



# Acid Base Disorders



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# Objectives

- To provide a simple, systematic approach to interpreting arterial blood gas (ABG) samples.

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- Multiple formulas and rules exist to help guide us through the forest of diagnoses and complex problems
  - All that is needed is a little clinical information obtained from a history and physical examination, a few readily available laboratory tests, and the knowledge of five simple steps.

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- Getting in the routine of performing these steps on each patient in which an ABG and electrolytes are performed will help decrease the rate of missed complex acid-base disturbances and hopefully improve patient care

# Five Steps of Acid-Base Analysis 1-5

- ▶ **Step 1:** Acidemia (pH <7.38) or alkalemia (pH >7.42)?
- ▶ **Step 2:** Primary respiratory or metabolic disturbance? (Look at PCO<sub>2</sub> on ABG or HCO<sub>3</sub> on metabolic panel.)
- ▶ **Step 3:** Is there appropriate compensation for the primary disorder?
  - Metabolic acidosis:  $PCO_2 = [1.5 \times (\text{serum HCO}_3)] + 8 (\pm 2)$
  - Metabolic alkalosis:  $\uparrow PCO_2 = 0.6 \times \uparrow HCO_3 (\pm 2)$
  - Respiratory acidosis:  $\uparrow PCO_2$  10,  $\uparrow HCO_3$  by 1 (acute) or 4 (chronic)
  - Respiratory alkalosis:  $\downarrow PCO_2$  10,  $\downarrow HCO_3$  by 2 (acute) or 5 (chronic)
- ▶ **Step 4:** Is there an anion gap metabolic acidosis (AGMA)?  $AG = Na - (HCO_3 + Cl)$ . If > 12, an AGMA is present.
- ▶ **Step 5:** If metabolic acidosis, is there another concomitant metabolic disturbance?
  - If AGMA, then calculate  $\Delta Gap = \Delta AG - \Delta HCO_3 = (AG - 12) - (24 - HCO_3)$
  - If the  $\Delta Gap$  is > 6, there is a combined AGMA and metabolic alkalosis.
  - If the  $\Delta Gap$  is < -6, there is a combined AGMA and NAGMA.
  - If NAGMA, for every 1 mEq/L  $\uparrow Cl$ , there should be a 1 mEq/L  $\downarrow HCO_3 (\pm 5)$ .
  - If HCO<sub>3</sub> decrease is less than predicted, then NAGMA and metabolic alkalosis.



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# Five Steps of Acid-Base Analysis 1-5

- **Step 2:** Primary respiratory or metabolic disturbance?  
(Look at PCO<sub>2</sub> on ABG or HCO<sub>3</sub> on metabolic panel.)



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- **Respiratory alkalosis:**  $\downarrow PCO_2$  10,  $\downarrow HCO_3$  by 2 (acute) or 5 (chronic)





# Five Steps of Acid-Base Analysis 1-5

- **Step 4:** Is there an anion gap metabolic acidosis (AGMA)?
- $AG = Na - (HCO_3 + Cl)$ .
- If  $> 12$ , an AGMA is present

# Five Steps of Acid-Base Analysis 1-5

- **Step 5:** If metabolic acidosis, is there another concomitant metabolic disturbance?
- If AGMA, then calculate  $\Delta\text{Gap} = \Delta\text{AG} - \Delta\text{HCO}_3 = (\text{AG} - 12) - (24 - \text{HCO}_3)$
- If the  $\Delta\text{Gap}$  is  $> 6$ , there is a combined AGMA and metabolic alkalosis
- If the  $\Delta\text{Gap}$  is  $< -6$ , there is a combined AGMA and NAGMA.

