Acid-base balance

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Basic principles of acid-base balance

- 1g of H^+ produced daily!

  Nutrients, intracellular metabolism
- 22 mol CO_2 exhaled every day

  Respiratory side (lungs)
- Removal of fixed acids (sulphates, phosphates)

  Metabolic side (kidneys)
- Reference range of arterial blood: 7.35-7.45

  35-45 nmol/l H^+

  Regulation: by buffer systems!

Major buffers in the blood

- Carbonic acid/bicarbonate

    Volatile, changes rapidly

- Intra – extracellular proteins (hemoglobin + plasma proteins)

    Strongest buffer!

- Organic molecules (anions)

    Of minor significance, might be important under pathological conditions

Buffers

- **Intracellular:** approx**. 50% buffering capacity**
  - **Hemoglobin and others: without hemoglobin pH of venous blood: 4.5**

K^+ ⟷ H^+, inverse behaviour

every 0.10 decrease in pH results in 0.2 -0.6 mmol/l K^+ increase

- **Bone: can compensate up to 40% of acute acid load**

Buffers: carbonic acid/bicarbonate buffer

$$\text{Acid} = H^+ + \text{Base}$$

$$HA = H^+ + A^-$$

$$pH = pKa + \log \frac{[HA]}{[A-]}$$

$$pH = 6.1 + \log \frac{[HCO_3^-]}{[H_2CO_3]}$$

$$pH \propto \frac{[HCO_3^-]}{PaCO_2}$$

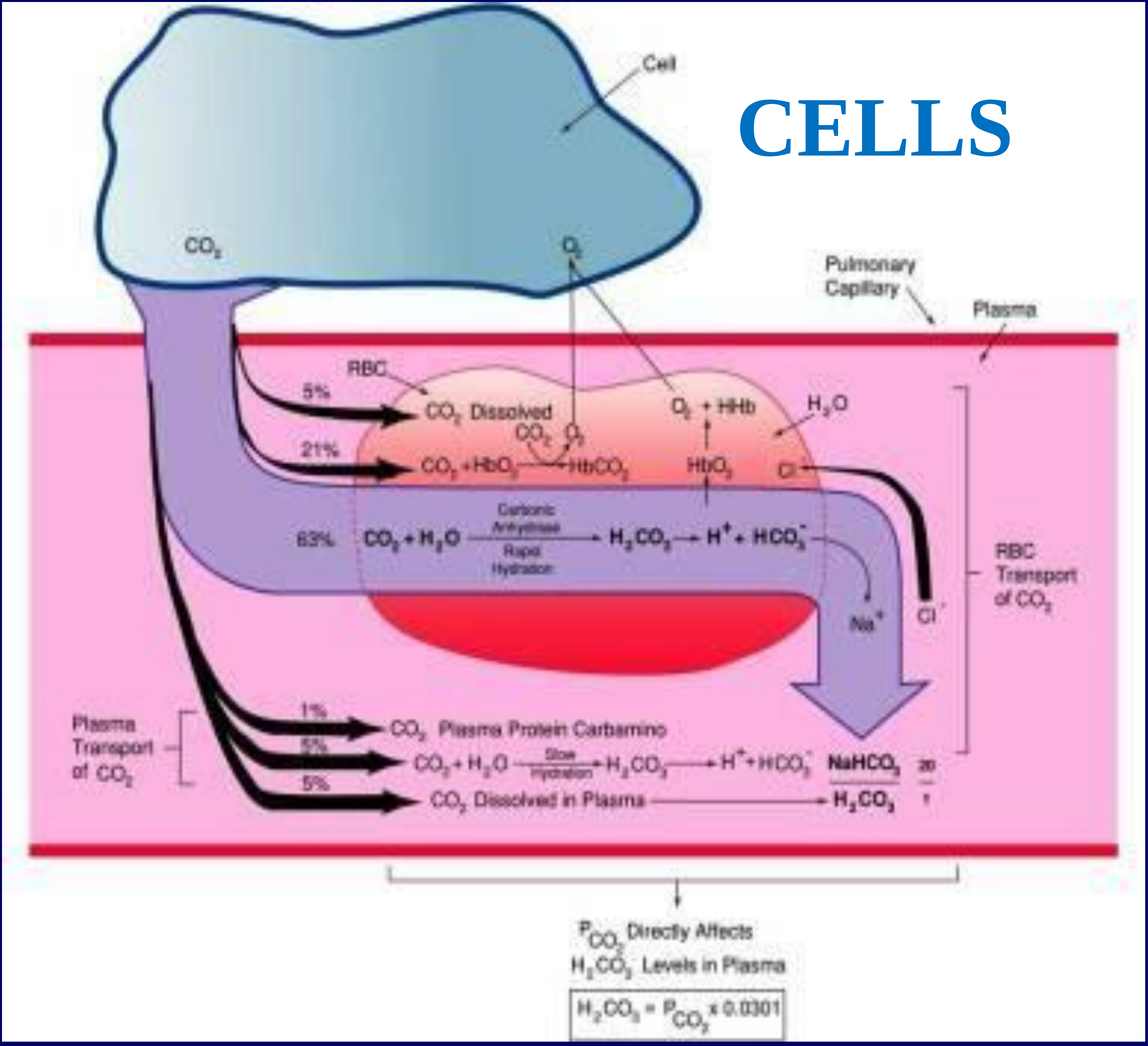
The Henderson - Hasselbalch equation

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

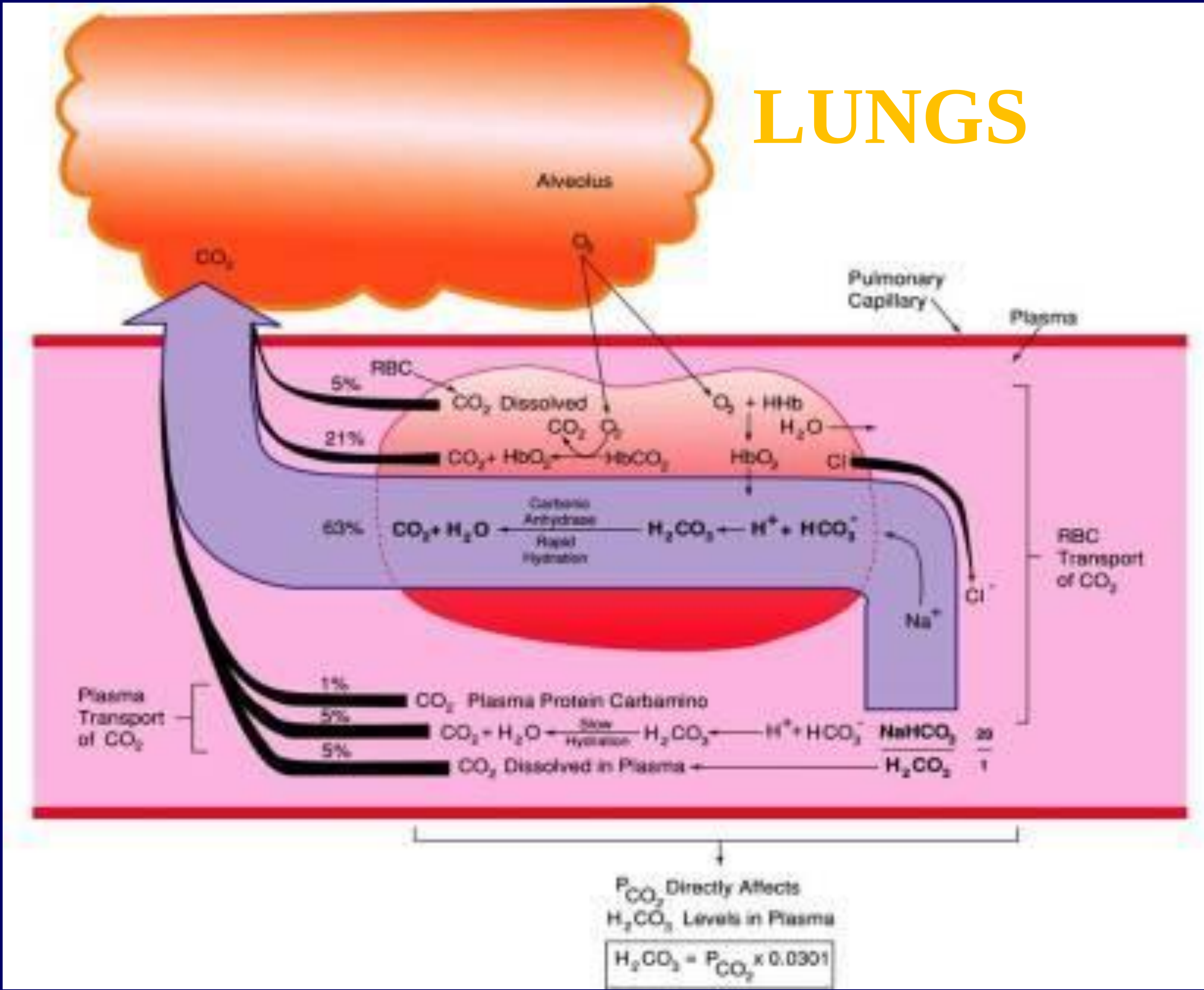
$$pH = pK_a + \log\frac{[HCO_3^-]}{[CO_2]}$$

$$pH = 6.1 + \log\frac{24\,mM}{1.2\,mM} = 7.40$$

CELLS


Cell
CO2
O2
Pulmonary
Capillary
Plasma
RBC
5%
CO2 Dissolved
CO2 O2
O2 + HHb
H2O
21%
CO2 + HbO2 → HbCO2
HbO2
Cl⁻
63%
CO2 + H2O → H2CO3 → H⁺ + HCO3⁻
Carbonic Anhydrase
Rapid Hydration
Na⁺
Cl⁻
RBC
Transport
of CO2
Plasma
Transport
of CO2
1%
CO2 Plasma Protein Carbamino
5%
CO2 + H2O → H2CO3 → H⁺ + HCO3⁻
Slow Hydration
NaHCO3
H2CO3
20
1
5%
CO2 Dissolved in Plasma
PCO2 Directly Affects
H2CO3 Levels in Plasma
H2CO3 = PCO2 x 0.0301

