*

WATER
IONS

The total body water :

body weight

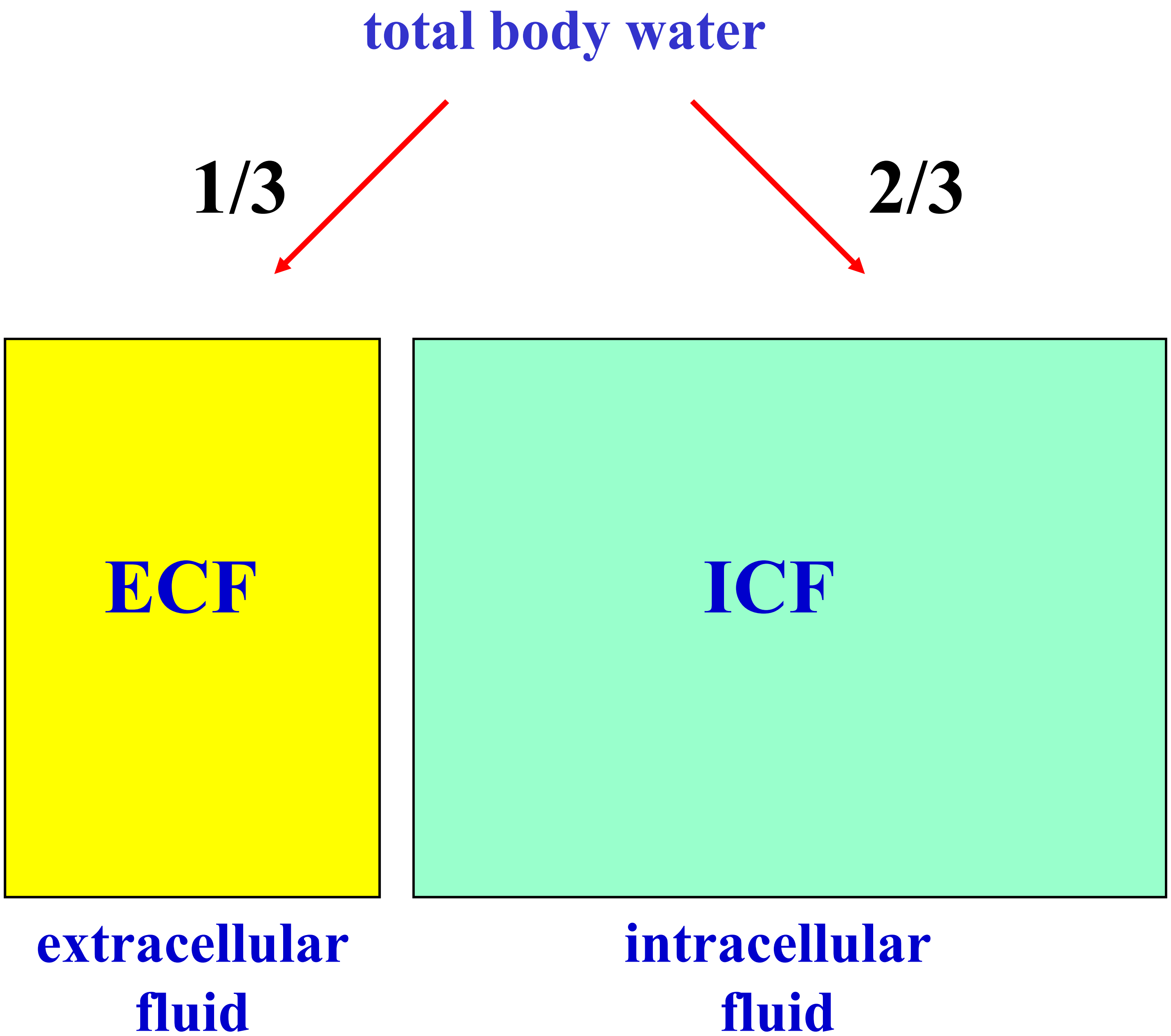
↓ **60 %**

(less usual: in women calculated **55 %** of body weight)

TBW

the total body water

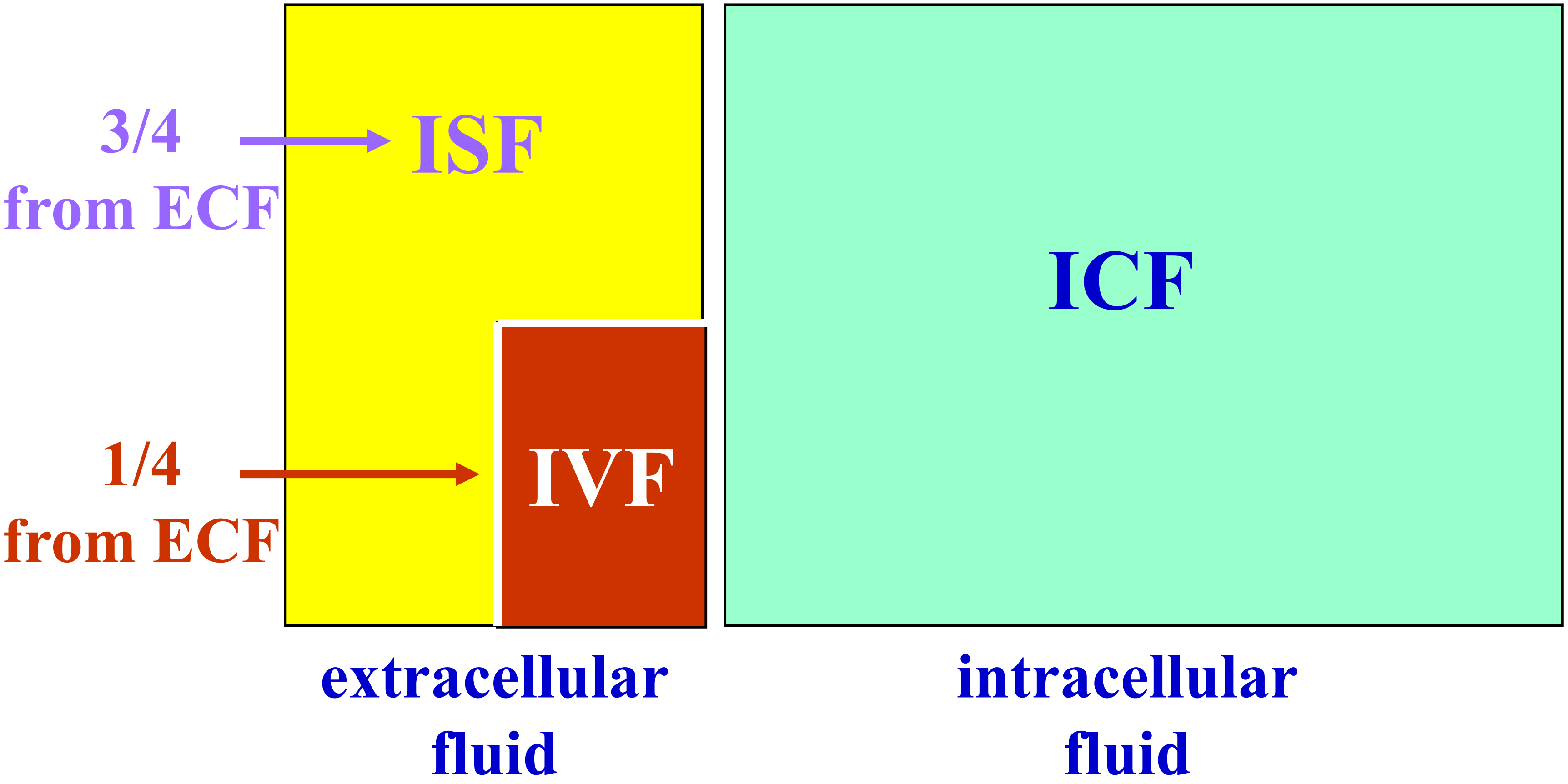
ECF a ICF :


total body water
1/3
2/3
ECF
ICF
extracellular fluid
intracellular fluid

The intravascular fluid (IVF) :

= blood plasma,
= ¼ of ECF volume

The rest of ¾ ECF volume is the interstitial fluid (ISF)



The recapitulation of fluid volumes with respect to the body weight :

body weight (100 %) 70 kg → TBF (60 %) 42 L

TBF → ECF (20 %) 14 L
TBF → ICF (40 %) 28 L

ECF → blood plasma = IVF (5 %) 3,5 L
ECF → interstitial fluid = ISF (15 %) 10,5 L

~~„transcellular“ fluid (see later)~~

it is not calculated to TBF

TBW – changes with age :

	% of body weight
newborn	~ 79 (!)
1 year	~ 65
10 – 50 years	~ 60
over 50 years	decrease of 4 – 6

Because of greate content of water, small children are extremly sensitive to loss/deficit of water, which can very easily threat thair life !

