Acid-base equilibrium

Physiologic pH

- **Plasma and most extracellular fluids**

$$pH = 7.40 \pm 0.02$$

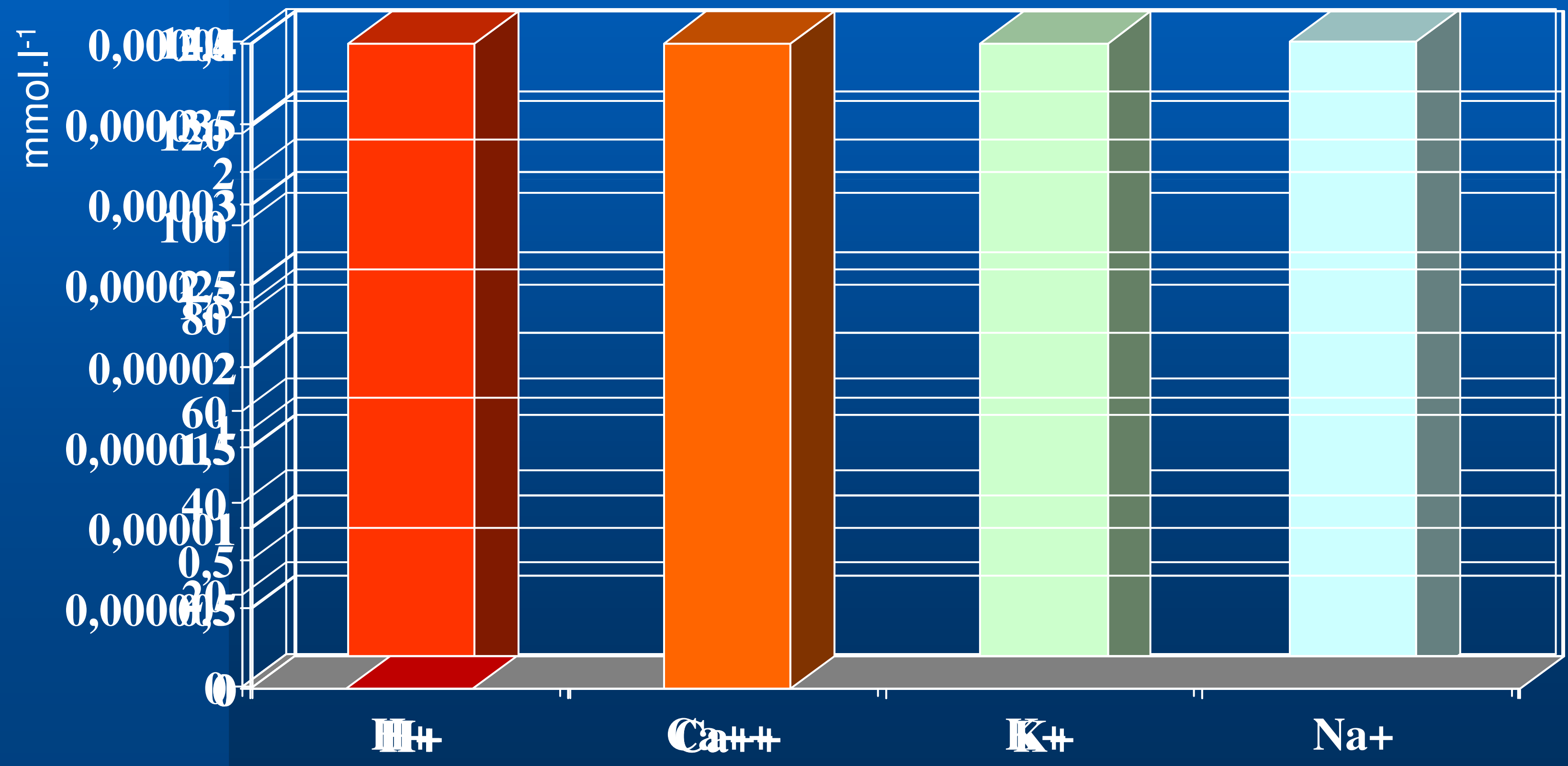
Significance of constant pH

pH influences

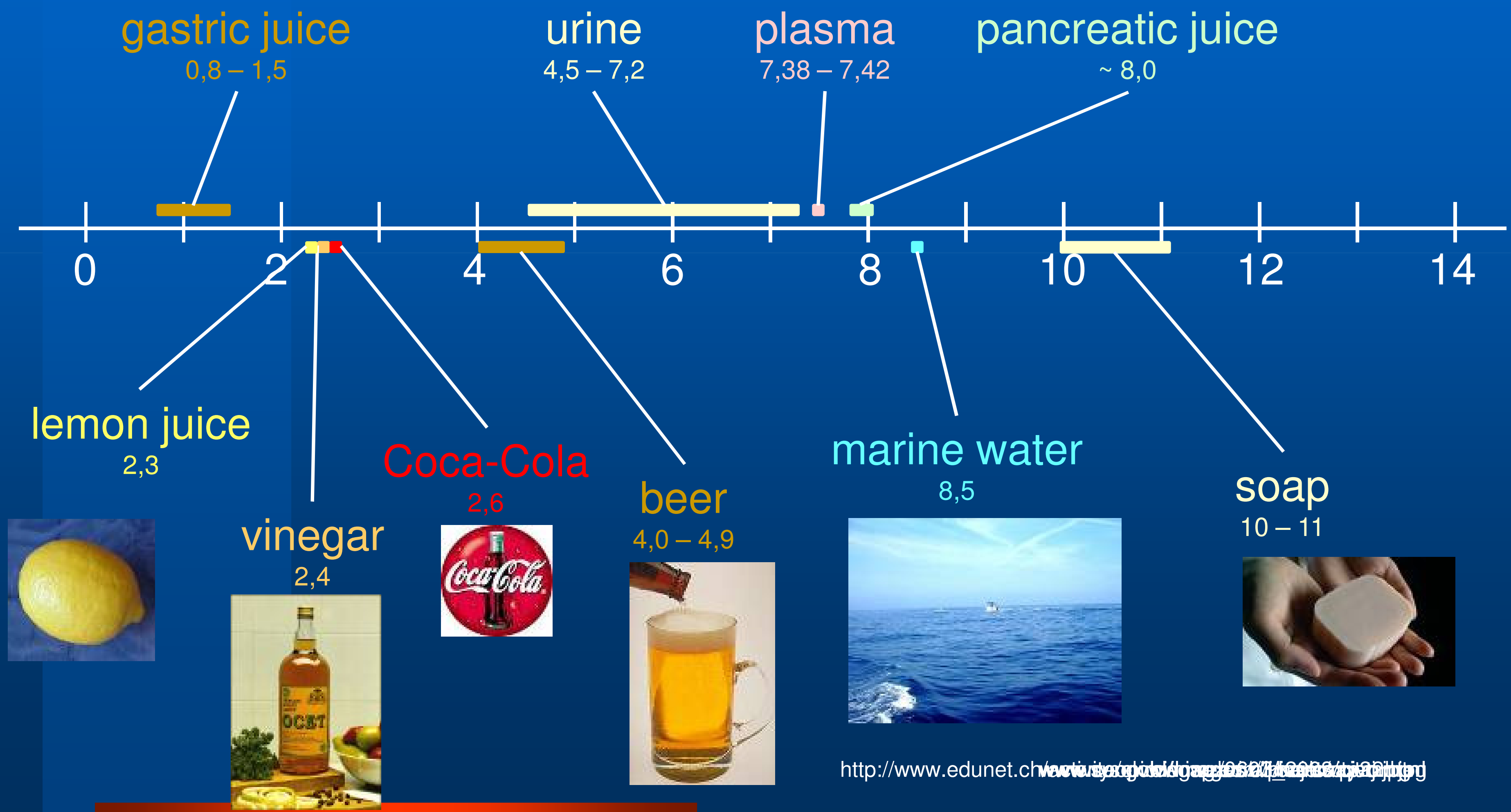
- **properties of proteins**
  - **enzyme activity**
  - **structure of cell components**
- **permeability of membranes**
  - **distribution of electrolytes**

pH < 7.0 or > 7.7 is lethal

H^+ and other cathions



pH



http://www.edunet.ch/...

Proton sources

- **Anaerobic glycolysis**

  $1Glc \rightarrow 2lactate^{-} + 2H^{+}$

- **Lipolysis**

  $TAG \rightarrow 3FA^{-} + glycerol + 3H^{+}$

- **Formation of ketone bodies**

  $FA^{-} \rightarrow \rightarrow acetoacetate^{-} + hydroxybutyrate^{-} + nH^{+}$

Proton sources

- **Oxidation of S-containing AA**
- **Metabolism of org. phosphates**
- **Oxidation of other AA**
- **Ureasynthesis from NH_4^+**

$$CO_2 + 2NH_4^+ \rightarrow \text{urea} + H_2O + 2H^+$$

MV6

Consumption of protones

- **Oxidation of lactate**

$$\text{lactate}^- + 3O_2 + H^+ \rightarrow 3CO_2 + H_2O$$

Anaerobic glycolysis

$$1Glc \rightarrow 2\text{lactate}^- + 2H^+$$

May be separated in time or space

$$2\text{lactate}^- + 2H^+ + 6O_2 \rightarrow 6CO_2 + 2H_2O$$

Oxidation of lactate

Snímek 8

MV6 Udělat ještě jeden obrázek?

Martin Vejražka; 9.4.2006

MV4

Consumption of protones

- **Gluconeogenesis**

  $2lactate^{-} + 2H^{+} \rightarrow Glc$

- **Oxidation of neutral AA**
- **Oxidation of dicarboxylic AA**
- **Oxidation of anions of org. acids**