LUNGS



Alveolus
CO2
O2
Pulmonary Capillary
Plasma
RBC
5%
CO2 Dissolved
CO2 O2
O2 + HHb
H2O
21%
CO2 + HbO2
HbCO2
HbO2
Cl-
Carbonic Anhydrase
63%
CO2 + H2O
Rapid Hydration
H2CO3
H+ + HCO3-
RBC Transport of CO2
Cl-
Na+
1%
CO2 Plasma Protein Carbamino
Plasma Transport of CO2
5%
CO2 + H2O
Slow Hydration
H2CO3
H+ + HCO3-
NaHCO3
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CO2 Dissolved in Plasma
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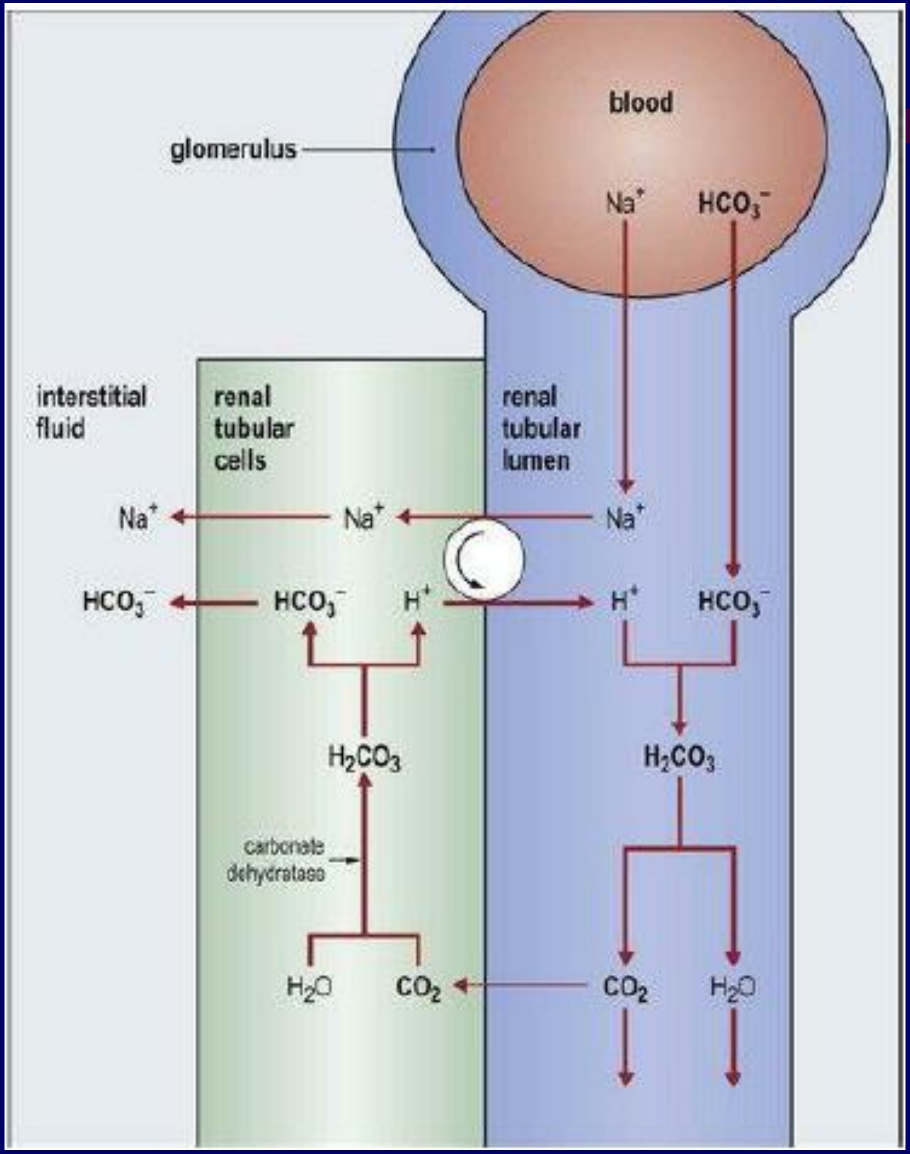
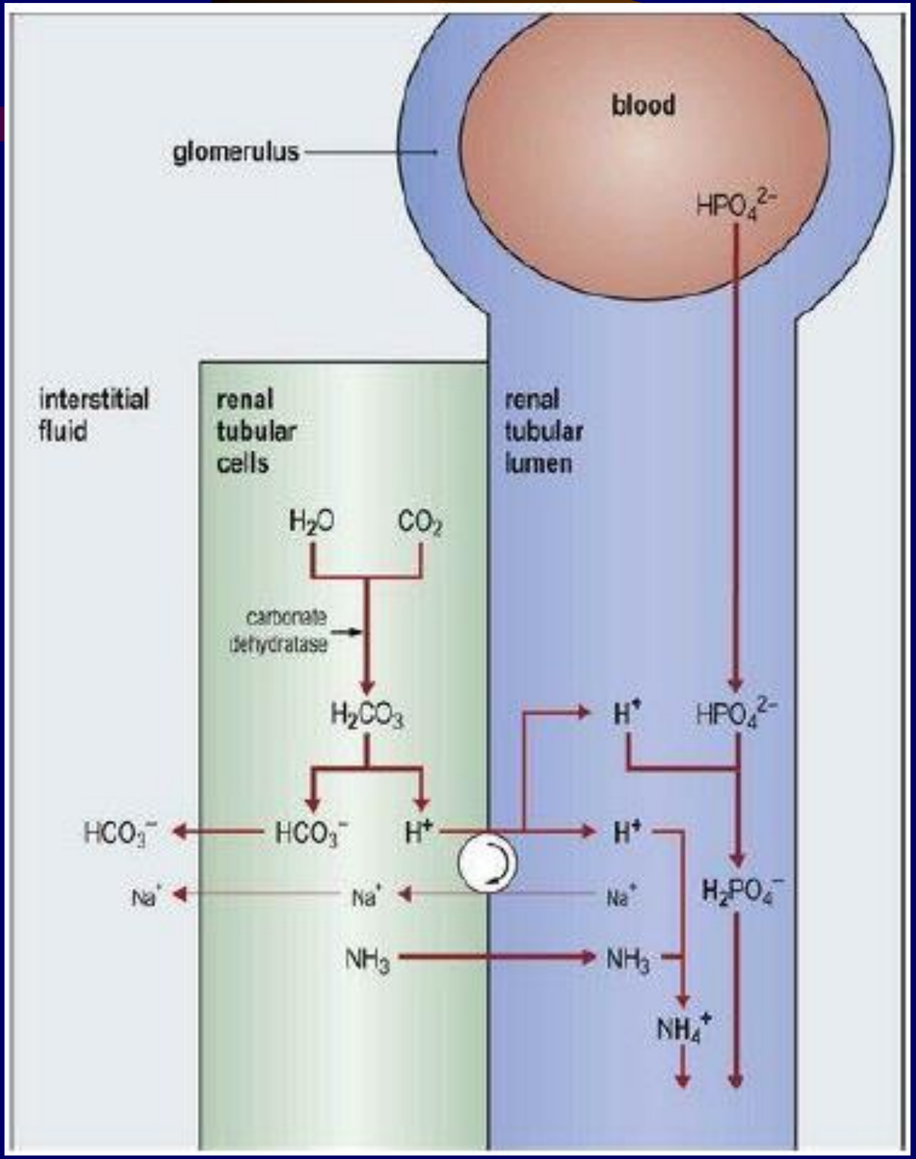
KIDNEYS

