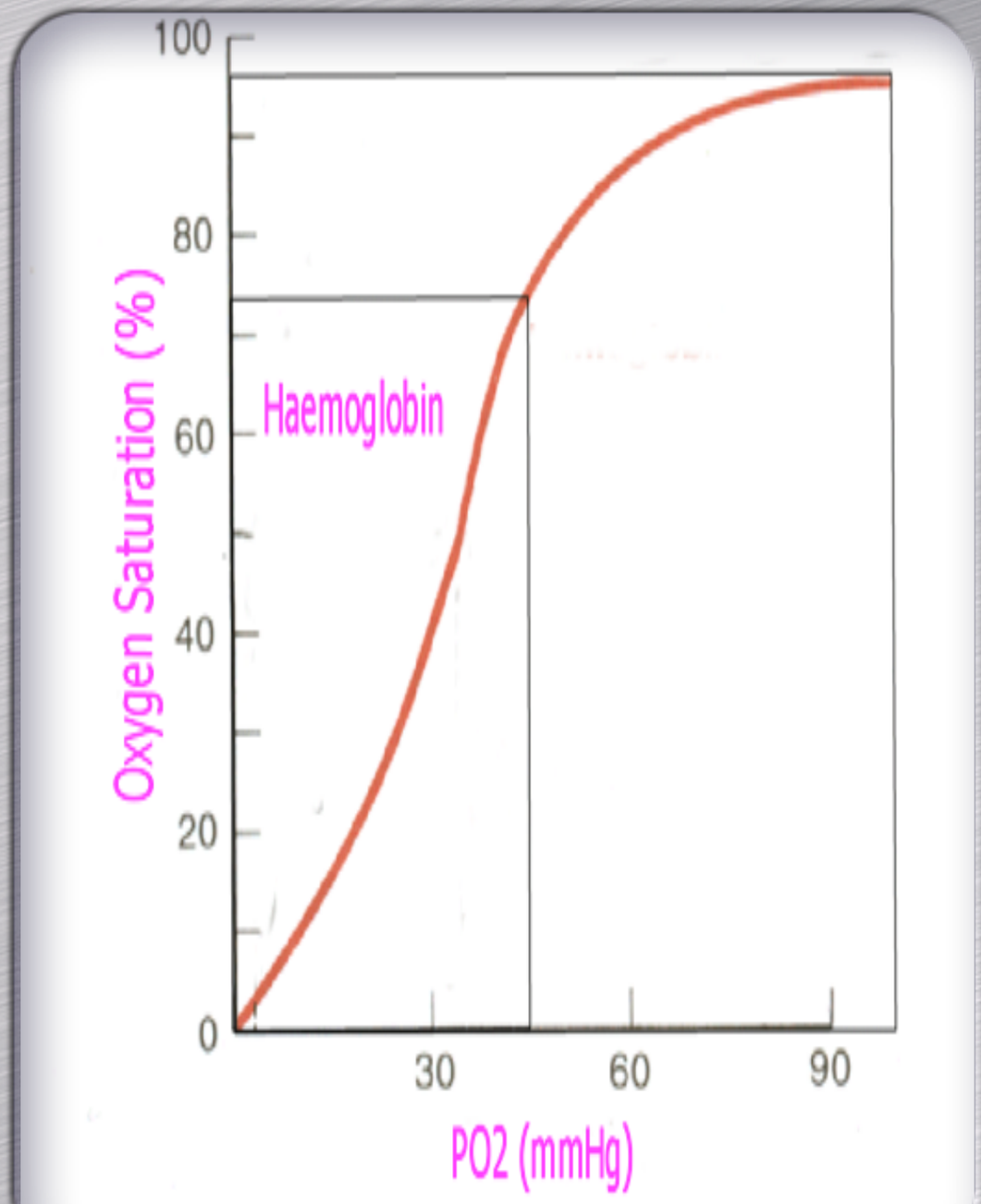
# Where to sample?

- Arterial Blood
  - Arterial Stab
  - Arterial Line
- Venous Blood
  - PA catheter
  - Blood from a vein isn't mixed

# Oxygen Flux

# Blood $O_2$ Levels

- Arterial Blood
  - $PaO_2$ – 100 mmHg
  - $SaO_2$ – 98%
- Venous Blood
  - $PaO_2$ – 40 mmHg
  - $SvO_2$ – 75%



# Oxygen Content

Oxygen Flux

# Oxygen Content

- Content can be expressed mathematically

$$CaO_2 = SaO_2 \times Hb \times 1.34 + PaO_2 \times 0.03$$

- So the oxygen is mostly found on haemaglobin, not in the plasma.

# Blood $O_2$ content

- Arterial Blood Content: 200 ml/L
- Venous Blood Content: 150 ml/L
- 50 ml of oxygen is taken out of every litre of blood sent to the tissues.

# Oxygen Delivery & Return

# Normal $DO_2$ & $VO_2$

- Arterial blood 200 ml/L oxygen
- Venous blood 150 ml/L oxygen
- Cardiac output 5 L/min

- What is the normal amount of oxygen
  - Delivered to the tissues?
  - Returned from the tissues?
  - Used by the tissues?

