# Respiration Module

Session 4 – Carbon dioxide in blood

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# Carbon dioxide in blood

- $CO_2$ is more soluble than oxygen
- but also reacts chemically with water

# Carbon dioxide in blood

- there is much more $CO_2$ in blood than oxygen
- both more dissolved
- and more reacted chemically

# Carbon dioxide in arterial blood

- there is almost three times as much $CO_2$ in arterial blood as there is oxygen
- why?

# Acid base balance

- $CO_2$ is a major part of the system controlling pH of blood
- much more important process than its transport from tissues to lungs
- therefore consider first $CO_2$ in arterial blood

# Dissolution of $CO_2$ in water

- at a $pCO_2$ of 5.3 kpa
- water dissolves 1.2 $mmol.l^{-1}$
- dissolved $CO_2$ can then react with water in different components of blood

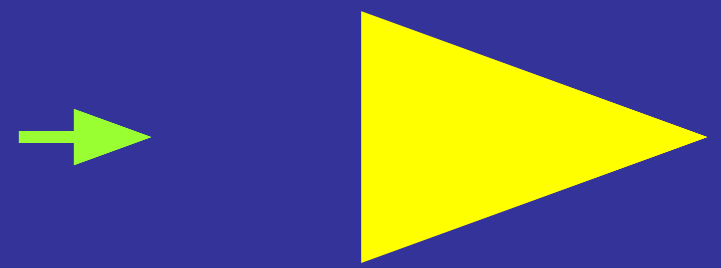
# $CO_2$ in plasma

- dissolved $CO_2$ reacts with water to form
- $H^+$ and $HCO_3^-$
- reaction reversible
- amount reacting depends on concentrations of reactants and products

[Dissolved $CO_2$] [$HCO_3^-$]

$CO_2 + H_2O \rightarrow H^+ + HCO_3^-$

1.2 $mmol.l^{-1}$ 25 $mmol.l^{-1}$



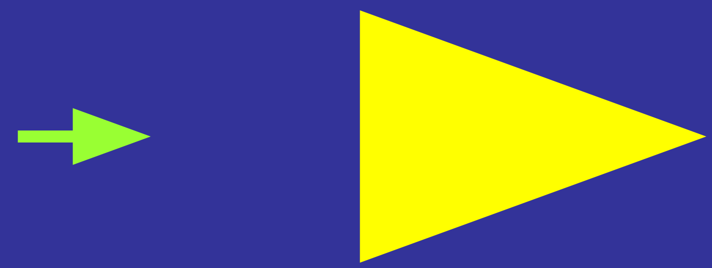
# pH of plasma

- depends on how much $CO_2$ reacts to form $H^+$
- which depends on [dissolved $CO_2$ ]
- pushing the reaction one way
- and $[HCO_3^-]$
- pushing it the other

**[Dissolved $CO_2$]** **$[HCO_3^-]$**

**$CO_2 + H_2O$** **$H^+ + HCO_3^-$**

**1.2 $mmol.l^{-1}$** **25 $mmol.l^{-1}$**



# Dissolved $CO_2$

- depends directly on $pCO_2$
- if $pCO_2$ rises pH will fall
- if $pCO_2$ falls pH will rise

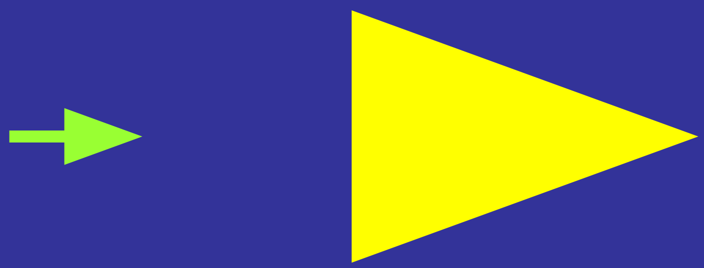
# Hydrogen carbonate in plasma

- plasma has 25mmol.l$^{-1}$ hydrogen carbonate
- not from $CO_2$ in plasma (sodium hydrogen carbonate)
- stops nearly all dissolved $CO_2$ from reacting
- so pH is alkaline