Bicarbonate reabsorption



Renal hydrogen ion excretion



Why the carbonic acid/bicarbonate buffer?

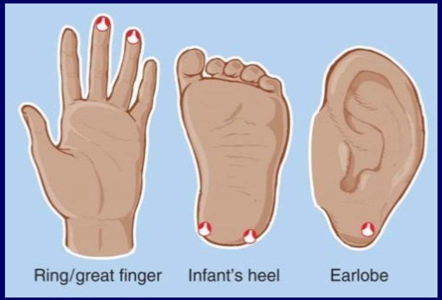
- It can change rapidly: volatile
- It has high buffering capacity
- It can be easily measured
- It needs a small sample size (capillary, arterial blood)
- It is suitable for monitoring of therapy
- It gives practical therapeutical guides

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

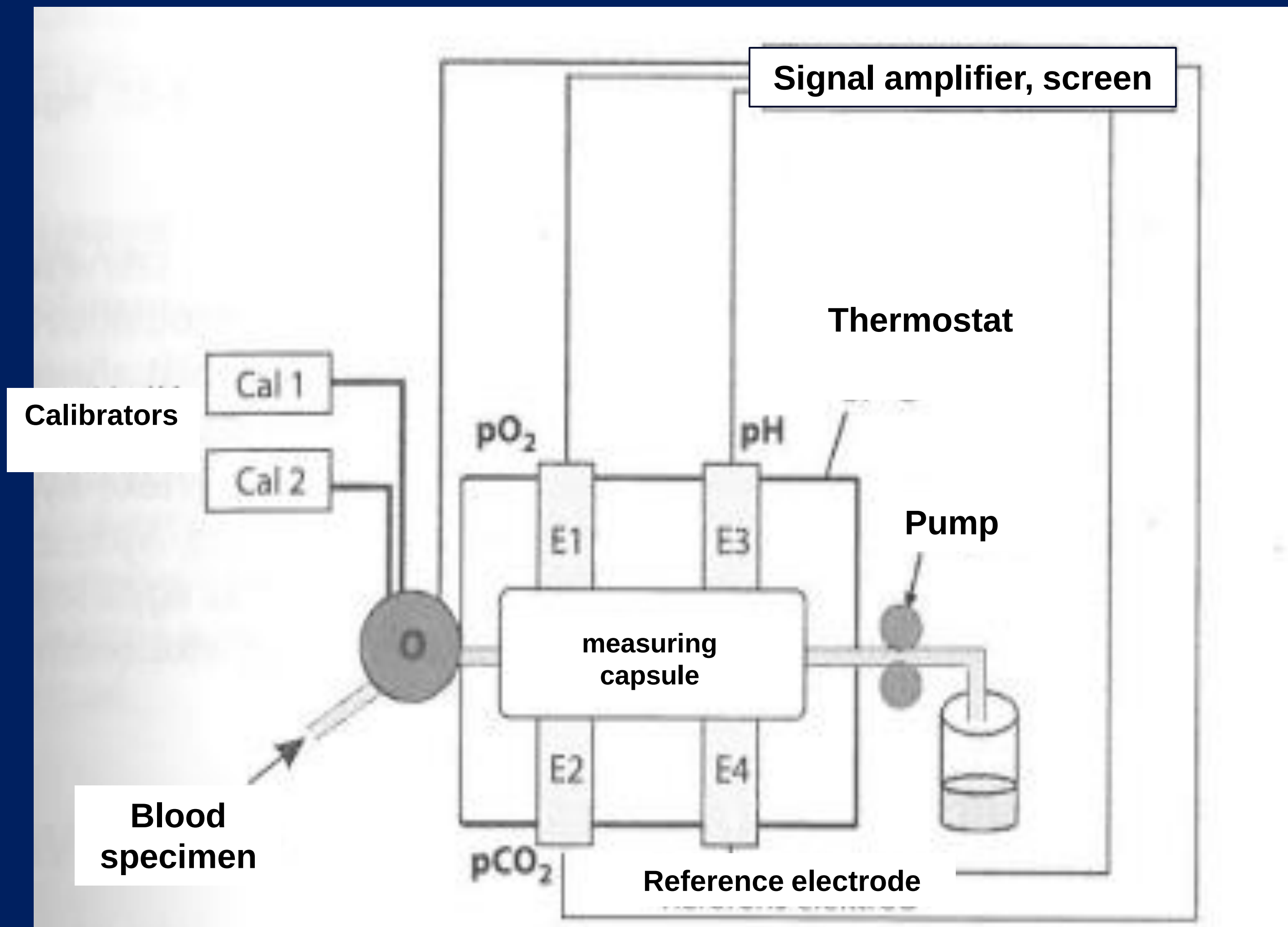
Sampling for acid-base balance tests

Always whole blood!

- **Arterial blood**
- **Capillary blood (arterialized)**
- **Anticoagulant - heparin**
- **Anaerobic conditions, no air bubbles, immediately closed capillary or syringe, anticoagulant mixed with blood**
- **The test is always urgent!**

