Acid Base Disorders

a practical approach
four step approach

Acid Base Problem?

Example A	Example B
7.39 / 39	**7.40 / 40**

Example A:

140	**105**
	23

Example B:

145	**100**
	24

Definitions

- Syntax
  - Acid<u>osis</u> vs acid<u>emia</u>
  - Alkal<u>osis</u> vs alkal<u>emia</u>
- normal ranges
  - pH 7.40
  - $PaCO_2$ 40
  - HCO^-_3 24

ABG 101

- Standard nomenclature
  - pH / $PaCO_2$ / PaO_2
- Measured
  - pH / $PaCO_2$ / PaO_2
- Calculated
  - HCO^-_3 / Base Excess / O_2 Sat

Relationship H^+ / HCO^-_3 / CO_2

- Henderson-Hasselbalch Eq
- Simplified formula:

$$[H^+] = \frac{24\,[PaCO_2]}{[HCO^-_3]}$$

$[H^+]$ and pH Relationship

$[H^+]$	pH
30	7.5
40	7.**40**
50	7.3
60	7.2
80	7.1
1**00**	7.**00**

Step Zero

- Henderson-Hasselbalch Eq
- Simplified formula:

$$[H^+] = \frac{24\ [PaCO_2]}{[HCO^-_3]}$$

- **Implications:**
  - **If CO_2 ↑ then H^+ ↑ and pH ↓**
  - **If HCO_3 ↑ then H^+ ↓ and pH ↑**

Steps One & Two

- Identify all abnormalities
  - pH, $PaCO_2$ and HCO^-_3

1. Look at the pH
   - acidemia vs alkalemia
2. Determine which process is primary
   - acidosis cause acidemia
   - alkalosis cause alkalemia

Examples

Case 1

- Case 1

  7.50 / 29 HCO^-_3 22

- Alkalemia
  - low $PaCO_2$
  - 1^o respiratory alkalosis, acute
- Differential diagnosis

Differential Diagnosis

- Anxiety
- Hypoxia
- CNS disease
- Drugs
  - salicylates
  - catecholamine
  - progesterone
- Pregnancy
- **Sepsis**
- Hepatic encephalopathy
- Mechanical Vent
- Lung disease
  - with hypoxia
  - without hypoxia

Examples

Case 2

- Case 2

  7.25 / 60 HCO^-_3 26

- Acidemia
  - high $PaCO_2$
  - 1^o respiratory acidosis, acute
- Differential diagnosis

Differential Diagnosis

- CNS depression
- Neuromuscular disorders
  - myopathies
  - neuropathies
- Acute airway obstruction
- Severe pneumonia or pulmonary edema
- Impaired lung motion
  - pneumothorax
  - hemothorax
  - flail chest

Examples

Case 3

- Case 3

  7.34 / 60 HCO^-_3 31

- Acidemia
  - high $PaCO_2$
  - 1^o respiratory acidosis, chronic

Examples

Case 4

- Case 4

  7.50 / 48 HCO_3^- 36
- Alkalemia
  - high HCO_3^-
  - 1° metabolic alkalosis
- Cl^- responsive vs unresponsive

Differential Diagnosis

Urinary Cl^-

- **Low**
  - **vomiting**
    - NG suction
  - **diuretic use**
    - in past
  - Post-hypercapnia
- **Normal to high**
  - **excess mineralocorticoid activity**
  - excess alkali
  - **diuretic use**
    - current / recent
  - refeeding

Examples

Case 5

- Case 5

  7.20 / 21 HCO_3^- 8
- Acidemia
  - low HCO_3^-
  - 1° metabolic acidosis
- Gap vs non-gap acidosis

Anion Gap (AG)

