Department of Medicine
MED 442 Lectures

Approach to Common Electrolytes and Acid-Base Disorders: A Case Discussion

Ahmad Raed Tarakji, MD, FRCPC, PGDipMedEd, FACP, FASN, FNKF

Assistant Professor
Nephrology Unit, Department of Medicine, King Saud University
Consultant Internist & Nephrologist, King Khalid University Hospital

Notes by Jumana Alghtani
There are 2 extra pages I've added one explaining what is required from us in the exam and the other is solving the case briefly

In the OSCE you will be expected to do the following:

1- is it acidemia or Alkalemia > by looking at the PH

2- is it metabolic or respiratory > by looking at PCO2

3- look for compensation > by looking at [HCO3]

4- if metabolic look for the anion gap and list the DDx if either high or normal

Intended Learning Outcomes:

By the end of the lecture the student should be able to:

1. Interpret Arterial Blood Gas report
2. Recognize Acidemia/Acidosis and Alkalemia/Alkalosis
3. Calculate Respiratory Compensation for metabolic disturbances
4. Calculate Anion Gap with correction for serum Albumin
5. Recognize the difference between volume status disturbance and dysnatremia
6. Formulate a management plan for DKA

A 22 year-old male was brought in to ER by his family unresponsive!

131 135 - 145	**99** 96 - 104	**2.0**	**16.1**
3.8 3.6 - 5.2	**9.7** 23 - 29	**77**	

1. Please interpret each component of this chemistry lab report.
2. What else you need to know? (History? Exam? Lab?)

BMP: Basic Metabolic Panel

Na^+	Cl^-	Urea	Gluc
K^+	TCO_2	Creat	

Venous vs. Arterial vs. Capillary Blood Gases

VBG: 7.24/22.5/47.6/9

VBG: pH/pCO_2/pO_2/$HCO3^-$/BE

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From Google

TABLE I: Arterial and venous blood gas reference range

	Arterial	Venous
pCO_2 (mmHg)	35 -45	41 - 51
Bicarbonate (mmol/L)	22-28	23-29
PO_2 (kPa)	10.6 - 13.3	4.0 -5.3
pO_2 (mmHg)	80-100	30 -40

35-45

Venous Gas **VBG: 7.24/22.5/47.6/9** 22-26

PH PCO2 PO2 [HCO3]

3. **What is Henderson equation?**
4. **What is the difference between pCO_2 and Total CO_2 (TCO_2 or "CO_2")?**

TCO2 measures the CO2 in every compound that contains CO2 in slide 9

5. **What is the difference between Total CO_2 and $[HCO_3^-]$?**

The value of TCO2 has to be close to HCO3 with difference less than 2 , if the difference is more then request re-calibration and re-draw the sample

Let's solve it;

1- it's Acidemia.

2- metabolic acidosis because the CO_2 is low not high and the HCO_3 is low.

3- compensation of metabolic acidosis we use **Winter's formula** of expected $pCO_2 = 1.5 [HCO_3] + 8$ = the answer +/-2
1.5 [10] + 8 = 23 +/-2 = 21_25 >>> so in this case there is full respiratory compensation.

4- find the **anion gap** to classify the metabolic acidosis by using this formula= [Na] - [cl] + [HCO_3] = 131 - 99 + 9.7 = 22 >> high anion gap metabolic acidosis with full respiratory compensation.

5- the **DDX** for high anion gap are: **MUD PILES** →

Normal Anion Gap	Increased Anion Gap
✓ Diarrhea	✓ Methanol
✓ RTA	✓ Uremia
✓ Renal failure	✓ DKA
	✓ Paraldehyde
	✓ Iron
	✓ Lactate
	✓ Ethylene glycol
	✓ Salicyclates

*Note: the Dr. used the value of TCO2 in place of HCO3 in every calculation since the difference is less than 2 , there is no problem

From page 22

General notes:

- **the lung compensate to any metabolic disorder within minutes while the kidneys take days to compensate for respiratory disorders.**
- **There is a limit of how much the lungs can compensate and there is NO FULL compensation , so if the PH in normal range suspect Mixed disorders.**

What is Henderson equation?