Ionts in ECF a ICF :

ECF

Na^+ = 140 mmol . L^{-1}
K^+ = 4,4 mmol . L^{-1}
Cl^- = 100 mmol . L^{-1}

Ca^{2+} = 2,5 mmol . L^{-1}

Mg^{2+} = 1 mmol . L^{-1}

HCO_3^- = 24 mmol . L^{-1}

HPO_4^{2-} + $H_2PO_4^-$ =
= 1 mmol . L^{-1}

SO_4^{2-} = 0,5 mmol . L^{-1}

org. acids = 4 mmol . L^{-1}

proteins = 2 mmol . L^{-1}

pH = 7,40

ICF

Na^+ = 10 mmol . L^{-1}
K^+ = 155 mmol . L^{-1}
Cl^- = 8 mmol . L^{-1}

Ca^{2+} = 0,001 mmol . L^{-1} (cytosol)

Mg^{2+} = 15 mmol . L^{-1}

HCO_3^- = 10 mmol . L^{-1}

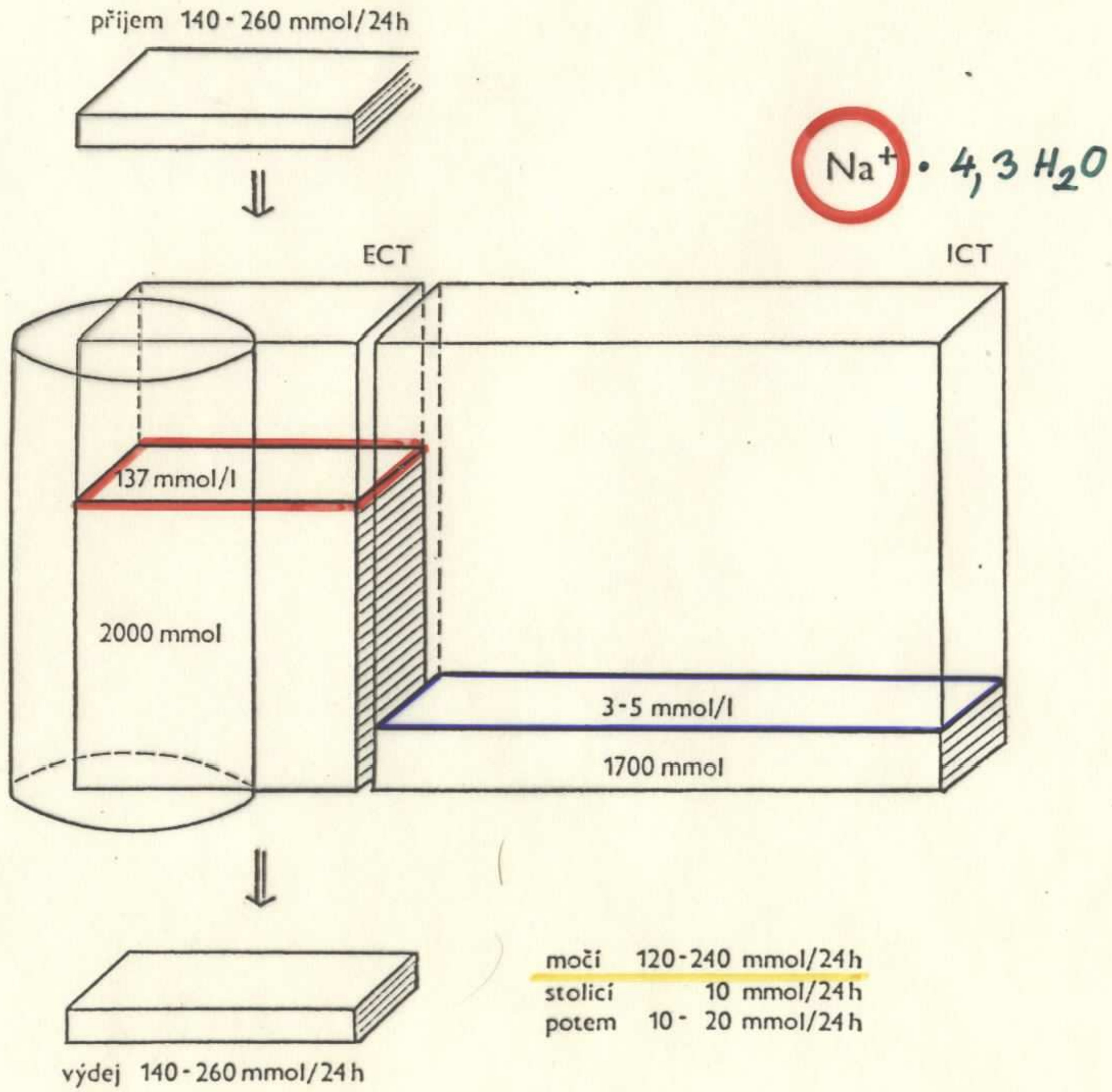
HPO_4^{2-} + $H_2PO_4^-$ = 65 mmol . L^{-1}
(the greatest part in org. form)