- Calculation

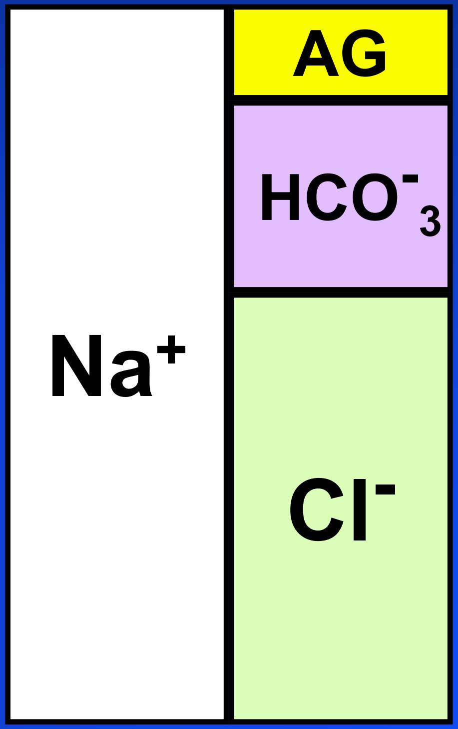
  positive ions

  - Na = 140

  minus

  negative ions

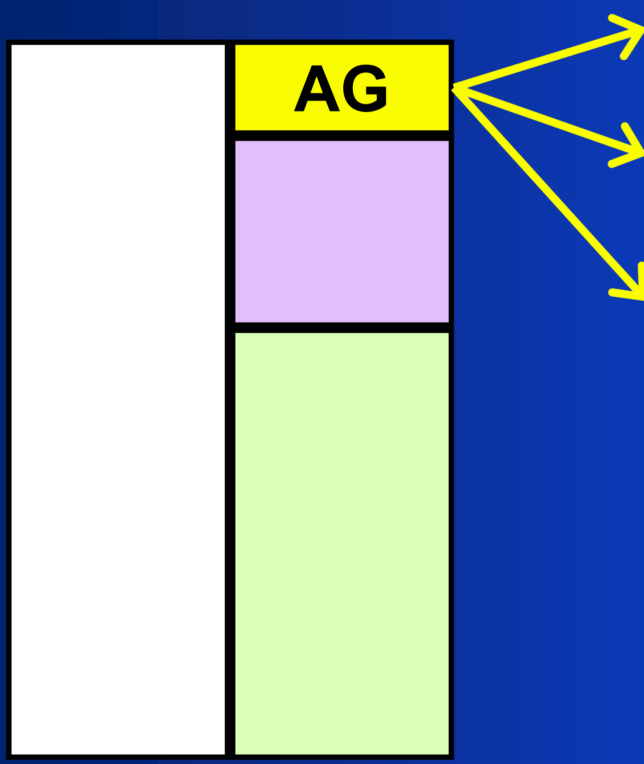
  - Cl = 104
  - HCO_3 = 24



What would happen if there really was an AG?

Anion Gap (AG)