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO3^-$$

$$[H^+] = 24 \times \frac{pCO2}{[HCO3^-]}$$

40 (nmol/L) = 24 x [40 (mmHg)/24 (mmol/L)]

$$pH = pK + \log \frac{[HCO_3^-]}{[PCO_2 \times 0.03]}$$

$$= 6.1 + \log \frac{24\ mEq/L}{(40 \times 0.03)}$$

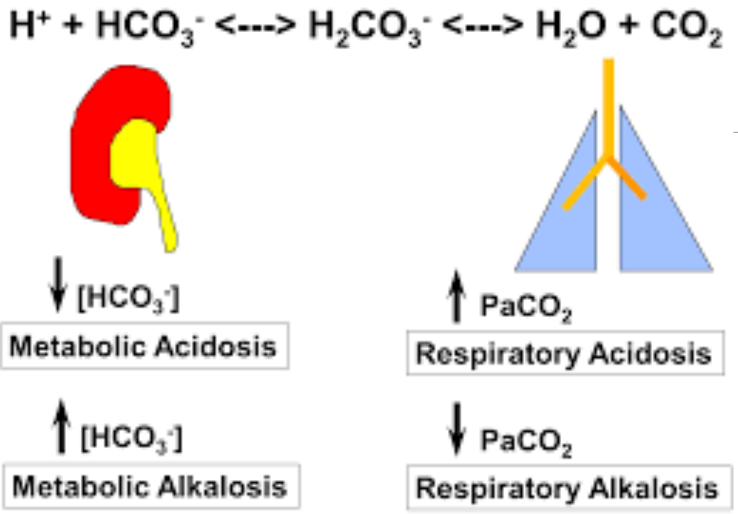
$$= 6.1 + \log \frac{24\ mEq/L}{(1.2\ mEq/L)}$$

$$= 6.1 + \log \frac{20}{1} \quad (20{:}1\ \text{ratio})$$

$$= 6.1 + 1.3$$

$$= 7.4$$

https://media.lanecc.edu/users/driscolln/RT127/Softchalk/Acid_Base_Lesson/Acid_Base_Lesson5.html



Hamilton, P. K., Morgan, N. A., Connolly, G. M., & Maxwell, A. P. (2017). Understanding Acid-Base Disorders. *The Ulster medical journal*, *86*(3), 161–166.

What is Henderson equation?

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO3^-$$

$$\text{Total } CO_2 = [CO_2] + [H_2CO_3] + [HCO3^-]$$

Venous Total CO_2 > Arterial $[HCO3^-]$ by 1.5-2 mmol/L

Internally consistent data!

Metabolic vs. Respiratory Disorders

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO3^-$$

$$[H^+] = 24 \times \frac{pCO2}{[HCO3^-]}$$

If there is CO2 disturbance, initially we see some HCO3 compensation (not full) from the equation itself shifting to the right not form the kidneys b/c it takes days .. so if we see higher compensation(≈28) we know that the problem has been going for days

6. Why do we have two metabolic compensations for respiratory disorders?

Metabolic vs. Respiratory Disorders

$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO3^-$

$$[H^+] = 24 \times \frac{pCO2}{[HCO3^-]}$$

Lungs

Metabolism & Kidneys

6. Why do we have two metabolic compensations for respiratory disorders?

Acid Base Disorders

Primary disorder	Compensatory response
Metabolic acidosis	PCO_2=1.5 X (HCO_3^-) + 8 +/- 2[Winter's formula]
Metabolic alkalosis	0.6 mm ↑ pCO_2 per 1.0 mEq/L ↑ HCO_3^-
Acute respiratory acidosis	1 mEq/L ↑ HCO_3^- per 10 mm ↑ pCO_2
Chronic respiratory acidosis	3.5 mEq/L ↑ HCO_3^- per 10 mm ↑ pCO_2
Acute respiratory alkalosis	2 mEq/L ↓ HCO_3^- per 10 mm ↓ pCO_2
Chronic respiratory alkalosis	5 mEq/L ↓ HCO_3^- per 10 mm ↓ pCO_2

https://www.grepmed.com/images/1324/compensation-respiratory-nephrology-metabolic-diagnosis-alkalosis-acidbase