Snímek 9

MV4 Udělat ještě jeden obrázek?
Martin Vejražka; 9.4.2006

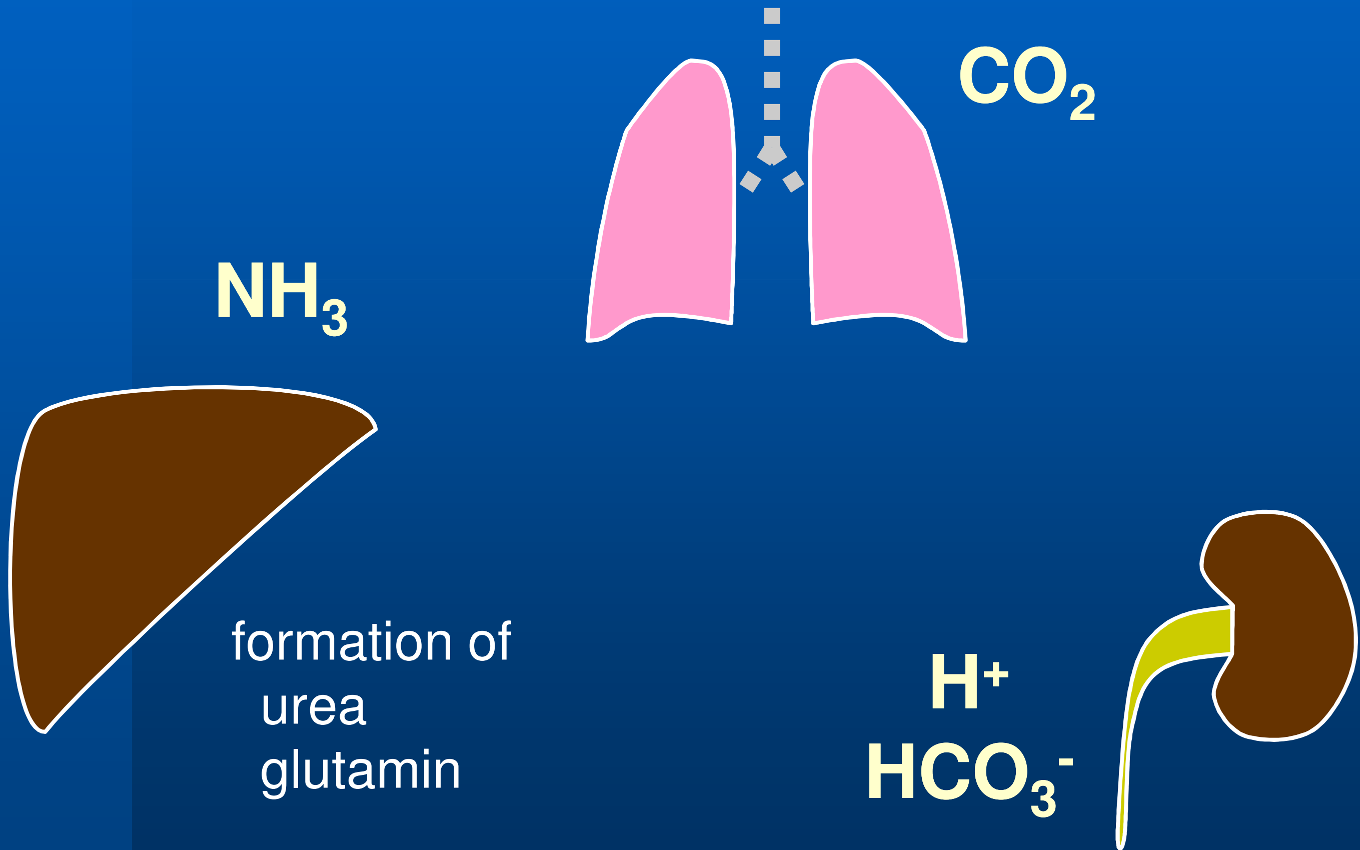
Proton sources

- Food contains
  - Compounds metabolised to organic acids
  - compounds metabolised to sulphuric acid
  - compounds metabolised to phosphoric acid

Maintaining pH

- Fast but incomplete
  – BUFFERS
- Complete but slow
  – CONTROL of METABOLISM respiration, transporting mechanisms…

Maintaining acidity of inner environment



Respiration

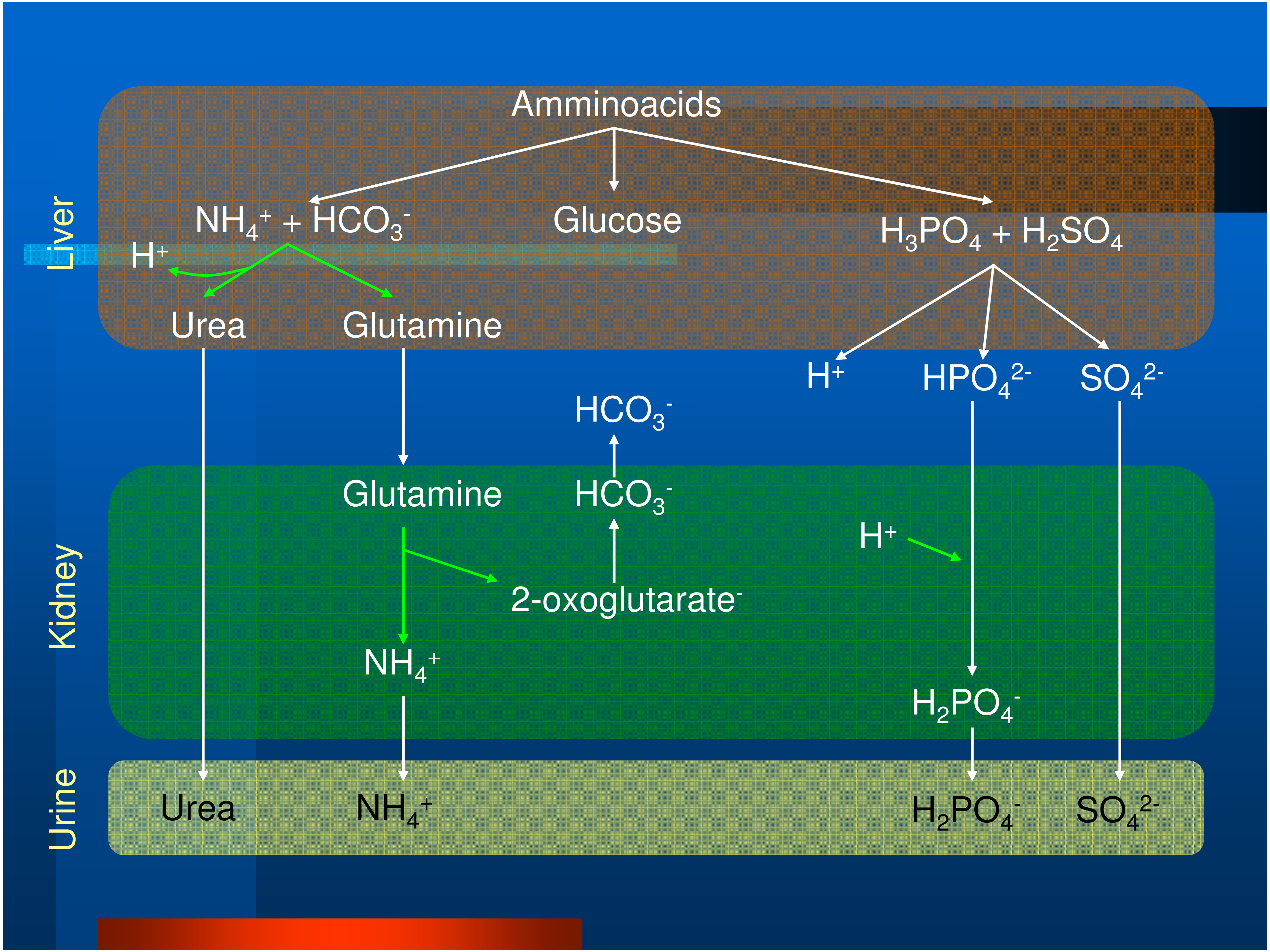
- $CO_2 + H_2O \rightleftharpoons H_2CO_3$

- $\uparrow$ ventilation $\rightarrow \downarrow pCO_2 \rightarrow$ alkalinisation
- $\downarrow$ ventilation $\rightarrow \uparrow pCO_2 \rightarrow$ acidification

Liver

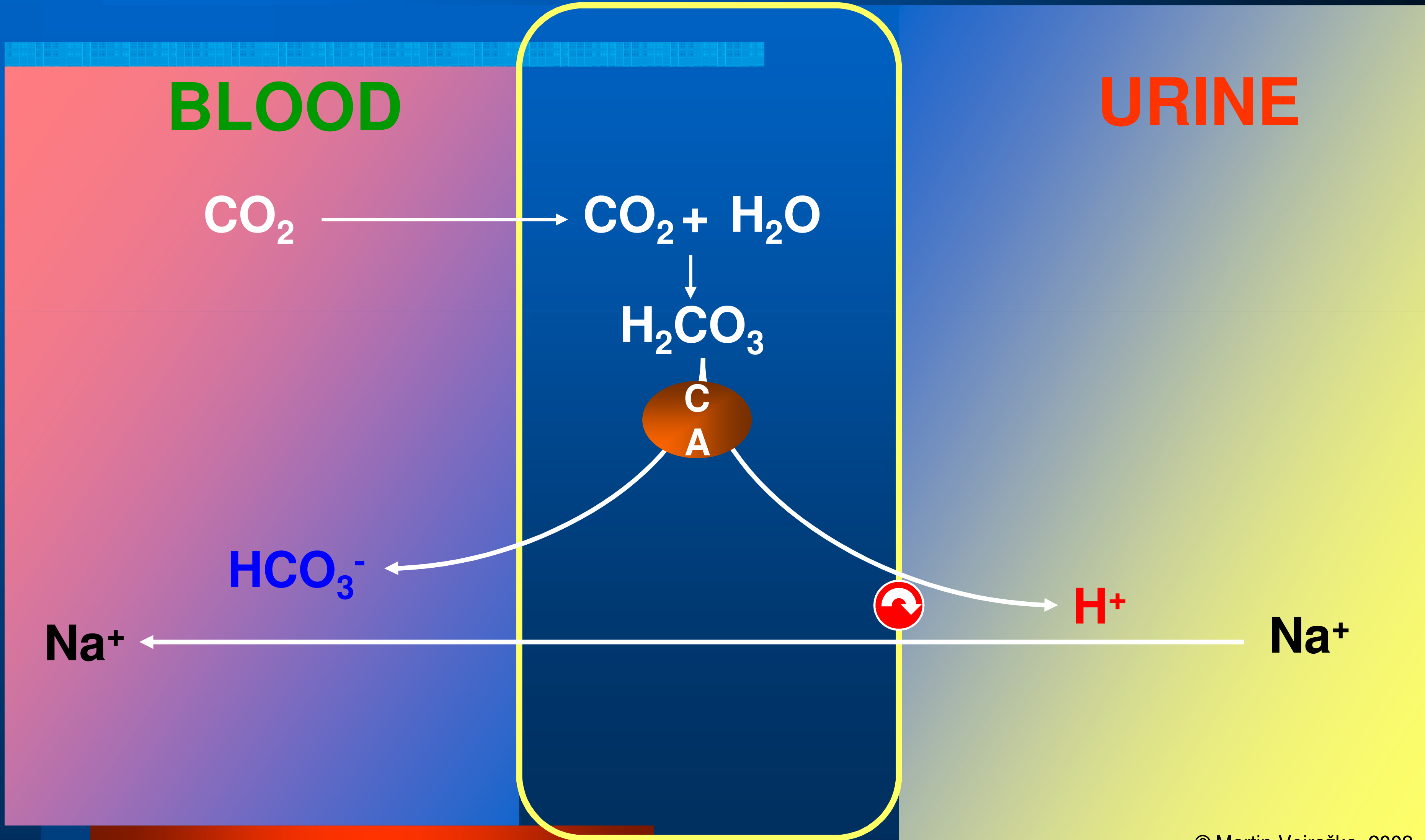
$$CO_2 + 2NH_4^+ \rightarrow urea + 2H^+ + H_2O$$