- Gap composed of "unmeasured" anions

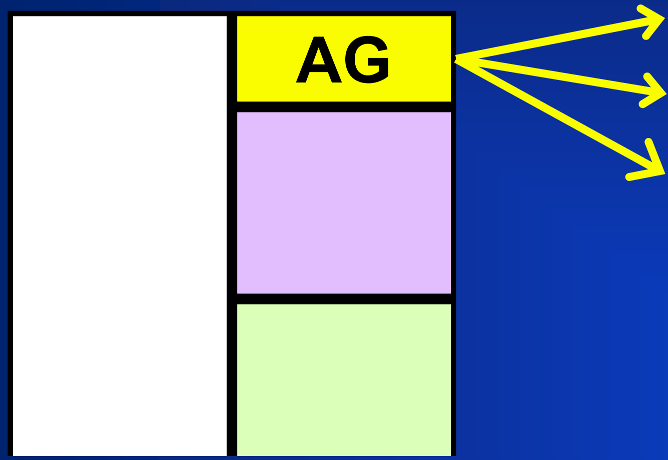


phosphates

sulfates

albumin

Differential of Low Anion Gap

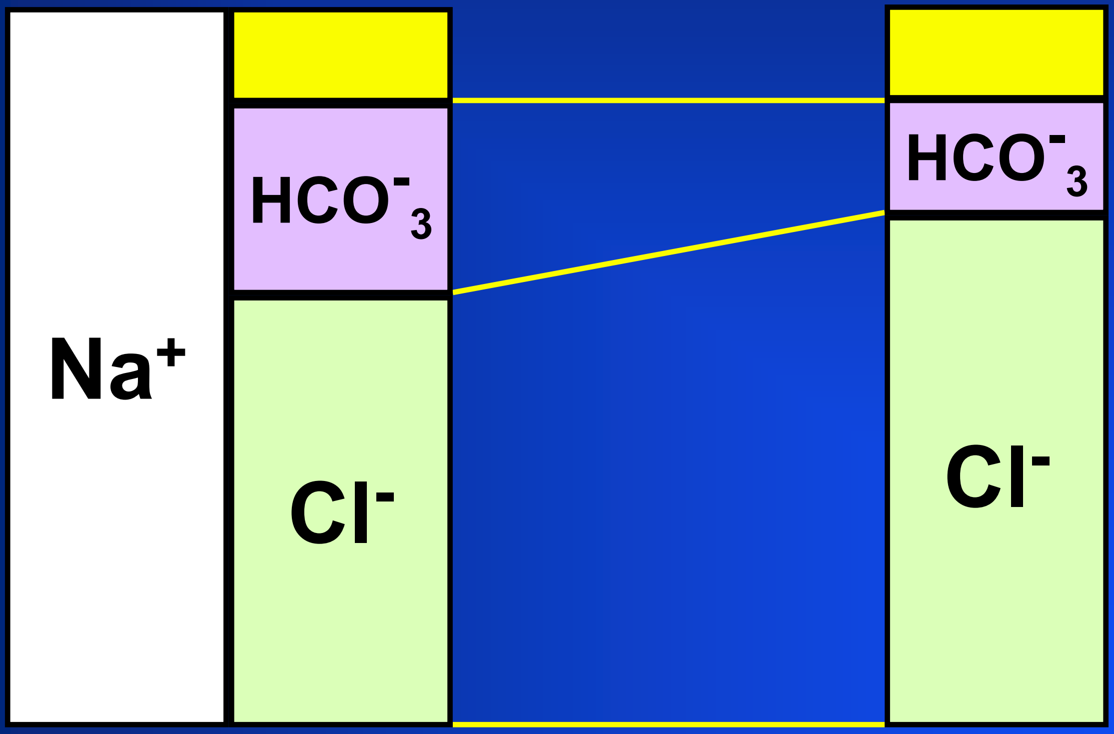


phosphates
sulfates
albumin

1. **Hypoalbuminemia**
   decreases 2.3 - 2.5 for every 1 g/dL
2. **Hypercalcemia**
3. **Paraproteinemia**