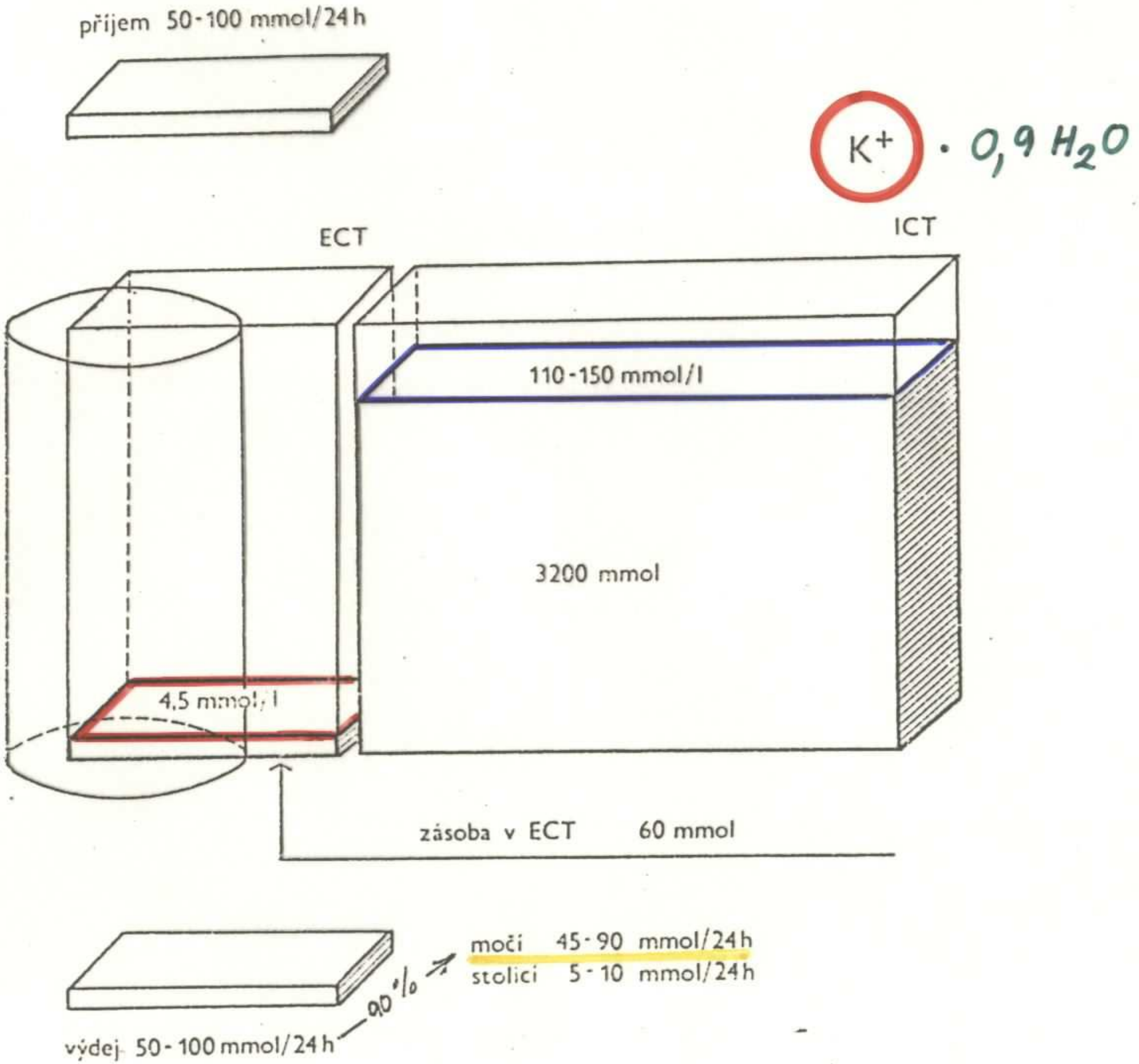
SO_4^{2-} = 10 mmol . L^{-1}

org. acids = 2 mmol . L^{-1}

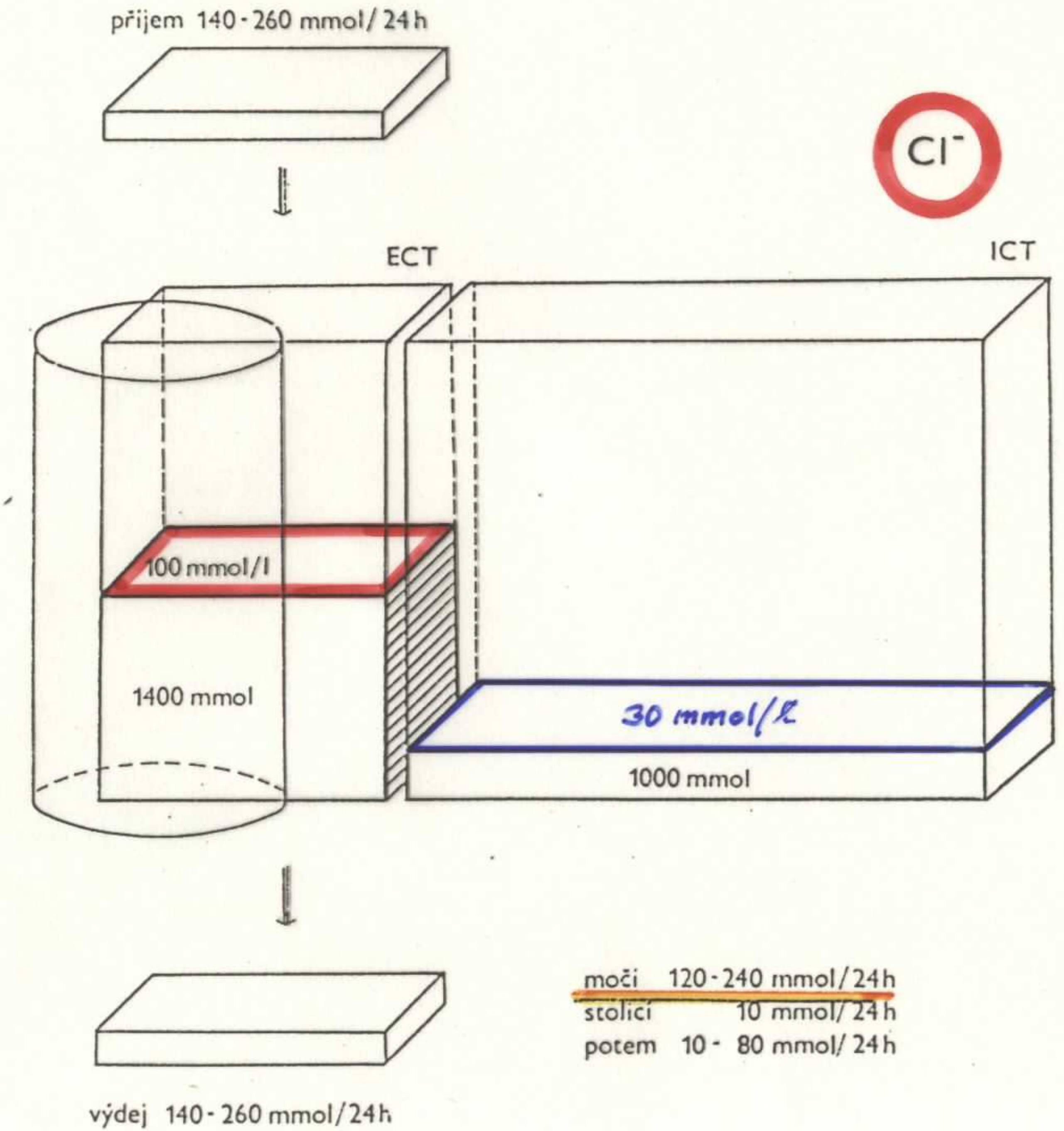
proteins = 6 mmol . L^{-1}

pH = 7,20


příjem 140 - 260 mmol/24h
Na^+ · 4,3 H_2O
ECT
ICT
137 mmol/l
2000 mmol
3 - 5 mmol/l
1700 mmol
moči 120 - 240 mmol/24h
stolicí 10 mmol/24h
potem 10 - 20 mmol/24h
výdej 140 - 260 mmol/24h



příjem 50-100 mmol/24 h
K^+ · 0,9 H_2O
ECT
ICT
110-150 mmol/l
3200 mmol
4,5 mmol/l
zásoba v ECT 60 mmol
moči 45-90 mmol/24 h
stolici 5-10 mmol/24 h
90 %
výdej 50-100 mmol/24 h


příjem 140 - 260 mmol/ 24 h
Cl⁻
ECT
ICT
100 mmol/l
1400 mmol
30 mmol/l
1000 mmol
močí 120 - 240 mmol/24 h
stolicí 10 mmol/ 24 h
potem 10 - 80 mmol/ 24 h
výdej 140 - 260 mmol/24 h

Plasma electrolytes concentrations :

Krevní plasma	**Na^+** mmol . l^{-1}	**K^+** mmol . l^{-1}	**Cl^-** mmol . l^{-1}	**HCO_3^-** mmol . l^{-1}	**Ca_{total}** mmol . l^{-1}	**Mg^{2+}** mmol . l^{-1}
Rozpětí průměr	130 – 143 137 (**140**)	4,0 – 5,5 4,4	95 – 107 101 (**100**)	21 – 27 24	2 – 3 2,5	0,7 – 1 "**1**"

The law of electroneutrality :

→ **agreement in the sum of positive and negative charges (blood plasma, simplifiedly).**

If ionts with more charges are present, the sum of molar concentrations is different from the sum of charges !

cation	molarity (mmol . L^{-1})	
	cation	(+) charge
Na^+	140	140
K^+	4	4
Ca^{2+}	2,5	5
Mg^{2+}	1	2
-		
-		

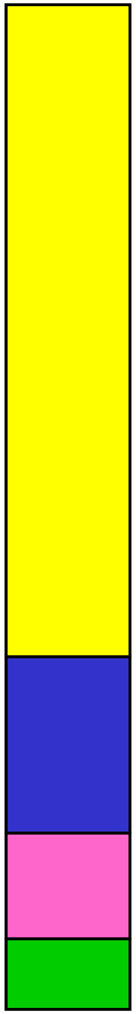
anion	molarity (mmol . L^{-1})	
	anion	(-) charge
Cl^-	100	100
HCO_3^-	24	24
prot $^-$	2	~ 20
HPO_4^{2-}	1	2
SO_4^{2-}	0,5	1
org. acids	4	4

the total positive charge: 151

the total negative charge: 151

Anionts in blood plasma :

the molar concentrationes
of negative charges are given !



chloride 100 mmol . L^{-1}

bicarbonate (hydrogencarbonate)
24 mmol . L^{-1}

(proteinate ~ 16 mmol . L^{-1})

(residual anions ~ 10 mmol . L^{-1})

Σ = cca 150 mmol . L^{-1}

Hydrogencarbonate („bicarbonate“) :

