Acid-Base and Electrolytes

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Objectives

- Identify the 4 major acid-base disturbances, giving typical values for PCO_2, pH, and HCO_3
- List the most common causes for each of the major acid-base disturbances
- Describe the significance of the “anion gap”
- Differentiate pseudohyponatremia from genuine hyponatremia

Important Fact #1

- Venous Blood Gas (VBG) samples can be used for Acid-Base analysis
  - Arterial Blood Gas (ABG) samples are required only for PO_2 and for PaO_2
  - VBG samples are acceptable because
    - pH and PCO_2 are comparable to ABG samples
    - ***exception:*** patients in severe circulatory failure (shock)
    - VBG samples can also be used to measure carboxyhemoglobin and methemoglobin

Important Fact #2
(from high school chemistry)

$$H_20 + CO_2 \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$$

$$K = \frac{[H^+]\ [HCO_3^-]}{[H_2O]\ [CO_2]} = \frac{[H^+]\ [HCO_3^-]}{PCO_2}$$

$$[H^+] = K\ \frac{PCO_2}{[HCO_3^-]}$$

$$[H^+] = K \frac{PCO_2}{[HCO_3^-]}$$

Implications

- [H+] is inversely proportional to HCO_3
  - decreases as HCO_3 increases (obvious)

- [H+] is directly proportional to PCO_2
  - increases (more acid) as PCO_2 increases

- If PCO_2/HCO_3^- does not change

  ➔➔ ***$[H^+]$ does not change!***

- pH is $-\log_{10}[H^+]$

  if H^+ does not change, pH does not change

Important Fact #3

- Know 3 "normal" values
  - PCO_2 = 40
  - HCO_3^- = 24
  - H+ = 40 (pH=7.40)

$$[H^+] = K \frac{PCO_2}{[HCO_3^-]}$$

- → you can derive K =24

- Also:
  - 40 nmol/L [H+] = 7.40
  - 30 nmol/L [H+] = 7.50 → +10 nmol ~ -0.10 pH
  - 50 nmol/L [H+] = 7.30 → -10 nmol ~ +0.10 pH

A Normal H+ (pH) Does Not Exclude an Acid-Base Disturbance

- In each of the following cases,
  the H+ (and pH) are the same:

$$\frac{PCO_2}{HCO_3^-} = \frac{40}{24} = \frac{10}{6} = \frac{80}{48}$$

- But only the first case (40/24) is normal;
  the others (10/6 and 80/48)
  represent severe disturbances!

pH & Henderson-Hasselbalch

this is an example of a <u>buffer,</u>
a topic covered elsewhere in the course

$$[H^+] = K \frac{PCO_2}{[HCO_3^-]}$$

↓

$$-\log_{10}[H+] = -\log_{10} K - \log_{10} \frac{PCO_2}{[HCO_3^-]}$$

$$pH = pK + \log_{10} \frac{[HCO_3^-]}{PCO_2}$$

Important Fact #4

- The body does not try to maintain H^+,
  but it helps to think it does

- In most acid-base disturbances, there is
  - a 1º disturbance, followed by
  - a 2º compensation
    which may take time to develop
    which partially, but ***never fully***,
    corrects the 1º disturbance

This Method for Acid-Base Analysis

- Exploits these four important facts
- Enables you to correctly
  - diagnose ~95% of acid-based disturbances
  - recognize the other ~5% as exceptions

Respiratory Alkalosis

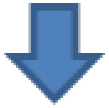
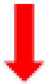
Disturbance	PCO_2	$HCO3^-$	H^+	pH	Common Causes
Respiratory Alkalosis	↓	↓	↓	↑	Sepsis Anxiety

compensation

PCO_2 (40)	$HCO3^-$ (24)	H^+ (40)	ΔH^+ (from 40)	Predicted pH
20	18	24(20/18)=27	-13	7.53

“normal values” in parentheses

Acute Respiratory Alkalosis
(no renal compensation)

Disturbance	PCO_2	$HCO3^-$	H^+	pH	Common Causes
Respiratory Alkalosis					Sepsis Anxiety

PCO_2 (40)	$HCO3^-$ (24)	H^+ (40)	ΔH^+ (from 40)	Predicted pH
20	24	24(20/24)=20	-20	7.60

no compensation

PCO_2 (40)	$HCO3^-$ (24)	H^+ (40)	ΔH^+ (from 40)	Predicted pH
20	18	24(20/18)=27	-13	7.53

compensation

Respiratory Acidosis

Disturbance	PCO_2	$HCO3^-$	H^+	pH	Common Causes
Respiratory Acidosis	↑	↑	↑	↓	Chronic Lung Disease Poor Ventilator Settings