Non-Gap Acidosis

- Infuse 10 mEq of $H^+ Cl^-$



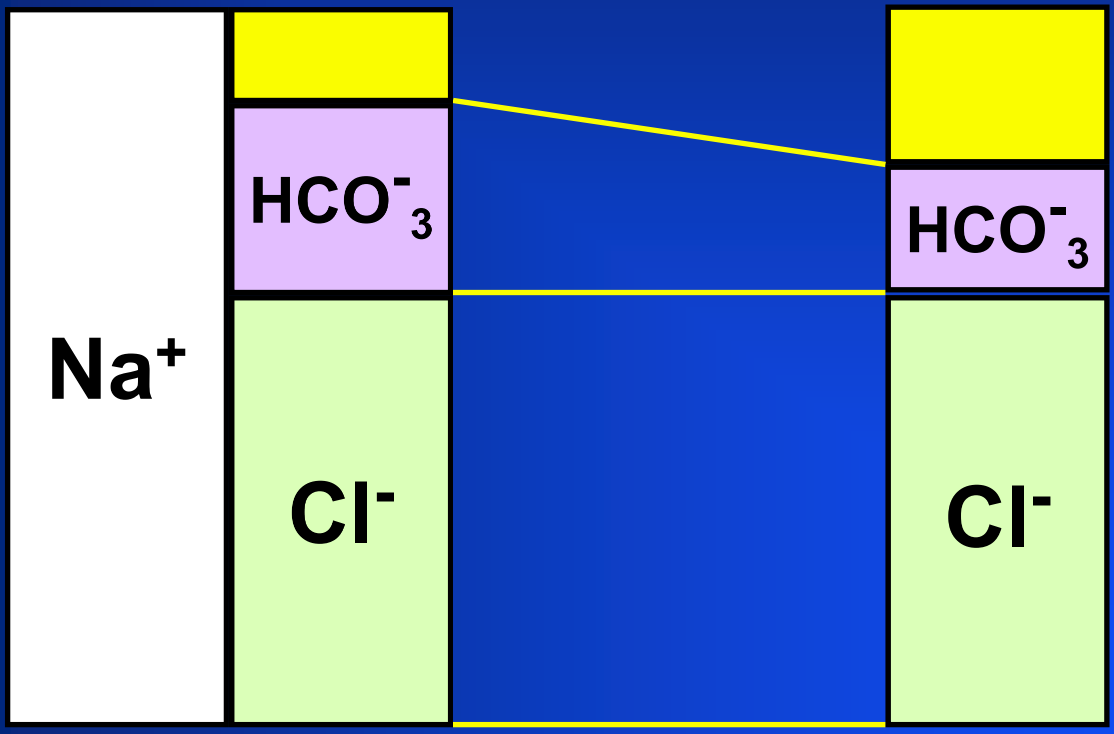
- or $Na^+ HCO^-_3$ loss - stool

Differential Diagnosis

- **Non-Gap**
  - **H** - hyperalimentation (TPN)
  - **E** - expansion acidosis (IV NS)
  - **A** - acetazolamide
  - **R** - renal tubular acidosis (RTA)
  - **T** - loose stools (T-Diarrhea)
  - **C** - cholestyramine (or any bile acid sequestrant)
  - **C** - carbonic anhydrase inhibitors
  - **U** - ureterosigmoidostomy

Gap Acidosis

- Infuse 10 mEq of $H^+ X^-$



- What is the unmeasured anion?

Differential Diagnosis

- **Non-Gap**
  - **H**
  - **E**
  - **A**
  - **R**
  - **T**
  - **C**
  - **C**
  - **U**
- **Gap**
  - **M** methanol
  - **U** uremia
  - **D** DKA
  - **P** paraldehyde
  - **I** INH / infection
  - **L** lactic acidosis
  - **E** ethylene glycol
  - **S** salicylates

Differential Diagnosis

- **Non-Gap**
  - **H**
  - **E**
  - **A**
  - **R**
  - **T**
  - **C**
  - **C**
  - **U**
- **Gap**
  - **M** methanol
  - **U** uremia
  - **D** DKA
  - **P** **propylene glycol**
  - **I** **ingestion**
  - **L** lactic acidosis
  - **E** ethylene glycol
  - **S** salicylates

Step Three

1. Look at the pH
   - acidemia vs alkalemia
2. Determine which process is primary
   - acidosis cause acidemia
   - alkalosis cause alkalemia
3. Calculate the anion gap

The Anion Gap (AG)

- **Always calculate AG**
- **If AG $\geq$ 20**
  - metabolic acidosis is present, regardless of the pH or $[HCO^-_3]$
- **Always calculate AG !**
- **Always calculate AG !!**

For Example

140	103
	15

- AG = 22 (which is ≥ 20)
- a primary metabolic acidosis present
- even if pH 7.9!

Acid Base Problem?

Example A	Example B
7.39 / 39	7.40 / 40

Example A

140	105
	23

Example B

145	100
	24

Step Four

1. Look at the pH
   - acidemia vs alkalemia
2. Determine which process is primary
   - acidosis cause acidemia
   - alkalosis cause alkalemia
3. Calculate the anion gap
4. Calculate the excess anion gap ($\Delta\Delta$)
   - used only if there is an anion gap
   - determines “corrected” bicarbonate

Excess Anion Gap

- **$\Delta\Delta$ = total anion gap (calculated) minus normal (predicted) anion gap**
- **Add $\Delta\Delta$ to measured HCO_3^-**
  - **if new $[HCO_3^-] \geq 30$**
    - underlying 1° metabolic alkalosis
  - **if new $[HCO_3^-] \leq 23$**
    - underlying 1° metabolic acidosis
    - non-gap

