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# What do these have in common?

Martin Krbec

# Outline

① **Comparison of the approaches**

② Combining strengths of each approach into a single algorithm
(+ a bonus tool for UI detection)

③ Structured technique for evaluation of acid-base disorders

## Do they lead to the same conclusions?

- Yes, most of the time.

| |
|---|
| The classical approach |
| Stewart's approach |
| Boston approach |

# Analytic calculation of physiological acid-base parameters in plasma

E. WRENN WOOTEN
*Department of Medicine, Vanderbilt University Medical Center, Nashville, Tennessee 37232*



Differentiation of *Eq. 15* with respect to pH yields

$$\frac{\partial C_B}{\partial pH} = \frac{\partial[HCO_3^-]}{\partial pH} - \sum_i C_i \frac{\partial \overline{n}_i}{\partial pH} \quad (16)$$

It turns out that because of the large number of buffer groups on plasma proteins $\partial\overline{n}_i/\partial pH$ is approximately linear over the physiological pH range, so that *Eq. 16*, using *Eq. 15*, can be recast in integrated form as

$$C_B = [HCO_3^-] - \left(\sum_i C_i \frac{\partial \overline{n}_i}{\partial pH}\right) pH + \sum_i C_i \overline{n}_{max(i)} + C \quad (17)$$

The constant $C$ depends on the concentrations and identities of the various species $i$ and is given by

$$C = -\sum_i C_i b_i \quad (18)$$

where $b_i$ is a constant that depends on the difference between the pH at which the slope is determined and the negative base ten logarithm of the dissociation constant (p$K$) of species $i$. *Equation 17* is referred to as the Van Slyke equation (25).

Physiological pH is determined under the simultaneous solution of the Van Slyke equation and the Henderson-Hasselbalch equation (1a)

$$pH = pK' + \log \frac{[HCO_3^-]}{S \cdot P_{CO_2}} \quad (19)$$

where p$K'$ = 6.103 and $S$ is the equilibrium constant

By virtue of the principle of electroneutrality, SID can also be calculated, in analogy to *Eq. 12*, by

$$SID = C - \sum_i C_i \overline{z}_i - D \quad (22)$$

where $\overline{z}_i$ is the average charge per molecule for species $i$ and is given by

$$\overline{z}_i = \sum_{j(i)=0}^{\overline{n}_{max(i)}} [\overline{z}_{min(i)} + j(i)\,\alpha_{j(i)}] \quad (23)$$

$\overline{z}_{min(i)}$ is the minimum possible charge for species $i$. *Equation 22* is a more general form of the equations of Stewart (29) and Figge et al. (7). After neglecting the terms with small values under physiological conditions as before, *Eq. 22* gives, in analogy with *Eq. 14*

$$SID = [HCO_3^-] - \sum_i C_i \overline{z}_i \quad (24)$$

In analogy with *Eq. 15*

$$SID = [HCO_3^-] - \sum_i C_i \overline{n}_i - \sum_i C_i \overline{z}_{min(i)} \quad (25)$$

Several additional relations are worth pointing out, including

$$\overline{n}_i + \overline{z}_{min(i)} = \overline{z}_i \quad (26)$$

Hence

$$\frac{\partial \overline{n}_i}{\partial pH} = \frac{\partial \overline{z}_i}{\partial pH} \quad (27)$$

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**Q1 Do they lead to the same conclusions?**

- Yes, most of the time.

**Q2 So why bother?**

- Some algorithms are more intuitive than others.
- There are certain unique strengths in each.

| | Respiratory parameter | Metabolic parameter | UI calculation | Additional properties |
|---|---|---|---|---|
| The classical approach | $pCO_2$ | | | |
| Stewart's approach | $pCO_2$ | | | |
| Boston approach | $pCO_2$ | | | |

Everyone agrees.

| | Respiratory parameter | Metabolic parameter | UI calculation | Additional properties |
|---|---|---|---|---|
| The classical approach | $pCO_2$ | BE | | |
| Stewart's approach | $pCO_2$ | SID and $A_{TOT}$ | | |
| Boston approach | $pCO_2$ | $HCO_3^-$ | | |

BE is a better overall parameter than $HCO_3^-$.

