Acid – base balance

Terms

- ICF = intacellular fluid
- ECF = extracellular fluid
- IVF = intravascular fluid
- EVF = extravascular fluid

Water

Body water

50-80 % of body weight (depending on age)

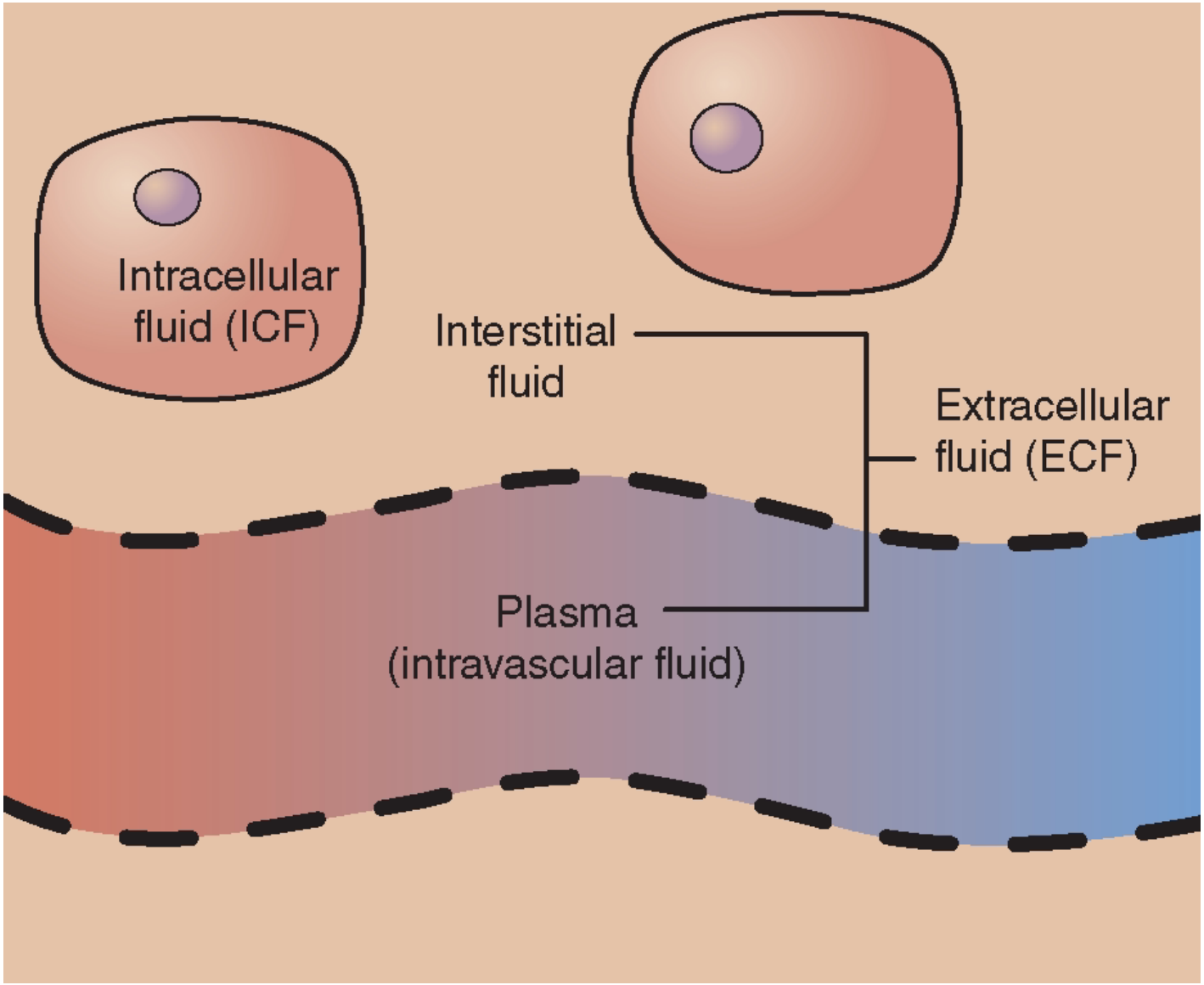
- 80 % - newborns
- 60 % - slim adults
- 55 % - obese adults
- 50 % - seniors

Body water distribution

Fluid

- ICF 40 % of body weight
- ECF 20 % of body weight
  - Interstitial 15 %
  - Intravascular 5 %

Body water distribution



Body – water distribution

Transcellular fluid

- Physiologically
  - GIT (2-3 litres after food intake)
  - CSF (cerebrospinal fluid)

- Patologically
  - Abdominal cavity (ascites)
  - Thoracic cavity (hydrothorax)
  - Intestine (ileus)
  - Bruises

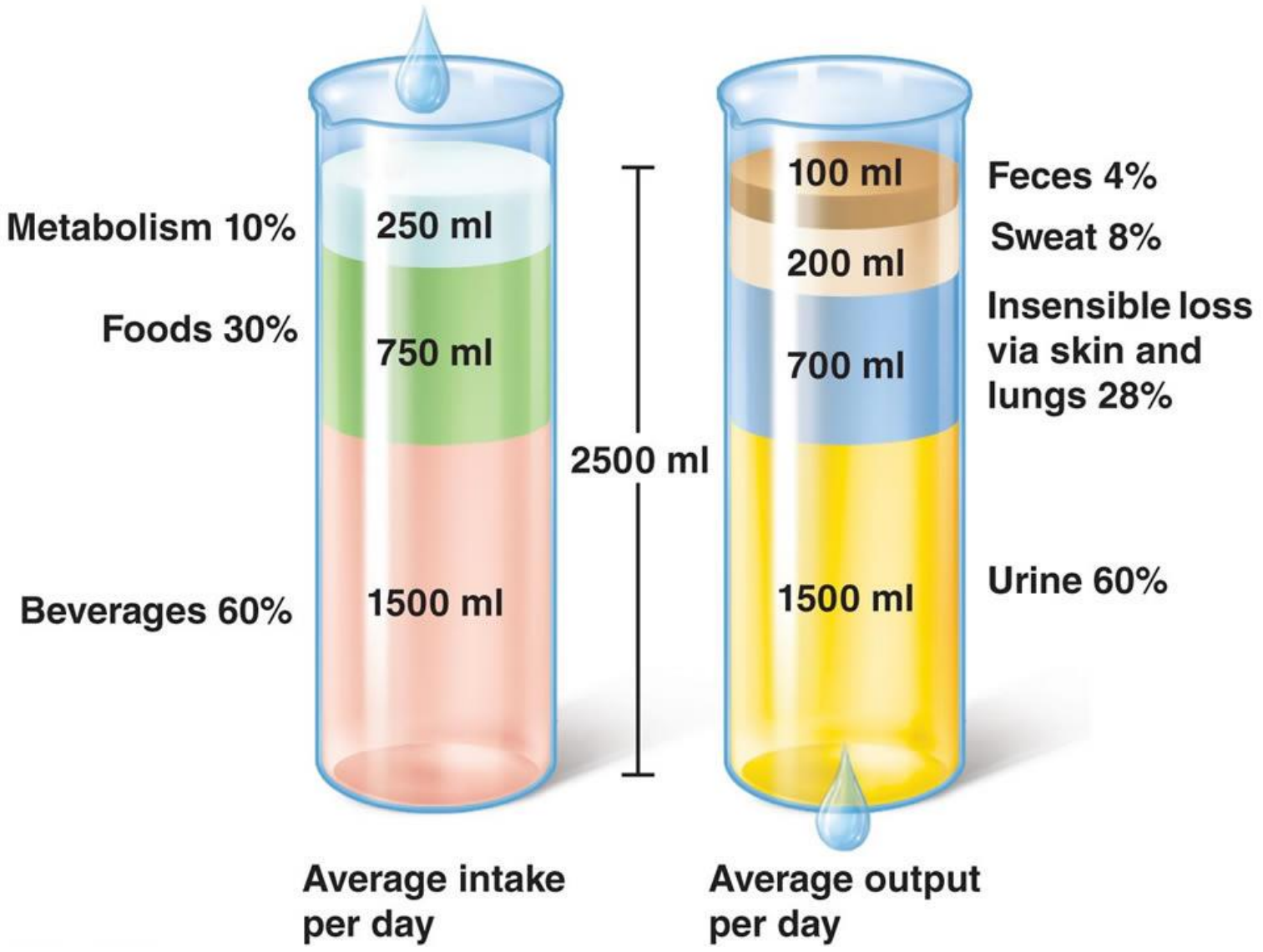
Water balance

Intake (ml)		Excretion (ml)	
Drinking	1500	Urine	1500
Food	700	Perspiration	400
Nutrition oxid.	300	Breathing	400
		Sweating	100
		Faeces	100
Total	2500		2500

Can be measured

Can be estimated

Water balance



Distribution of substances in water

1. Substances, which pass freely through cell membranes

2. Substances, which make concentration gradient (ICF x ECF)

3. Substances, which make concentration gradient (IVF x EVF)

1. Substances, which pass freely through cell membranes

- Endogenous substances: urea
- Exogenous substances: ethanol

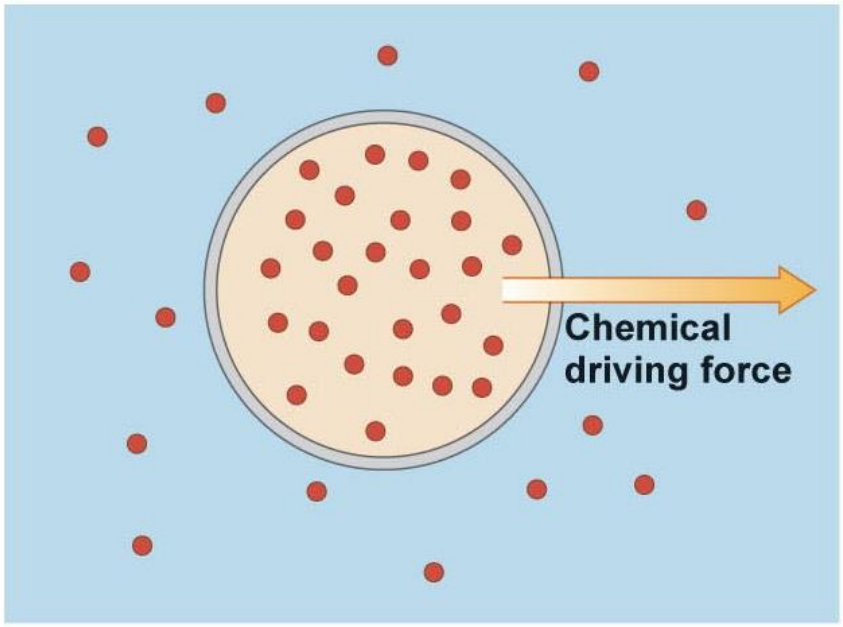
2. Substances, which make concentration gradient (ICF x ECF)