Examples

Case 6

- Case 6

7.50 / 20

140	103
	15

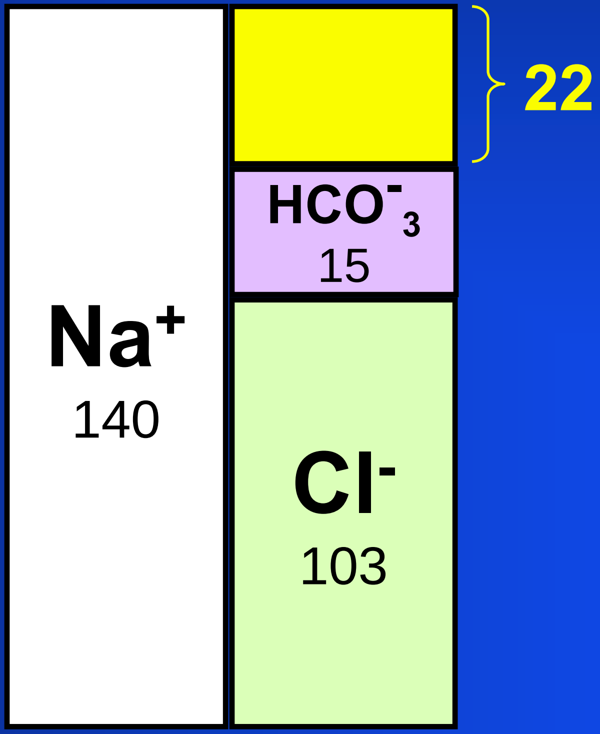
Case 6

- Alkalemia with low $PaCO_2$
  - 1^{o} respiratory alkalosis

- Next step:
  - calculate AG

Calculate Anion Gap

140 - 103 - 15 =

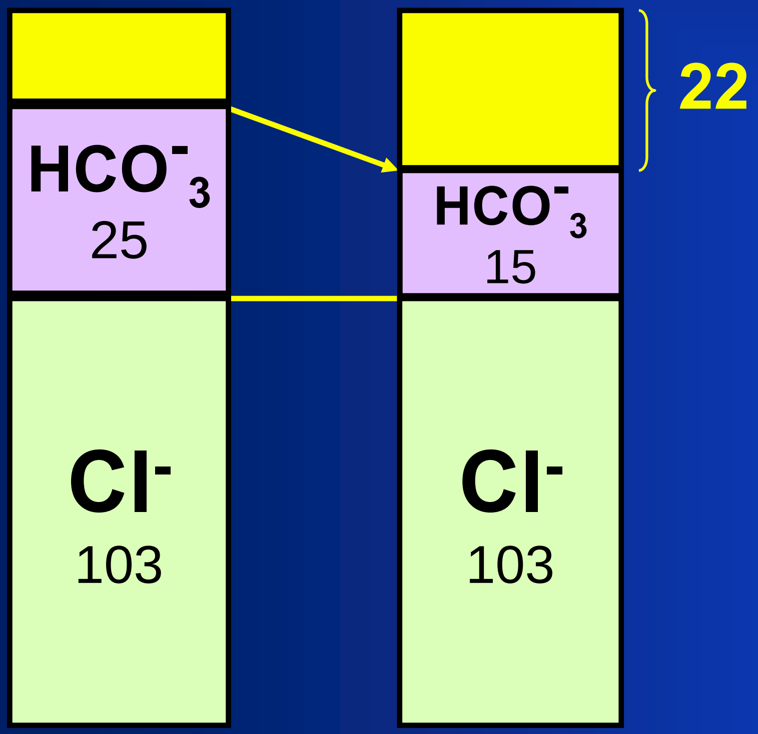


Case 6

- Alkalemia with low $PaCO_2$
  - 1^{o} respiratory alkalosis
- Anion Gap 22
  - underlying 1^{o} metabolic acidosis
- Remember
  - one <u>never</u> compensates by creating AG