| [Dissolved $CO_2$] | [$HCO_3^-$] |
| --- | --- |

$$CO_2 + H_2O \rightarrow H^+ + HCO_3^-$$

| 1.2 mmol.l$^{-1}$ | 25 mmol.l$^{-1}$ |
| --- | --- |



# Henderson Hasselbalch equation

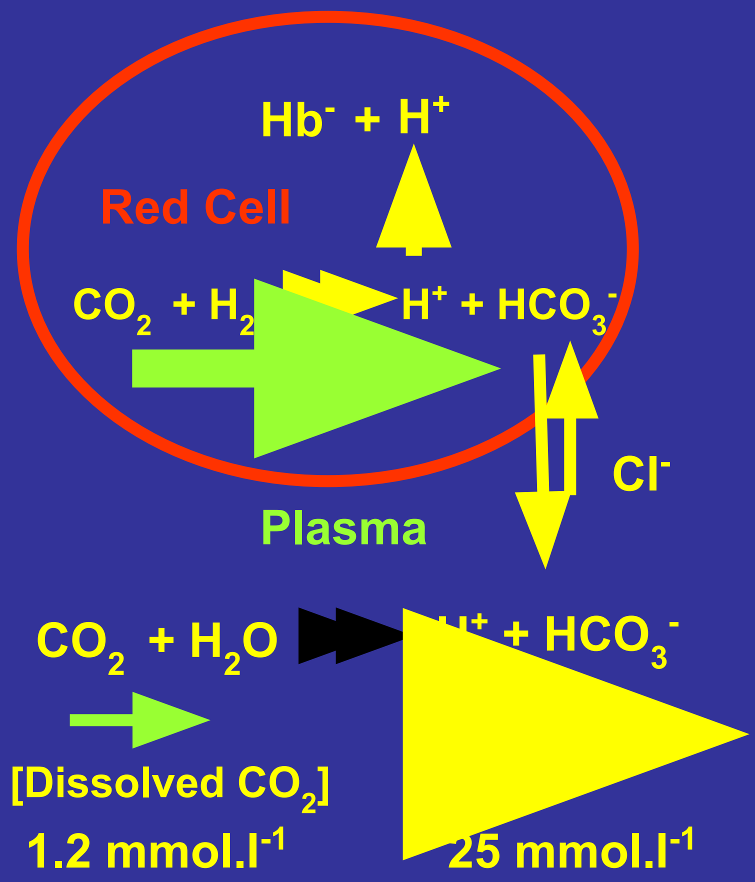
- the above in maths
- $pH = pK + \log([HCO_3^-]/(pCO_2 \times 0.23))$
- $pK = 6.1$
- 20 times as much hydrogen carbonate as dissolved $CO_2$
- $\log 20 = 1.3$
- $pH = 6.1 + 1.3 = 7.4$

# In arterial blood

- the $pCO_2$ is a critical determinant of pH
- but so is $[HCO_3^-]$
- where does the hydrogen carbonate come from?