$$NH_4^+ + Glu^- \rightarrow Gln + H_2O$$

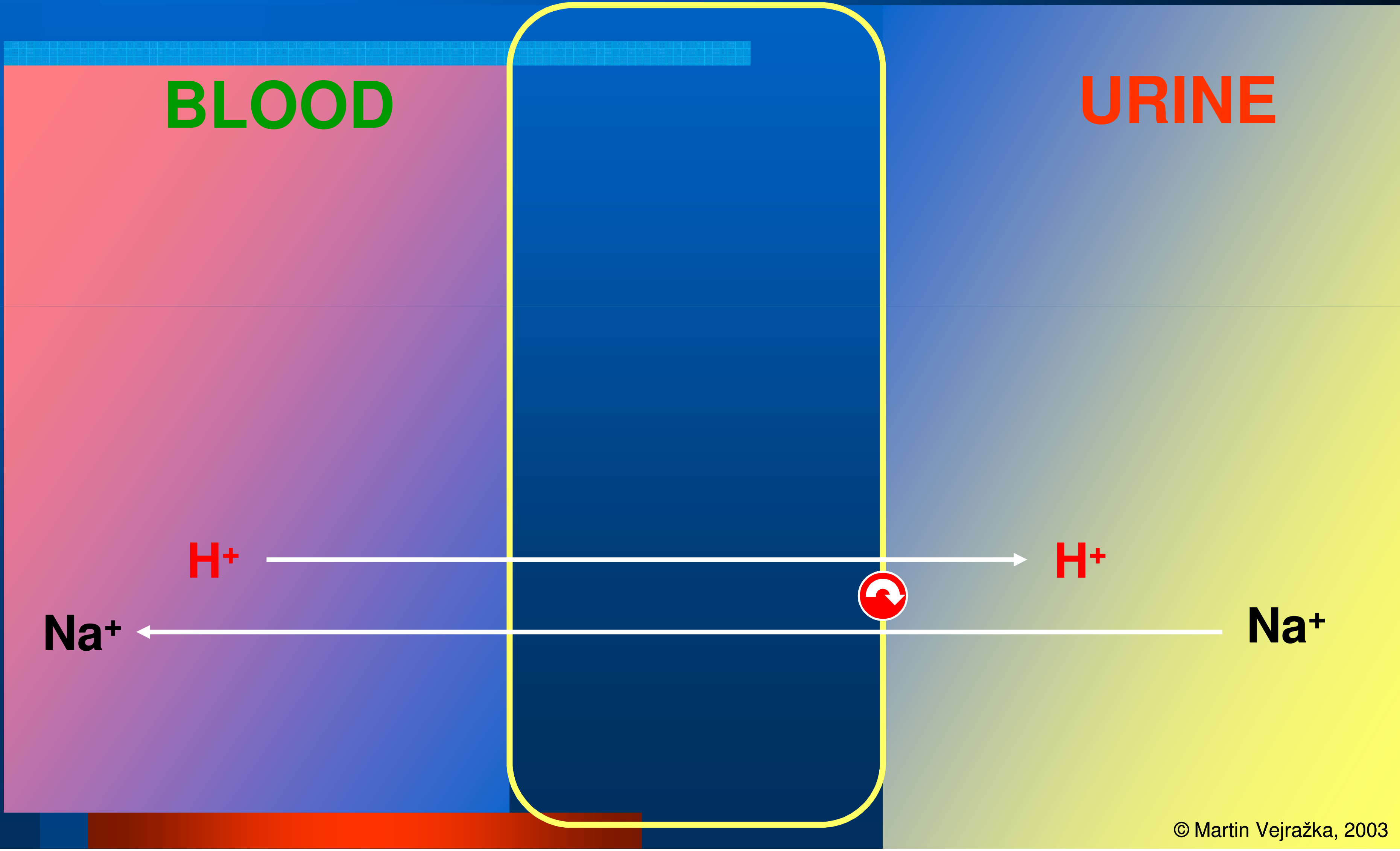


Liver
Kidney
Urine
Amminoacids
NH4+ + HCO3-
Glucose
H3PO4 + H2SO4
H+
Urea
Glutamine
H+
HPO4 2-
SO4 2-
HCO3-
Glutamine
HCO3-
H+
2-oxoglutarate-
NH4+
H2PO4-
Urea
NH4+
H2PO4-
SO4 2-