Case 6

A normal AG = 12, but here it is 22

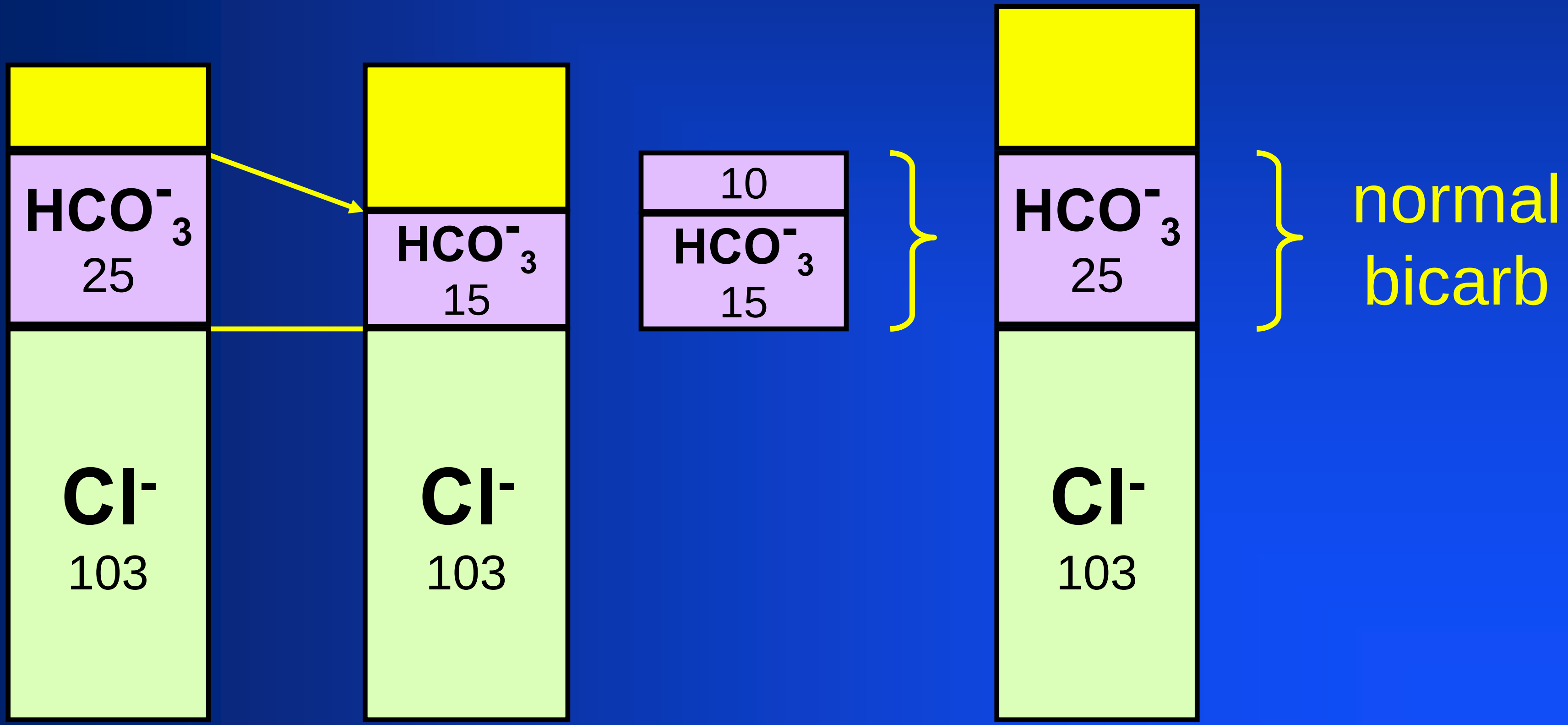


Subtracting measured AG	22
with the predicted AG	<u>12</u>
	10 ΔΔ

Therefore, suspect that 10 units of H^+X^- have been added to the system

ΔΔ is 10

Therefore, the measured bicarb should be down by 10
If add back 10 to actual bicarb. . .