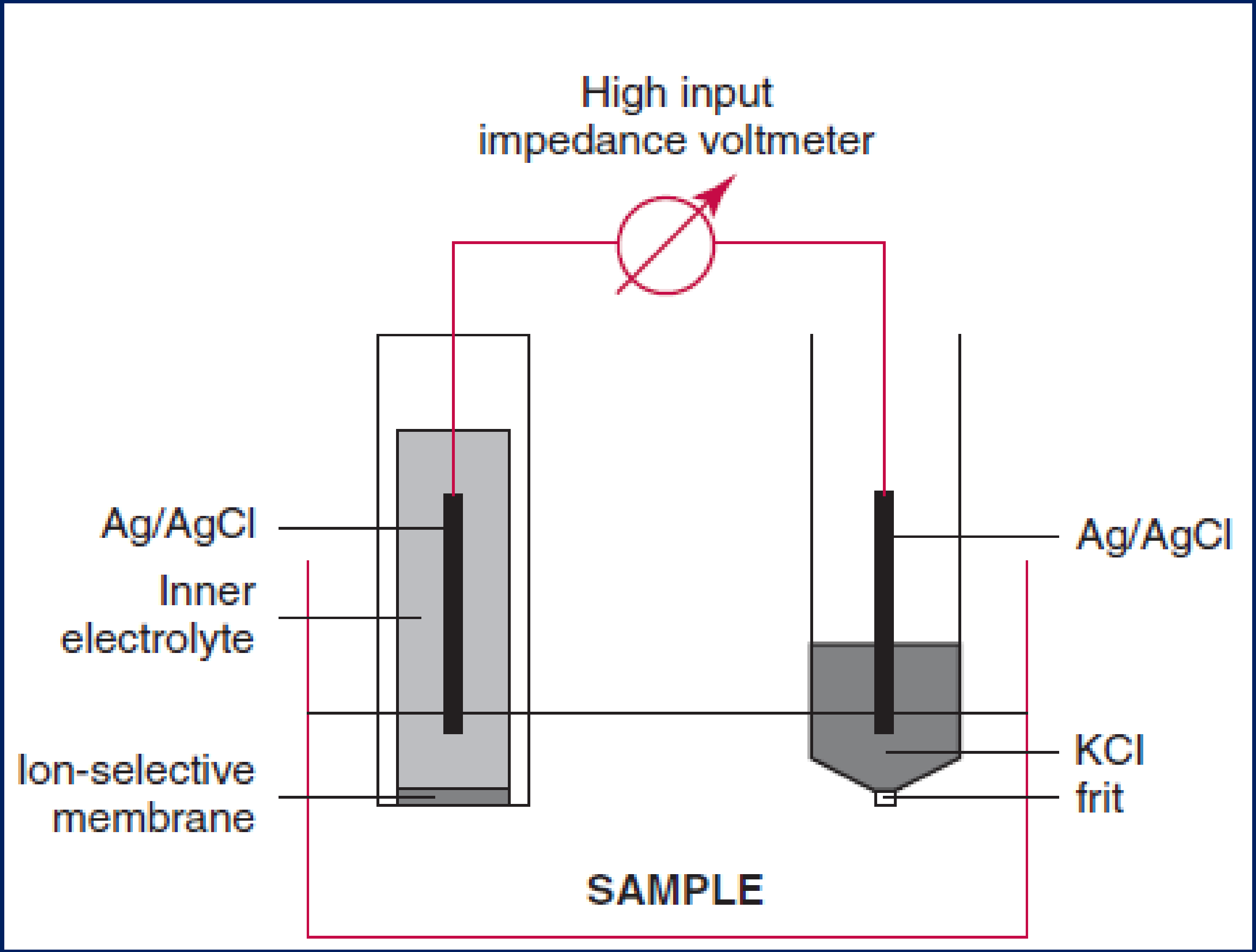


Analyzer



Signal amplifier, screen
Thermostat
Calibrators
Cal 1
Cal 2
pO2
pH
E1
E3
Pump
O
measuring capsule
E2
E4
Blood specimen
pCO2
Reference electrode

Potentiometry and ion-selective electrodes



Measurement of acid-base balance

- Hydrogen ion-selective microelectrode
- CO_2 selective microelectrode
- O_2 selective microelectrode