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131	99	2.0	16.1
3.8	9.7	77	

VBG: 7.24/22.5/47.6/9

7. What is the acid-base status for this patient?

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VBG: 7.24/22.5/47.6/9

Winter's Formula: Expected pCO_2 = 1.5 [10] + 8 (+/- 2) = 23 +/- 2 mmHg

Metabolic Acidosis with full Respiratory compensation

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3.8	9.7	77	

VBG: 7.24/22.5/47.6/9

8. What type of Metabolic Acidosis does he have?

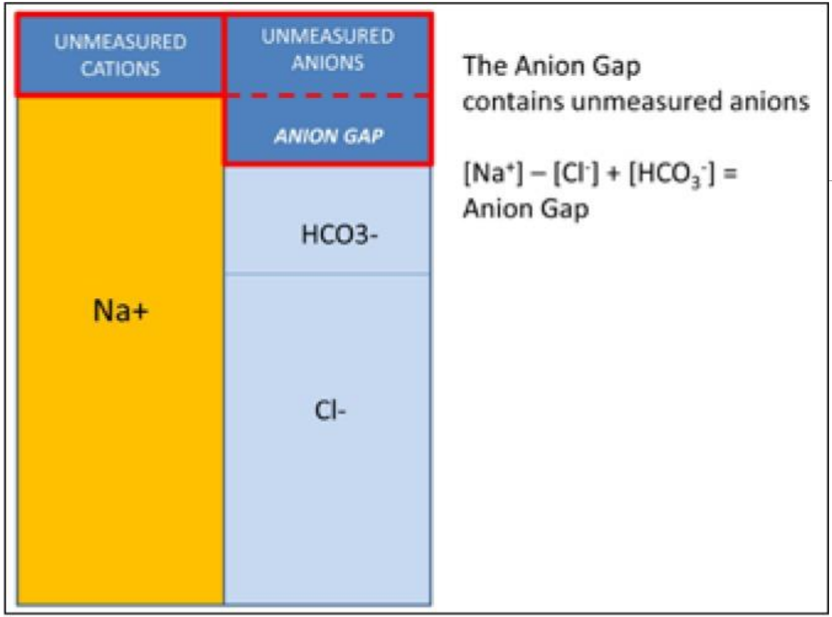


Fig 3

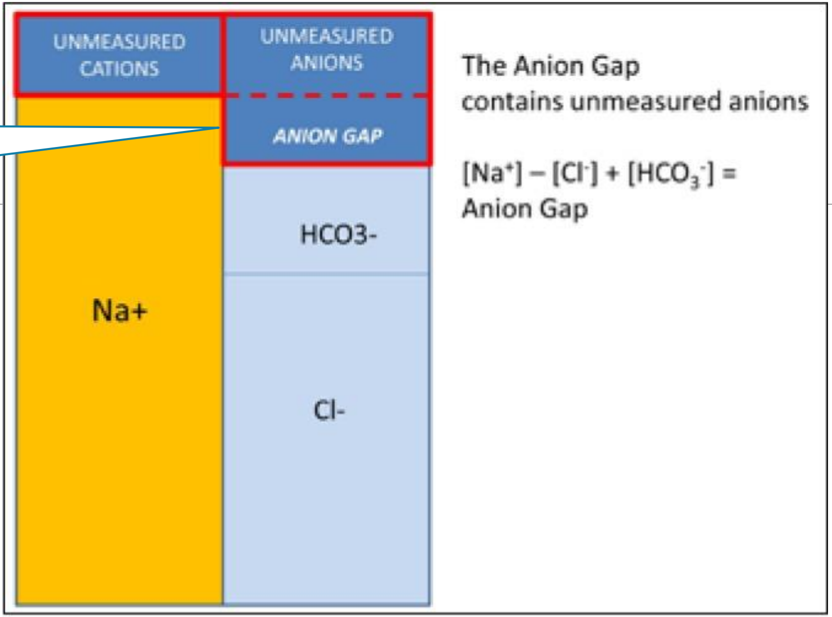
(a) Illustration of the "normal" anion gap