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

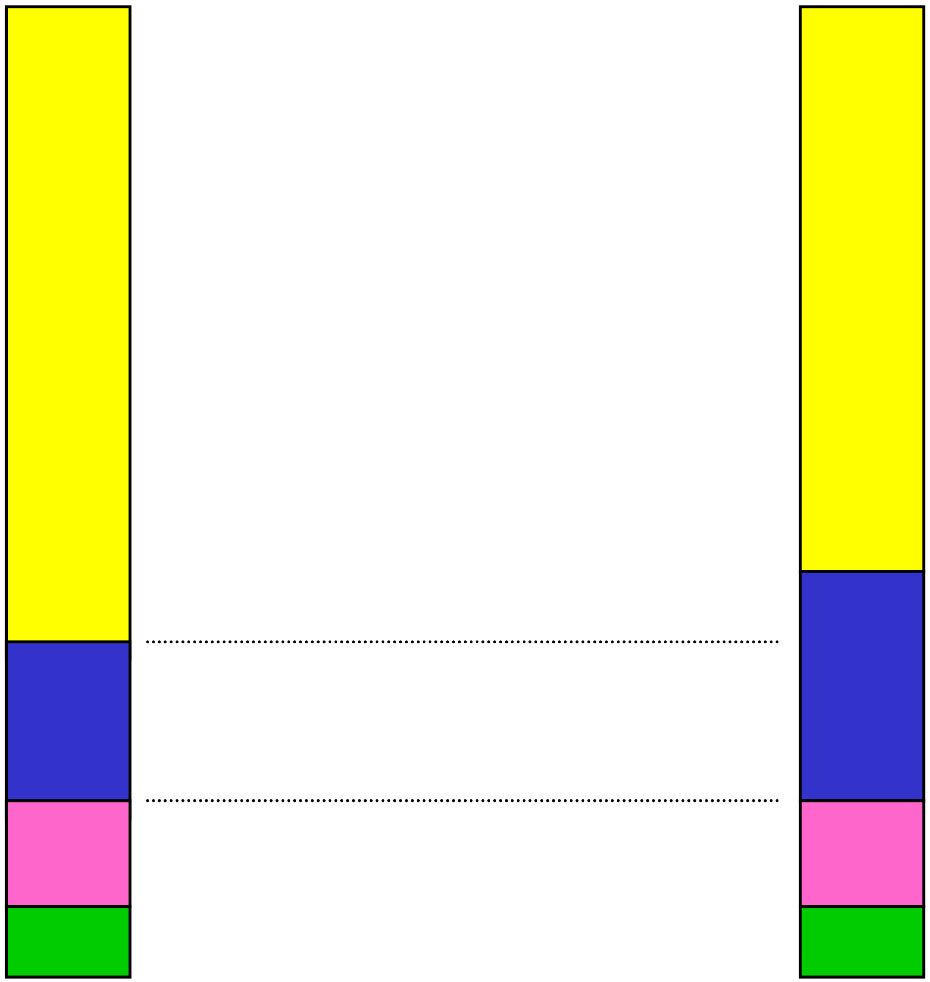
anion, which can adapt its concentration rapidly to the changing conditions

$$NaHCO_3 + H_2O \rightleftharpoons H_2CO_3 + Na^+ + OH^-$$

as consequence of hydrolysis the substance with alkalic reaction

(The carbonic acid in oval symbolizes a weak - practically undissociated electrolyte. The sodium hydroxide is a strong base, e.g. almost total dissociated electrolyte. - In the aqueous solution the excess of OH^- ions makes the solution basic.)

Hypochlor(id)emic alkalose :

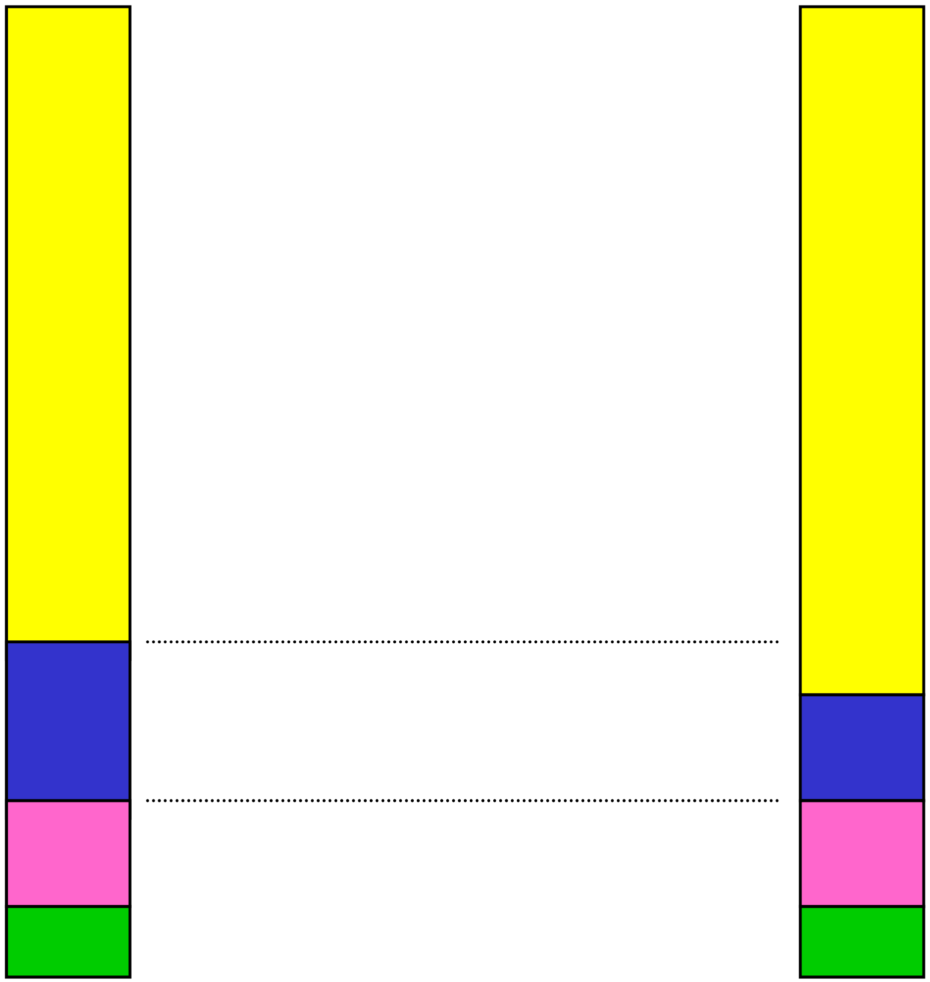


normal hypochlor(id)emia

the decrease in chloride (yellow) is compensated for increase of alkalic bicarbonate (blue), others anions unchanged

(for example:
gastric juice suctioning after operations
= the loss of HCl)

Hyperchlor(id)emic acidose :

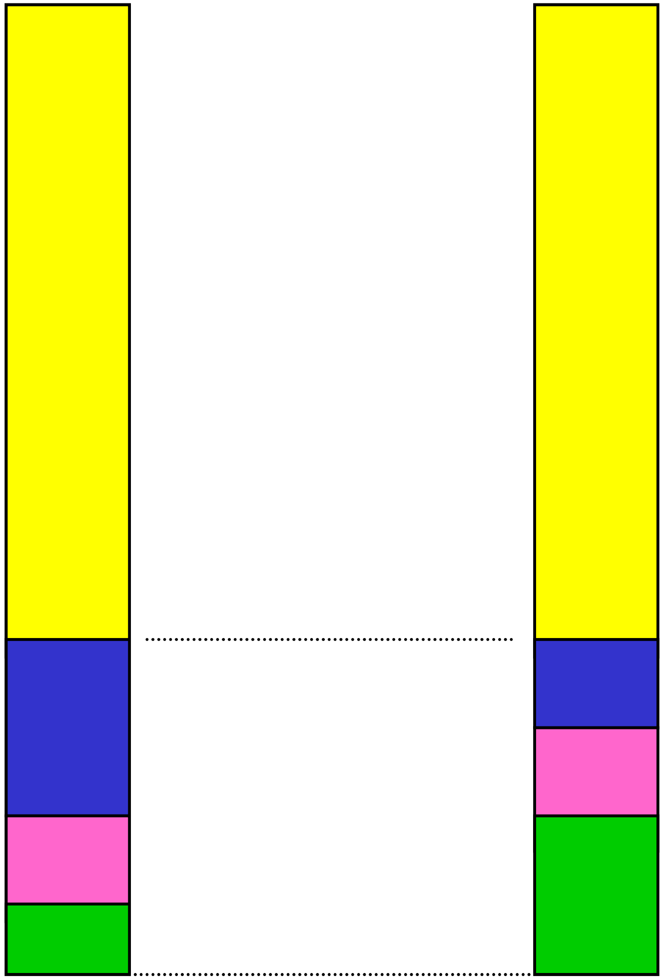


the excess of chloride (yellow) is compensated for decrease of of alkalic bicarbonate (blue), others anions unchanged

(for example:
longer administration of „physiological“ solution)

normal hyperchlor(id)emia

Normochlor(id)emic acidose :