$A_{TOT}$ ← albumin
$A_{TOT}$ ← phosphate
SID ← inorganic strong ions (mainly $Na^+$ and $Cl^-$)
SID ← lactate and unmeasured ions
BE ← $A_{TOT}$
BE ← SID

*Anesthesiology*. 2023;139(6):860-867.

| | Respiratory parameter | Metabolic parameter | UI calculation | Additional properties |
|---|---|---|---|---|
| The classical approach | $pCO_2$ | BE | Anion gap | |
| Stewart's approach | $pCO_2$ | SID and $A_{TOT}$ | Strong ion gap | |
| Boston approach | $pCO_2$ | $HCO_3^-$ | Anon gap | |

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

ref. 12 – 16 mmol/L

$$SIG = [Na^+] + [K^+] + 2 \times [Ca^{2+}] + 2 \times [Mg^{2+}] - [Cl^-]$$
$$- [HCO_3^-] - Alb \times (0.123 \times pH - 0.631) - Pi \times (0.309 \times pH - 0.469)$$

ref. < 4 mmol/L


Medicine. 1977;56(1):38-54.

*J Lab Clin Med*. 1992;120(5):713-9.

| | Respiratory parameter | Metabolic parameter | UI calculation | Additional properties |
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| Stewart's approach | $pCO_2$ | SID and $A_{TOT}$ | Strong ion gap | |
| Boston approach | $pCO_2$ | $HCO_3^-$ | Anon gap | Quantitative rules for compensation |

e.g.: Winters' formula for expected compensation in MAC

$$pCO_2(kPa) = \frac{HCO_3^-}{5} + 1$$

*Ann Intern Med*. 1967;66(2):312-322.

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| The classical approach | $pCO_2$ | BE | Anion gap | |
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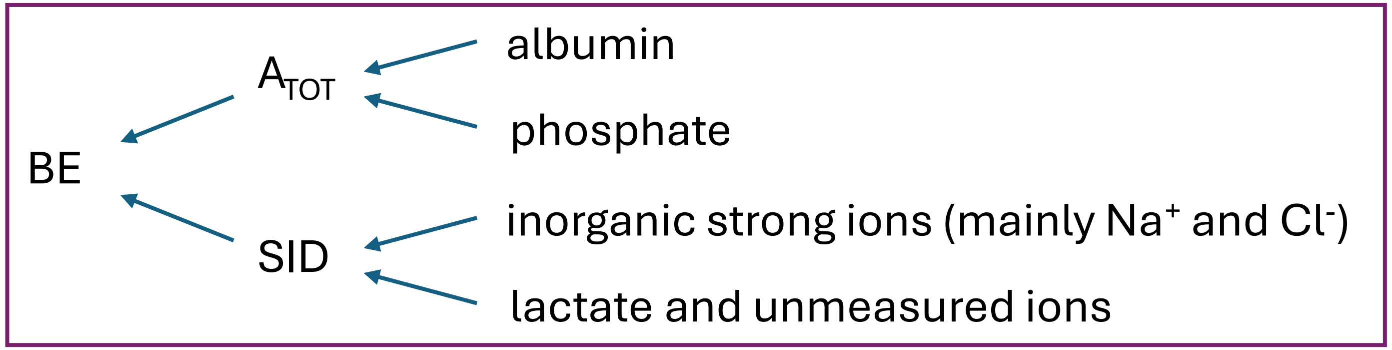
| Boston approach | $pCO_2$ | $HCO_3^-$ | Anon gap | Quantitative rules for compensation |
| | | | BE not explained by known factors | |