PCO_2 (40)	$HCO3^-$ (24)	H^+ (40)	ΔH^+ (from 40)	Predicted pH
60	30	24(60/30)=48	+8	7.32

Metabolic Alkalosis

Disturbance	PCO_2	$HCO3^-$	H^+	pH	Common Causes
Metabolic Alkalosis	↑	↑	↓	↑	Vomiting Diuretic Therapy

PCO_2 (40)	$HCO3^-$ (24)	H^+ (40)	ΔH^+ (from 40)	Predicted pH
45	32	24(45/32)=34	-6	7.46

Metabolic Acidosis

Disturbance	PCO_2	$HCO3^-$	H^+	pH	Common Causes
Metabolic Acidosis	↓	↓	↑	↓	Diarrhea Diabetic Ketoacidosis

PCO_2 (40)	$HCO3^-$ (24)	H^+ (40)	ΔH^+ (from 40)	Predicted pH
30	15	24(30/15)=48	+8	7.32

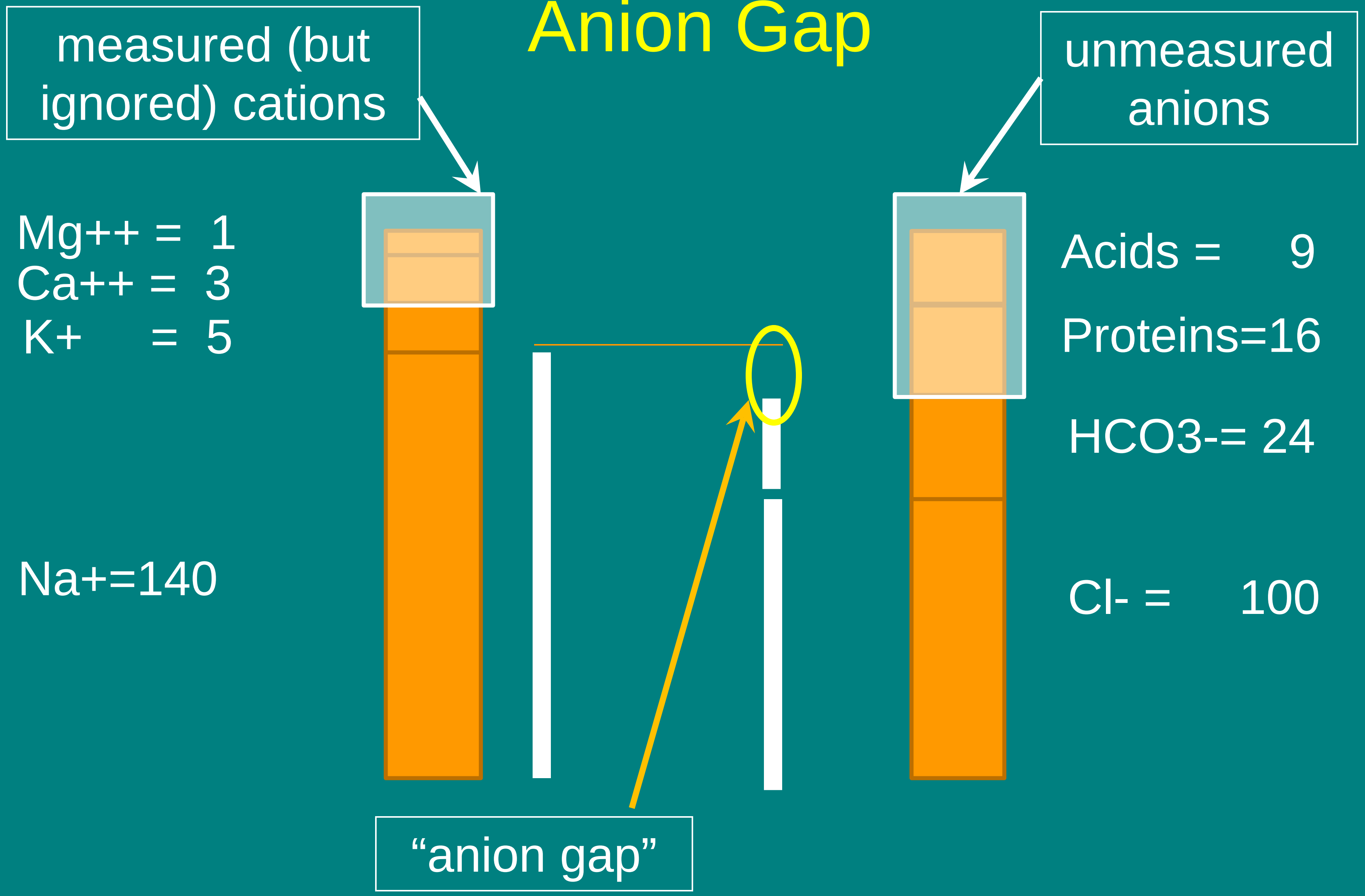
Summary: Acid-Base Disturbances (with compensation)