Normal AG = 140 – (104 + 24) = 12 mmol/L (Unmeasured Anions)

Hamilton, P. K., Morgan, N. A., Connolly, G. M., & Maxwell, A. P. (2017). Understanding Acid-Base Disorders. *The Ulster medical journal*, *86*(3), 161–166.

Albumin
40 gr/L = 12 mmol/L

Correct AG per serum Albumin:
Every 10 gr/L drop of Albumin from 40 gr/L add 2.5 mmol/L to Calculated AG



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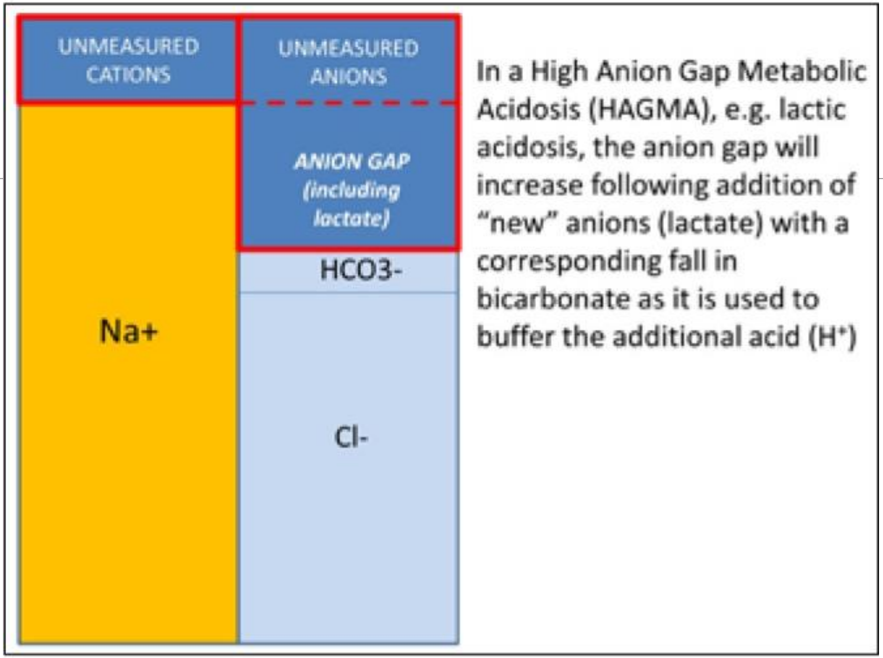