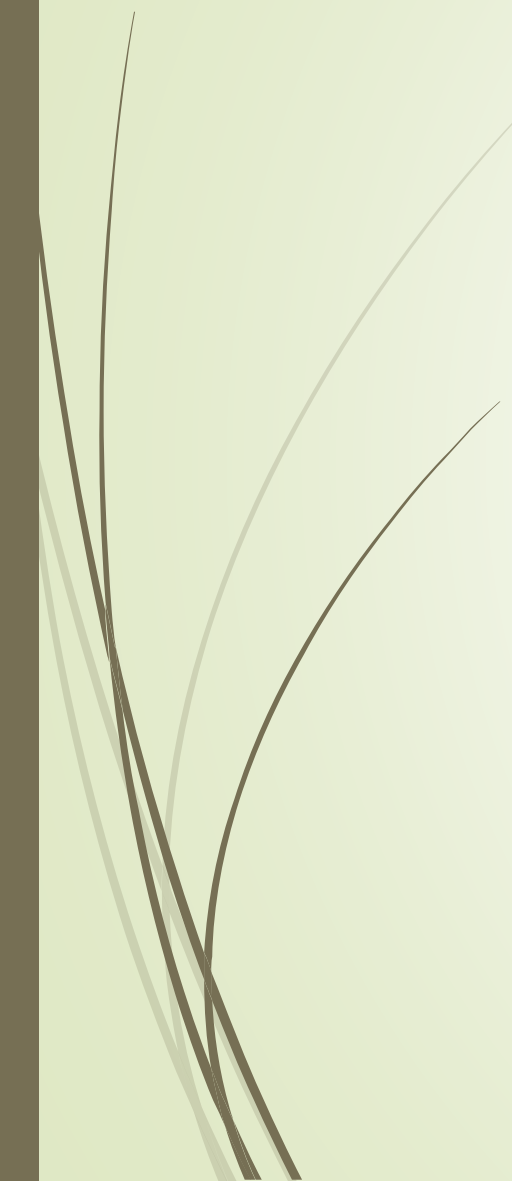



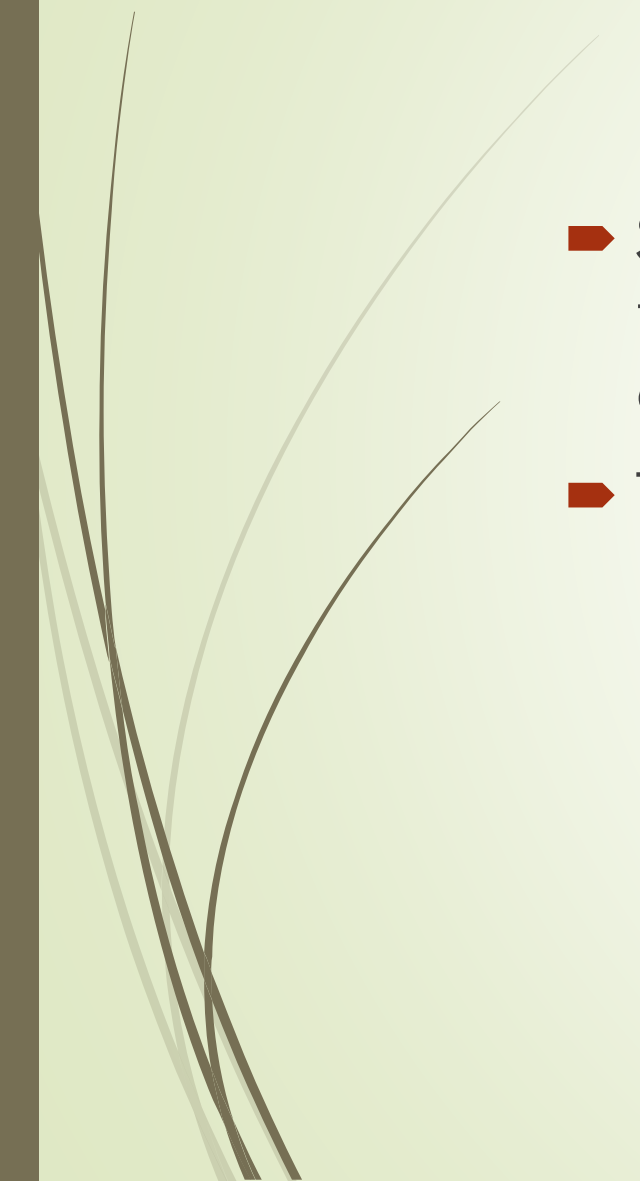
# Five Steps of Acid-Base Analysis 1-5

- ▶ If NAGMA, for every 1 mEq/L  $\uparrow$ Cl, there should be a 1 mEq/L  $\downarrow$  HCO<sub>3</sub> ( $\pm 5$ ).
- ▶ If HCO<sub>3</sub> decrease is less than predicted, then NAGMA and metabolic alkalosis