Disturbance	PCO_2	$HCO3^-$	H^+	pH	Common Causes
Respiratory Alkalosis	⬇	↓	↓	↑	Sepsis Anxiety
Respiratory Acidosis	⬆	↑	↑	↓	Chronic Lung Disease Poor Ventilator Settings
Metabolic Alkalosis	↑	⬆	↓	↑	Vomiting Diuretic Therapy
Metabolic Acidosis	↓	⬇	↑	↓	Diarrhea Diabetic Ketoacidosis

PCO_2 and HCO_3 always move in same direction!

- if only one changes → acute disturbance
- if different direction → >1 disturbance!

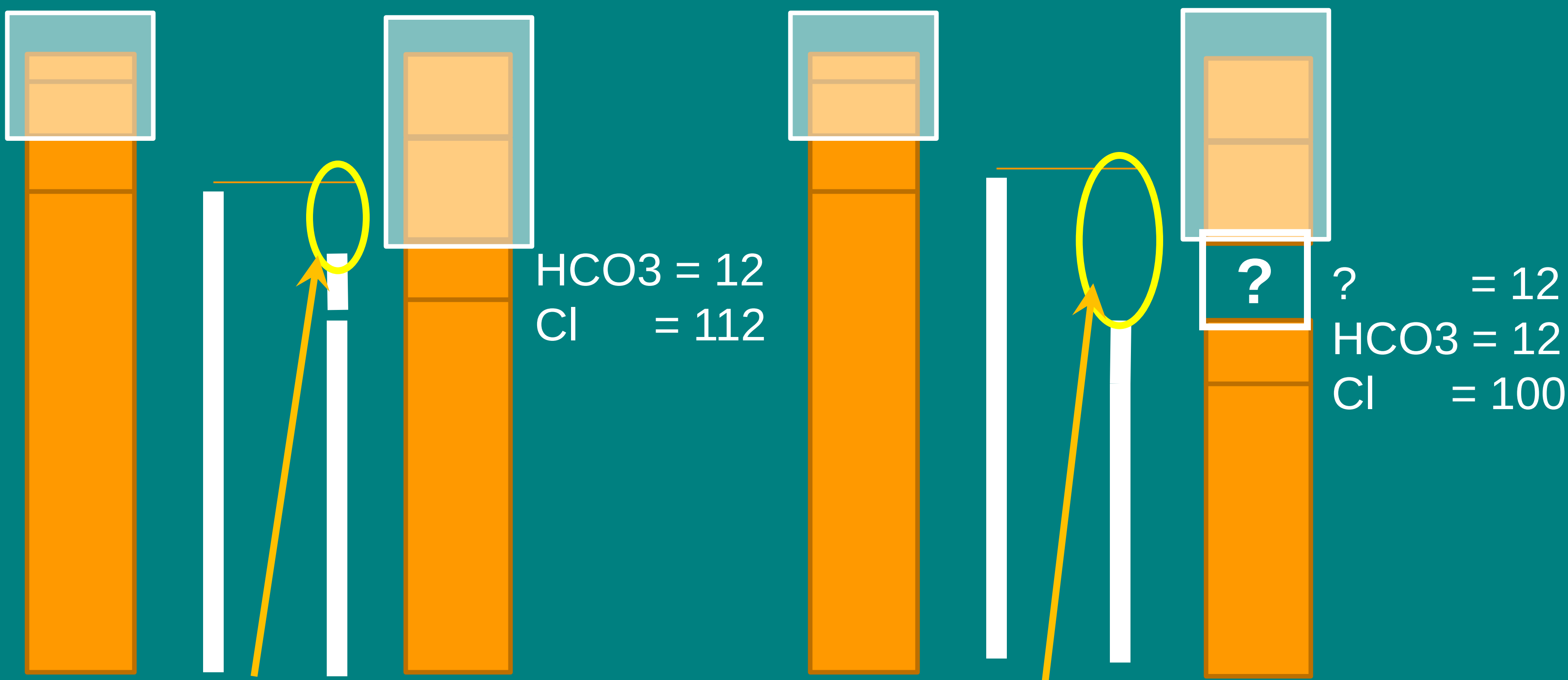
Anion Gap



measured (but ignored) cations
unmeasured anions
Mg++ = 1
Ca++ = 3
K+ = 5
Na+=140
Acids = 9
Proteins=16
HCO3-= 24
Cl- = 100
“anion gap”

Metabolic Acidosis

HCO_3- Decreases from 24 to 12



Normal anion gap
Chloride has increased,
replacing lost HCO3