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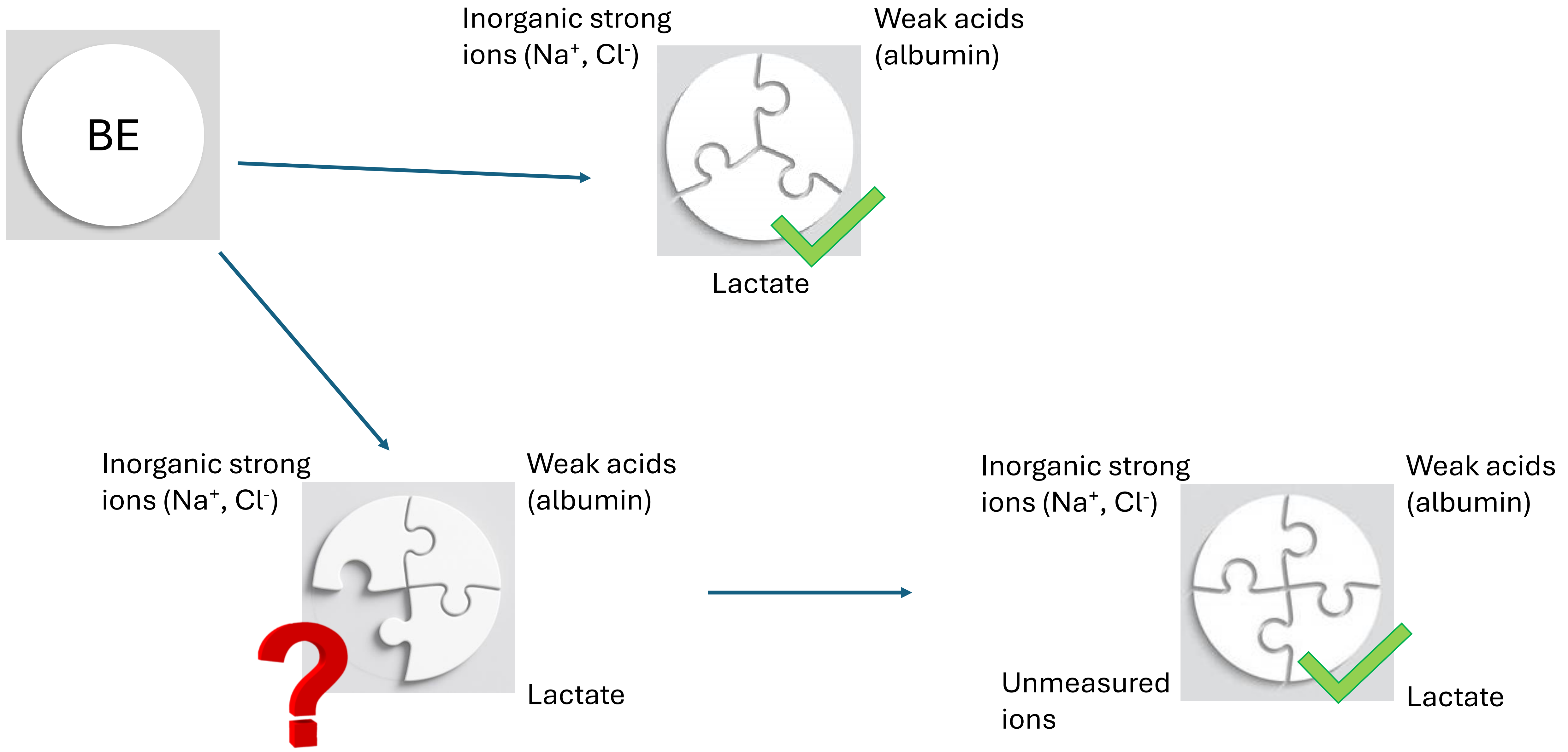
# UI detection by BE partitioning



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**③ Structured technique for evaluation of acid-base disorders**