- Other parameters: Point of Care Testing (POCT), ions, lactate, urea, glucose

Interpretation of acid-base balance data

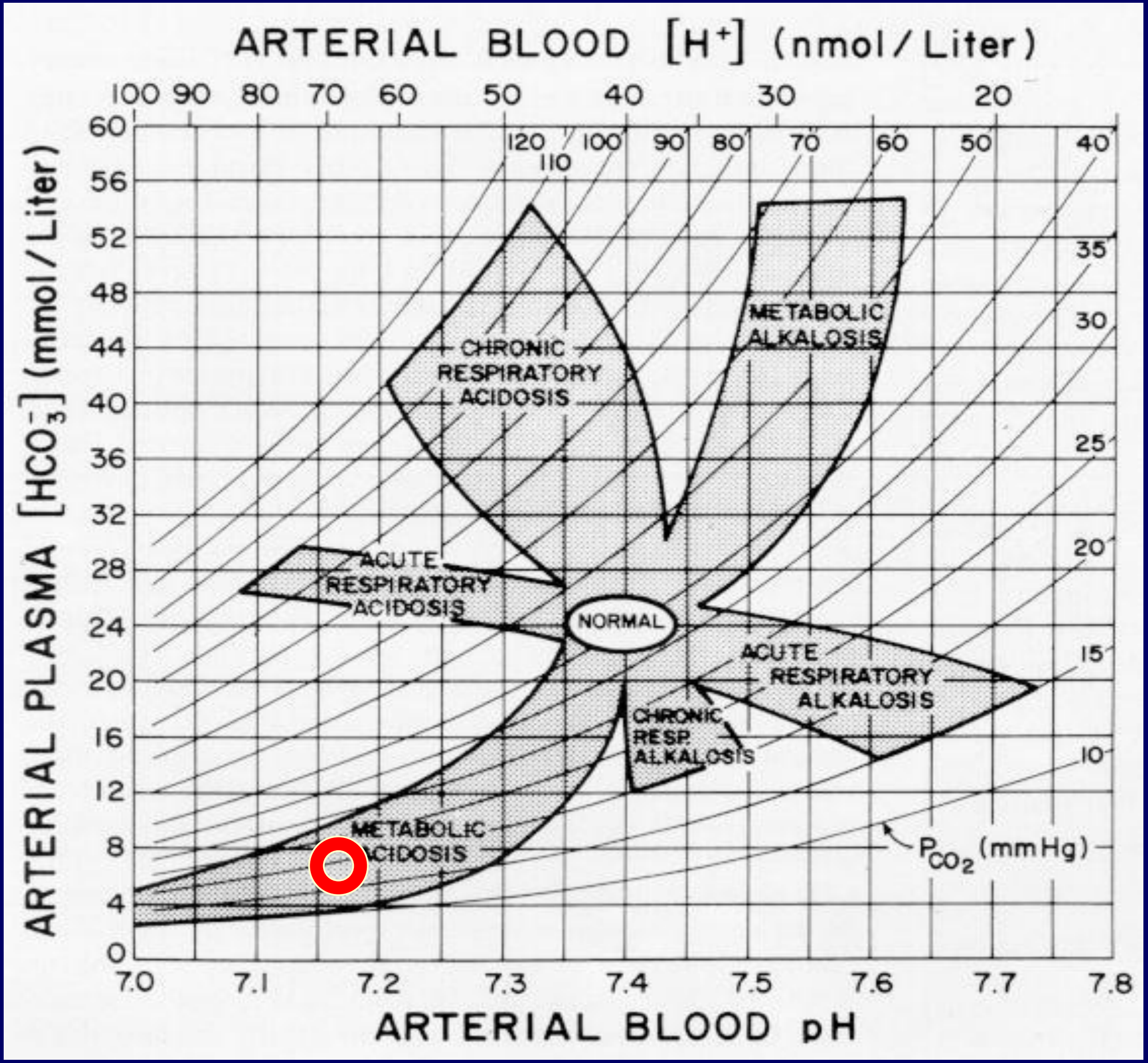
• pH	7.35 – 7.45
• pCO_2	35 - 45 Hgmm
• HCO_3^- actual	22 - 28 mmol/l
• HCO_3^- standardized	22 - 28 mmol/l
• Base excess (BE)	+- 0 - 3 mmol/l
• pO_2	90 - 100 Hgmm
• Oxygen saturation	95 - 100 %