Case 6

- Alkalemia
  - 1° respiratory alkalosis
  - 1° metabolic acidosis
- ΔΔ:
  - 22 - 12 = 10
- Add ΔΔ to measured bicarb
  - 15 + 10 = 25 ⟶ **normal**
  - **therefore no hidden acid / alkalosis**
- **Clinical story: ASA overdose**

Examples

Case 7

- Case 7

7.40 / 40

145	100
	24

Case 7

- **Normal pH!**
- **Anion Gap = 21**
  - **1° metabolic acidosis**
- **ΔΔ:**
  - $21 - 12 = 9$
  - add to bicarb $(9 + 24) = 33$
  - **1° metabolic alkalosis**
- **Clinical story: CKD c/b acute emesis**

Examples

Case 8

- Case 8

7.10 / 50

145	100
	15

Case 8

- Acidemia - high $PaCO_2$ & low $[HCO^-_3]$
  - 1° respiratory acidosis
  - 1° metabolic acidosis
- Anion Gap = 30
- ΔΔ:
  - 30 - 12 = 18 + 15 = 33
  - 1° metabolic alkalosis
- Clinical story: DKA, obtunded with emesis

Examples

Case 9

- **Case 9**

7.15 / 15

140	110
	5

Case 9

- Acidemia - low [HCO^-_3]
  - 1° metabolic acidosis
- Anion Gap = 25
- ΔΔ:
  - 25 - 12 = 13 + 5 = 18
  - 1° non-anion gap metabolic acidosis (a second metabolic process)
- Clinical story: DKA recovery phase

Other Cases
Dr Weir's Case 1

- 38-year-old woman
  - recurrent pyelonephritis
  - progressive CKD
  - admitted increased weakness & emesis
- PE
  - VS BP 174110, RR 22, T 98.0
  - moderate hypertensive retinopathy
  - displace PMI with mid-systolic murmur
  - no crackles, hepatomegaly or edema

Dr Weir's Case 1

7.26 / 27

139	95	159
5.6	12	24.0

- What is the acid-base disturbance(s)?
- What is the most likely etiology(s)?

Dr Weir's Case 5

- 22-year-old man
  - previously healthy
  - choked while eating
- PE
  - VS BP 170/111, HR 125, RR 16 labored
  - marked cyanosis
  - stridor

Dr Weir's Case 5

7.08 / 94

143	104	
4.8	17	

- **What is the acid-base disturbance(s)?**

Dr Weir's Case 5

- Does this make sense?

$$[H^+] = \frac{24\ [PaCO_2]}{[HCO^-_3]}$$

$$[H^+] = \frac{24 * 94}{17}$$

$$[H^+] = 133 \longrightarrow \text{pH } 6.88$$

Dr Weir's Case 5

7.08 / 94

143	104	
4.8	27	

- **What is the acid-base disturbance(s)?**
- **What is the most likely etiology(s)?**

Dr Weir's Case 2

- 68-year-old woman
  - acute Salmonella enteritis
  - profuse diarrhea x 1 week

7.24 / 12

133	118	
2.5	5	6.3

Dr Weir's Case 2

Day 1

7.24 / 12

133	118	
2.5	5	6.3

AG 10

Day 2

7.51 / 17

137	114	
4.2	13	

AG 10

- **Although the bicarbonate deficit was only partially corrected on day 2, the plasma became quite alkaline. Why?**

Dr Weir's Case 3

- 35-year-old woman
  - Glasgow Coma Scale 5
  - progressive weakness 2 months PTA
- PE
  - decreased DTRs without lateralizing signs

Dr Weir's Case 3

6.88 / 40

135	118	
1.5	7	

- **What is the acid-base disturbance(s)?**
- **What is the most likely etiology(s)?**