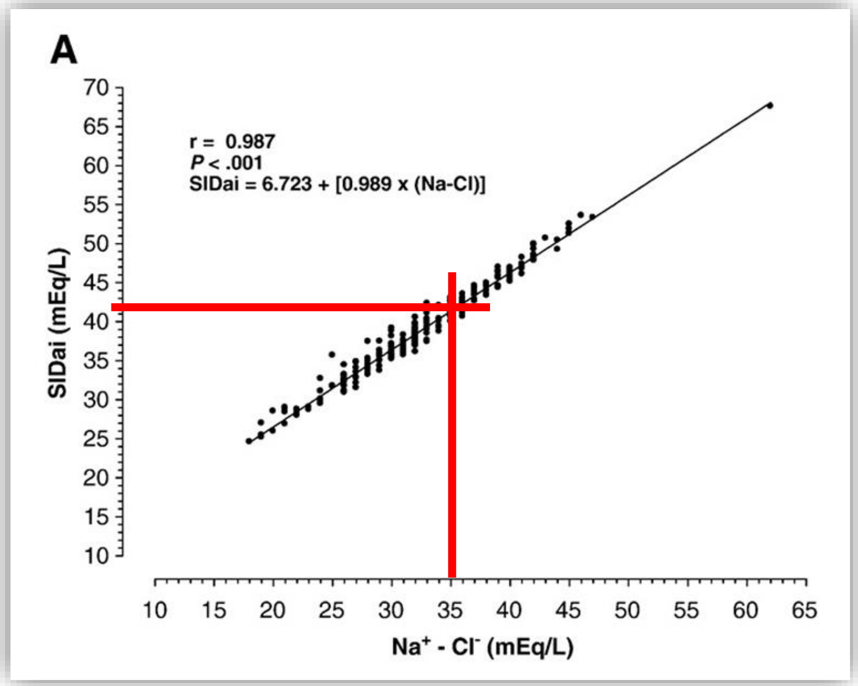
# The principle

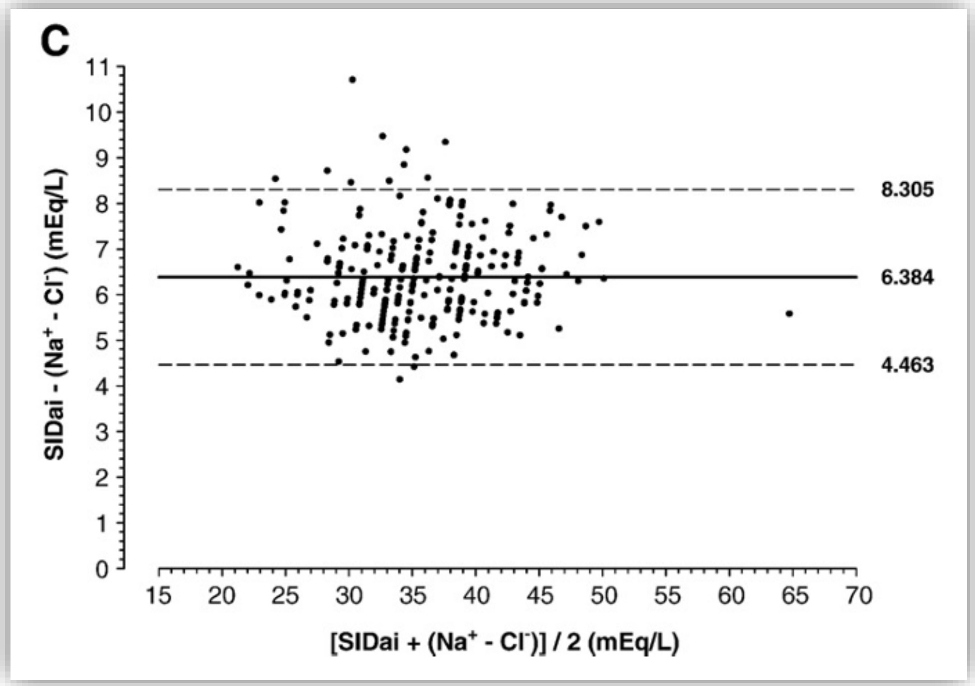
**The effect of strong ions on BE**

$BE_{SID} = SID - SID_{norm}$

$BE_{SID} = \boxed{SID} - 42$

$BE_{SID} = \boxed{[Na^+] - [Cl^-]} - 34$




J Crit Care. 2010; 25, 525–531.

# The principle

| pH | Normal $[Na^+]–[Cl^-]$ |
|---|---|
| 7.0 | 40 |
| 7.2 | 37 |
| 7.4 | 34 |
| 7.6 | 31 |
| 7.8 | 28 |

**The effect of strong ions on BE – pH correction**

**Why?**

pH-driven strong ion redistribution causes
discrepancy between ΔBE and ΔSID

**Remedy?**

For every 0.1 pH unit the reference SID (or $[Na^+]–[Cl^-]$) changes by 1.5 mEq/L in the opposite direction.