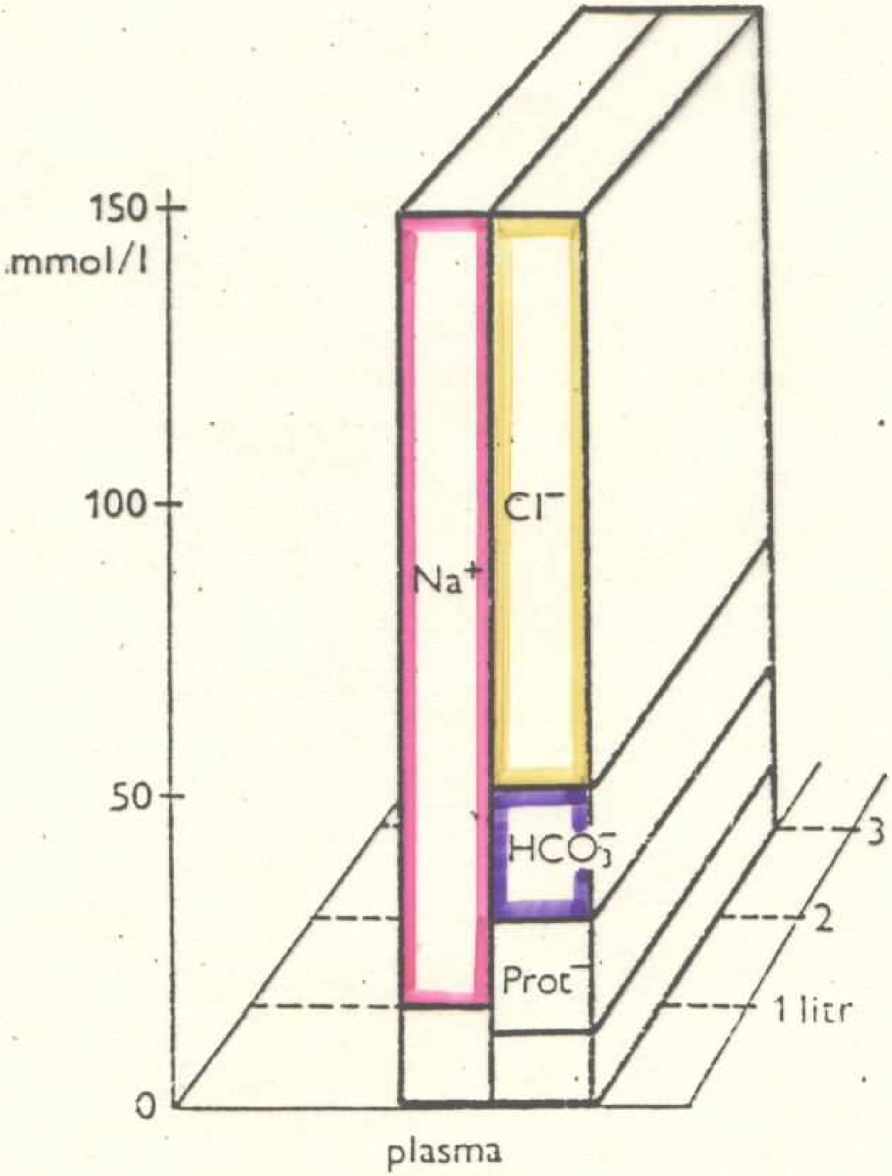


normal

increase in residual anions

the excess of residual anionts (green) is compensated for decrease of alkalic bicarbonates (blue), others anions unchanged

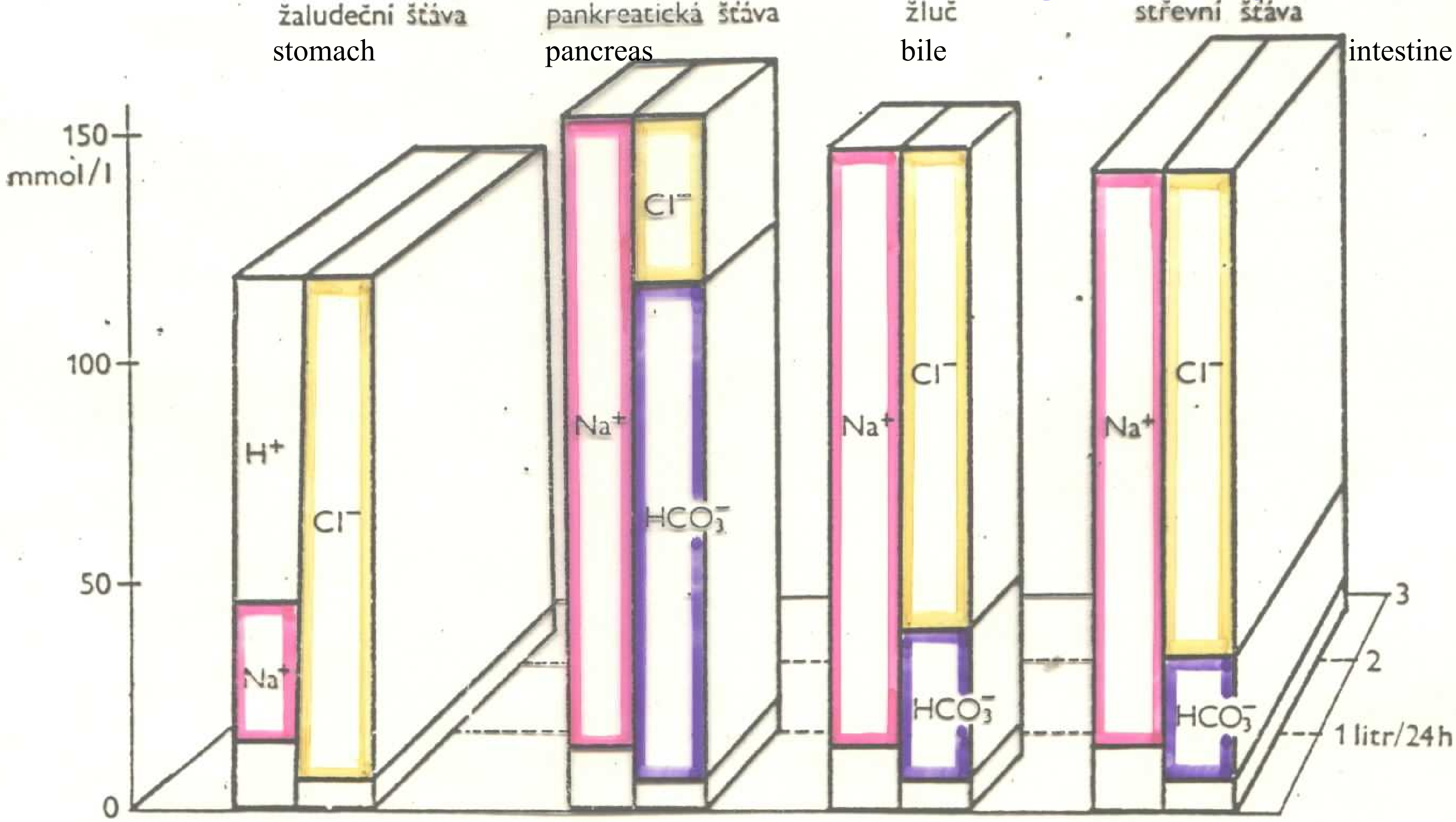
(from the residual anions for example: increase in lactate or in ketobodies = acetoacetát, hydroxybutyrát).



Blood plasma

Iontové složení tělesných tekutin a jejich průměrná tvorba za 24 hodin. Pro srovnání uvedeno složení a objem krevní plasmy.

Složení trávicích šťáv: The composition of digestive juices :



(význam: pro ev. odhad ztrát sondou neb drénem)
(significance: for the possible estimate of losses by sound or drain)

„Strong ions“ (1):

There are the ions (mostly strong) acids and bases, which do not have the buffer ability under physiological pH of blood (~ 7,4).

„Strong“ cations: Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}
„Strong“ anions: Cl^{-}, SO_4^{2-}...

The unidentified/unmeasured anions (UA$^-$) belong among „strong anions“.
UA$^-$ *) comprise anions of acids (increased) in metabolic acidose (MAc) :

- **anions of organic acids: lactate $^-$, acetoacetate $^-$, 3-hydroxybutyrate $^-$, in intoxications possible formiate $^-$, salicylate $^-$, ...**
- **anions of strong anorganic acids: sulfate $^-$ (in chronic kidney failure...)**

*) UA$^-$ = **u**nidentified **a**nions ['anai,dentifaid ,aen'aiəns]

„Strong ions“ (2):

The pK_A values of organic acids (from the group of UA^-) are usually three order of magnitude lower (~ 1.000times greater !) than the pH of blood.
Then the acids are dissociated in the blood > 99,9 % and their anions have properties of „strong ions“.

Organic acids are „kept“ (in the blood) in the state of complete dissotiation, they „lost“their properties of weak acids (as are known in the water medium) and therefore they „lost“ also the buffering ability.

(The buffering ability is given by the $pH = pK_A \pm 1$ in the water medium. In the blood (at pH ~ 7,4) the region exceeds the value $pK_A + 3$ for an organic acid !! - see the table farther).

Former equilibrium of dissociation of an organic acid (known from the water solution) disappeared in the blood - the buffering systems of blood maintain the pH, which leads to almost complete dissociation of organic acid.