(b) High anion gap present in a metabolic acidosis

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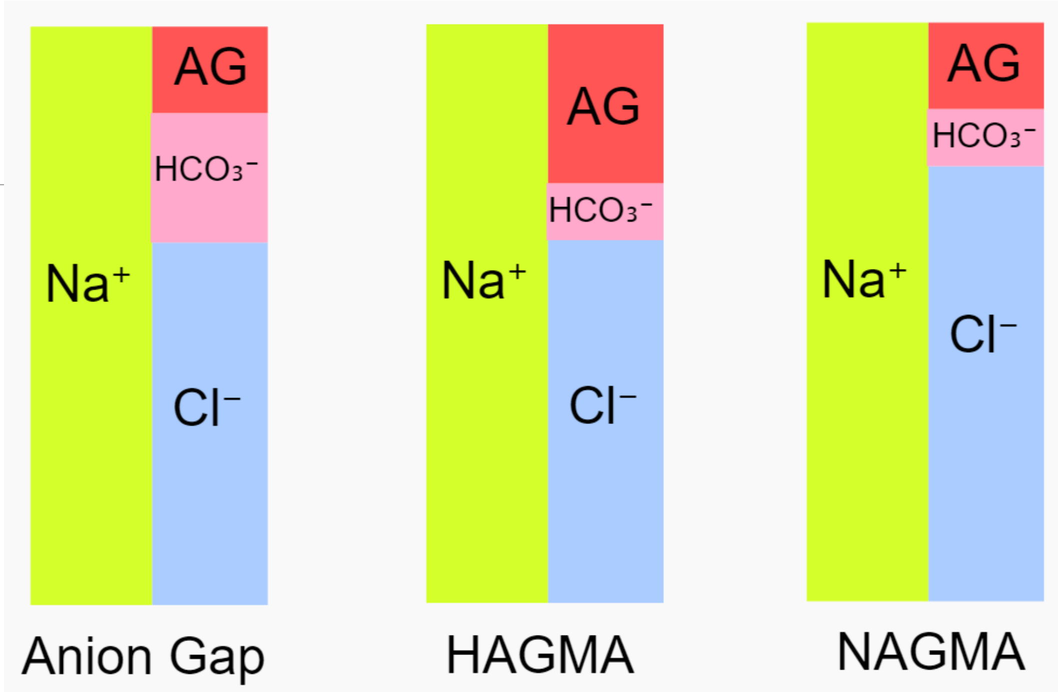
AG
HCO₃⁻
Na⁺
Cl⁻
Anion Gap
AG
HCO₃⁻
Na⁺
Cl⁻
HAGMA
AG
HCO₃⁻
Na⁺
Cl⁻
NAGMA

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3.8	9.7	77	

VBG: 7.24/22.5/47.6/9, Albumin 38

AG = 131 – (99 + 9.7) = 22 mmol/L

Normal AG = 12 mmol/L (Unmeasured Anions)

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Pt. In DKA there is no insulin so the potassium will shift to the extracellular leading to false norma K reading

Higher Glucose will increase the osmolality diluting Na = **hyperosmolar hyponatremia**

VBG: 7.24/22.5/47.6/9

High Anion Gap Metabolic Acidosis with full Respiratory compensation

ACID-BASE DISTURBANCES

Key Terms
- ✓ *Metabolic Disorder*
  - ✓ Imbalance b/w bicarbonate and a fixed (non-volatile) acid.
- ✓ *Respiratory Disorder*
  - ✓ Imbalance b/w bicarbonate and CO_2 (volatile) acid.

Anion Gap
- ✓ Used to determine etiology of metabolic acidosis.
- ✓ Unmeasured anions = (measured cations) − (measured anions)

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

12 mEq/L

- ✓ ↑ Anion gap (>12) means HCO_3^- has been lost and replaced by unmeasured ions.
- ✓ Normal anion gap means that Cl^- is the ion that replaced HCO_3^-