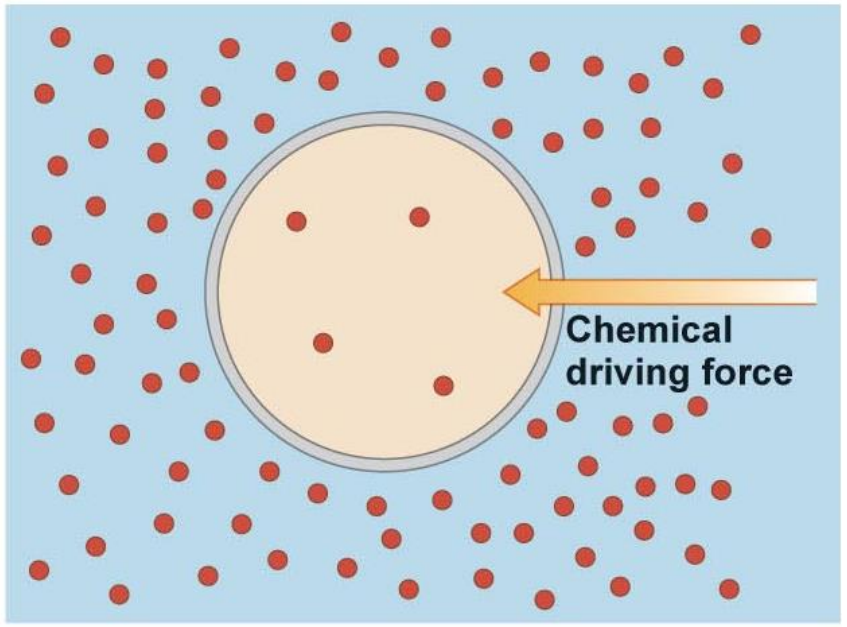
Different concentration of these substances in ICF and ECF.

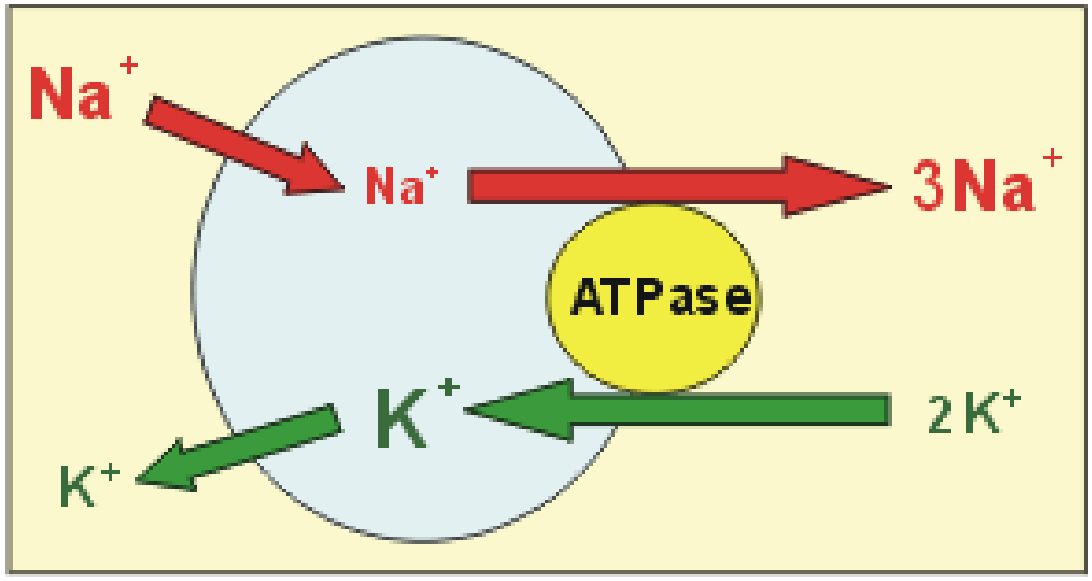
- Mainly ions (Na, K, Cl, Ca, Mg, P)

Mechanisms

- Semipermeable membrane (glucose)
- Iont pumps (active transport - Na/K ATPases, energy required)


Chemical
driving force


Chemical
driving force


Na+
Na+
3Na+
ATPase
K+
2K+
K+

Main ions

	ECF (blood) mmol/l	ICF (cells) mmol/l
Na	140	10
Cl	102	8
K	4,0	155
Ca	2,2	0,001
Mg	1,0	15
P	1,0	65

3. Substances, which make concentration gradient (IVF x EVF)

Different concentrations of substances in IVF and EVF.

- Proteins (albumin)
- Proteins are responsible for keeping the water in vessels
- Hypoproteinemia leads to edema

Osmolality

- Osmolality = total amount of osmotic active particles dissolved in one kg of water – mmol/kg.

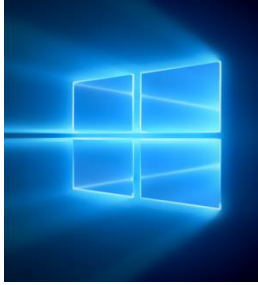
How to count osmolality

Plasma-osmolality (mmol . kg –1)

2[Na+] + [glucose] + [urea]

2 * 140 + 5 + 5 = 290 mmol . kg –1

Osmolal gap



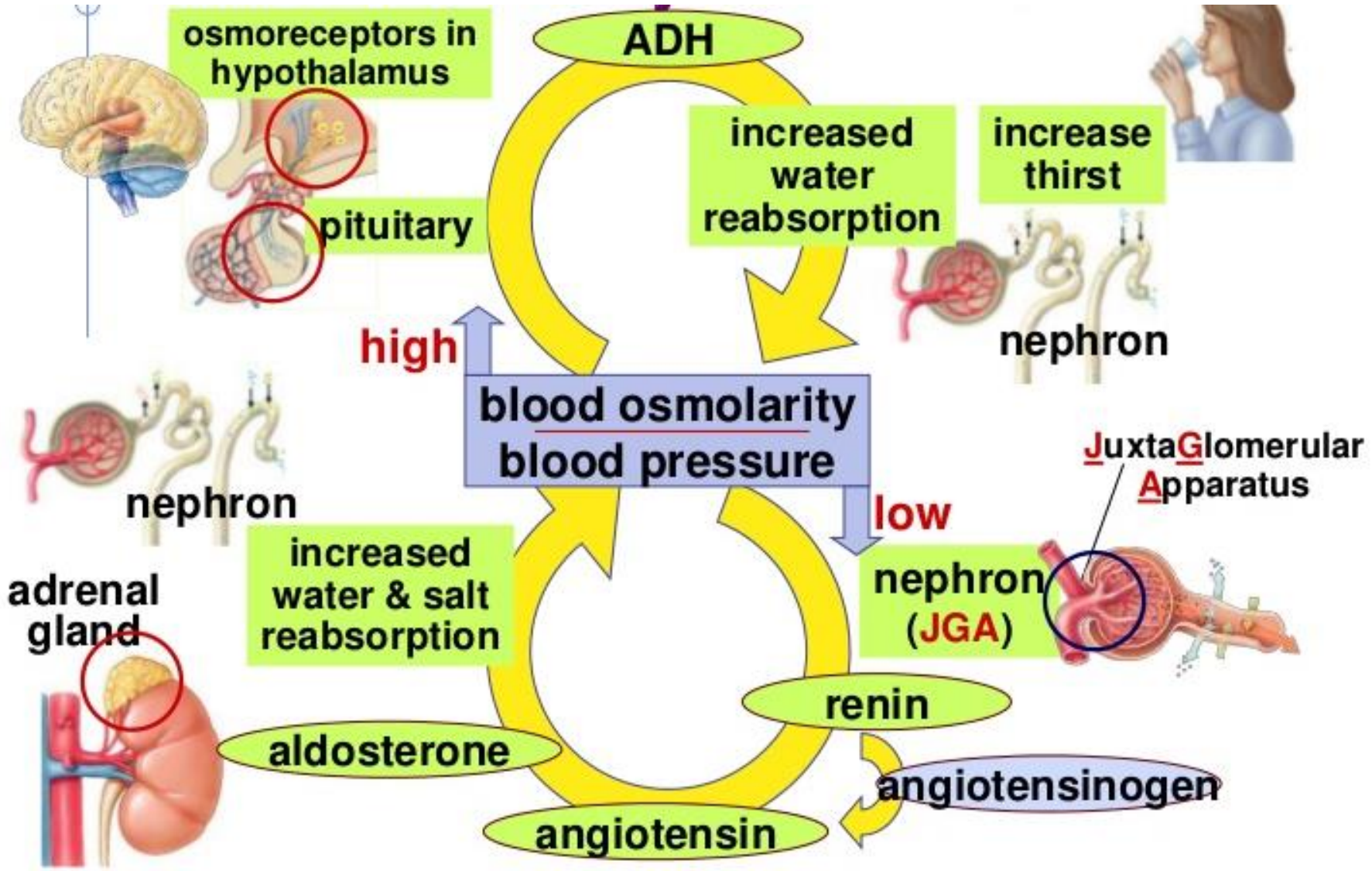
- Difference between measured and counted osmolality

$$OsmGap = POsm_{measured} - POsm_{calculated}$$

- Discovers a presence of alcohol or etylenglycol
- If OsmGap > 10 mmol/kg , then presence of these substances is very probable
- 1 g of ethanol in 1 litre of plasma (1 per mille of alcohol) rises osmolality by 23 mmol/kg.