„Strong ions“ (3):

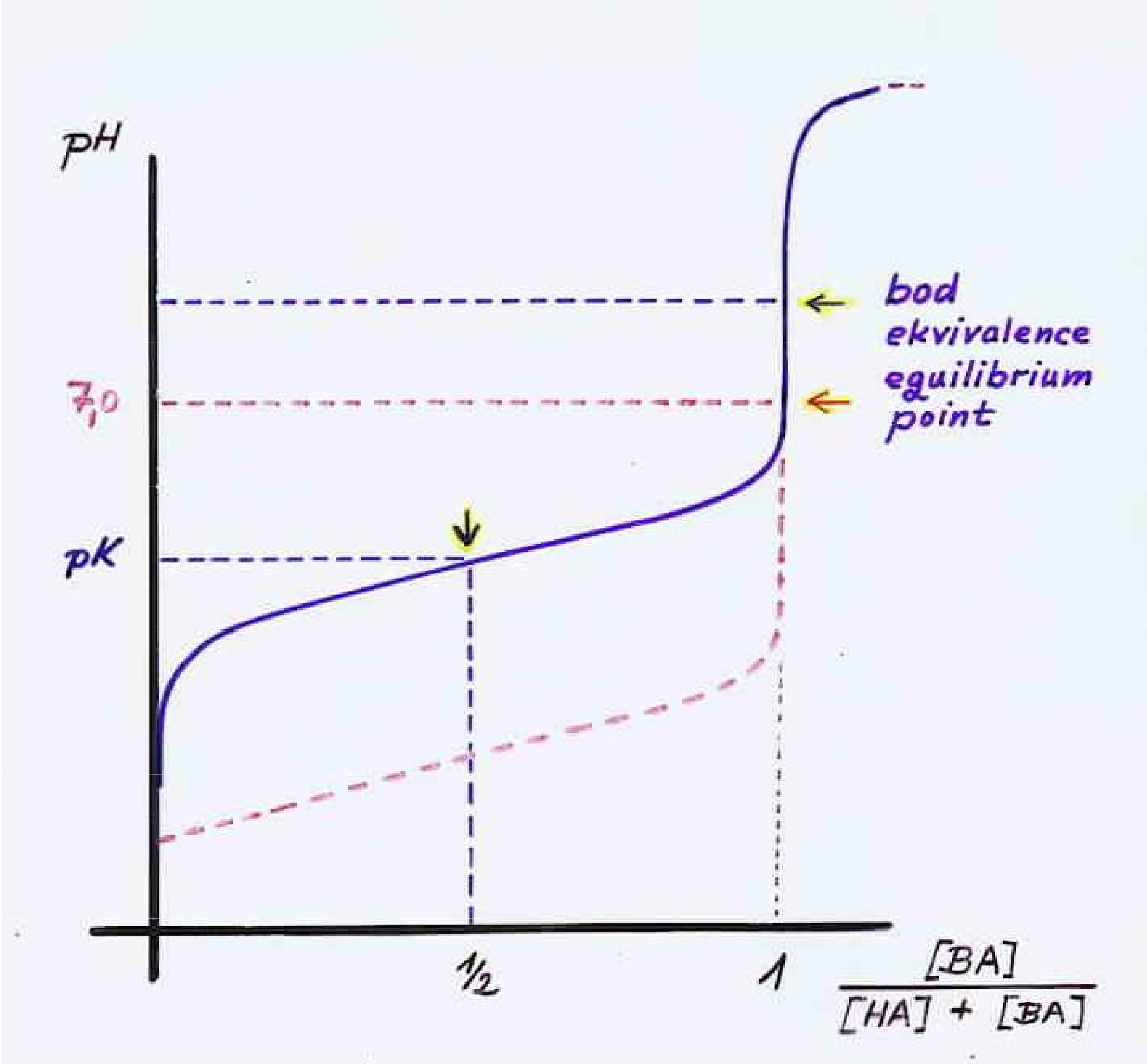
acid	pK_A	pH = 7,40	dissociation
salicylic +)	3,00	$pK_A + 4,40$	> 99,9 %
acetoacetic	3,52	$pK_A + 3,92$	> 99,9 %
formic +)	3,75	$pK_A + 3,65$	> 99,9 %
lactic	3,86	$pK_A + 3,54$	> 99,9 %
β-hydroxybutyric	4,70	$pK_A + 2,7$	

At the pH = pK_A, an acid is dissociated from 50 %,
if the pH is > (pK_A + 3), an acid is dissociated from > 99,9 %

+) the acids present in intoxication

The titration curve and ability to buffer

„$pK_A \pm 1$"



Independent variables
which determine the state of ABE (1):

1/ pCO_2

2/ strong ion difference (SID)

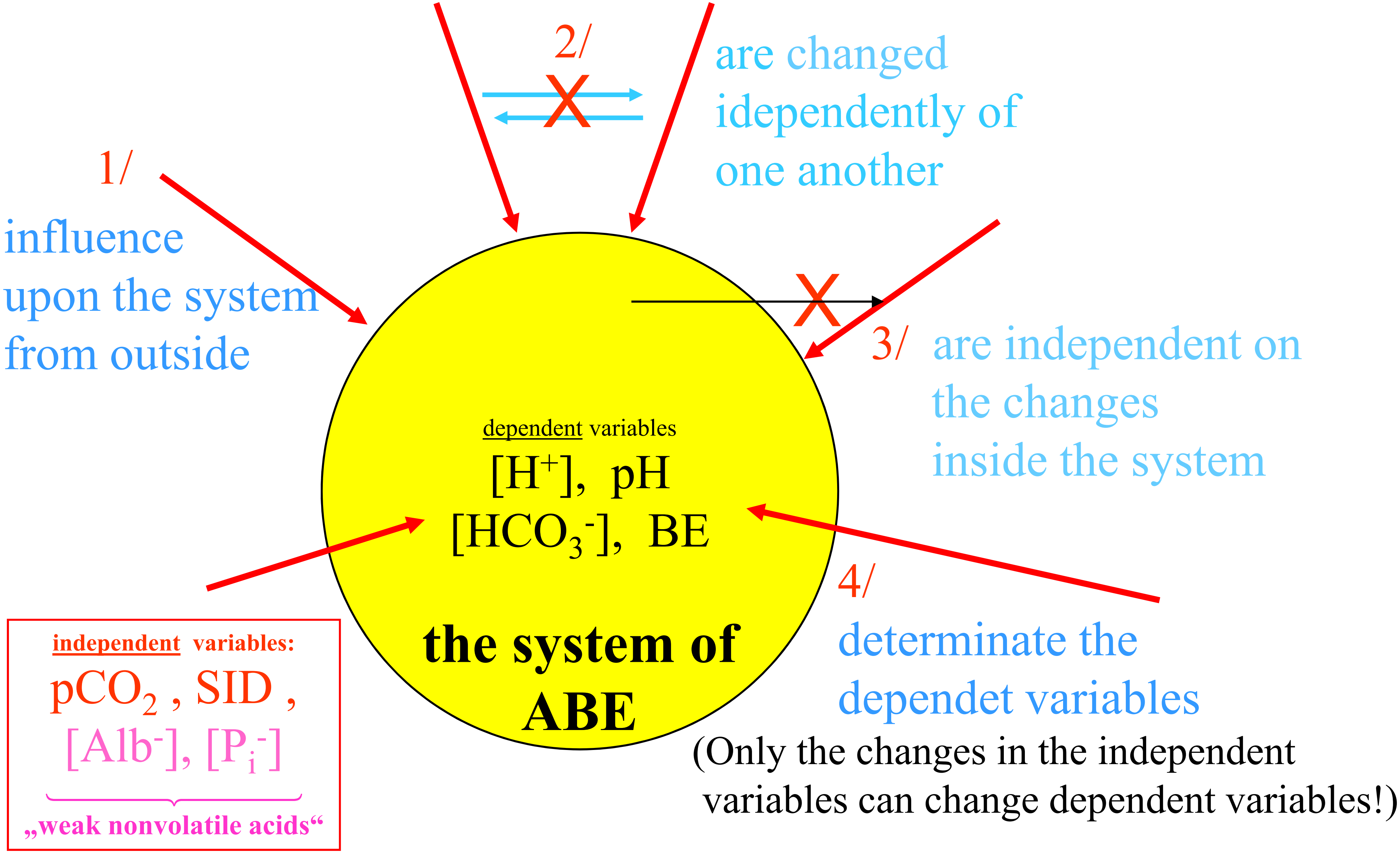
It is the difference among the sum of all strong cations (completely dissociated, chemically non-reacting)
(Na^+ + K^+ + Ca^{2+} + Mg^{2+})
and the sum of all strong anions (Cl^- + another strong anions)

3/ total weak nonvolatile acids (A_{tot})

It is the sum of molar concentration of negative charges of albumin (Alb^-) and inorganic phosphate (P_i^-)

independent variables can change primarily and independently of one another

Independent variables (2) :



(It is fully abstract model constructed for the system of acidbase equilibrium!
It gives only the relationships among variables.)