DISORDER	Metabolic Acidosis: Gain H^+/Loss HCO_3^-	Metabolic Alkalosis: Loss H^+/Gain HCO_3^-	Respiratory Acidosis: Gain CO_2	Respiratory Alkalosis: Loss CO_2
ARTERIAL BLOOD PROFILE	↓pH; ↓HCO_3^-; ↑H^+	↑pH; ↑HCO_3^-; ↓H^+	Acute: ↓↓pH; Chronic: ↓pH; ↑Pa_{CO_2}; ↑HCO_3^-	Acute: ↑↑pH; Chronic: ↑pH; ↓Pa_{CO_2}; ↓HCO_3^-
RESPIRATORY COMPENSATION	Hyperventilation; ↓Pa_{CO_2}; CO_2	Hypoventilation; ↑Pa_{CO_2}; CO_2	None	None
RENAL COMPENSATION	HCO_3^-; TA, NH_4^+; Conserve HCO_3^-; Excrete H^+	TA; NH_4^+; HCO_3^-; Excrete HCO_3^-; Conserve H^+	HCO_3^-; TA, NH_4^+; Conserve HCO_3^-; Excrete H^+	TA; NH_4^+; HCO_3^-; Excrete HCO_3^-; Conserve H^+
COMMON CAUSES	*Normal Anion Gap*: ✓ Diarrhea ✓ RTA ✓ Renal failure *Increased Anion Gap*: ✓ Methanol ✓ Uremia ✓ DKA ✓ Paraldehyde ✓ Iron ✓ Lactate ✓ Ethylene glycol ✓ Salicyclates	✓ Vomiting (↓H^+) ✓ Loop & Thiazide diuretics (↑HCO_3^-) ■ ↓ ECF volume triggers HCO_3^- reabs. ✓ Hyperaldosteronism (↓H^+)	*Hypoventilation* ✓ Medullary resp. center inhib. ■ Sedatives, lesions ✓ Neuromuscular defects ✓ Gas exchange defects ■ COPD	*Hyperventilation* ✓ Medullary resp. center stimulation ✓ Hypoxemia ✓ Physical/mental distress

https://drawittoknowit.com/course/physiology/acid-base/acid-base-balance/1326/alkalosis-and-acidosis

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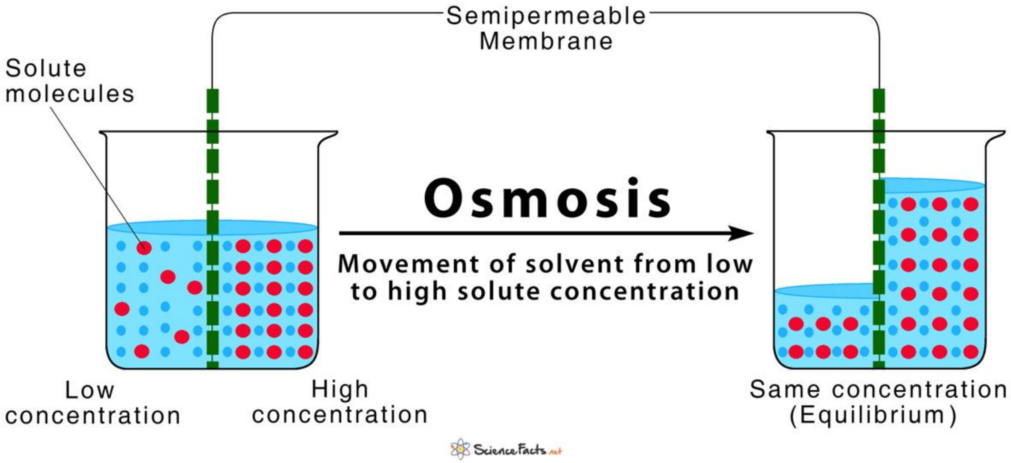
9. What type of hyponatremia does he have? And why?

ECF and ICF compartments are in ***osmotic equilibrium***

ICFosm = ECFosm = Posm



https://www.sciencefacts.net/osmosis.html

Correction of Serum $[Na^+]$ for Hyperglycemia

- ✓ **Every 5.5 mmol/L increase in serum Glucose from 5.5 mmol/L add 2.4 mmol/L to measured serum $[Na^+]$**

- ✓ Gluc 16.1 mmol/L → 16.1-5.5 = 10.6 mmol/L

- ✓ So (10.6/5.5) x 2.4 = 1.92 x 2.4 = 4.6 mmol/L

- ✓ **Corrected $[Na^+]$ = 131 + 4.6 = 135.6 mmol/L**

Spasovski et al. Clinical practice guideline on diagnosis and treatment of hyponatraemia. Nephrol Dial Transplant (2014) 0: 1–39.

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10. What is the difference between measured serum osmolarity and calculated serum osmolality? And what is serum osmol gap?