Regulation of osmolality

- Osmoreceptors
- Antidiuretic hormone (ADH) – regulates resorption of pure water in kidneys


osmoreceptors in hypothalamus
ADH
increased water reabsorption
increase thirst
pituitary
nephron
high
blood osmolarity
blood pressure
low
nephron
JuxtaGlomerular Apparatus
increased water & salt reabsorption
adrenal gland
nephron (JGA)
renin
aldosterone
angiotensinogen
angiotensin

Hyperosmolality

Deficiency of water, many solutes

- Dehydratation
- fever, burns, inability of drinking

or

↑ concentration of glucose, urea, alcohol in blood (osmotic active) but without dehydratation

Reaction: ↑ ADH → resorption of water in kidneys, feeling thirsty

Hypoosmolality

Too much water and not enough soluts

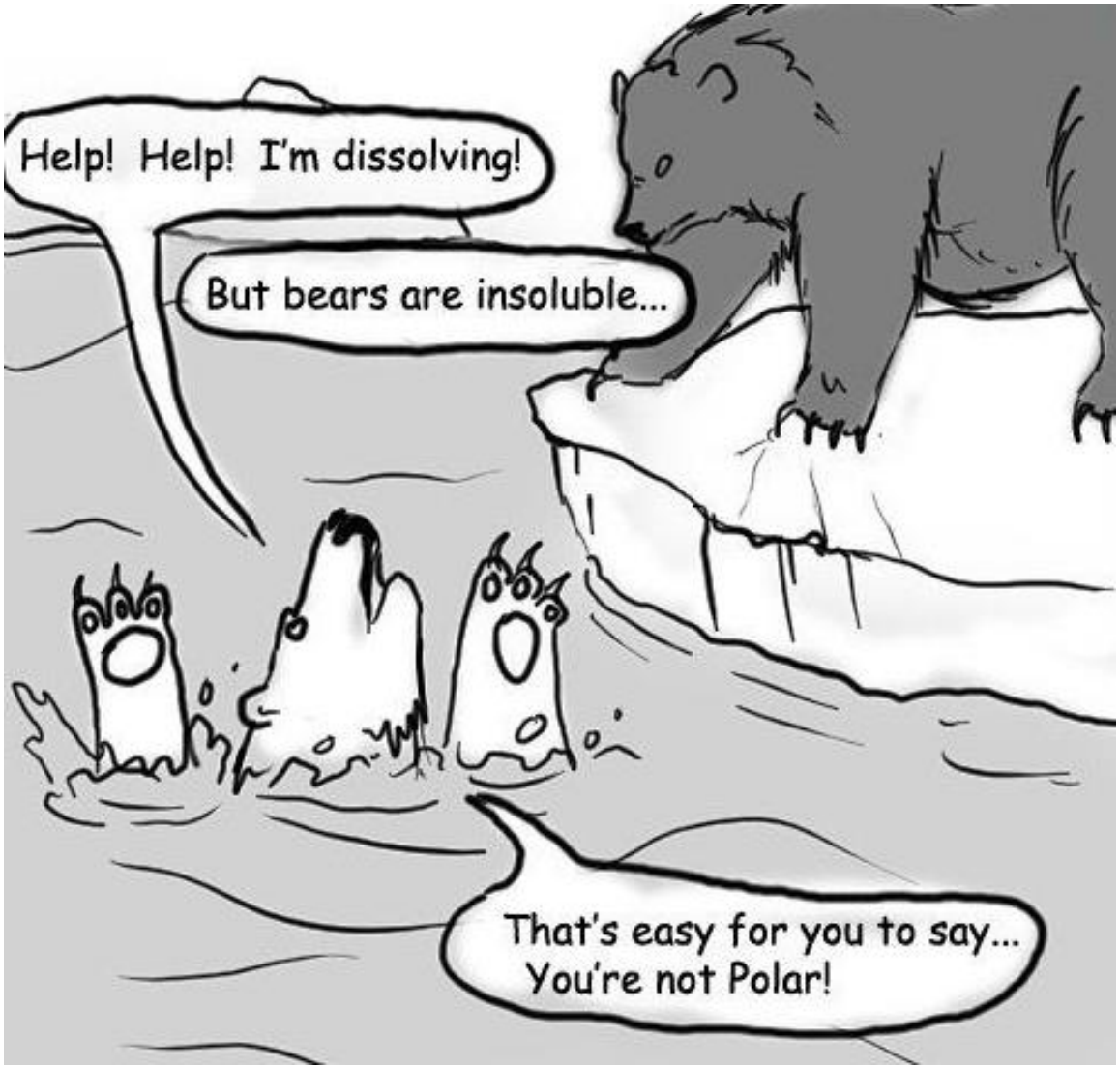
- „overhydratation“
- too much infusions (glucose)
- Brain injury, defective secretion of ADH

Reaction: ↓ ADH, polyuria

Osmolality of urine

- 50 - 1400 mmol/kg H_2O
  – old people: max. 800

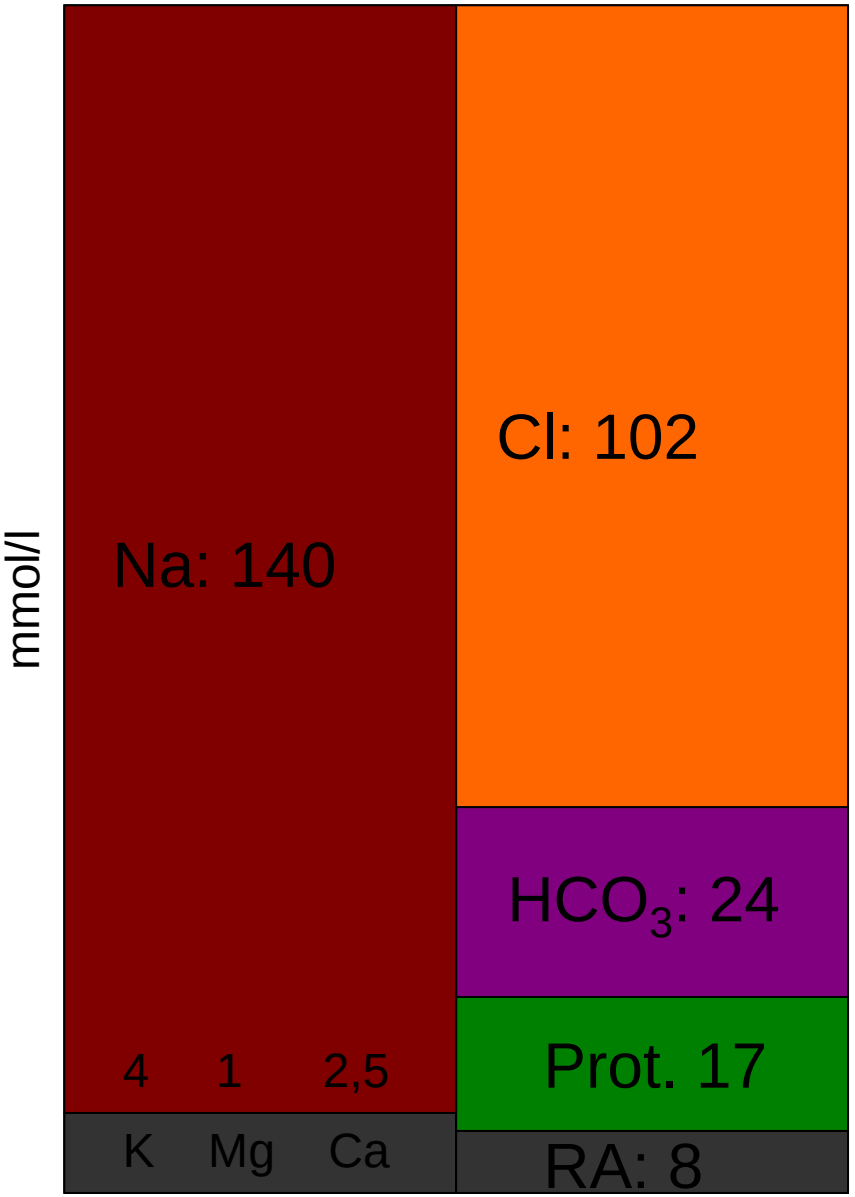
Ions


Help! Help! I'm dissolving!
But bears are insoluble...
That's easy for you to say...
You're not Polar!

Ions in blood and cells

	ECF (blood) mmol/l	Cells mmol/l
Na	140	10
Cl	102	8
K	4,0	155
Ca	2,2	0,001
Mg	1,0	15
P	1,0	65

Main ions in blood



Na (sodium): 135 - 145 mmol/l

Distribution

- ECF 50 %
- Bone tissue 40 %
- ICF 10 %

Na ions are followed by water

Intake: NaCl (salt) 8-11 g/day (1 g/day is enough)

Excretion:

- urine: 120 - 240 mmol/l
- sweat: 10 - 20 mmol, faeces 10 mmol

Importance of Na: state of hydrataion, osmolality

Hypernatremia + loosing water

- Fever - sweating, hyperventilation
- Inability of drinking

Results:

- ↑ osmolality → transfer of water from ICF to ECF
- ↑ ADH - ↑ water resorption in kidneys

Symptoms: ↑ protein, hemoglobin, dehydratation, hyperosmolality

Hypernatremia + increased intake of Na

Intenstive infusion therapy

Results:

- hyperhydration

Symptoms: hyperhydration, polyuria

Hyponatremia

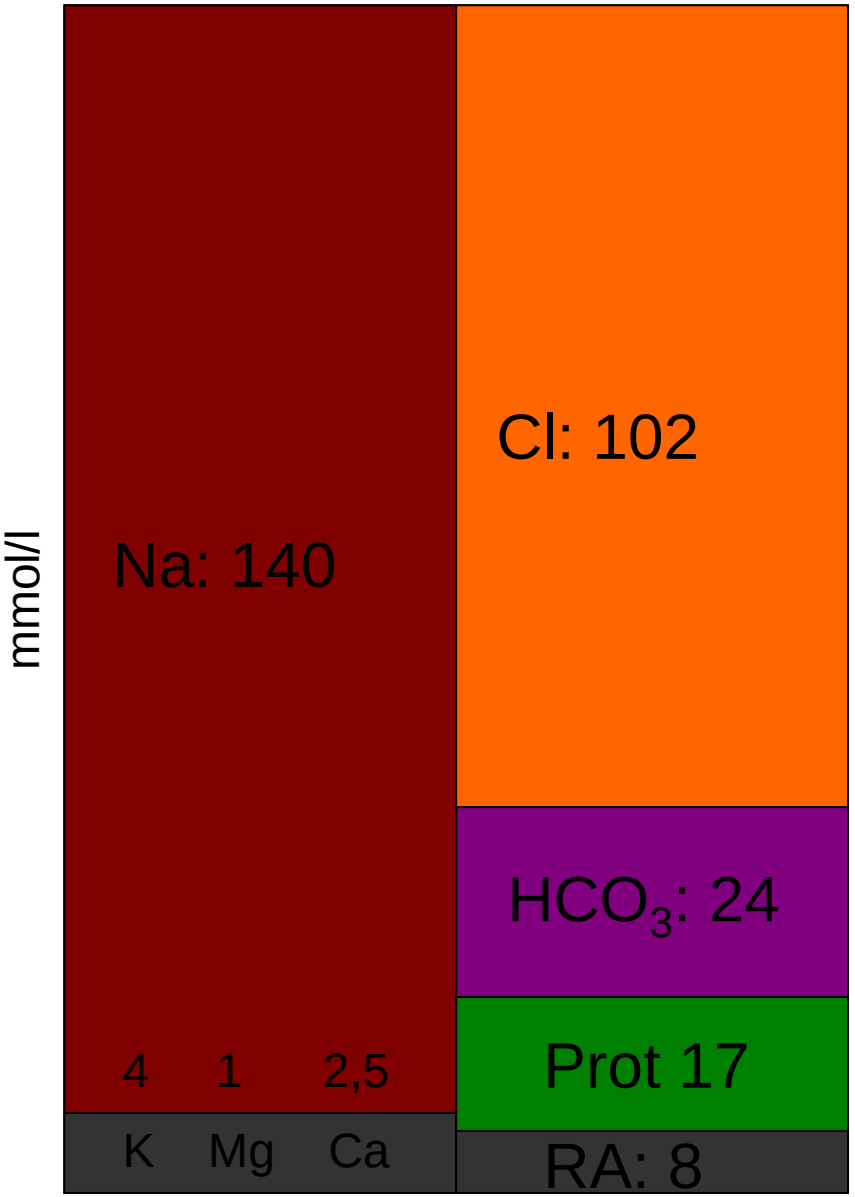
Too much of water

- Hyperhydration with glucose infusions
- Restriction of Na intake

Symptoms:

- edema, pulmonaly edema
- Encephalopathy
- ↓ osmolality

Main ions in blood



K (potassium): 3,7 - 5,1 mmol/l

Reserves 3 500 mmol, main iont of ICF

Distribution

- ICF 98 %
- ECF 2 %

Concentration

- plasma 3.7 - 5.1 mmol/l
- cells 110 - 160 mmol/l (ery 95 mmol/l)

Potassium - K

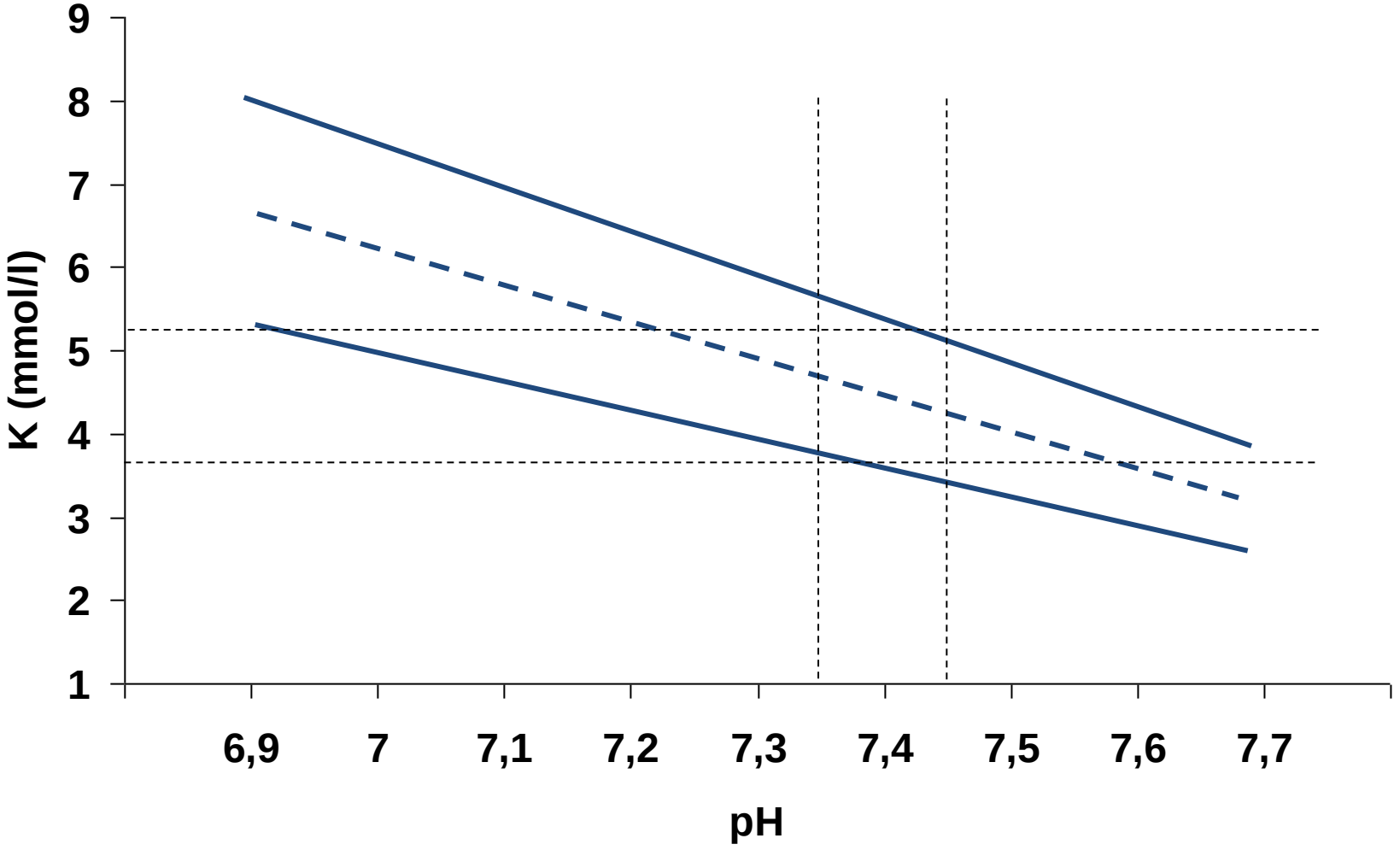
Excretion

- Urine: 45 - 90 mmol/24 hrs
- Faeces: 5-10 mmol/24 hrs

Sources – plant food

Importance: neuromuscular excitability, related to pH in organism

Dependence of K on pH

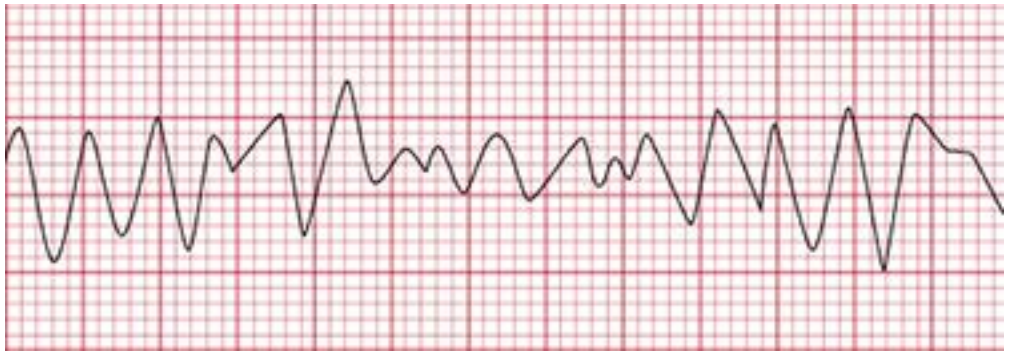


HyperK

- Decreased excretion by kidneys (oliguria, anuria)
- Transfer from cells to blood (acidosis, hemolysis, katabolism)

Symptoms

- arrhythmia
- muscle weakness



Dangerous values:

- > 6,5 mmol/l
- > 9-10 mmol/l → ventricle fibrilation
- Requires HD (dialysis)

HyperK - therapy

If kidney are not affected by disease

- diuretics (furosemide i.v)

In case of renal insufficiency

- Infusion: glucose + insulin
- Ion exchanger (Resonium)
- dialysis

HypoK

- Increased excretion: diuretics, diarrhoea
- Low intake
- Transfer into cells (alkalosis, anabolism)

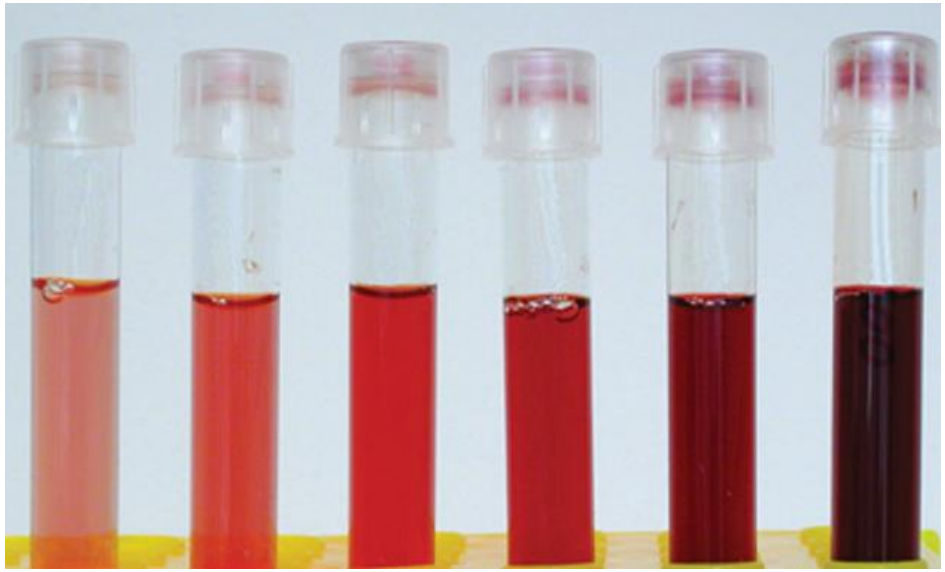
Symptoms:

- arrhythmia
- muscle weaknes, ileus

K - other

Blood exams K (red blood cells!)