Diagnostic approaches

- **Acid-base nomogram**

- **Anion gap**
- **Delta gap**
- **Osmotic gap**

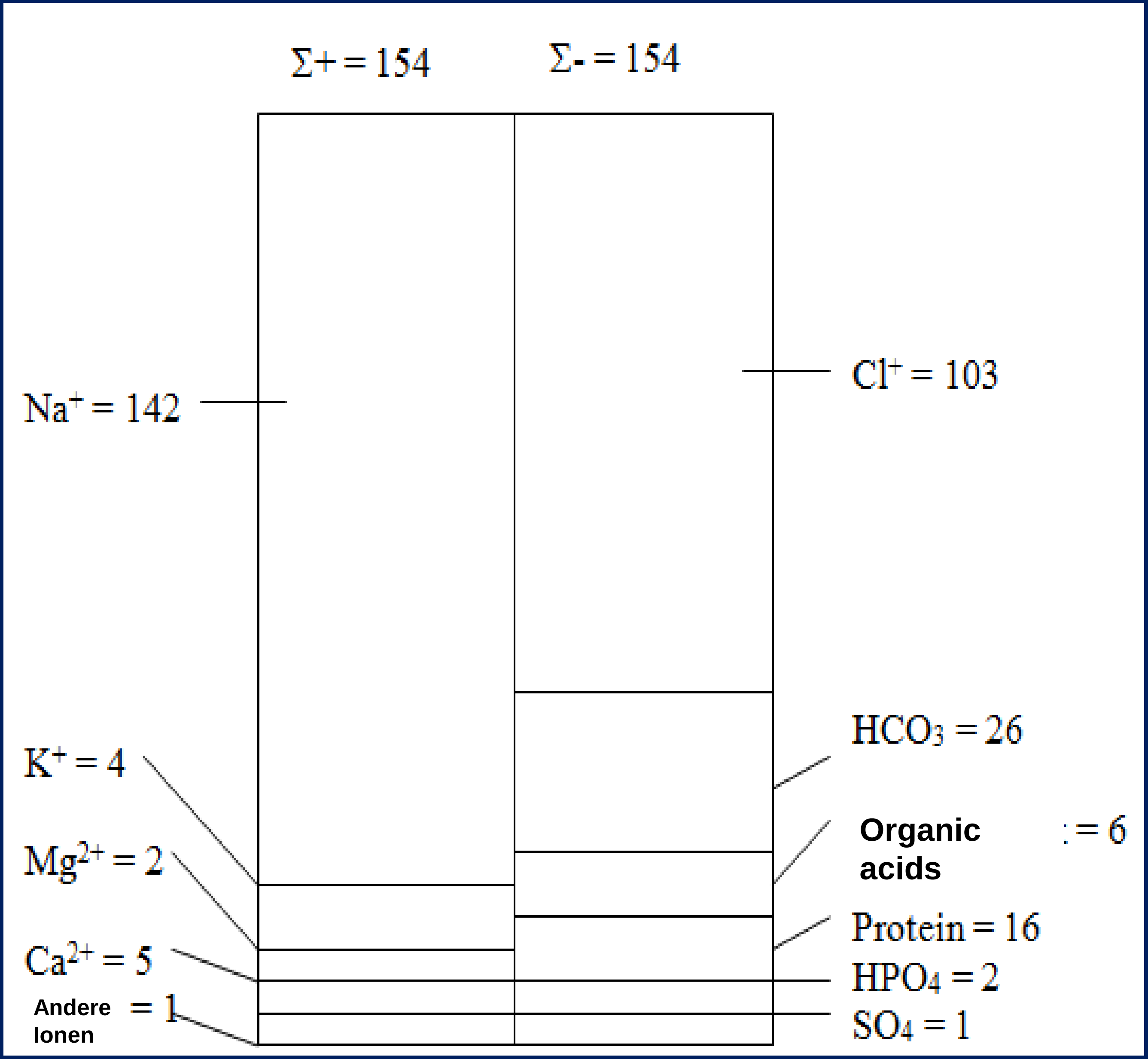
Acid-base nomogram



Metabolic acidosis

	ACUTE	CHRONIC
pH	↓	compensation: Decrease of pCO_2
pCO_2	normal	
HCO_3	↓	
Std.HCO_3	↓	
BB	↓	
BE	↓	