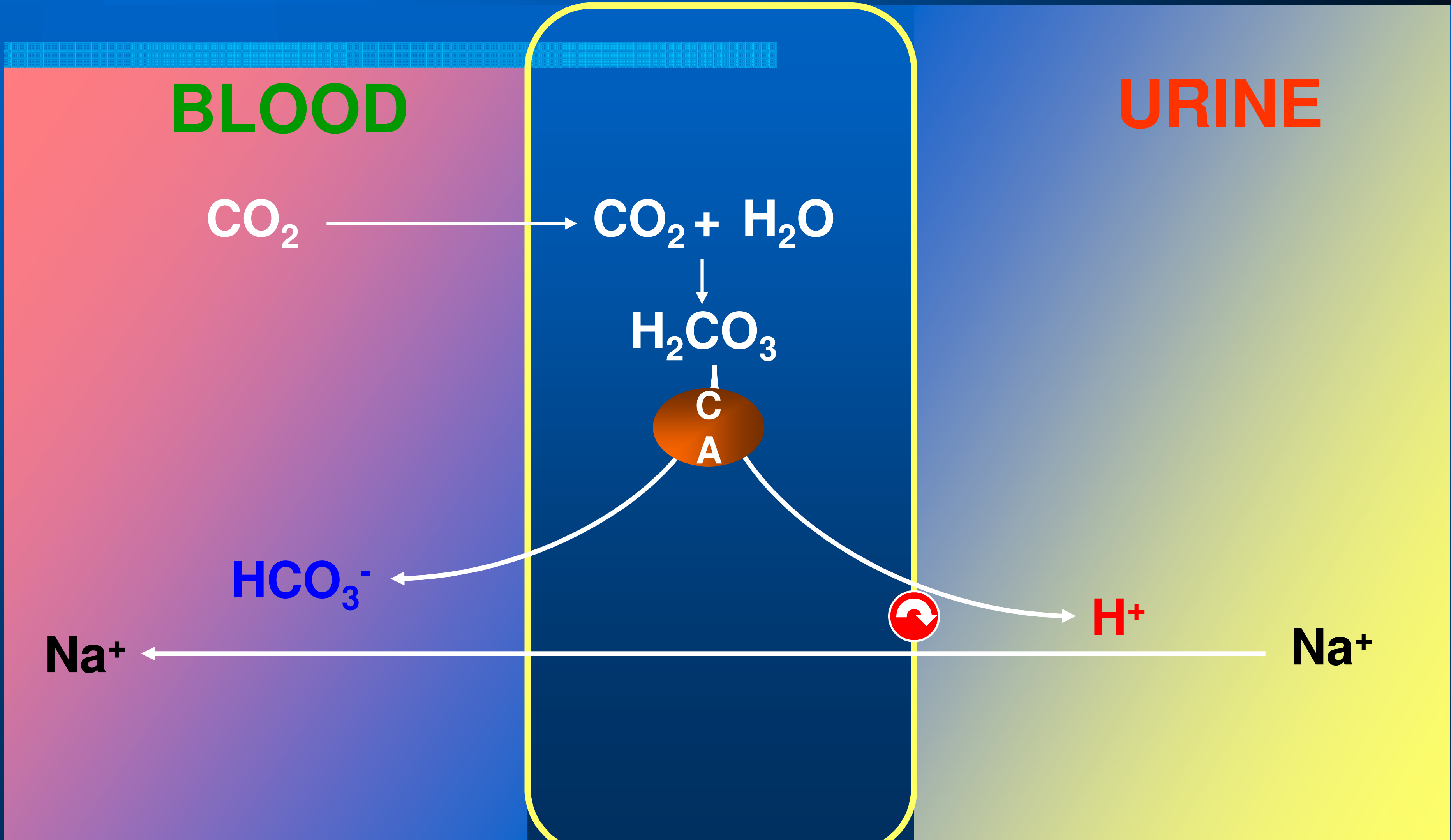
Kidney



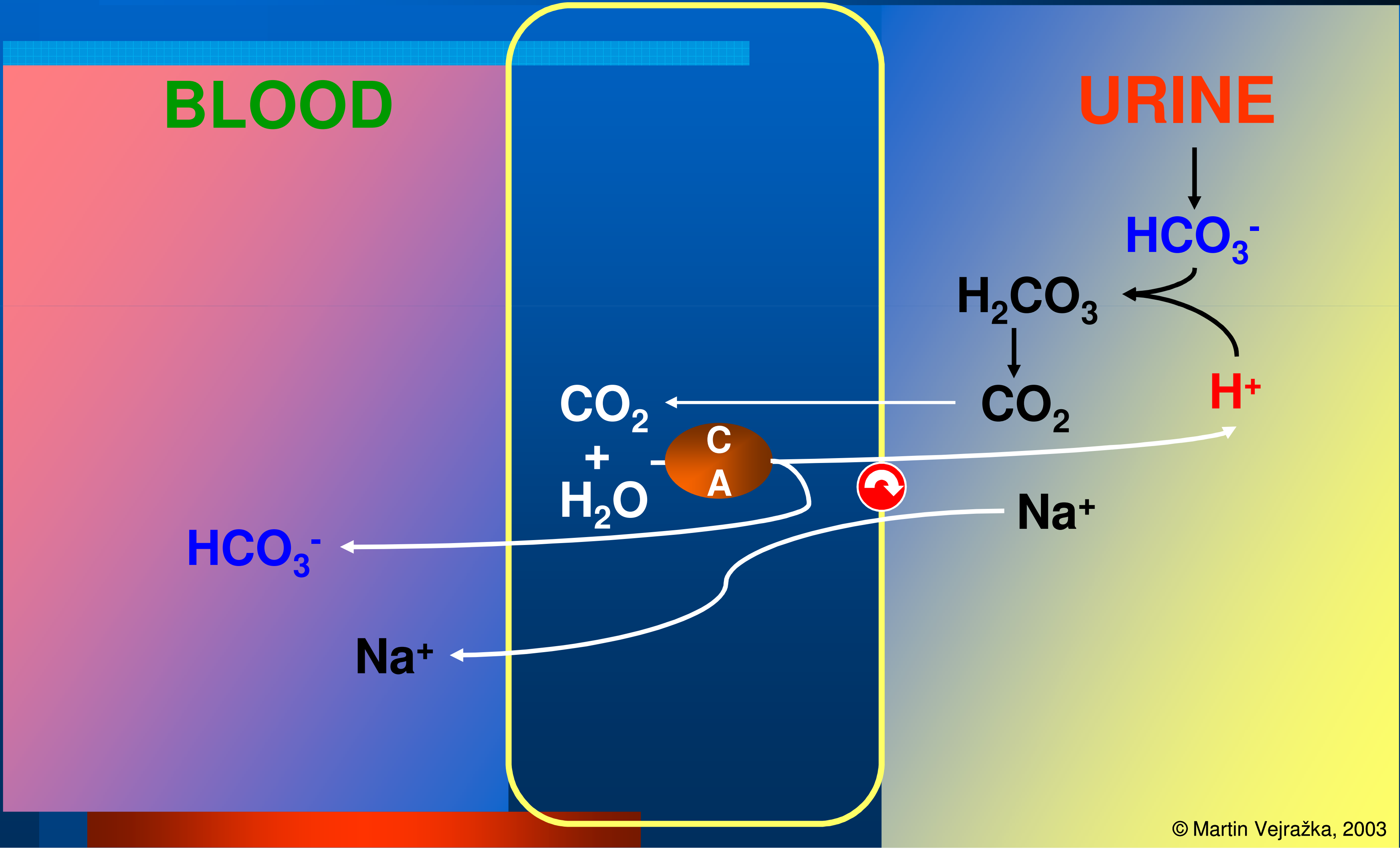
Kidney



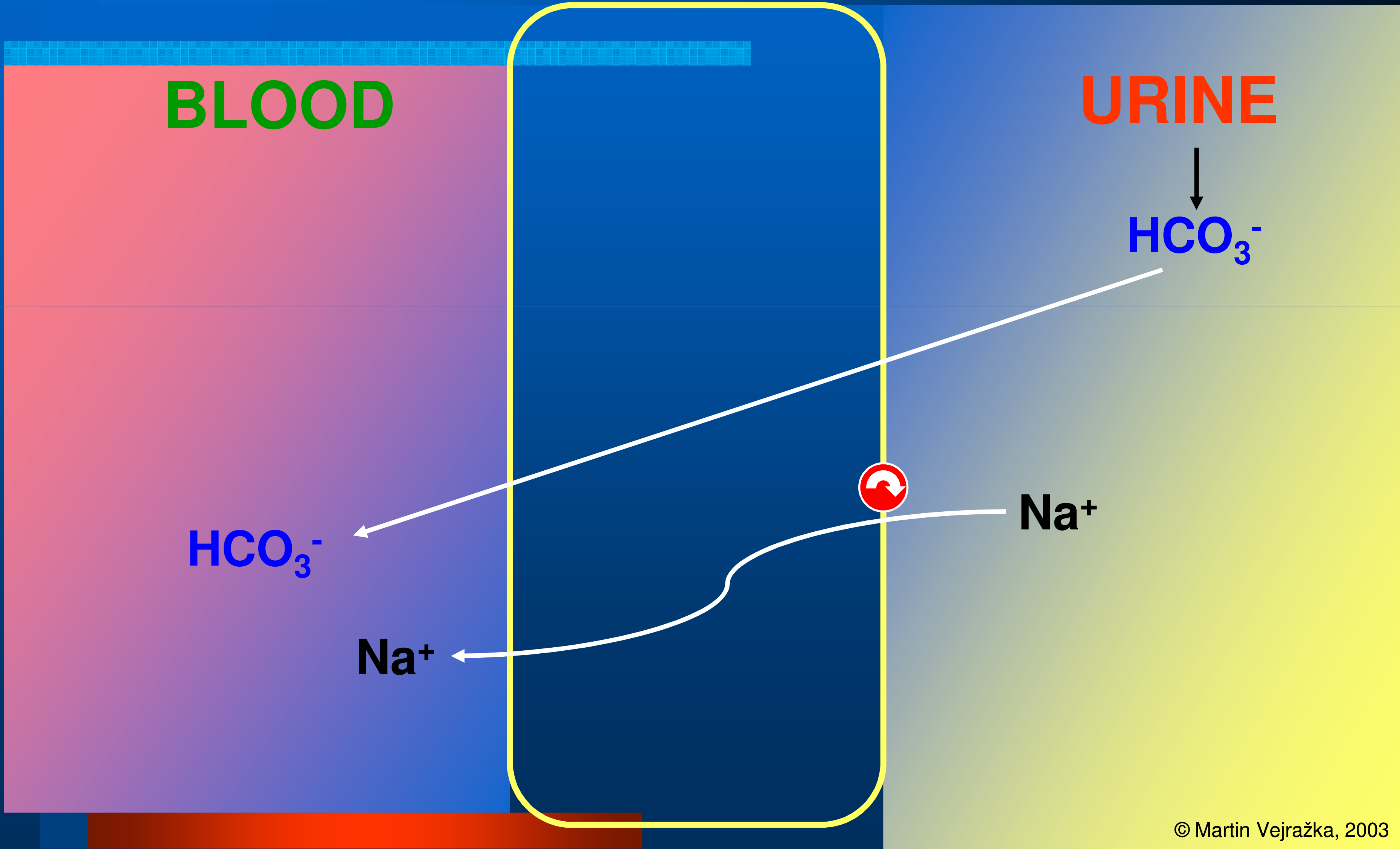
Kidney



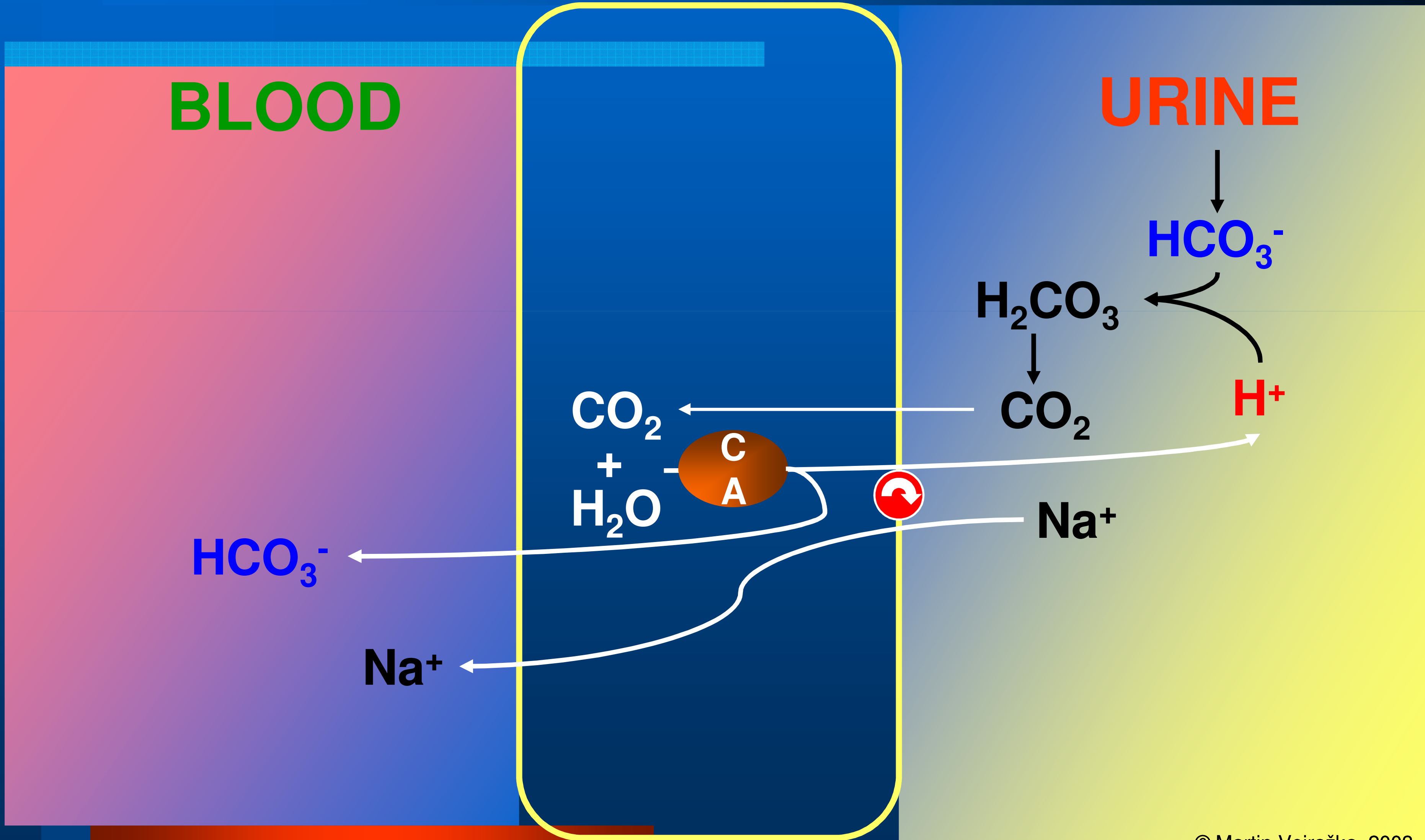
Kidney



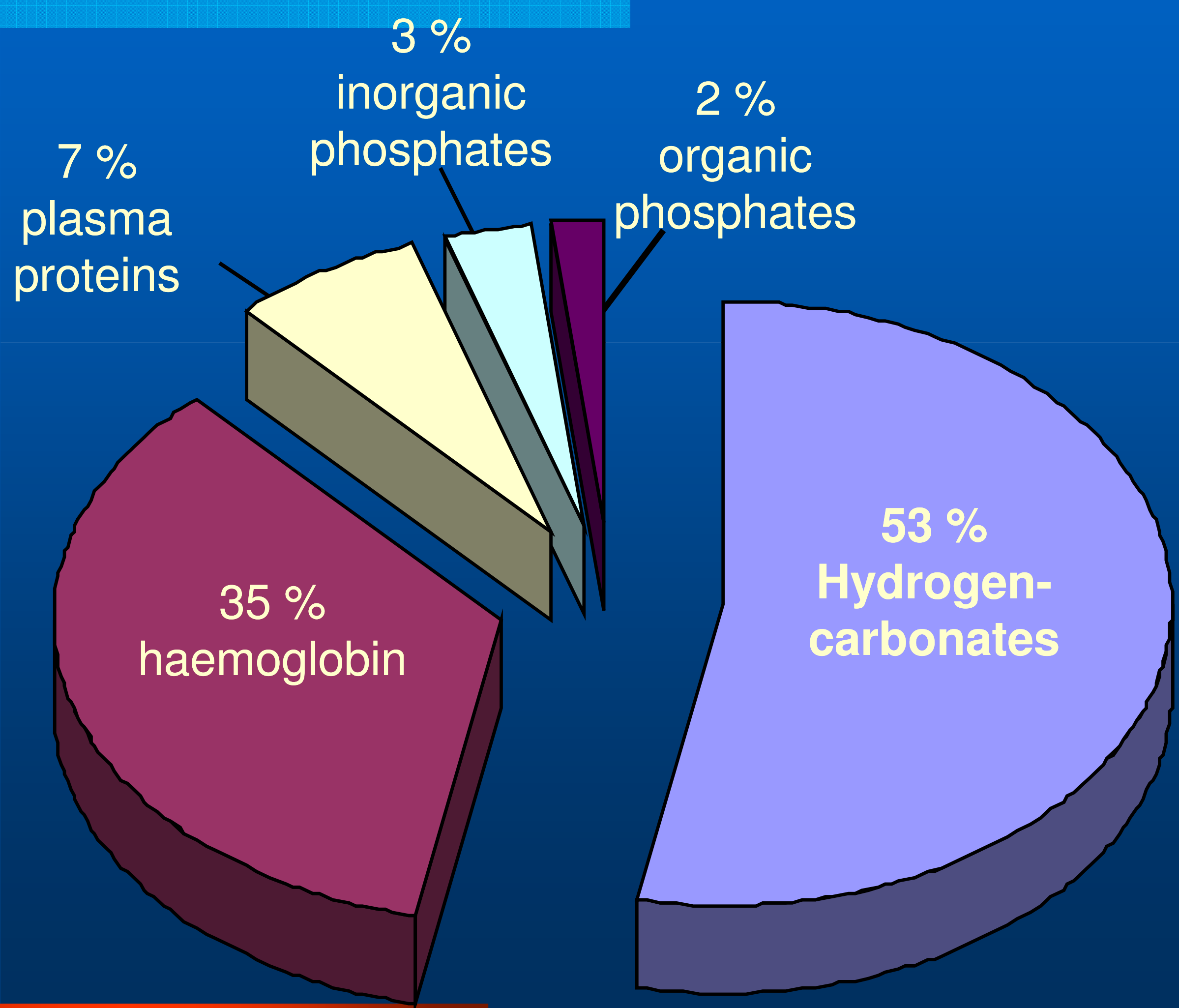
Kidney



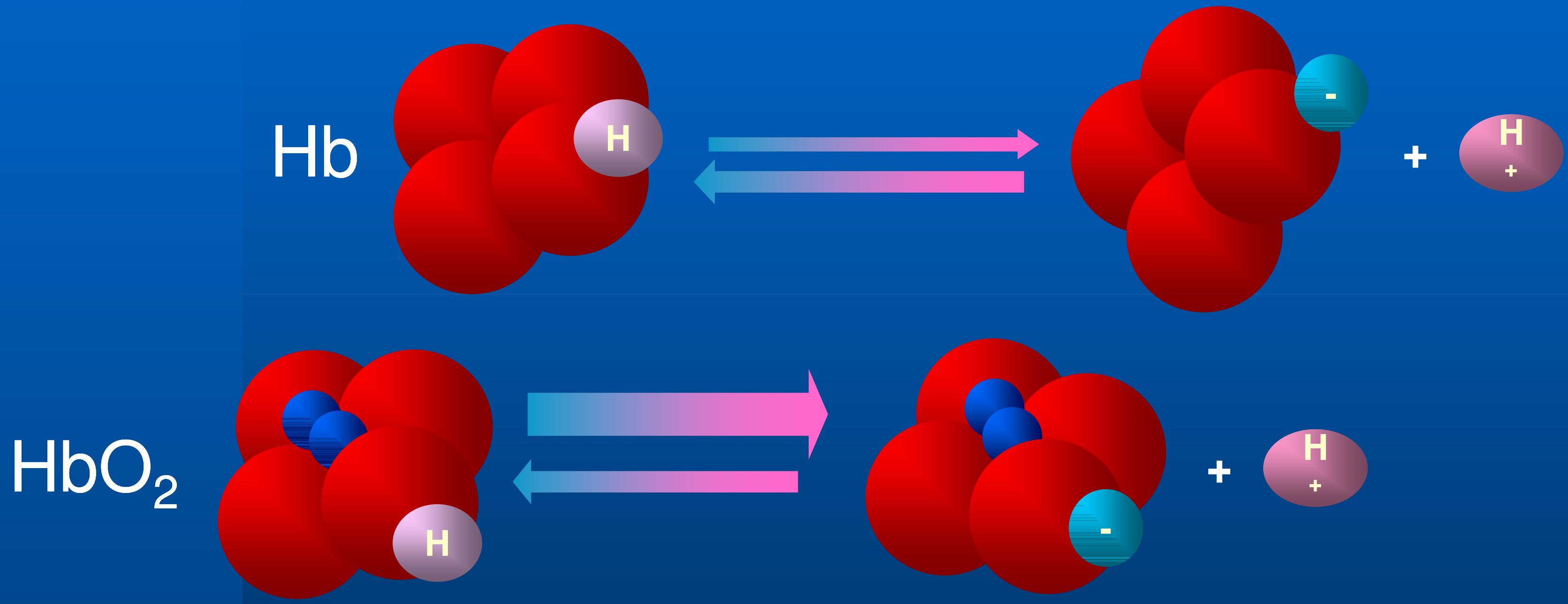
Kidney



Buffers


3 %
inorganic
phosphates
2 %
organic
phosphates
7 %
plasma
proteins
53 %
Hydrogen-
carbonates
35 %
haemoglobin

Haemoglobin buffer



Oxyhaemoglobin is more acidic than desoxyHb

- partially compensates pH change in lungs after exhalation CO_2
- easier to release O_2 in acidic environment (hypoxic tissue)

Bicarbonate buffer

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

Henderson-Hasselbalch equation

$$pH = pK_a + \log \frac{[HCO_3^-]}{[H_2CO_3]}$$

- $pK_a = 6,1$