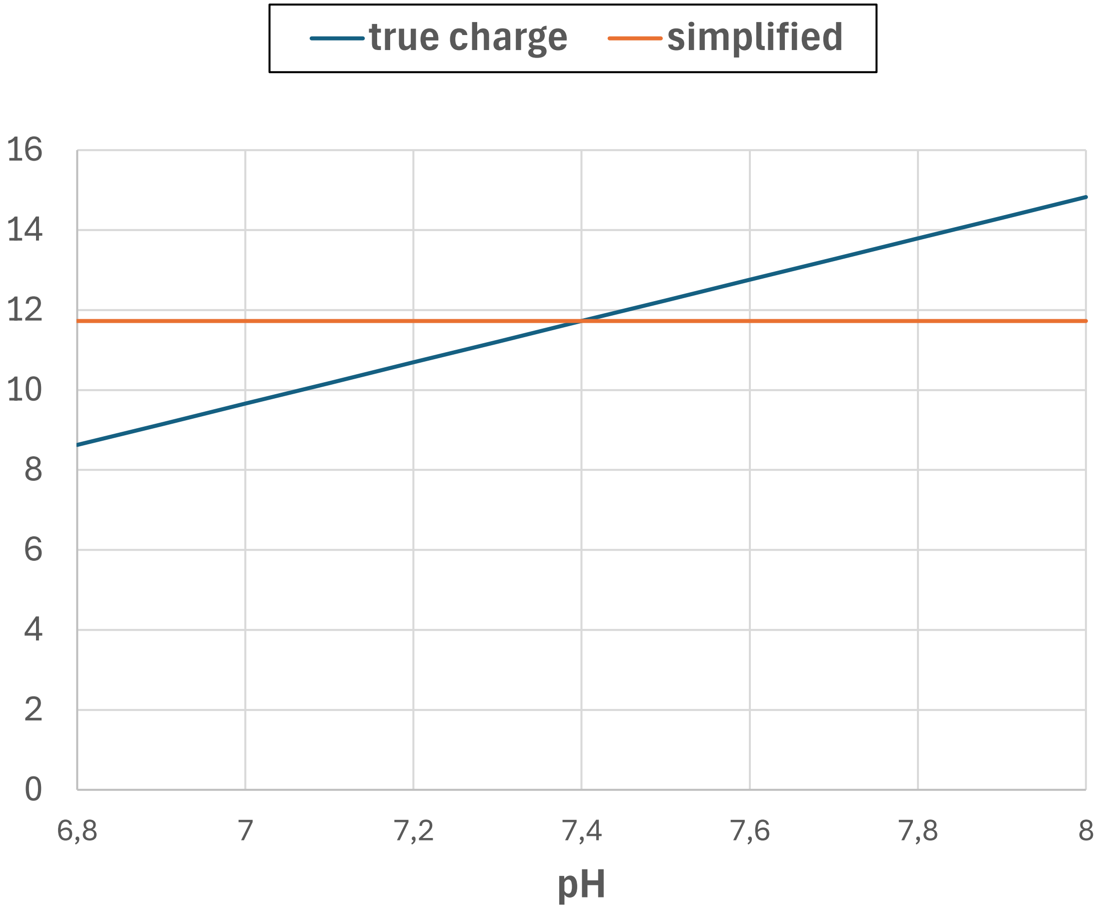
# The principle

**The effect of albumin on BE**

$$BE_{Alb} = \boxed{0.3} \times \boxed{[Alb] - [Alb]_{norm}}$$

the charge of albumin (mEq/g)

the deviation in albumin concentration (g/L)



1. $[Na^+]$-$[Cl^-]$ disorders caused by SID

   Compare Na-Cl with 34 mM

   (apply correction to 34 if pH is extreme: +1.5 for pH -0.1)

2. [Alb] disorders caused by $A^-$

   Add 3mM to predicted SBE for each 10g/L below 40 g/L

3. SBE Identify unmeasured anions

   Compare BE on BG strip with BE predicted, Look at lactate

4. $pCO_2$

   Use „Bostron rules“, eg. Winters’ formula

5. Context Summarise

Thank you for your attention.

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