# Oxygen Delivery

- Oxygen delivery to tissues
- Oxygen returned from the tissues
- Oxygen used by the tissues

# Oxygen Delivery

- Oxygen delivery to tissues
  - 200 ml/L  x 5 L/min  = 1000 ml/min
- Oxygen returned from the tissues
- Oxygen used by the tissues

# Oxygen Return

- Oxygen delivery to tissues
- Oxygen returned from the tissues
  - 150 ml/L x 5 L/min = 750 ml/min
- Oxygen used by the tissues

# Oxygen Uptake

- Oxygen delivery to tissues
- Oxygen returned from the tissues
- Oxygen used by the tissues
  - (200 – 150) ml/L x 5 L/min = 250 ml/min

# Summary

- Arterial and Venous Blood
  - Where to sample?
  - Normal Values
- Oxygen
  - Content in blood
  - Delivery and Return

# Critical Care Examples

- Common scenarios
  - Emphysema
  - Sepsis
  - Low cardiac output
  - Anaemia
- Remember
  - Its all about oxygen delivery
    - 250 ml/min is normal

# Example

Emphysema

# Example

- 72 year old male.
- Smokes 30/day for all his life
- Now presents short of breath

Emphysema

# Measurements

- Output 5 L/min.  Hb  190 g/L
- Arterial Gases
  - Saturation 80%
  - Pressure 50 mmHg
- Venous Gases
  - Saturation 60%
  - Pressure 31 mmHg

Emphysema

# Calculations

- Oxygen Delivered:
  - 205 mL/L x 5 L/min = 1.02 L $O_2$/min
- Oxygen Returned
  - 154 mL/L * 5 L/min = 0.77 L $O_2$/min
- Oxygen Used
  - 250 ml oxygen per minute

Emphysema

# Conclusion

- Lung disease is associated with
- Low saturations and oxygen pressures
- Polycythaemia as compensation
- Normal uptake

# Example

sepsis

# Example

- 24 year old male – IV drug user
- Presents with fever, tachycardia and hypotension.
- Admitted to ICU, swan ganz inserted

Sepsis

# Measurements

- Output 12 L/min.  Hb  150 g/L
- Arterial Gases
  - Saturation 90%
  - Pressure 80 mmHg
- Venous Gases
  - Saturation 50%
  - Pressure 28 mmHg

sepsis

# Calculations

- Oxygen Delivered:
  - 180 mL/L x 12 L/min = 2.1 L $O_2$/min
- Oxygen Returned
  - 100 mL/L * 12 L/min = 1.2 L $O_2$/min
- Oxygen Used
  - 900 ml oxygen per minute

sepsis

# Conclusion

- Sepsis is associated with
  - High cardiac outputs
  - Low mixed venous returns
  - High oxygen utilisation
- Low $SaO_2$ with lung involvement

# Example

Low Output

# Low Output

- 55 year old man post AMI
- No other medical history
- Hypotensive and tachycardic

Low Output

# Measurements

- CO 2.5 L/min  Hb 150
- Arterial Gases
  - Saturation 97%
  - Pressure 100 mmHg
- Venous Gases
  - Saturation 50%
  - Pressure 29 mmHg

Flow Output

# Calculations

- Oxygen Delivered:
  - 195 mL/L x 2.5 L/min = 500 mL $O_2$/min
- Oxygen Returned
  - 100 mL/L * 2.5 L/min = 250 L $O_2$/min
- Oxygen Used
  - 250 ml oxygen per minute

Low Output

# Conclusion

- Low output states are associated with
  - Normal arterial saturation and content
- The venous side is abnormal
  - Low mixed venous saturation
- If you halve the cardiac output
  - Oxygen extraction doubles
  - Total oxygen delivery is maintained

# Example

Anaemia

# Example

- 25 year old woman post partum haemorrage
- No other medical history
- Normotensive and tachycardic

Anaemia

# Measurements

- CO 10 L/min  Hb 37
- Arterial Gases
  - Saturation 97%
  - Pressure 100 mmHg
- Venous Gases
  - Saturation 50%
  - Pressure 29 mmHg

Anaemia

# Calculations

- Oxygen Delivered:
  - 50 mL/L x 10 L/min = 500 mL $O_2$/min
- Oxygen Returned
  - 25 mL/L * 10 L/min = 250 L $O_2$/min
- Oxygen Used
  - 250 ml oxygen per minute

Anaemia

# Conclusion

- Anaemia states are associated with
  - Normal arterial saturations but low content
- The venous side is abnormal
  - Low mixed venous saturation
  - Very low mixed venous content
- If you reduce oxygen content in blood
  - Output and extraction increase

# Critical Care Examples

- Common scenarios
  - Emphysema/Sepsis/Low output/Anaemia
- Low arterial saturations matter when extraction is high
  - Anaemia
  - Low output states
  - High $O_2$ demand (sepsis)

# Oxygenation Summary

- Physiology
- Assessment of oxygenation
- Oxygen Flux equations
- Examples

veltman.org/education/ABG/