Anion gap (Gamble)



The anion gap (AG)

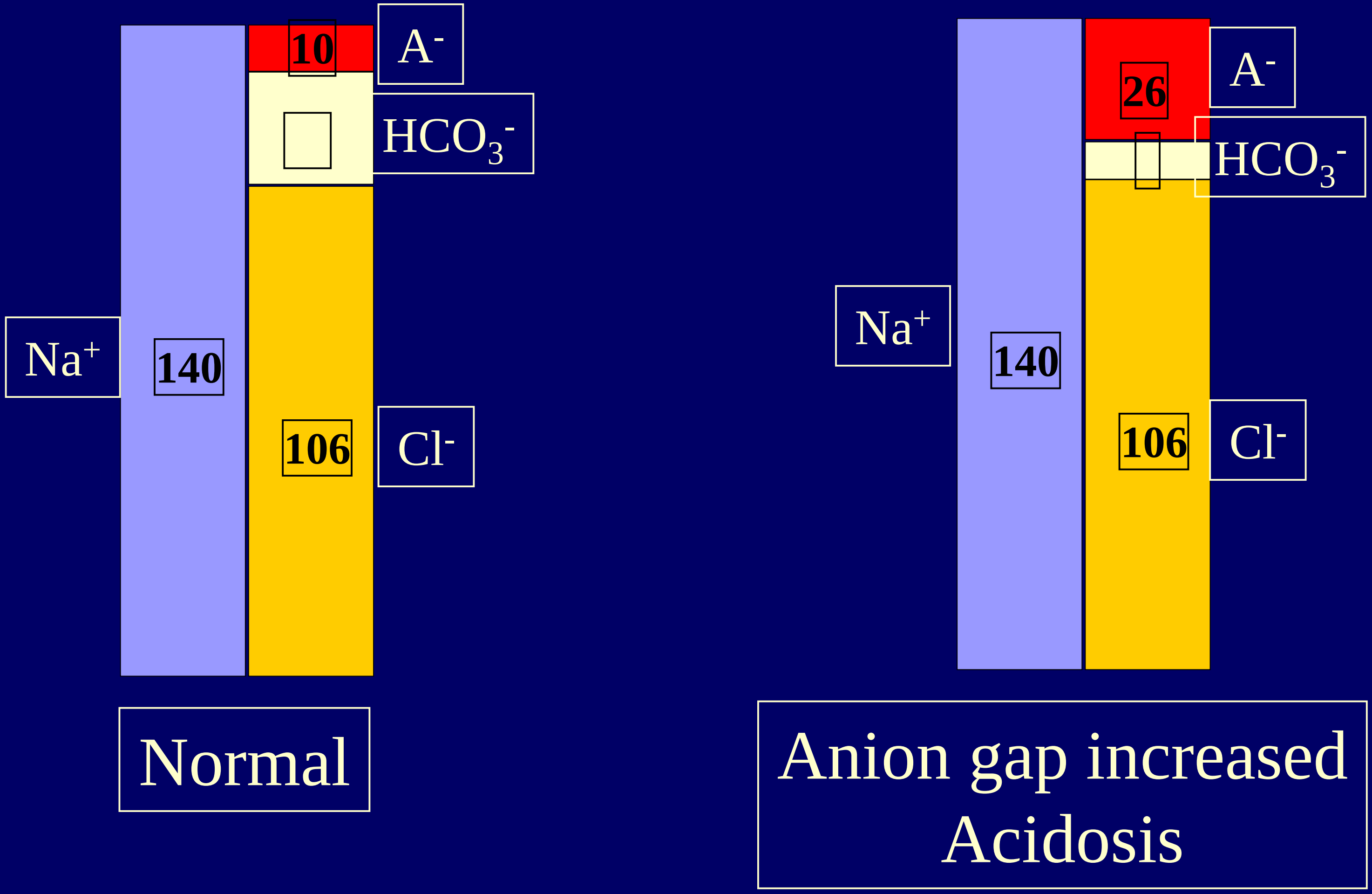
- AG = $[Na^+]$ - ($[Cl^-]$ + $[HCO_3^-]$)

  – Reference range: 12 +/- 2 mmol/l

- proteins, albumin, lactate, and other organic anions

AG = 140 - (106 + 4)
= 30

Examples for anion gap parameters



The osmotic gap

- Serum osmolality: Na^+, Cl^-, glucose, urea
- Exogenous, unmeasured substances present (e.g. methanol, ethylene glycol, etc.): increased osmotic gap

Osmotic gap = measured osmolality - estimated osmolality

Osmotic gap < 10
- normal

Osmotic gap > 10
- unmeasured solutes present

Example for osmotic gap interpretation

serum osmolality: = 323

Estimated osmolality = $2Na^+$ + Glucose + Urea

= 2(140) + 10 + 10

= 300

Osmotic gap = 323 - 300

= 23

OG > 10:

- must r/o methanol and ethylene glycol ingestion