Independent variables which determine the state of ABE (3):

1/ pCO2

2/ strong ion difference (SID)

$$SID = ([Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}]) - ([Cl^-] + [UA^-])$$

3/ total weak nonvolatile acids (A_{tot})

$$A_{tot} = [Alb^-] + [P_i^-]$$

Unidentified / unmeasured anions UA^- :

„ 3 "

$$[UA^-] = ([Na^+] + [K^+] + \underbrace{[Ca^{2+}] + [Mg^{2+}]}_{\text{„3"}})$$

$$- ([Cl^-] + [Alb^-] + [P_i^-] + [HCO_3^-])$$

$[Alb^-]$ ~ 12, $[P_i^-]$ ~ 2

In some formulas the number 3 is given instead the sum of $[Ca^{2+}] + [Mg^{2+}]$, both cations cannot be determinated (it becomes simpler).
At the $[Alb^-]$ and $[P_i^-]$ the normal average values of <u>molar concentration</u> of their negative <u>charge</u> are present for information.
All dimensions: mmol . l^{-1}

<u>Dependent variables</u>
which determine the state of ABE :

None of subsequent acidobasic variables (it is pH, $[HCO_3^-]$, BE) can change primarily.
There are the dependent values („dependent variables“) , which are modified only in dependence on <u>in</u>dependent variables changes.
The change all of them simultaneous by only if one/more the independent variables change/s.

⟶ the improved procedure of evaluation of AB parameters was developed by: Peter A. Stewart (Canada)
Vladimír Fencl (Czech Republic)

Annotation:

1/ in the next „blue graphs“ the proportionality of constituents is not maintanied. Only the oversimplified demonstration in columns is used

2/ there is the difference between the form of calculation and the content (and therefore its significance) of some indicator

E.g. the strong ion difference (SID):

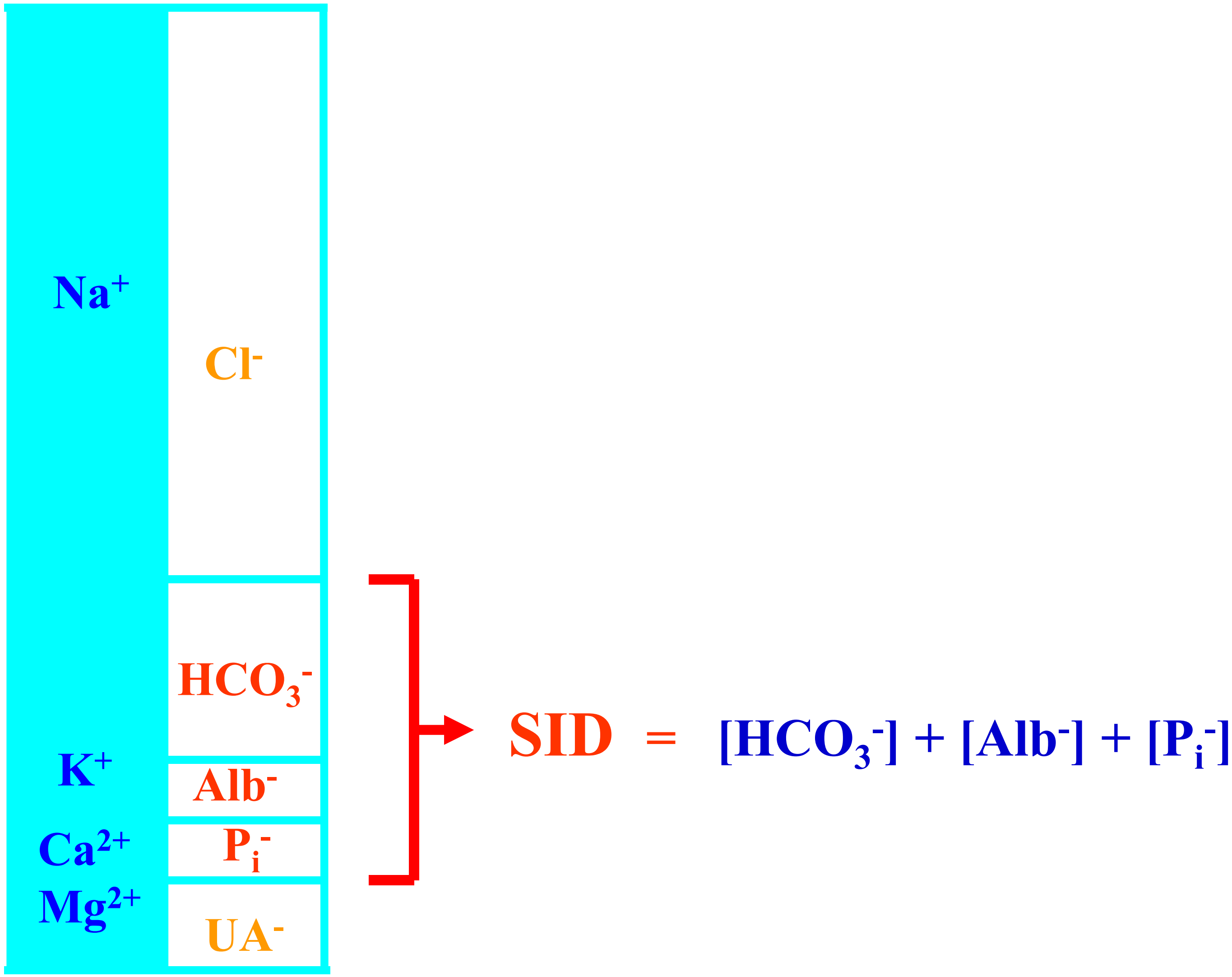
- is calculated as:

  $$SID = [Na^{+}] + [K^{+}] + [Ca^{2+}] + [Mg^{2+}] - [Cl^{-}] - [UA^{-}]$$

- its content includes:

  $$SID = [HCO_3^{-}] + [Alb^{-}] + [P_i^{-}]$$

SID = strong ion difference :

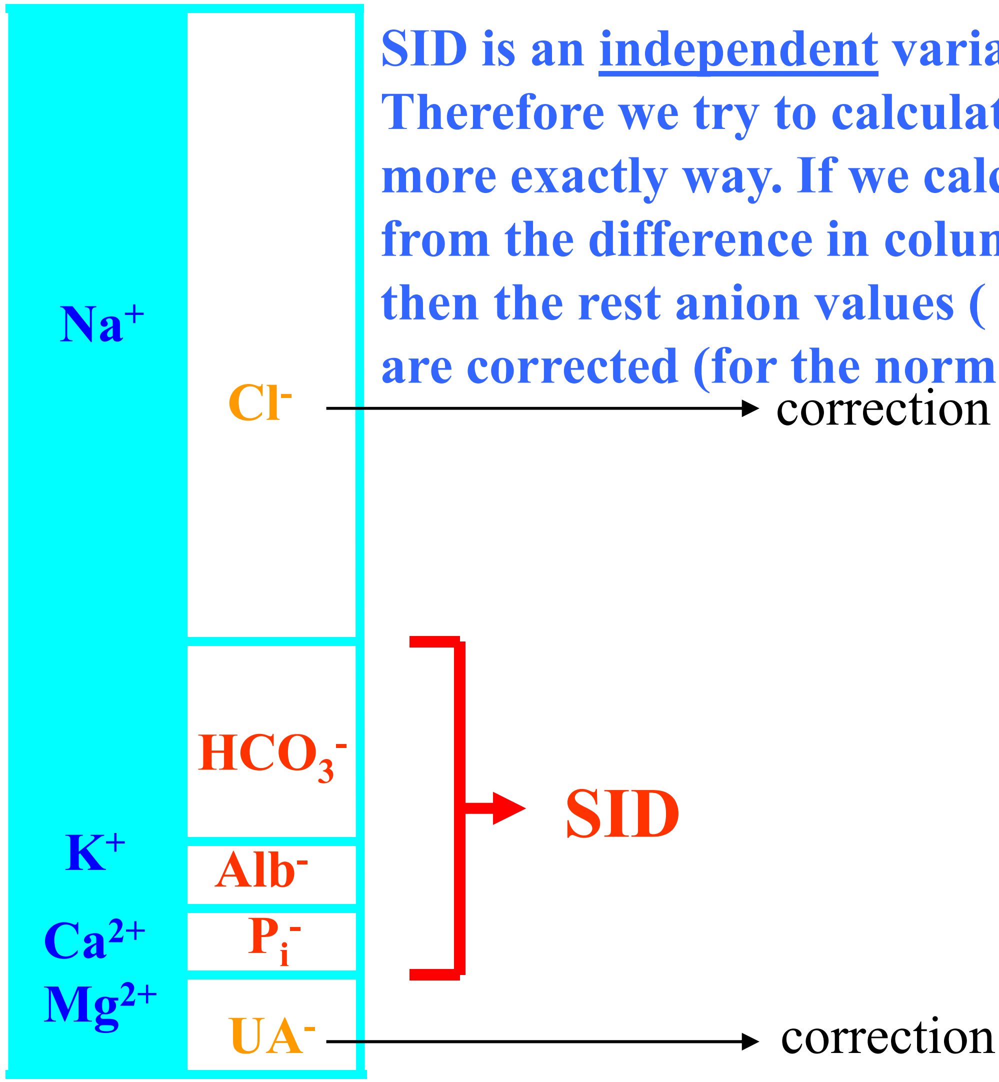


The strong ion difference - SID

$$SID = [Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] - ([Cl^-] + [UA^-])$$

$$SID = [HCO_3^-] + 0,28 \,.\, [Alb^-]\ g.l^{-1} + 1,8 \,.\, [P_i^-]\ mmol.l^{-1}$$