Increased anion gap
Chloride has not changed
A new anion has replaced
lost HCO3

On to Electrolytes

- HCO3-: covered already with acid-base
- Cl-: covered already with anion gap

- that leaves Na and K
- specifically --
  - pseudohyponatremia
  - pre-analytic issues affecting hyperkalemia

Some General Comments

- measurement of Na, K, Cl:
  - ISE (ion selective electrodes)
- measurement of HCO3:
  - usually, spectrophotometry
  - ABG analyzers: calculated from PCO_2 and pH

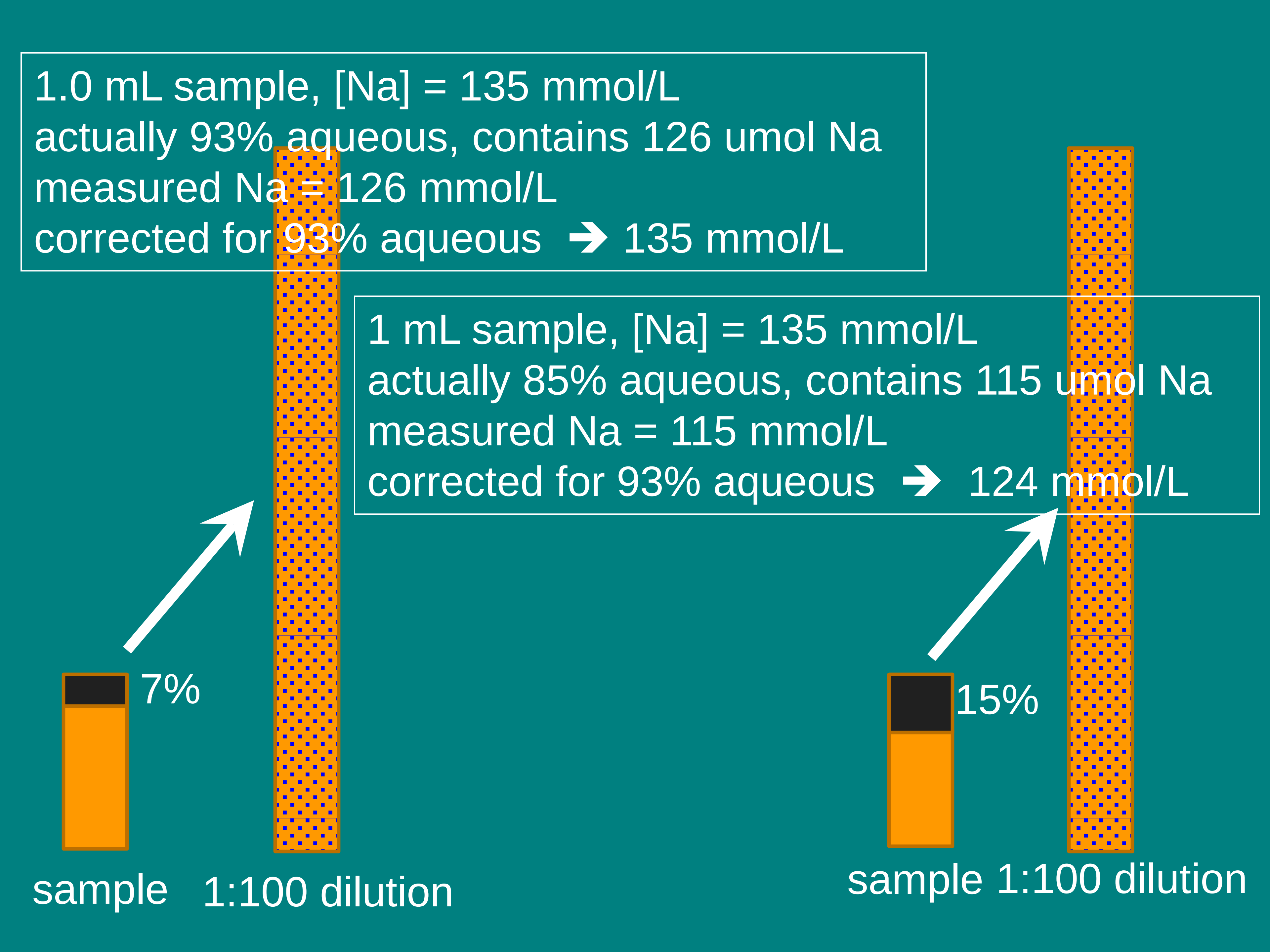
- focus in this talk will be measurement issues
- medical disorders will not be covered here
  - Hypo- and hyper-natremia are usually disorders of water (SIADH, lack of free access to water)