- hemolysis (potassium washed up from cells to plasma)
- samples have to be stored in fridge



Chlorides- Cl

Distribution

- Main iont of ECF 97 - 105 mmol/l
- ICF 3 - 10 mmol/l

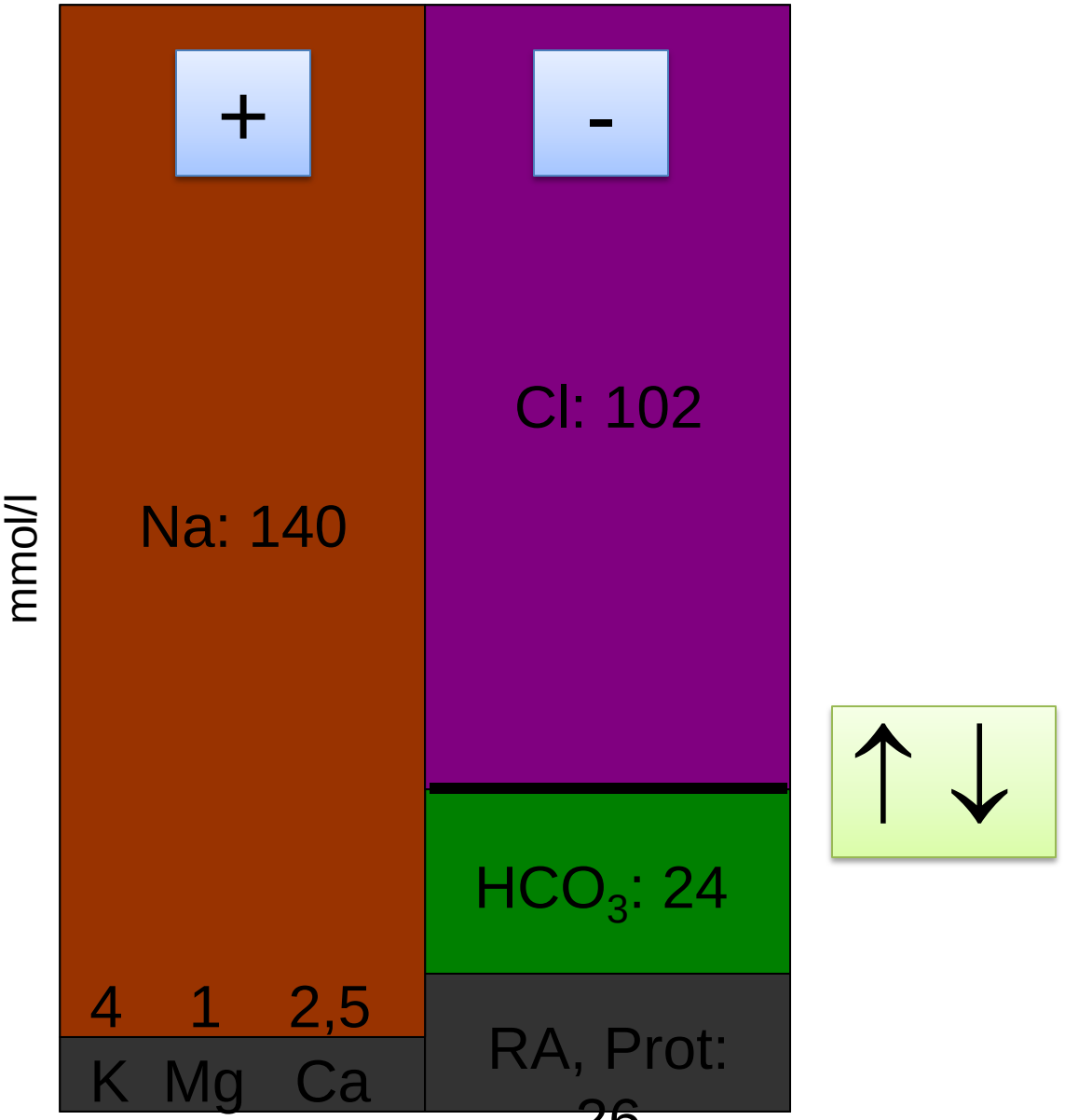
Importance:

- osmolality
- Acid-base balance (change in concentration of Cl^- → change in concentration of HCO_3^-)
- gastric juices - HCl

Balance

- Excretion by urine 120 - 240 mmol/24 hrs
- Sweat 10 - 20 mmol, stolice 10 mmol/24 hod

Main ions in blood



HyperCl

- Decreased excretion via kidneys
- Increased intake + renal insufficiency
- Increased intake of NaCl

Symptoms:

↑Cl^- → ↓HCO_3^- (buffer systém restricted – inability of catching H^+) → ↓ pH (acidosis)

HypoCl

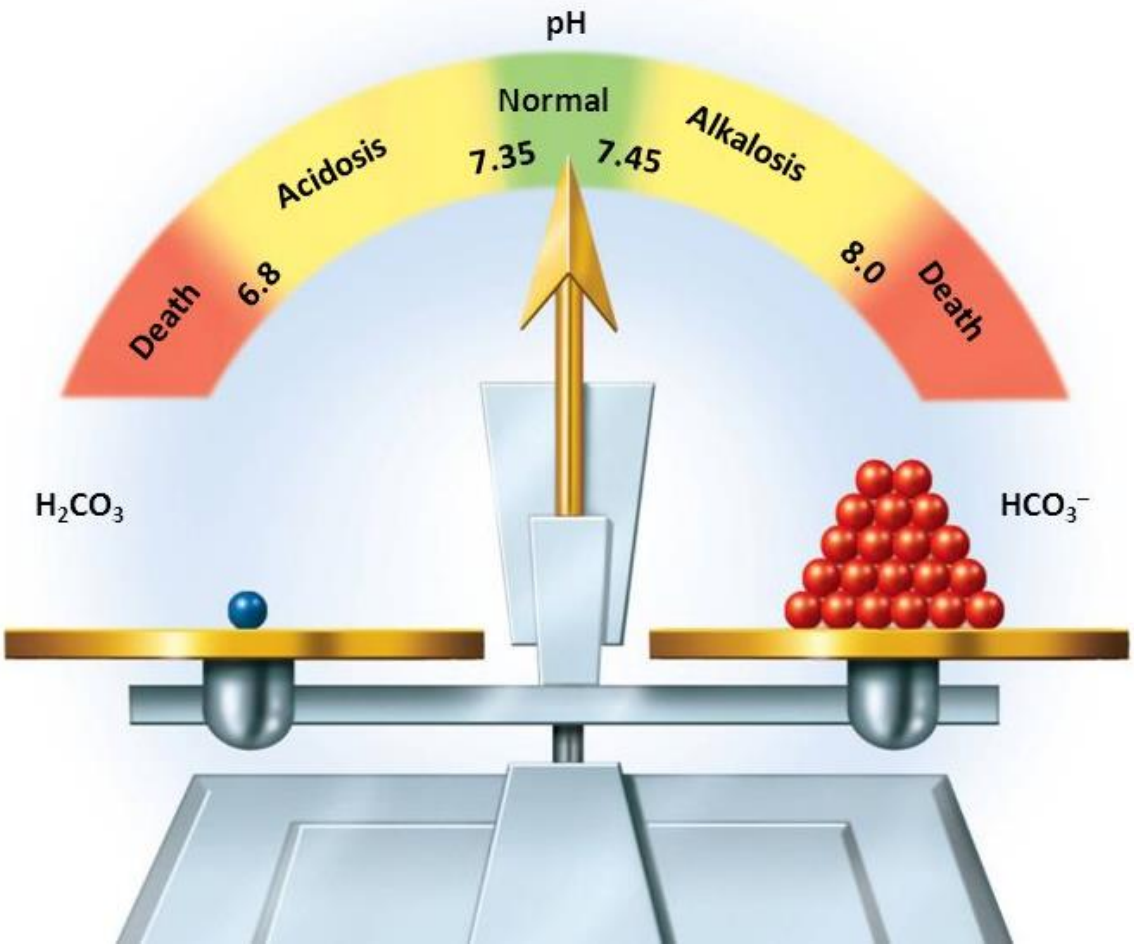
Excretions

- Gastric juices (vomiting)
- Kidneys (diuretics, polyuria)
- Sweating

Symptoms:

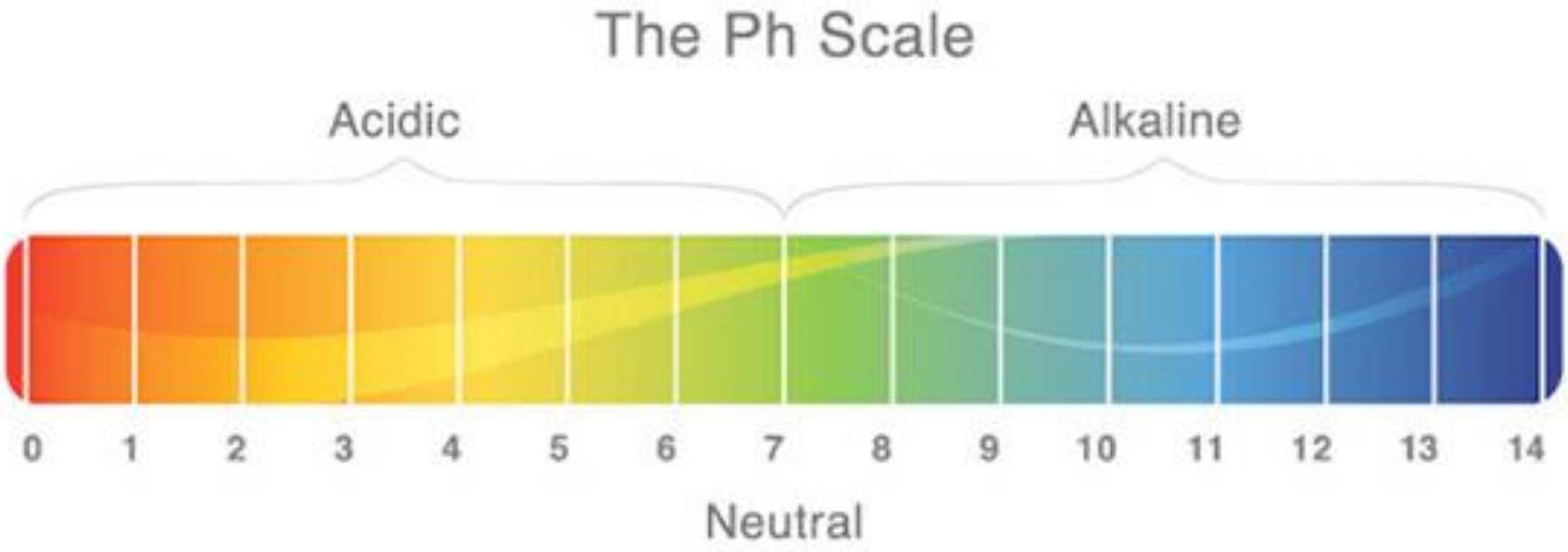
↓ Cl^- → ↑ HCO_3^- (abundance of buffers), ↓ H^+ → ↑ pH (alkalosis)

Acid - base balance



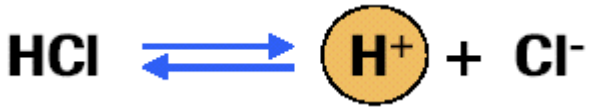
pH: 7.35-7.45

- Activity of hydrogen ions
- Increased $[H^+]$ = decrease pH.
- Low pH: blood is more acid
- High pH: blood is less acid

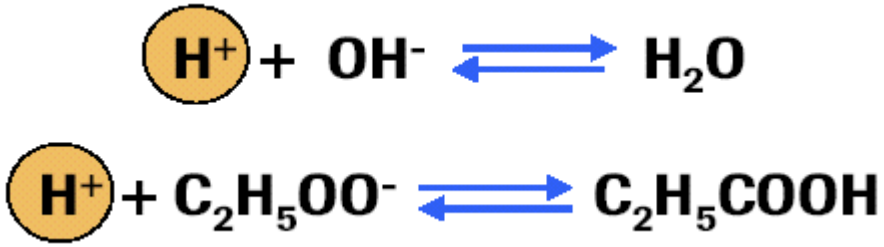

The Ph Scale
Acidic
Alkaline
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Neutral

Acids and bases

Acids: release H^+ iont



Bases: accept H^+ iont



- Acids: lactate, carbonic acid
- Bases: bicarbonate

Deviations in pH

Normal pH: 7,35 – 7,45.

In case of deviation:

- Affects contractility of myocard, nerve conductance
- enzymatic functions

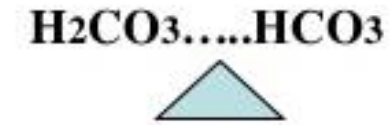
pH < 6,80 or > 7,80 is dangerous situation!

Keeping pH in normal ranges

3 systems:

- Extracelular buffers
- Lungs
- Kidneys

- **Buffering** by extracellular and intracellular buffers - **1st line emergency defence (rapid)**



- **Lungs: Alveolar ventilation**, which controls $PaCO_2$ (and increases efficiency of $H_2CO_3^-$ /$NaHCO_3^-$ buffer system)

- **Renal H^+ excretion**, which controls plasma [HCO_3^-] (and conserves Na^+ and excretes anion of the offending acid) (slow)

Acid – base balance

Normal pH: 7.35-7.45

Acidosis

- pH < 7.35
- Serious: pH < 6.80

Alkalosis:

- pH > 7.45
- Serious: pH > 7.70

Keeping pH in normal ranges

Buffer bases

- React with acids and bases
- bind extra H^+ ions (temporary solution)

Definitive solution = excretion of H^+ ions by lungs or kidneys.

Keeping pH in normal ranges

Main buffer systems:

Blood

- Natrium bicarbonate: $NaHCO_3$
- Hemoglobin
- Proteins

ICF

- Phosphates

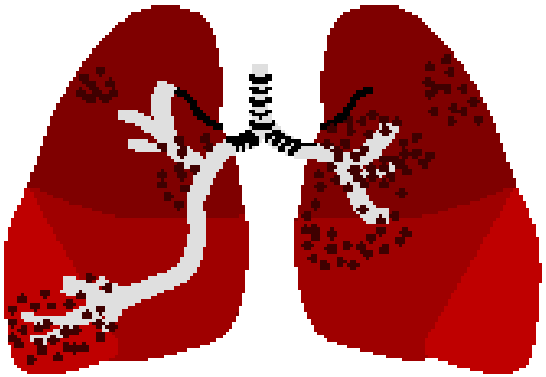
Bicarbonate buffer: $NaHCO_3$

$$H^+ + HCO_3^- \leftrightarrow \quad H_2CO_3 \quad \leftrightarrow \quad CO_2 + H_2O$$

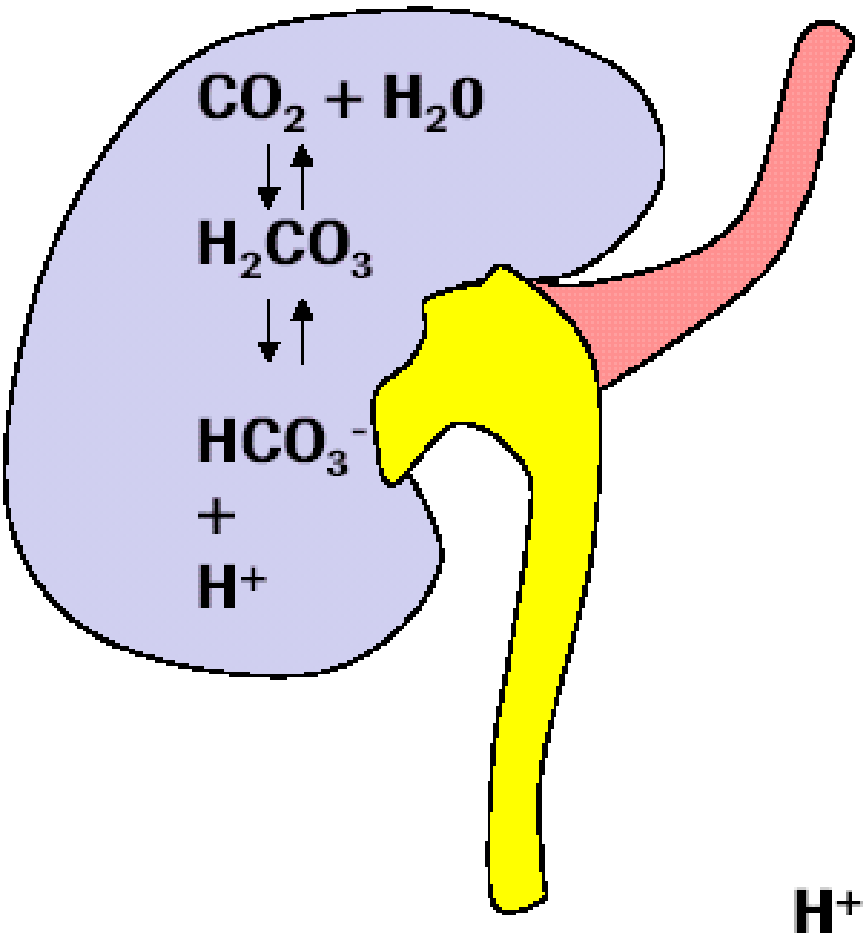
Lungs

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

Excretion of CO_2 by lungs drives reaction to right.



Kidneys



HCO_3^- resorption

Regeneration of bicarbonates

Excretion of H+

Dissolving CO_2 (carbon dioxide) in blood

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

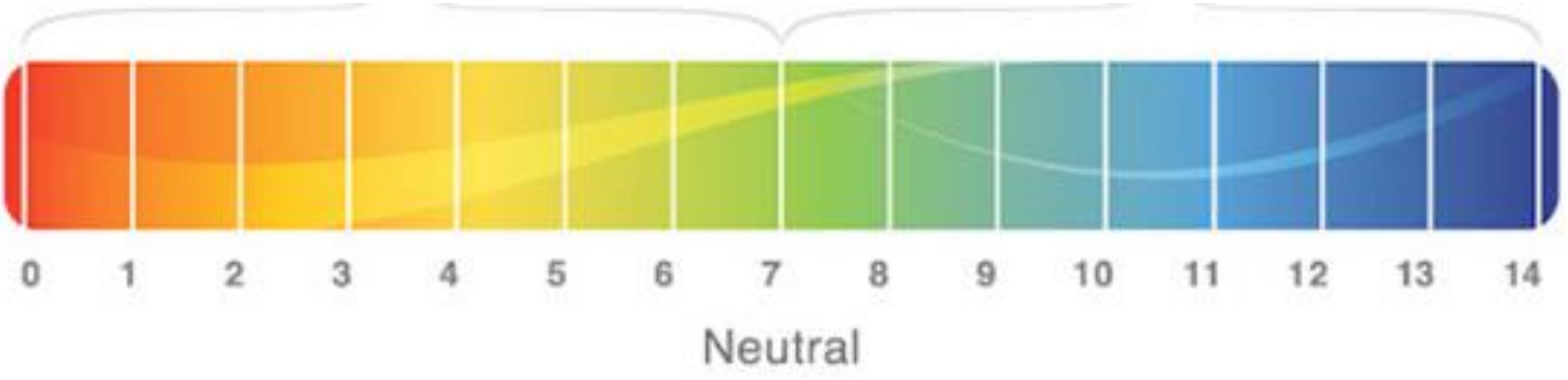
800 : 1 : 0.03

lungs (intensity of breathing - CO_2)

kidneys (excretion of H^+, synthesis HCO_3^-)

Bicarbonate (HCO_3^-)