Plasma OsmolaRity vs. Plasma OsmolaLity:

- ✓ **Calculated Posm** (mOsm/L) **= 2 x [SNa⁺]**(mmol/L) **+ Gluc** (mmol/L) **+ Urea** (mmol/L)
  - ✓ **Calculated Posm** = (2 x 140) + 5 + 3 = **288 mOsm/L Plasma**
  - ✓ **Bulk of Plasma osmolarity from [Na⁺]**
- ✓ **Measured Posm = 286 mOsm/Kg Water**
- ✓ **1 L of Plasma (Solution) ≠ 1 L of Water (Solvent)**
- ✓ **1 L Normal Saline:**
  - ✓ Calculated OsmolaRity = 308 mOsm/L Solution
  - ✓ Measured OsmolaLity = 286 mOsm/kg Water

Finfer, S., Myburgh, J. & Bellomo, R. Intravenous fluid therapy in critically ill adults. Nat Rev Nephrol 14, 541–557 (2018).

Plasma OsmolaRity vs. Plasma OsmolaLity:

- ✓ Calculated Posm (mOsm/L) = 288 mOsm/L Plasma
- ✓ Measured Posm = 286 mOsm/Kg Water
- ✓ Osmol Gap = Measured Posm – Calculated Posm (up to 10 mOsm)
- ✓ Unmeasured osmoles (Usually alcohols!)

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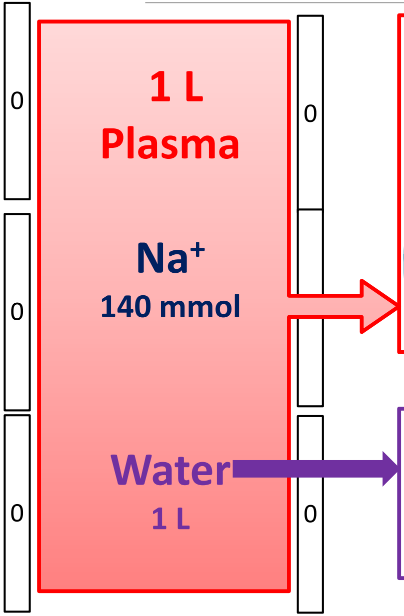
11. What is the difference between dysnatremia and volume status disturbance? And what are their controlling systems and their interaction?

Body Volume control vs. Body Water Balance control

- ✓ Volemia ~ Blood volume → ECF Volume → Total Body Volume
- ✓ 1 L Plasma = 1 L of water + 140 mmol of $[Na^{+}]$
- ✓ **Sodium Content ≠ Sodium Concentration**
  - ✓ **Sodium Content = Volume = Sodium Balance**
  - ✓ **Sodium Concentration = Natremia = Water Balance**

Sodium Content (Volume) vs. Sodium Concentration (*Natremia*)



Volume Control (Na Content *AND* Water) (Volume Receptors)

1. Salt Intake
2. Water Intake
3. RAAS
4. Natriuretic Peptides (ANP, BNP)
5. ADH

Water Control (Natremia = [Na^+]) (Osmoreceptors)

1. Thirst (Water Intake)
2. ADH

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Corrected $[Na^+]$ = 131 + 4.6 = 135.6 mmol/L