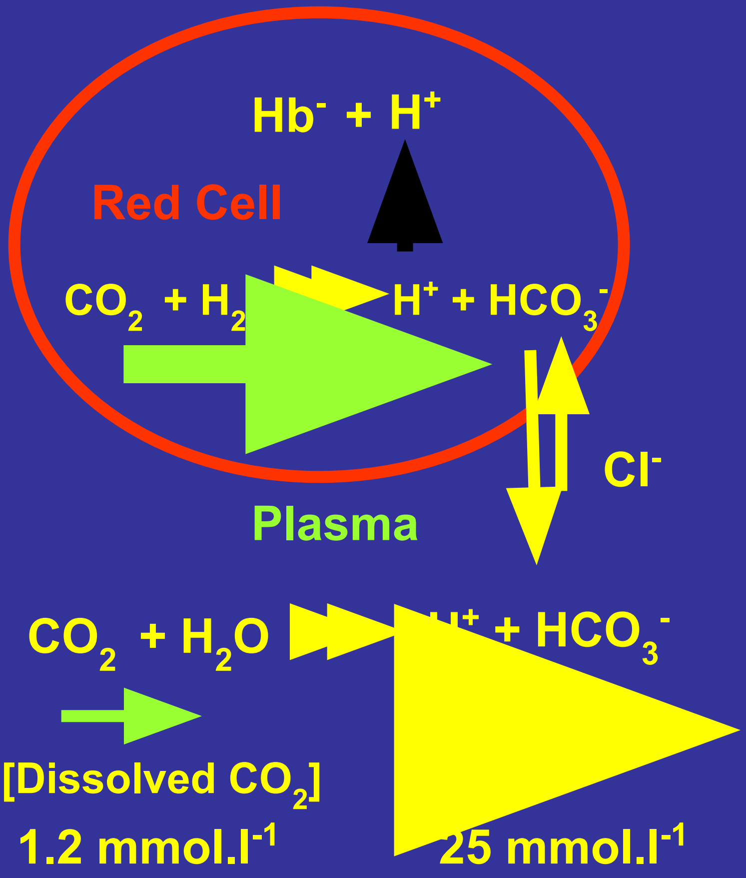
# Reactions of $CO_2$ in the red cell

- dissolved $CO_2$ reacts with water
- but now one of the products removed
- $H^+$ binds to haemoglobin
- so lots of $CO_2$ reacts
- and lots of hydrogen carbonate formed



# Reactions of $CO_2$ in the red cell

- hydrogen carbonate leaves red cell
- in exchange for inward movement of chloride
- forming the 25 mmol.l$^{-1}$ of $HCO_3^-$ in plasma



# So the pH of plasma

- depends on the ratio of
- the reaction of $CO_2$ in the red cell
- to the reaction of $CO_2$ in plasma

# Plasma hydrogen carbonate

- does not change much with $pCO_2$
- because the reactions of $CO_2$ in the red cell are mostly determined
- by how much $H^+$ binds to Hb

# Don’t forget the kidney

- in the whole body the kidney controls the hydrogen carbonate concentration in plasma
- by variable excretion
- so really
- pH = 6.1 + log (kidneys/lungs)

# Buffering

- if the body produces acid
- this reacts with hydrogen carbonate
- to form $CO_2$
- which is breathed out
- stops pH changing too much

# Arterial $pCO_2$

- determined by alveolar $pCO_2$
- determines dissolved $CO_2$
- and so affects pH

# What about venous blood?

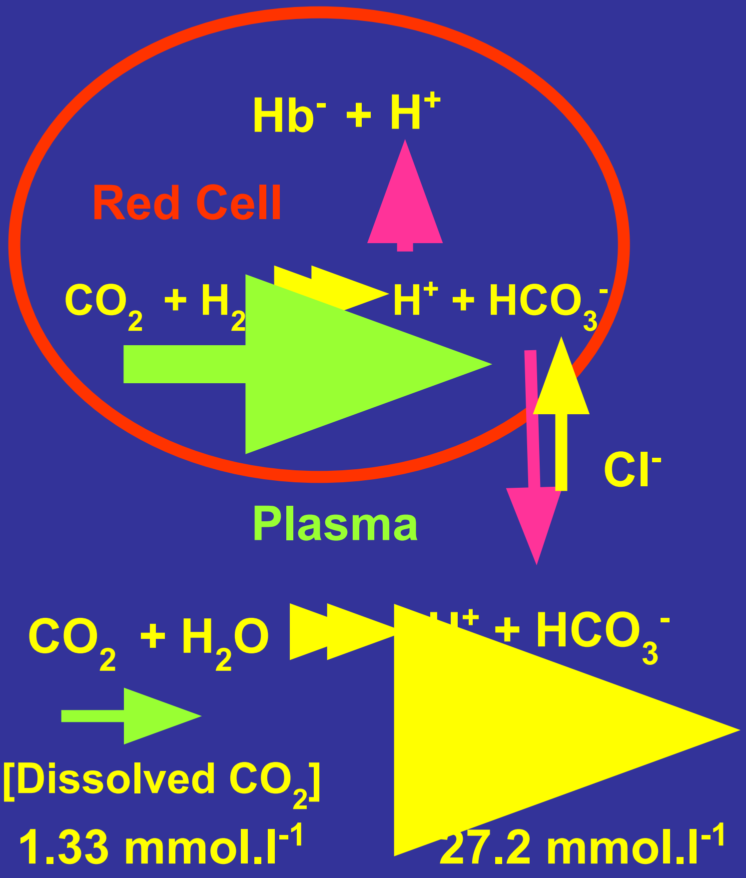
- in venous blood $pCO_2$ is higher
- so more $CO_2$ dissolves
- but