- Deficiency → acidosis
- Abundance → alkalosis



Compensation of acid-base dysbalances

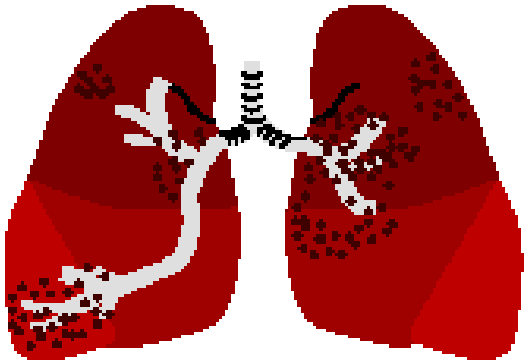
By:

- Lungs
- Kidneys

Pulmonary compensation

- Changing concentration of CO_2 leads to
- Changes in contrentration of H_2CO_3

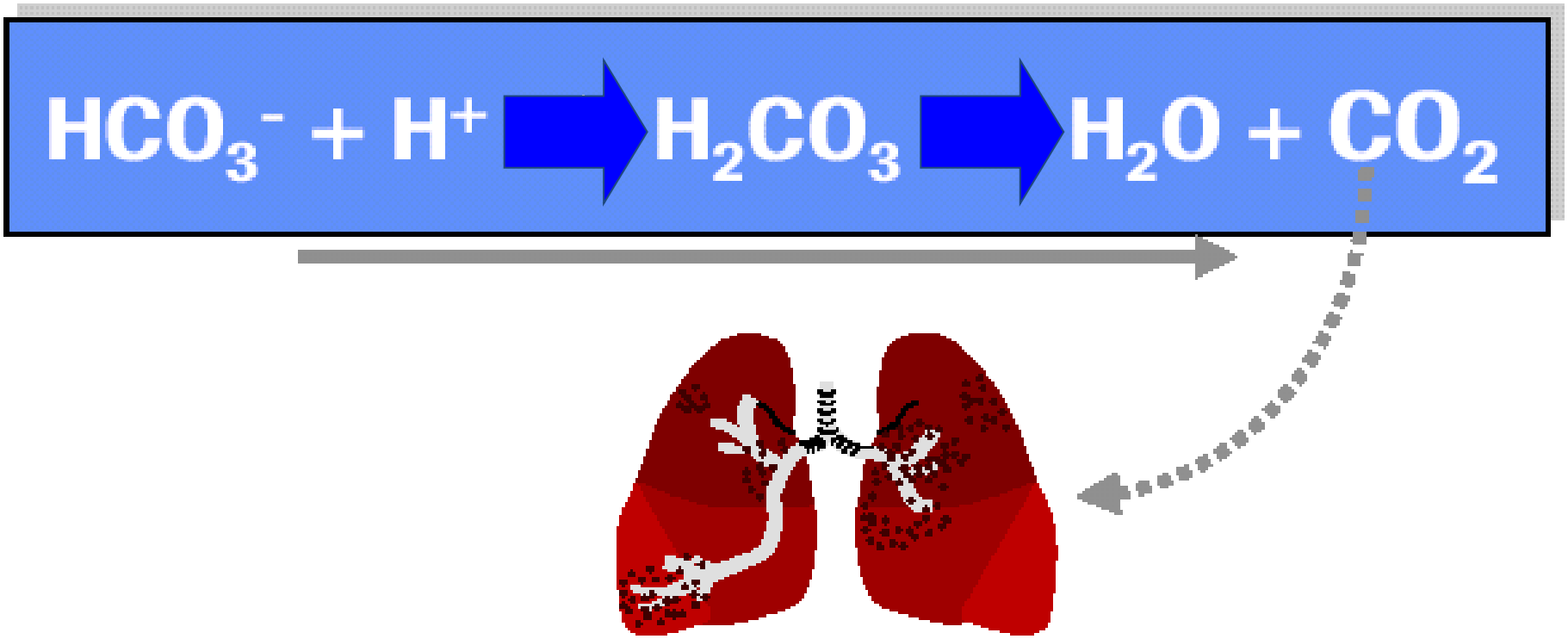
$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \rightleftharpoons H_2O + CO_2$$



Pulmonary compensation

Metabolic acidosis: hyperventilation

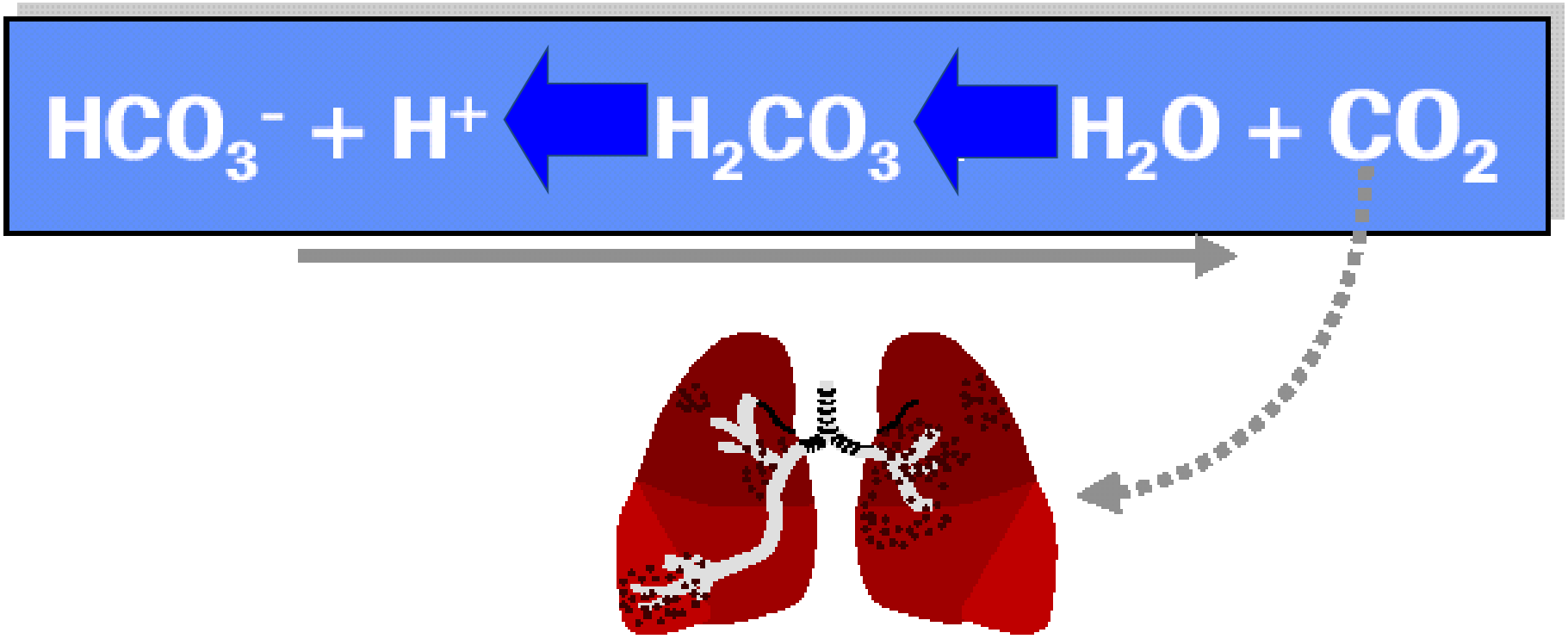
- breathing out CO_2, ↓ H_2CO_3
- very effective mechanism



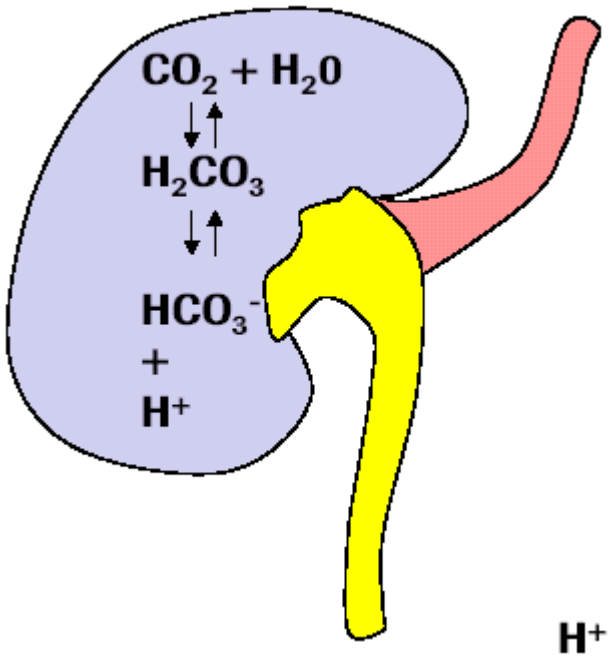
Pulmonary compensation

Matabolic alkalosis: hypoventilation

- ↑ pCO_2 , ↑ H_2CO_3 but ↓ pO_2, hypoxia
- not effective enough



Kidney compensation



Kidney compensation

Acidosis

- ↑ synthesis of HCO_3^-
- ↑ synthesis and excretion of NH_4^+, $H_2PO_4^-$

Alkalosis

- ↓ resorption HCO_3^-
- ↓ synthesis of NH_4^+ (↓ excretion H^+), ↑ synthesis of HPO_4^{2-}

AB dysbalance

- Acidosis
  - Metabolic
  - Respiratory (pulmonary)
- Alkalosis
  - Metabolic
  - Respiratory (pulmonary)

Combined AB dysbalance

Pulmonaly AB dysbalances

$CO_2 + H_2O \leftrightarrow \mathbf{H_2CO_3}$ (carbonic acid)

Respiration insufficiency

⇩

↑ Concentration of CO_2

⇩

↑ Concentration of H_2CO_3

⇩

Acidosis

Excessive breathing

⇩

↓ Concentration of CO_2

⇩

↓ Concentration of H_2CO_3

⇩

Alkalosis

Metabolic AB dysbalances

Concentration of acids and bases is changed

Too many acids

and/or

Low bicarbonate

⇩

Acidosis

Low amount of acids

and/or

Increased bicarbonates

⇩

Alkalosis

Metabolic acidosis

Accumulation of acids:

- ketoacids - diabetes
- intoxications (methanol, ethylenglycol etc.)