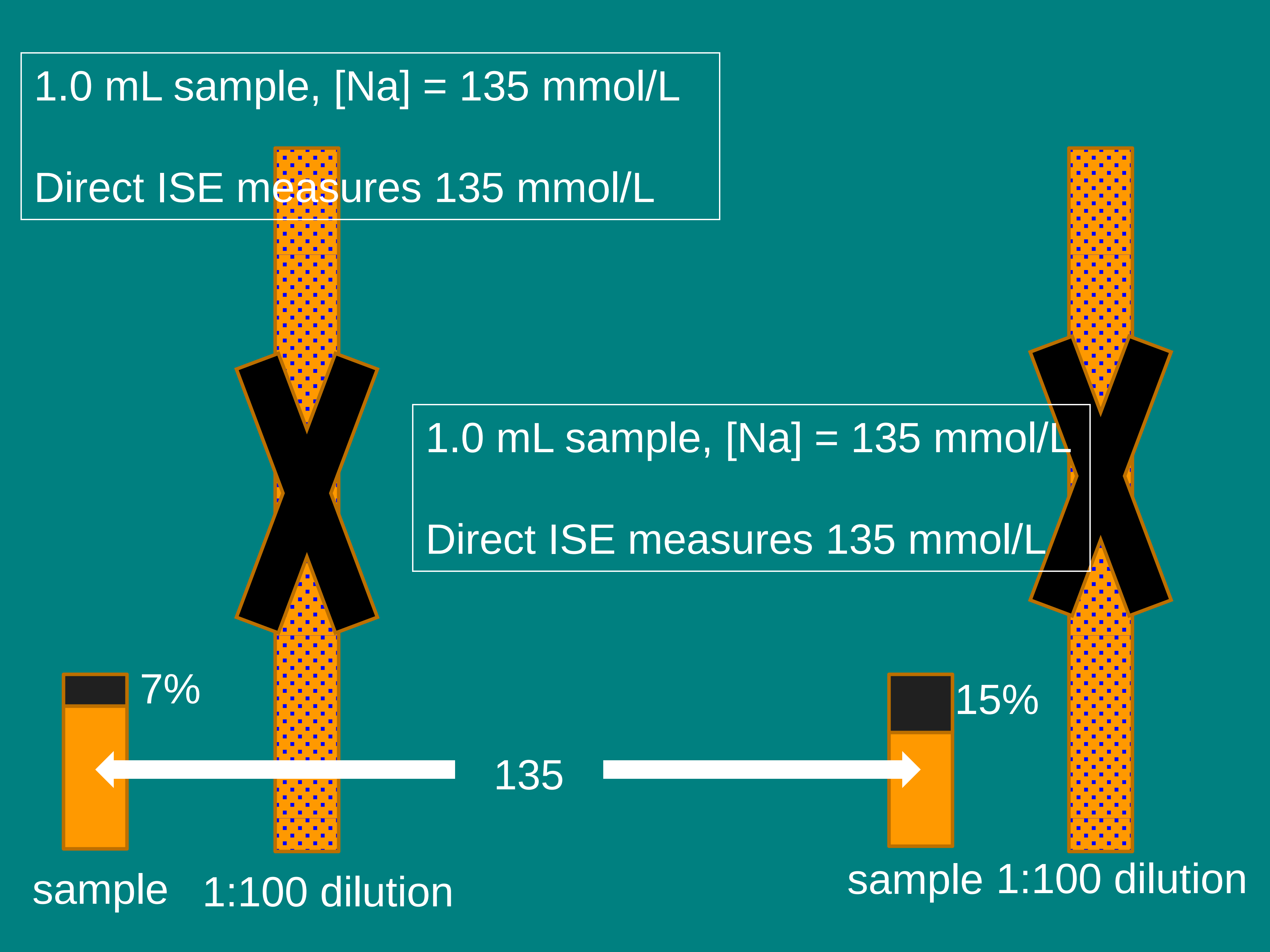
Pseudohyponatremia

- hyponatremia is a fairly common abnormality
- pseudohyponatremia is relatively rare,
  but one needs to be rule it out often,
  so that only the patients with real
  hyponatremia receive treatment

ISE Measurement

- Distinguish between
  - Activity (in aqueous phase)
  - Concentration (in total volume)
- Serum is normally 93% water and 7% solids
  - the latter is comprised of proteins and triglycerides
- ISE:
  - electrode is permeable to all but ion of interest
  - difference in concentration of ion across electrode yields voltage difference (Nernst equation)
- Samples typically undergo large dilution for ISE:
  - separate phases disappear
  - one needs to correct result back to original sample


1.0 mL sample, [Na] = 135 mmol/L
actually 93% aqueous, contains 126 umol Na
measured Na = 126 mmol/L
corrected for 93% aqueous → 135 mmol/L
1 mL sample, [Na] = 135 mmol/L
actually 85% aqueous, contains 115 umol Na
measured Na = 115 mmol/L
corrected for 93% aqueous → 124 mmol/L
7%
15%
sample
1:100 dilution
sample
1:100 dilution


1.0 mL sample, [Na] = 135 mmol/L
Direct ISE measures 135 mmol/L
1.0 mL sample, [Na] = 135 mmol/L
Direct ISE measures 135 mmol/L
7%
15%
135
sample
1:100 dilution
sample 1:100 dilution

Final Notes on Pseudohyponatremia

- If you suspect it, you can determine the true [Na] by
  - using a non-dilutional ISE (e.g., ABG analyzer)
  - measuring osmolality (more on this later)
- You can also suspect it when you come across samples with
  - very high total protein (e.g., multiple myeloma)
  - very high triglycerides (e.g., lipemic samples)
- You might consider confirming all very low [Na]
- Whenever a clinician inquires about falsely low [Na], you should confirm your results