# Buffering of $H^+$ by Hb

- depends on oxygenation
- the more oxygen bound
- the less $CO_2$ is

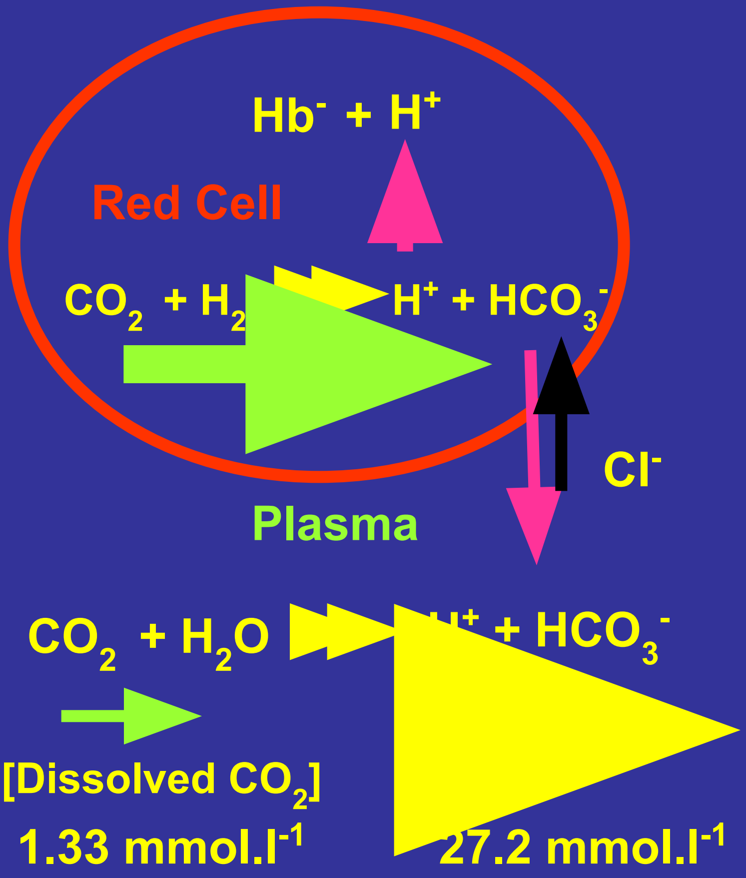
# In venous blood

- Hb has lost oxygen
- so binds more $H^+$
- which forms more $HCO_3^-$
- which is exported to plasma



# Extra $CO_2$ in venous blood

- a little more dissolves
- but much more is converted to hydrogen carbonate
- because Hb binds more $H^+$
- as both $pCO_2$ and $[HCO_3^-]$ increase pH does not change much



# When venous blood reaches the lungs

- Hb picks up oxygen
- so gives up $H^+$
- reacts with hydrogen carbonate
- to form $CO_2$ which is breathed out

# Carbamino compounds

- $CO_2$ also binds directly to proteins
- contributes to $CO_2$ transport
- but not acid base balance
- bit more formed in venous blood because $pCO_2$ higher

# The numbers - arterial blood

- plasma dissolves 0.7 mmol $CO_2$ per litre of blood (plasma only 60% total volume!)
- plasma contains 15.2 mmol $HCO_3^-$ per litre of blood
- cells dissolve 0.3 $mmol.l^{-1}$
- cells have 4.3 $mmol.l^{-1}$ $HCO_3^-$
- blood has 1 $mmol.l^{-1}$ carbaminos

# The total - arterial blood

- contains 21.5 mmol $CO_2$ per litre

# The numbers - venous blood

- plasma dissolves 0.8 mmol $CO_2$ per litre of blood (plasma only 60% total volume!)
- plasma contains 16.3 mmol $HCO_3^-$ per litre of blood
- cells dissolve 0.4 $mmol.l^{-1}$
- cells have 4.8 $mmol.l^{-1}$ $HCO_3^-$
- blood has 1.2 $mmol.l^{-1}$ carbaminos

## The total - venous blood

- contains 23.5 mmol $CO_2$ per litre

# Transported carbon dioxide

- = 23.5 -21.5
- = 2 mmol per litre of blood
- only about 10% of total

# Transported $CO_2$

- 80% travels as hydrogen carbonate
- 11% as carbamino compounds
- 8% as dissolved $CO_2$