- $[HCO_3^-] = 24\ mmol.l^{-1}$
- $[H_2CO_3] = 1,2\ mmol.l^{-1}$

In tables:
$pK_a = 6,35$

$$\frac{[HCO_3^-]}{[H_2CO_3]} = 20$$

> 10 !

Henderson-Hasselbalch equation

$$pH = pK_a + \log \frac{[HCO_3^-]}{\alpha \cdot pCO_2}$$

- $pK_a = 6{,}1$
- $[HCO_3^-] = 24\ mmol.l^{-1}$
- $\alpha = 0{,}224\ mmol.l^{-1} / kPa$

$pCO_2 = 5{,}3\ kPa$

Bicarbonate buffer

tissue

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

lungs

kidney

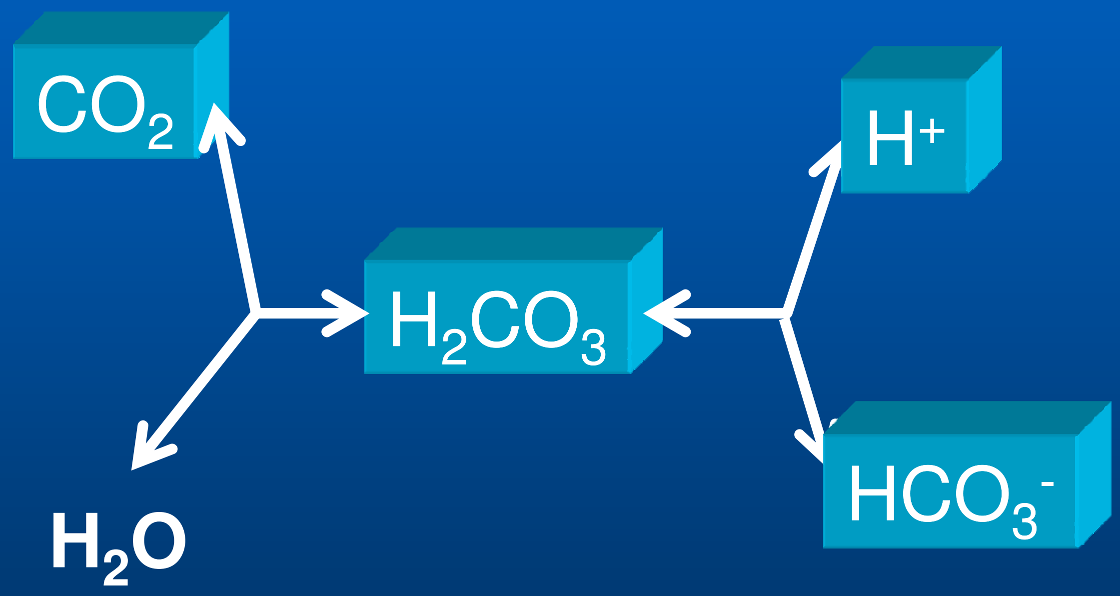
pH change in vomiting

- **loss of ca. 0.5 L of gastric juice, pH 0.8**

  - **w/o buffer pH 7,4 → > 14**
  - **insulated system 7,4 → 7,9**

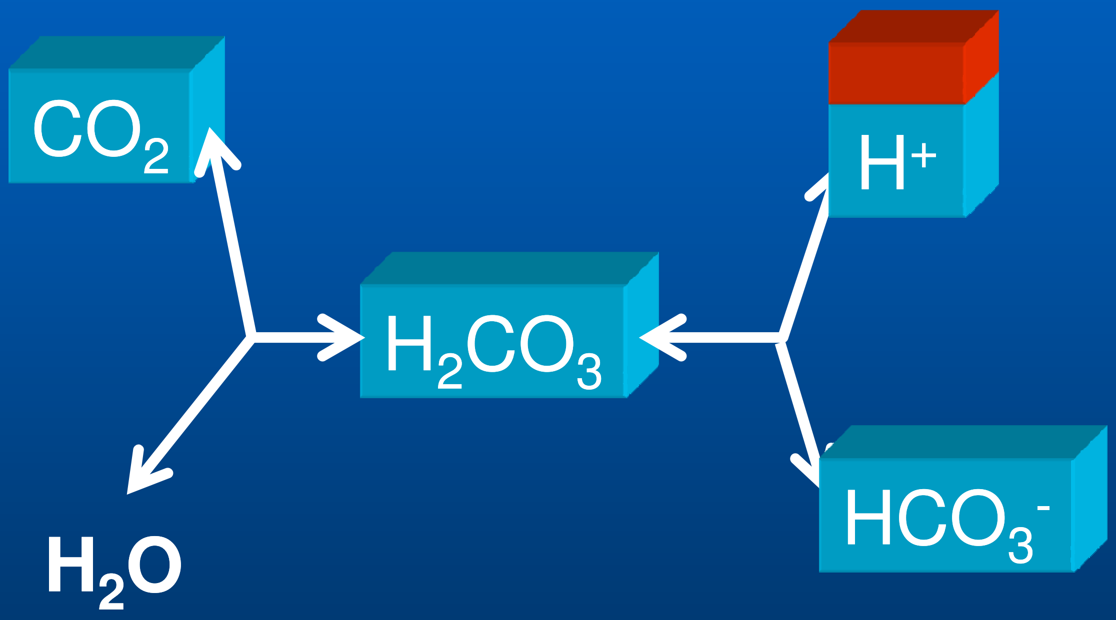
  - **opened system 7,4 → 7,415**

Bicarbonate buffer

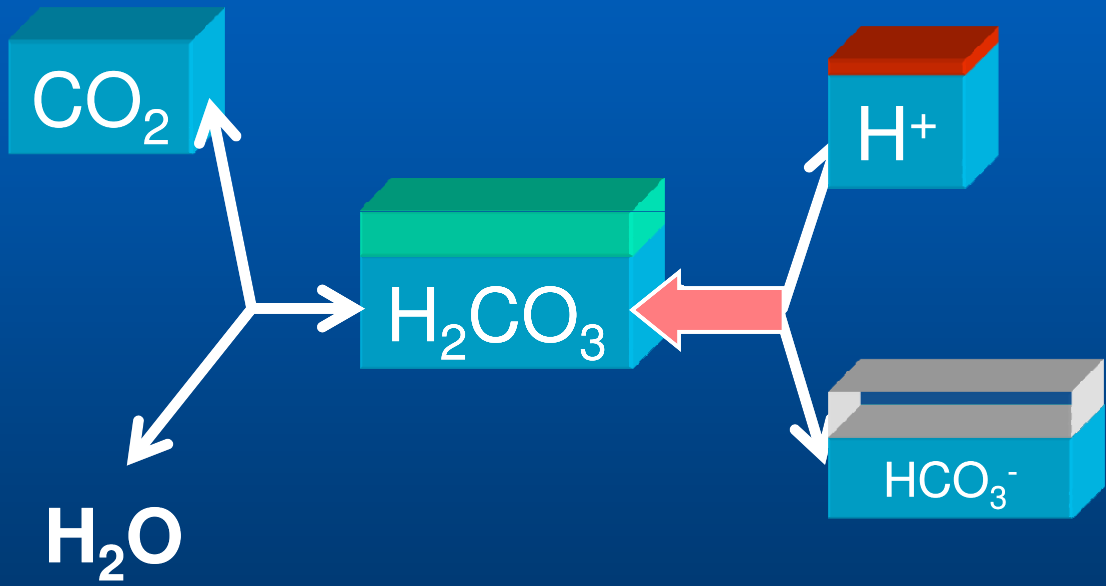


N.B.: Boxes differ in scale!