Hyperkalemia: Is It Real?
Things to Watch Out For (1)

- “Hemolysis”: ***in vitro vs in vivo***
  - in vitro (real but not present in patient)
    - poor phlebotomy, prolonged storage without centrifugation
    - rejecting such samples may not be the best solution
      - A normal or low K on a hemolyzed sample may be helpful
      - Hgb indices can be used to calculate degree of hemolysis
  - in vivo (real and present in the patient)
    - in vivo hemolysis can be life-threatening
      - e.g., acute transfusion reaction, babesiosis
    - importance of hemoglobinuria to distinguish from in vitro

Hyperkalemia: Is It Real?
Things to Watch Out For (2)

- High platelet counts
  - serum K is ~0.5 mmol/L higher than plasma K
  - difference is proportional to platelet count
  - during clotting, platelets release K
  - with platelet counts >500K, effect may become clinically significant
  - to prove this is the case,
    analyze a plasma sample (e.g., heparin)

- Also reported with high WBC counts (and/or fragile WBCs)

Self-Assessment Question 1

Which of the following represents the typical findings in a respiratory alkalosis?

A) increased PCO_2, decreased HCO_3

B) increased PCO_2, increased HCO_3

C) decreased PCO_2, decreased HCO_3

D) decreases PCO_2, increased HCO_3

Self-Assessment Question 2

Which of the following is a cause for a normal anion gap metabolic acidosis?

A) diarrhea

B) diabetic ketoacidosis

C) vomiting

D) lactic acidosis

Self-Assessment Question 3

Pseudohyponatremia can be caused by which of the following:

A) high glucose concentrations

B) low platelet counts

C) high concentrations of serum proteins (e.g., multiple myeloma)

D) high concentrations of ADH