Dilutional hyponatremia with hypovolemic hyponatremia

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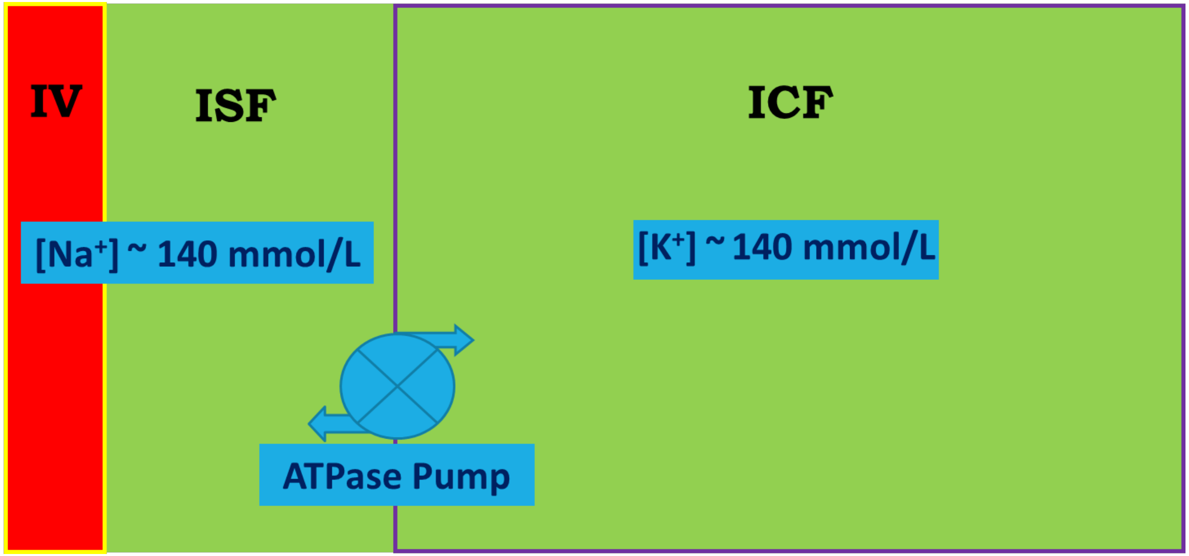
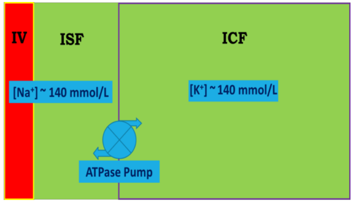
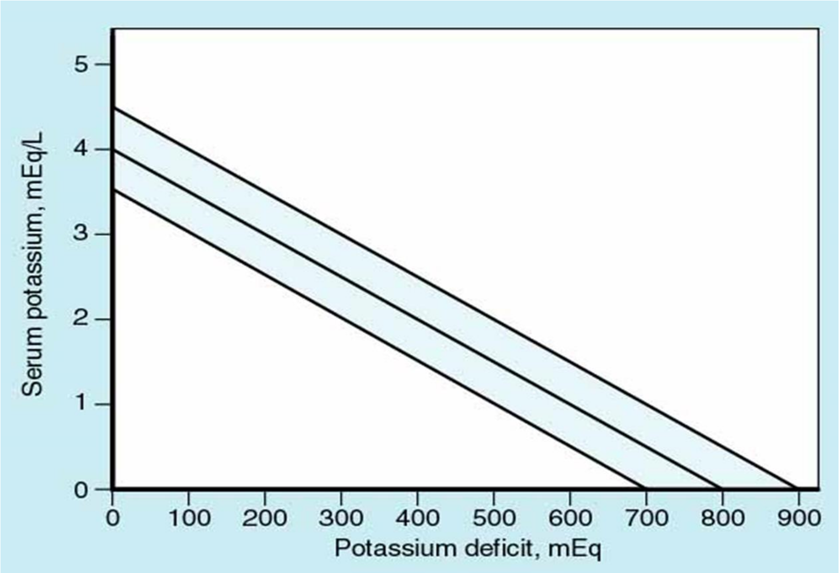
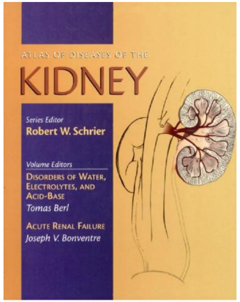
12. What is the potassium balance for this patient?


IV
ISF
ICF
[Na+] ~ 140 mmol/L
[K+] ~ 140 mmol/L
ATPase Pump

Potassium Deficit in relation to Serum SK$^+$







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13. What are the principles of Diabetic Ketoacidosis treatment?

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At the end of this lecture you should be able to:

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3. Calculate Respiratory Compensation for metabolic disturbances
4. Calculate Anion Gap with correction for serum Albumin
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6. Formulate a management plan for DKA

Thank You!

Questions?