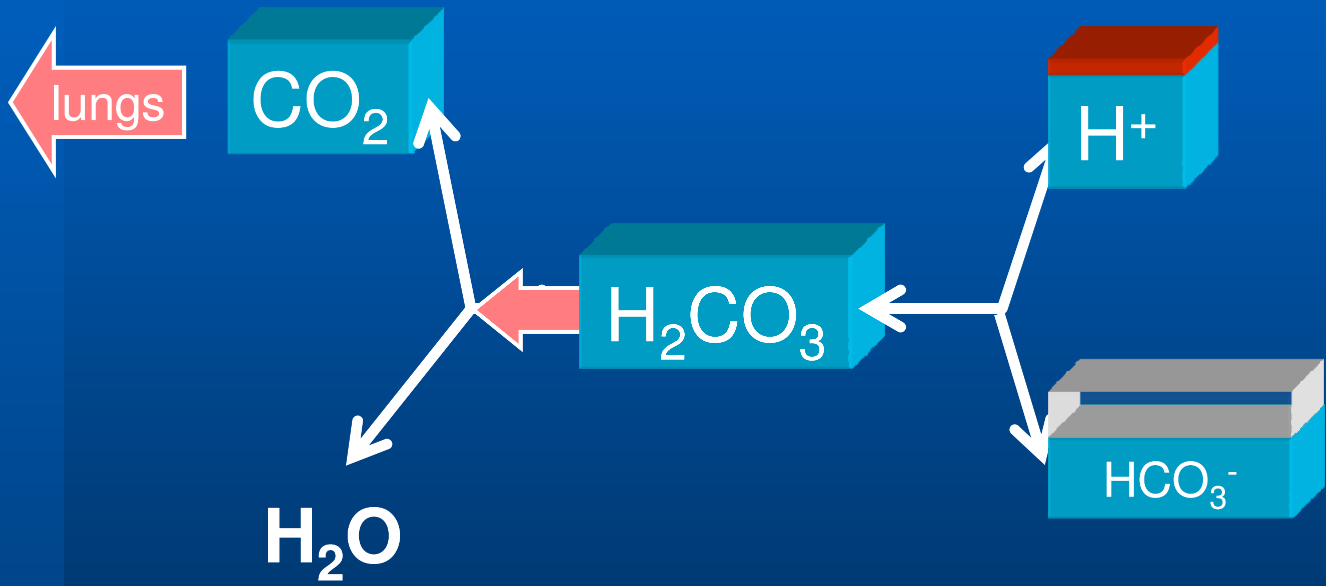
Bicarbonate buffer



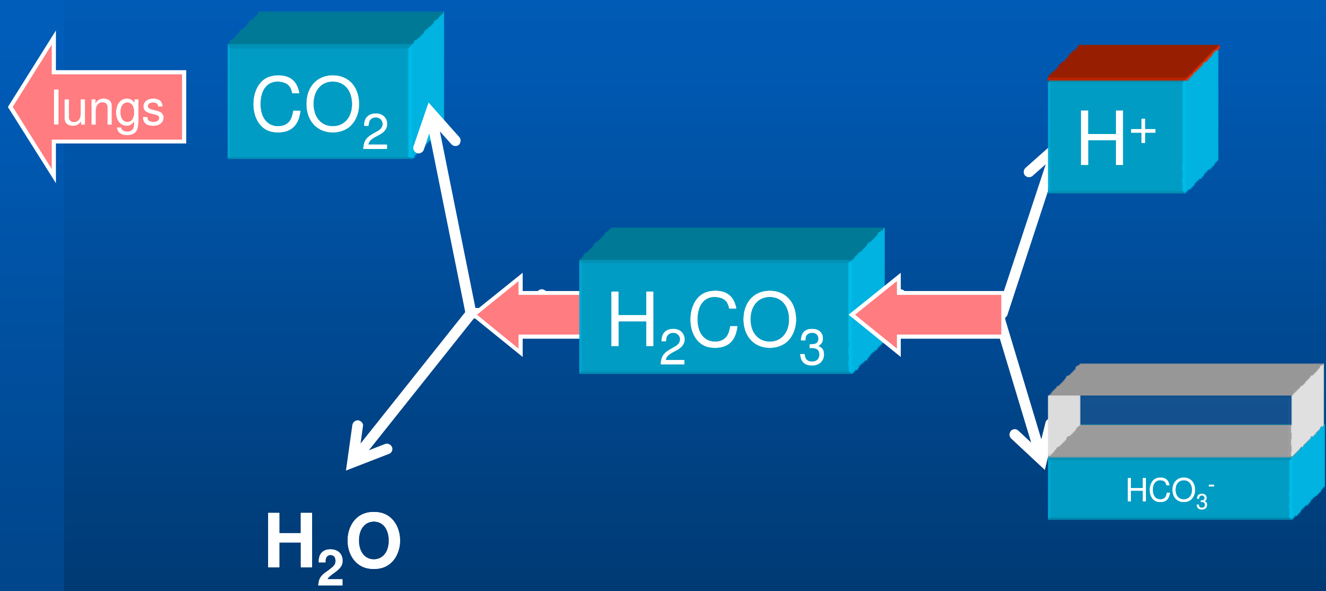
Bicarbonate buffer



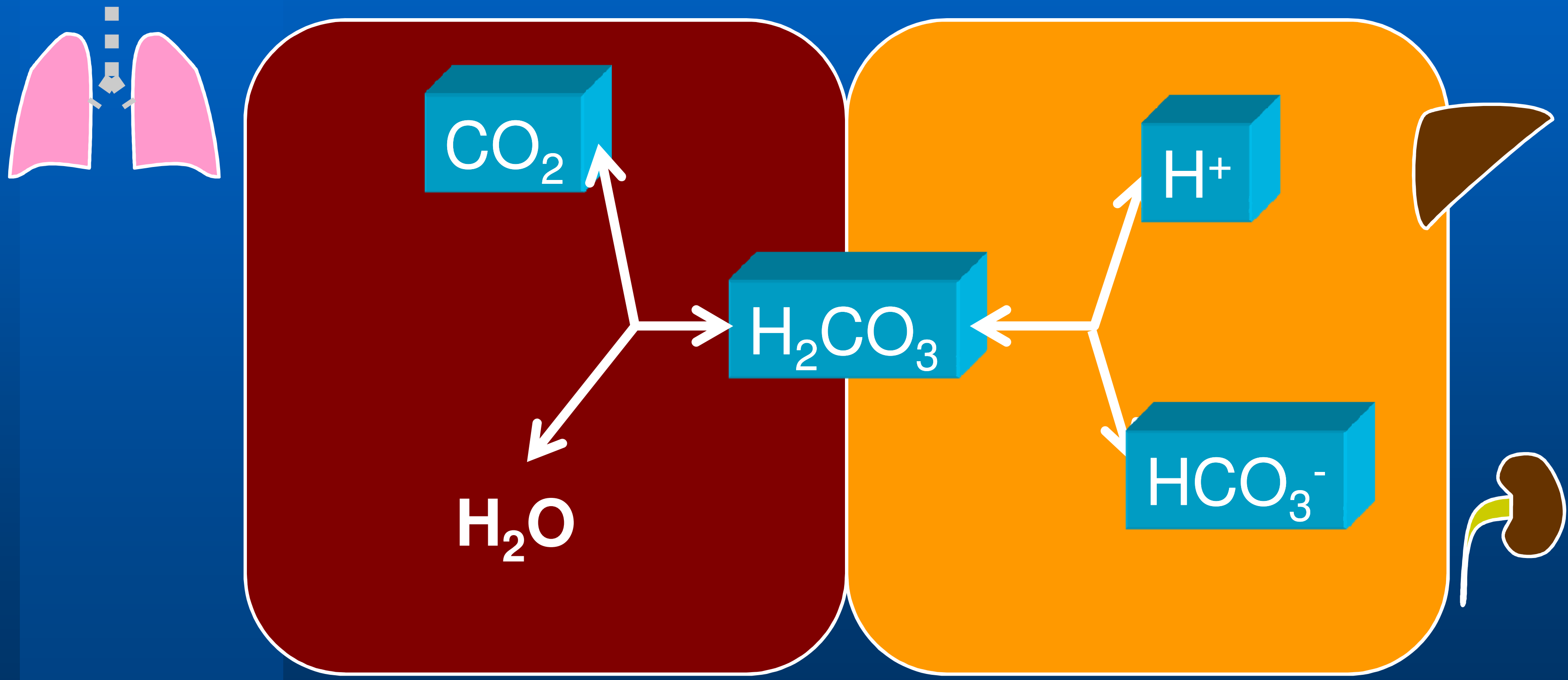
Bicarbonate buffer



Bicarbonate buffer



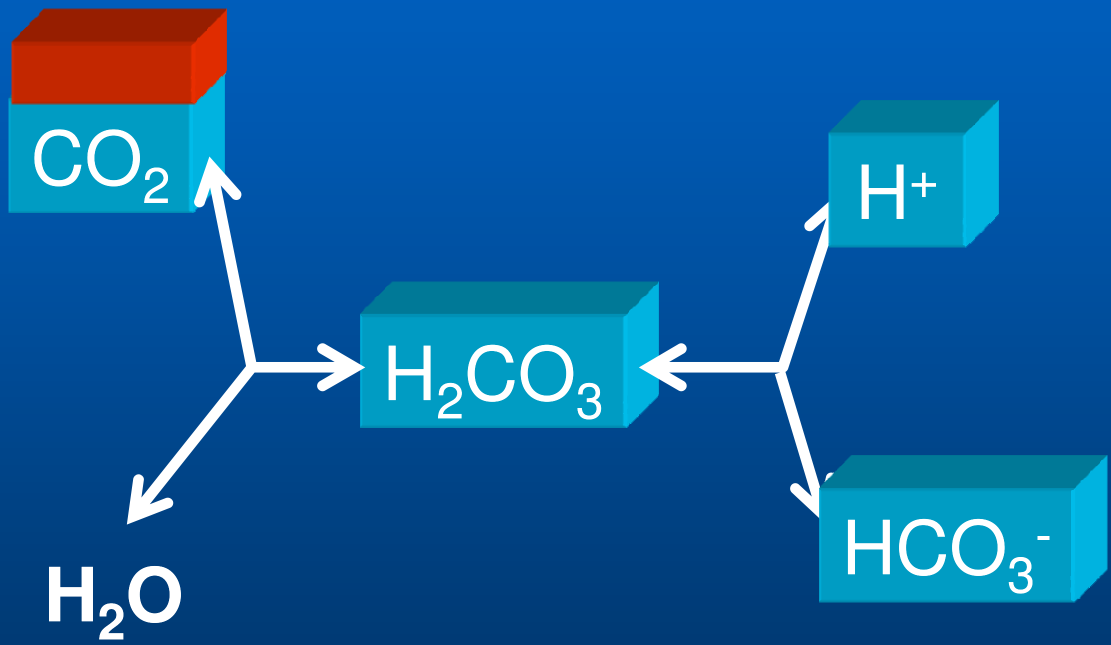
Bicarbonate buffer



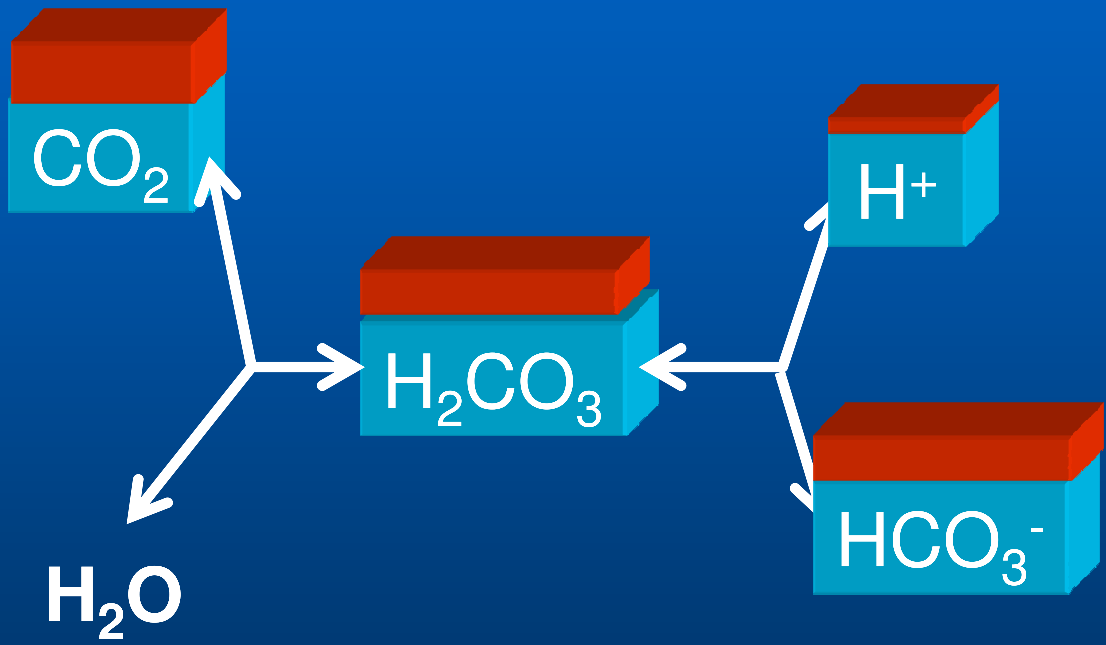
Respiratory part

Metabolic part

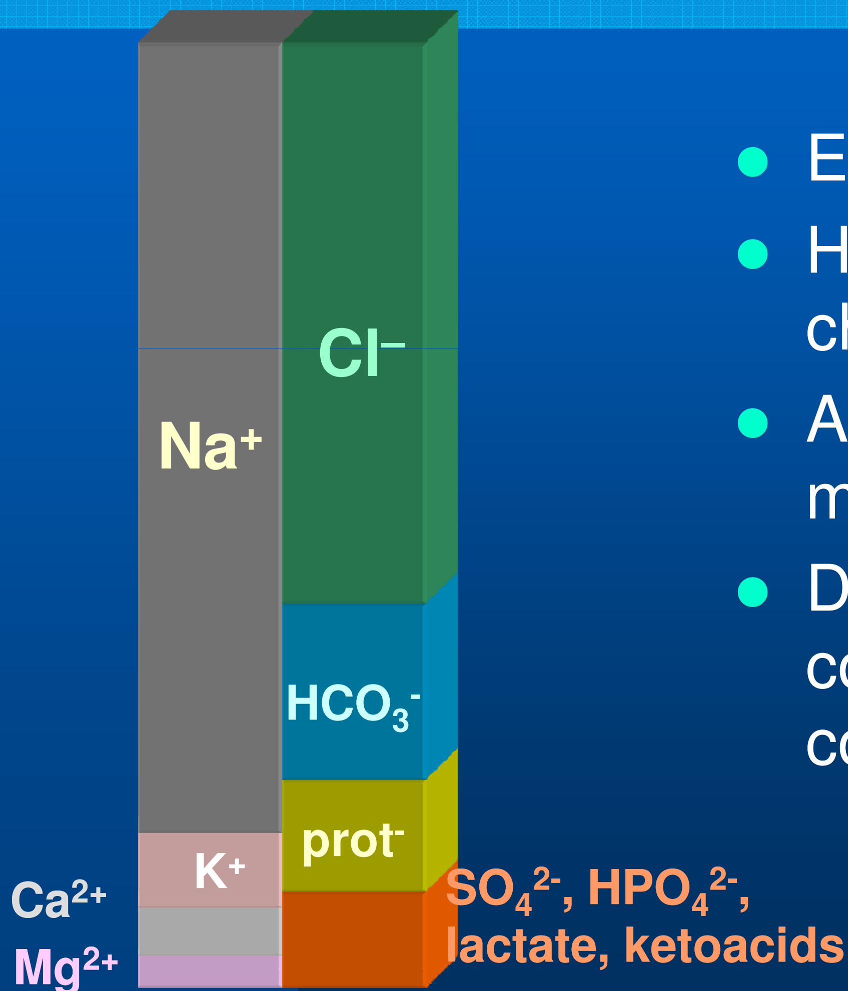
Actual and standard bicarbonates



Actual and standard bicarbonates