Loosing bicarbonates (diarrhoea)

Hyperchloridemia

Lactate acidosis

- Accumulation of lactate
- ↓ utilisation of lactate (liver failure, metformin)

Metabolic alkalosis

Loosing chlorides

- Vomiting HCl (hydrochloric acid)
- diuretics

Increase of bicarbonates

- When treating acidosis

Respiratory acidosis

Accumulation of carbonic acid, when pulmonary insufficiency (accumulation of CO_2)

- Pulmonaly diseases (COPD), intoxications leading to decreased respiratory centre function

Respiratory alkalosis

Low carbonic acid when excessive breathing (decrease of CO_2)

- Hyperventilation syndrom (anxiety, stress)
- encephalitis, meningitis

Parameters

- pH Measuring of [H+]
- pCO_2 respiratory part of AB balance
- HCO_3^- metabolic part of AB balance

AG – anion gap

- Difference between main plasmatic cations and anions $(Na^+ + K^+) – (Cl^- + HCO_3^-)$
- We can evaluate participation of lactate, ketoacids etc. on AB dysbalance.

Compensation of AB dysbalance

Respiratory deviations are compensated by kidneys and metabolic deviations are compensated by lungs.

When to take Astrup

Metabolic disorders

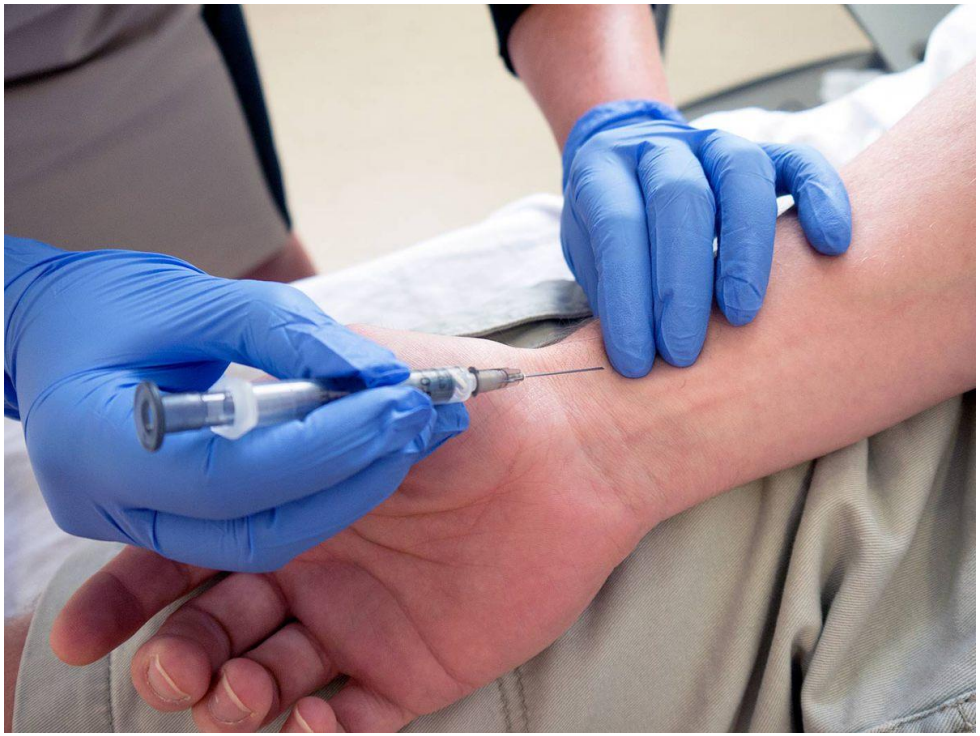
- Ketoacidosis, diabetes mellitus
- Intoxications
- Mineral dysbalances

Respiratory disorders

- Respiratory insufficiency
- COPD

Taking blood sample

- MD is responsible
- Taken from artery, without acess of the air



Save the 1st patient

- Patient is vomiting several days. What are the expected changes in AB balance?
- Answer: hypochloremic metabolic alkalosis (loosing hydrochloric acid)

- Because patient is really sick, he is starving. What are the expected changes in AB balance?
- Answer: metabolic ketoacidosis.

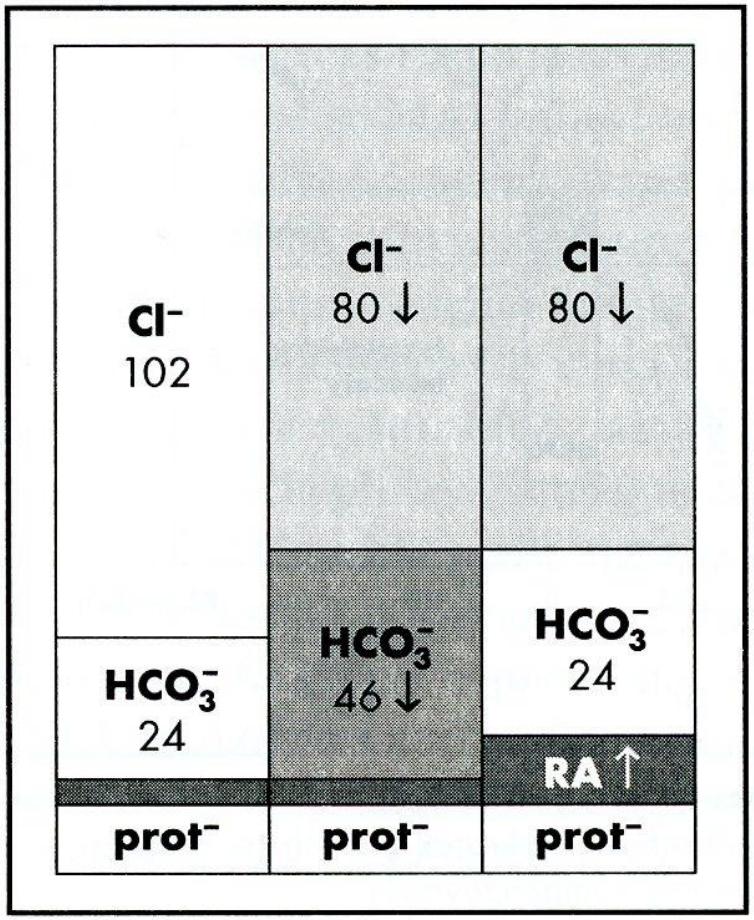
Type of AB dysbalance

- Combination of metabolic acidosis and metabolic alkalosis

Save the 1st patient

- What about pH? Will it be deviated or in normal ranges?
- Which biochemical parameters should be examinated?

Save the 1st patient



Obr. 13.5. Vývoj kombinované poruchy ABR při zvracení a současném hladovění podle aniontů v séru (čísla uvádějí koncentraci iontů v mmol/l, RA = reziduální anionty – jejich zvýšení je způsobeno hromaděním ketolátek)

Save the 1st patient - how to treat him?

Stop vomiting

- Antiemetic medication (metoclopramid/itoprium chlorid/ondansetron)

Rehydration

- Infusion with NaCl (substitution of Cl), glucose infusion (nutrition)

Nutrition

- Parenteral / later enteral

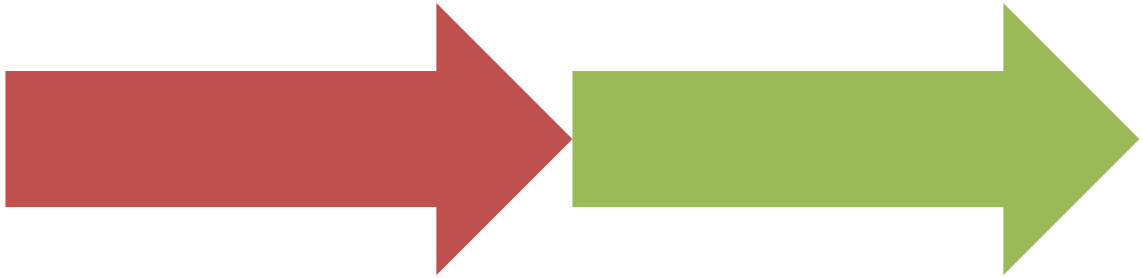
Save 2nd patient

- Patient with DM is not compliant and he decided not to take his insulin regularly. What are the expected changes in AB balance?
- Answer: hyperglycemia → ketoacidosis

Hyperglycemia → osmotic diuresis → polyuria and dehydration (hypovolemia) → tissue hypoxia → lactate acidosis

Type of AB dysbalance

- Combination of two metabolic acidoses (ketoacidosis from DM+ lactate acidosis from tissue hypoxia)



Save the 2nd patient - how to treat him?

- Treat the DM properly
- Insulin + rehydration, regular controls of potassium (beware of hypokalemia during treatment of hyperglycemia).
- Decrease glycemia slowly (brain edema).

Save 3rd patient

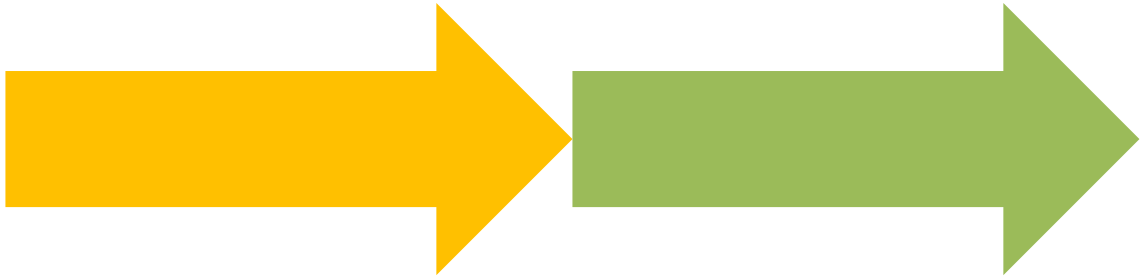
- Patient with cardiopulmonary arrest. What are the expected changes in AB balance?
- Answer: respiratory acidosis (CO_2 is rising up in organism)

+

- Tissue hypoxia → lactate acidosis

Type of AB dysbalance

- Combination of respiratory acidosis and metabolic acidosis.



Save the 3rd patient - how to treat him?

- CPR
- Artificial ventilation
- …