SID = strong ion difference :

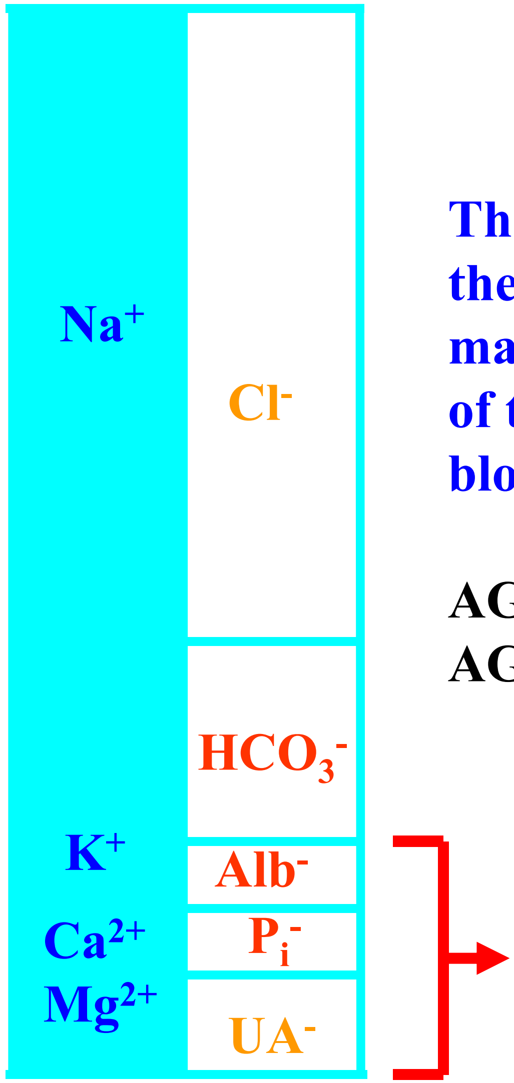


SID is an <u>independent</u> variable. Therefore we try to calculate it in the more exactly way. If we calculate it from the difference in columns of ions, then the rest anion values ($[Cl^-]$ and $[UA^-]$) are corrected (for the normal $[Na^+]$) !

The strong ion difference - SID

$$SID = [Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] - ([Cl^-] + [UA^-])$$

Anion gap AG :



$AG = [Alb^-] + [P_i^-] + [UA^-]$

The anion gap is usually calculated as the difference between the sum of two main cations ($Na^+ + K^+$) and the sum of two main anions ($Cl^- + HCO_3^-$) in blood plasma (see below)

AG = cca 18 mmol . l^{-1}

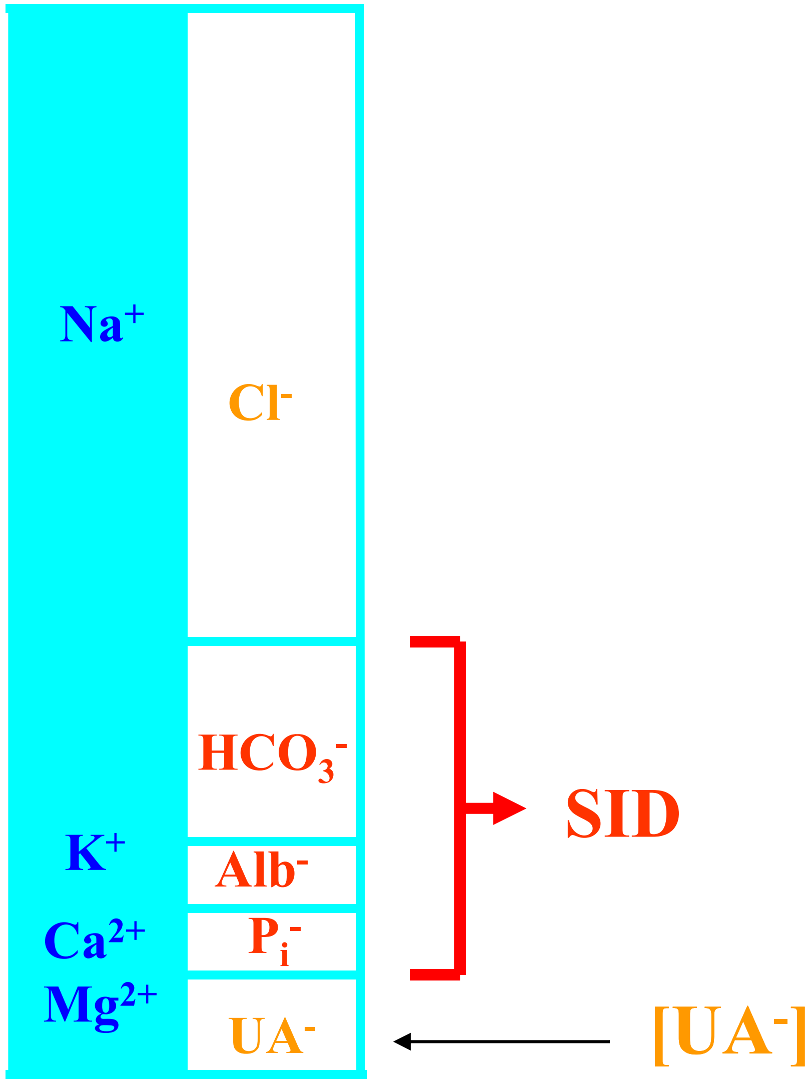
AG > cca 25 mmol . l^{-1} → MAc

Anion gap - AG

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

AG can be calculated from adjusted concentration of Alb

Unmeasured / unidentified anions UA^-:



Unmeasured anions UA^-

$$[UA^-] = [Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] - ([Cl^-] + SID)$$

Buffer base of serum BB_S :

$BB_s = [Na^+] + [K^+] - [Cl^-]$

$= 42 \pm 4 \ mmol \cdot l^{-1}$

← the $[Cl^-]$ is changed more frequently from this ions. For that reason

$BB_s < 38 \rightarrow$ metabolic acidosis hyperchlor(id)emic

$BB_s > 46 \rightarrow$ metabolic alkalosis hypochlor(id)emic

The concentration of ions of plasma, corrected for normal natriemia :

1/ for evaluation of ABE (Stewart, Fencl) is corrected :

- the determinated concentration of chlorides - $[Cl^-]$
- the calculated concentration of unmeasured/unidentified anions - $[UA^-]$

2/ the correction is made by multiplaying with the value $140 / [Na^+]$

3/ $$\frac{140}{[Na^+]}$$

140 ← ideal natraemia (the mean of normal range)

$[Na^+]$ ← determinated concentration Na^+ in plasma

4/ all dimensions: mmol . l^{-1}

The corrected concentration of Cl^- anion

$[Cl^-]_{correc.}$:

The calculation demonstrates, how would be changed the value of chlorides in plasma (serum) at current hypo-, ev. hypernatraemia, if the natraemia becomes normal.

The calculation determines if at the given deviation of natraemia is the chlorides concentration changed more or less correspond to natraemia.

$$[Cl^-]_{corrected} = [Cl^-] \cdot \frac{140}{[Na^+]}$$

The corrected concentration of unmeasured/unidentified anions $[UA^-]_{correc.}$:

$$[UA^-]_{correc.} = ([Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] - [Cl^-] - SID) \cdot \frac{140}{[Na^+]}$$

The contents (testify value) of calculated variables :

weak nonvolatile acids

$$AG = [UA^-] + [Alb^-] + [P_i^-]$$

$$SID = [HCO_3^-] + [Alb^-] + [P_i^-]$$

independent variables

pCO_2

$[Alb^-]$ ~ 12
$[P_i^-]$ ~ 2
$[HCO_3^-]$ ~ 24
(mmol / L)

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

weak acid

strong conjugated base („is buffering ")

$$HCl \rightleftharpoons H^+ + Cl^-$$

strong acid

weak conjugated base („is not buffering")