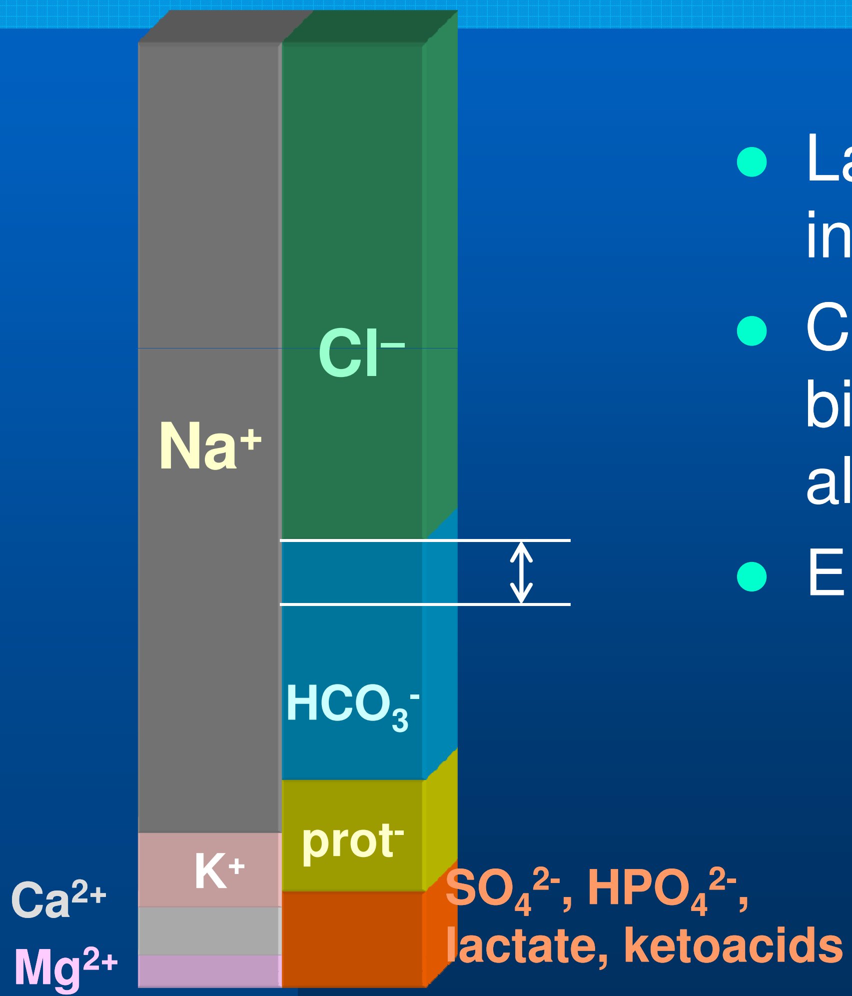


ABE and ions



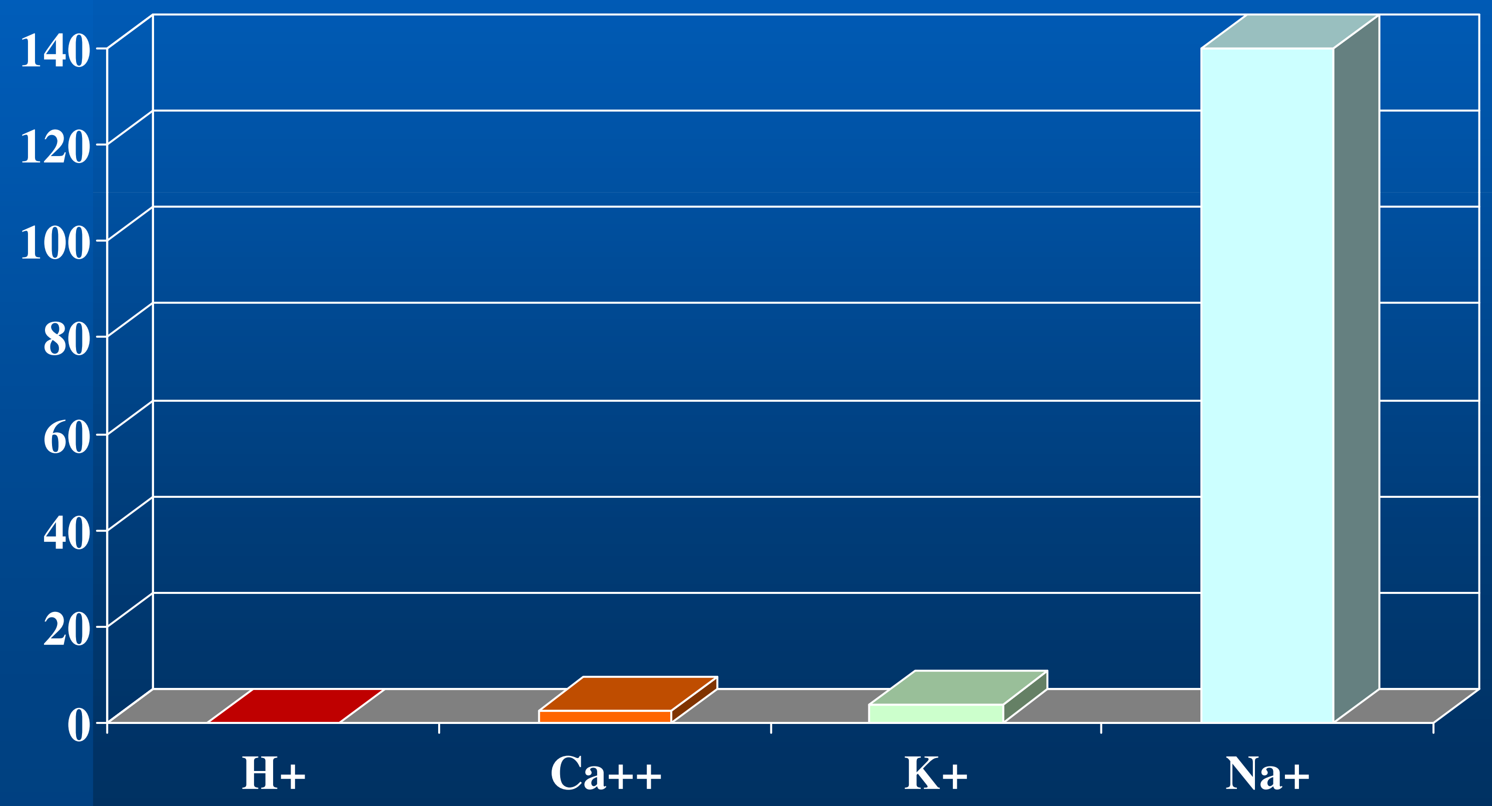
- Electroneutrality must be kept
- HCO_3^- charged, CO_2 w/o charge
- ABE connected with ion metabolism
- Disturbances in ion concentrations are most easily compensated by HCO_3^-

Hypochloremic alkalosis



- Lack of Cl^- is replaced with increased HCO_3^-
- Change of ration of bicarbonate and CO_2 leads to alkalosis
- E.g. vomitting