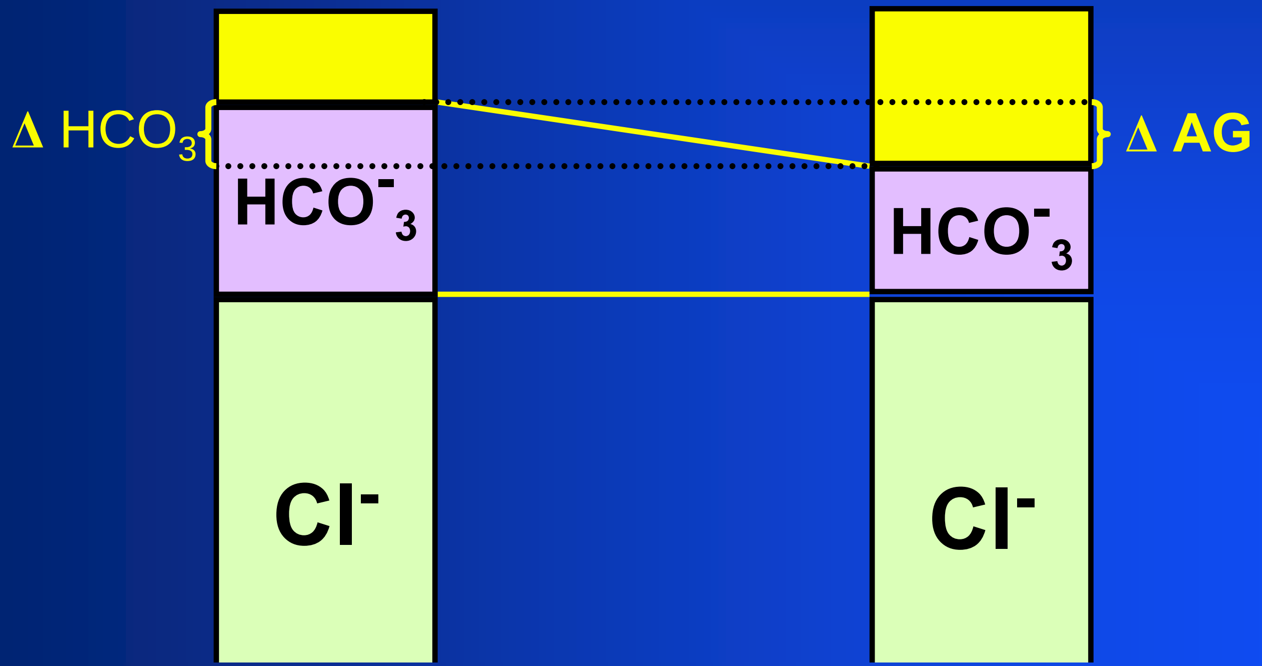
Formulas

- Winters' formula
  - $PaCO_2 = (HCO^-_3 * 1.54) + 8.36$
- Simplified
  - $PaCO_2 = (HCO^-_3 * 1.5) + 8.5$

Albert, Ann Intern Med. 1967 Feb;66(2):312-22

The Δ AG / Δ HCO_3

- **Some people use the Δ / Δ ratio**
  - Δ AG / Δ HCO_3
  - assumed to be 1:1



The Δ AG / Δ HCO_3

- Lactic acid (H^+ L^-)
  - volume of distribution L^- small
    - confined to extracellular space
    - "proportional" increase in AG
  - volume of distribution H^+ large
    - due to buffering in cells / bone
    - "smaller" decrease HCO_3^-
  - Δ / Δ ratio averages 1.6 : 1
    - If HCO_3^- 14 (Δ 10), then AG should be ~ 28 (Δ 16)

The Δ AG / Δ HCO_3

- **In metabolic acidosis**
  - **$1 < \Delta / \Delta < 2$**
    - uncomplicated disorder
  - **$\Delta / \Delta < 1$**
    - both gap and non-gap processes
  - **$\Delta / \Delta > 2$**
    - concurrent metabolic alkalosis

Questions?

Acid Dissociation

$$[HA] \overset{K_A}{\longleftrightarrow} [H^+] + [A^-]$$

$$K_A = \frac{[H^+]\,[A^-]}{[HA]}$$

$$-\log K_A = -\log \frac{[H^+]\,[A^-]}{[HA]}$$

$$-\log K_A = -\log\,[H^+] + \left(-\log \frac{[A^-]}{[HA]}\right)$$

Acid Dissociation

$$-\log K_A = -\log [H^+] + \left(-\log \frac{[A^-]}{[HA]} \right)$$

Define $pK_A = -\log K_A$, $pH = -\log [H^+]$

$$pK_A = pH - \log \left(\quad \right)$$

$$pH = pK_A + \log \left(\quad \right)$$

Henderson-Hasselbalch Eq

$$[HA] \overset{K_A}{\longleftrightarrow} [H^+] + [A^-]$$

$$[H_2O] + [CO_2] \overset{CA}{\longleftrightarrow} [H_2CO_3] \overset{K_A}{\longleftrightarrow} [H^+] + [HCO_3^-]$$

$$pH = 6.5 + \log \left(\quad \right)$$