H^+ and other cations



Henderson-Hasselbalch equation

$$pH = pK_a + \log \frac{[HCO_3^-]}{[H_2CO_3]}$$

5 – 6 orders more than $[H^+]$

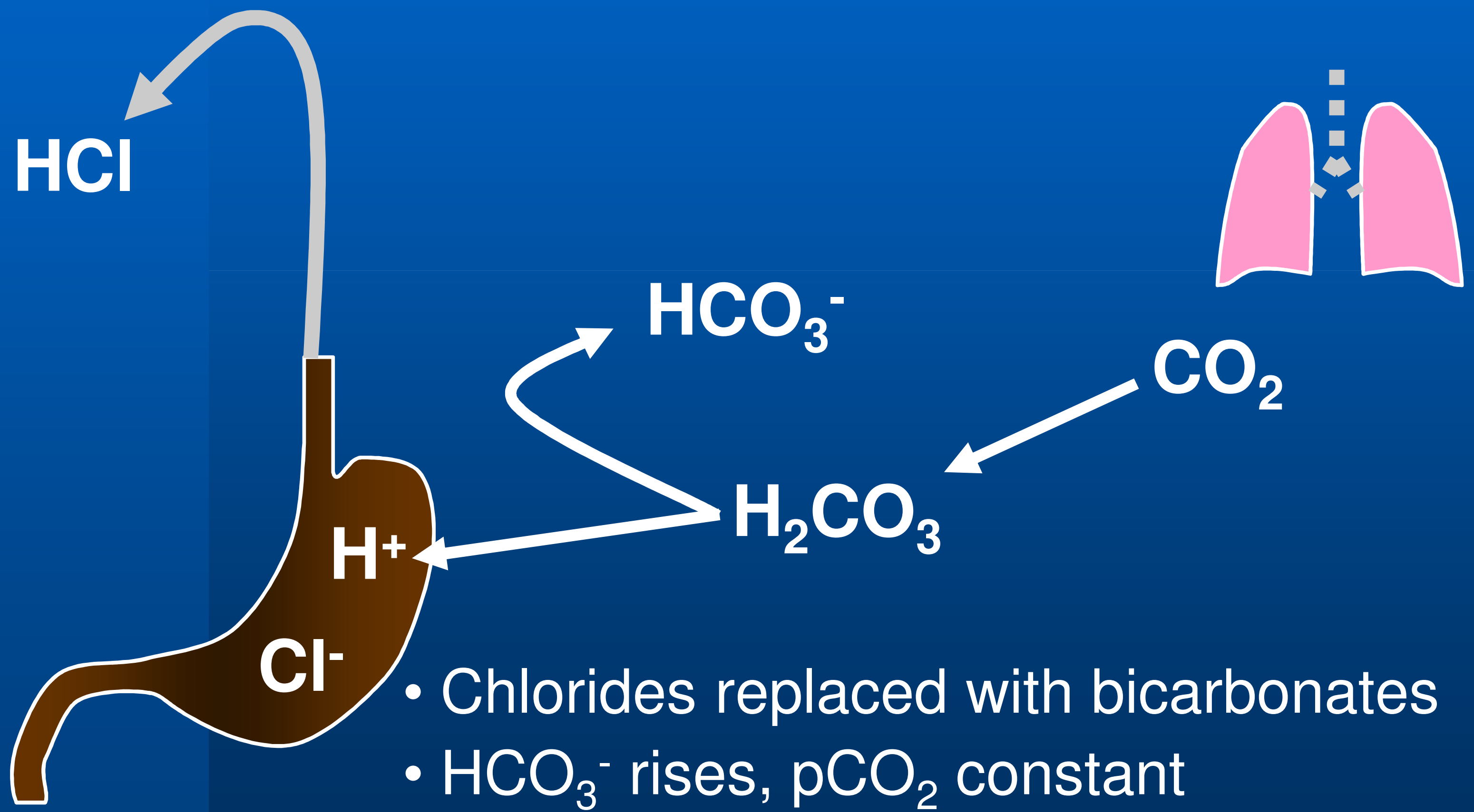
- $pK_a = 6{,}1$
- $[HCO_3^-] = 24\ mmol.l^{-1}$
- $[H_2CO_3] = 1{,}2\ mmol.l^{-1}$

$$\frac{[HCO_3^-]}{[H_2CO_3]} = 20$$

pH change in vomiting

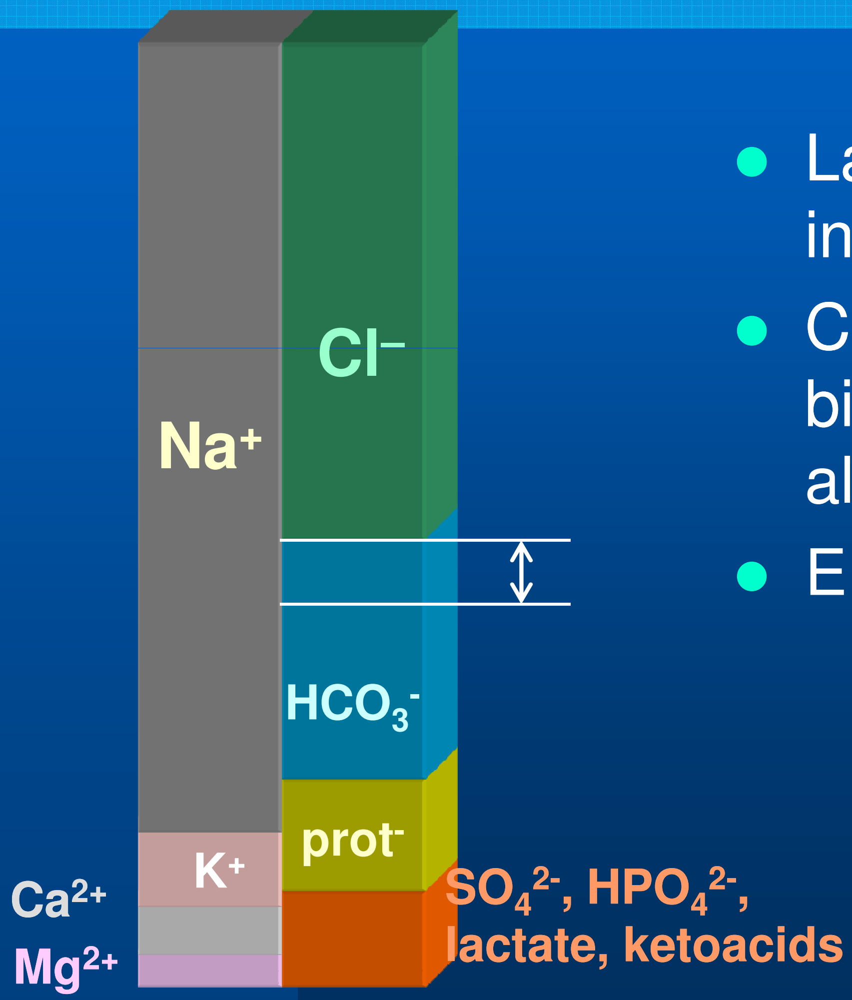
- loss of ca. 0.5 L of gastric juice, pH 0.8
  - w/o buffer pH 7,4 → > 14
  - insulated system 7,4 → 7,9
  - opened system 7,4 → 7,415

Hypochloremic alkalosis



- Chlorides replaced with bicarbonates
- HCO_3^- rises, pCO_2 constant

Hypochloremic alkalosis



- Lack of Cl^- is replaced with increased HCO_3^-
- Change of ration of bicarbonate and CO_2 leads to alcalosis
- E.g. vomitting

Acid-base equilibrium

Don't think about change in

~~**H^+ or OH^-**~~

but about changes in

<u>concentration of major ions</u>

pH change is secondary to change of HCO_3^- / pCO_2 ratio

Proton sources

- **Anaerobic glycolysis**

  1Glc → 2lactate⁻ + 2H⁺

- **Lipolysis**

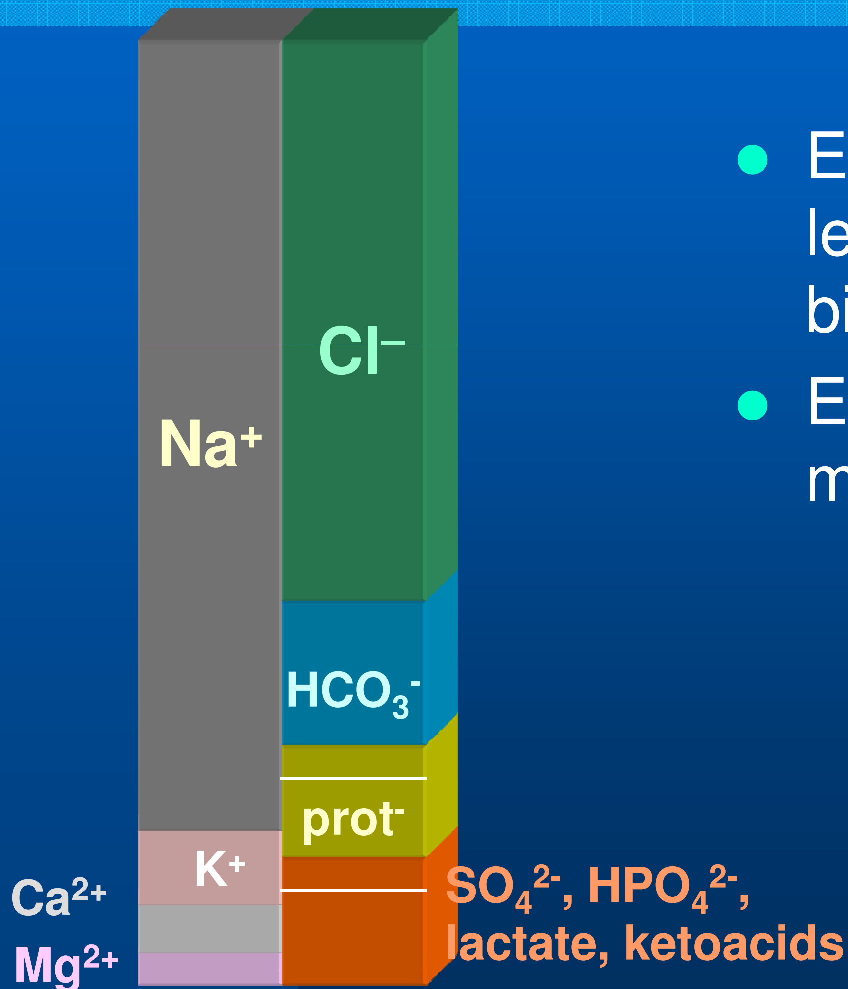
  TAG → 3FA⁻ + glycerol + 3H⁺

- **Formation of ketone bodies**

  FA⁻ → → acetoacetate⁻ + hydroxybutyrate⁻ + nH⁺

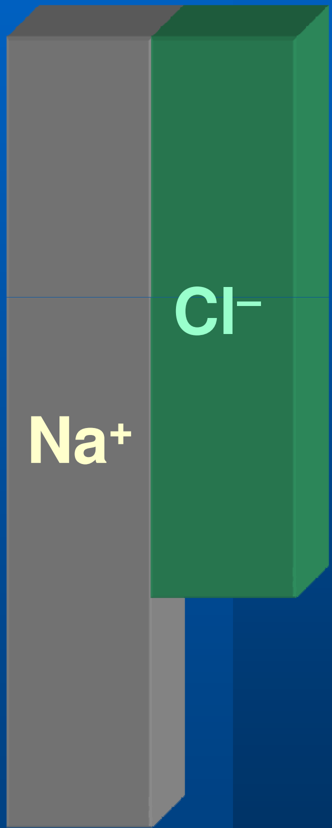
„strong“ acids

Ketoacidosis



- Excess of keto-acid anions leads to decrease of bicarbonate concentration
- E.g. decompensated diabetes mellitus type 1, starvation…

Physiologic saline is „acid“



plasma

Relative excess of chloride anions in physiologic saline

physiologic saline

ABE and potassium

- **Exchange of K^+ a H^+ on cell membrane**
  - acidemia → hyperkaliemia
  - alkalemia → hypokaliemia
  - hyperkaliemia → acidemia
  - hypokaliemia → alkalemia

ABE and calcium

- Exchange of H^+ and Ca^{2+} on plasma proteins
- acidemia → hypercalcemia
- alkalemia → hypocalcemia