# Metabolic Acidosis

- ▶ In the presence of a  $\text{pH} < 7.38$ , metabolic acidosis is diagnosed as a primary condition when the  $\text{pCO}_2$  is  $< 40$  mmHg or the bicarbonate is  $< 24$  mEq/L.
  - ▶ Metabolic acidosis can be further classified based on the presence of an anion gap.
  - ▶ The anion gap reflects the balance between positively and negatively charged particles in the blood.
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- ▶ Sodium is the only significant positively charge particle that is measured, while the measured anions are chloride and bicarbonate.
  - ▶ Therefore, the anion gap is calculated by the formula:

$$\text{Na} - (\text{Cl} + \text{HCO}_3).$$

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- One potential pitfall in the measurement of the anion gap is patients with low albumin.
  - Albumin has several negative charges on it and therefore, in a patient with a low albumin level, their “normal” anion gap might be much lower than 12.
  - For every 1 gram drop in serum albumin level, the anion gap decreases by 2.5.
  - A patient with a calculated anion gap of 10 and a 2 gram drop in their albumin may actually have an anion gap metabolic acidosis (recalculated AG 15).

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- ▶ Anion Gap Metabolic Acidosis (AGMA) Detection of an AGMA is important because only a few conditions commonly cause it.
  - ▶ In addition, in mixed acid-base disorders, an elevation in the anion gap may be the only signal that a metabolic acidosis is present.
  - ▶ The causes of an AGMA are divided into four main categories:  
renal failure, ketoacidosis, toxins, and lactic acidosis







# Metabolic acidosis

## ➤ A CAT MUDPILES:


- Analgesics (massive NSAID, acetaminophen) o
- Cyanide, Carbon monoxide
- Arsenic, Alcoholic ketoacidosis
- Toluene o Methanol, Metformin o
- Uremia o Diabetic ketoacidosis
- Paraldehyde, Phenformin
- Iron, Isoniazid
- Lactic acidosis
- Ethylene glycol
- Salicylates

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- ▶ In any patient with an *AGMA*, calculate an osmol gap.
  - ▶ Osmol gaps are a clue to a potentially life-threatening toxic alcohol ingestion (ie. ethylene glycol and methanol).
  - ▶ The osmol gap is determined by subtracting the calculated osmolality from the measured osmolality.
  - ▶ Calculated osmolality =  $2(\text{Na}) + \text{Glc}/18 + \text{BUN}/2.4 + \text{ETOH}/4.6$



***32 year old man with depression and alcohol abuse presents with altered mental status.***


- ABG: pH 6.9, pCO<sub>2</sub> 29, pO<sub>2</sub> 100
- Metabolic panel: Na 140, Cl 101, HCO<sub>3</sub> 5

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- **Step 1:** Acidosis
  - **Step 2:** Metabolic
  - **Step 3:**  $p\text{CO}_2 = 1.5(\text{HCO}_3) + 8 = 15$ , but the patient's  $p\text{CO}_2$  is higher than 15. Therefore, a respiratory acidosis is also present, possibly secondary to CNS depression.
  - **Step 4:**  $\text{AG} = 140 - (101 + 5) = 34$
  - **Step 5:** Delta gap =  $(34-12) - (24-5) = 3$ . No additional metabolic disorders other than AGMA.
  - **Answer: Anion gap metabolic acidosis and respiratory acidosis. The patient had an osmol gap of 174 and a methanol level of 510 mg/dL.**



# Non-Anion Gap Metabolic Acidosis (NAGMA)

- A NAGMA is due to either GI or renal losses of bicarbonate.
- If desired, GI mediated and renally mediated losses can be distinguished by obtaining urine electrolytes (ie. Na, K, and Cl) and calculating the urine anion gap.
- The urine anion gap :  $\text{Na} + \text{K} - \text{Cl}$
- The urine anion gap is the difference between the spot urine positive ions and spot urine negative ions.
- If an excess of negatively charged ions is present, the acidemia is due to the kidney

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- **A 68 year old man who recently took antibiotics for a skin infection presents with 10 episodes of watery diarrhea per day for the last 5 days.**
  - ABG: pH 7.34, pCO<sub>2</sub> 34, pO<sub>2</sub> 80
  - Metabolic panel: Na 135, Cl 108, HCO<sub>3</sub> 18



**Step 1:** Acidosis

➤ **Step 2:** Metabolic

➤ **Step 3:**  $p\text{CO}_2 = 1.5(\text{HCO}_3) + 8 = 35$

➤ **Step 4:**  $\text{AG} = 135 - (108 + 18) = 9$


➤ **Step 5:**  $\text{Cl} \uparrow$  by 8 and  $\text{HCO}_3 \downarrow$  by 6; therefore there is no metabolic alkalosis.

➤ **Answer: NAGMA due to diarrhea**







# Respiratory acidosis


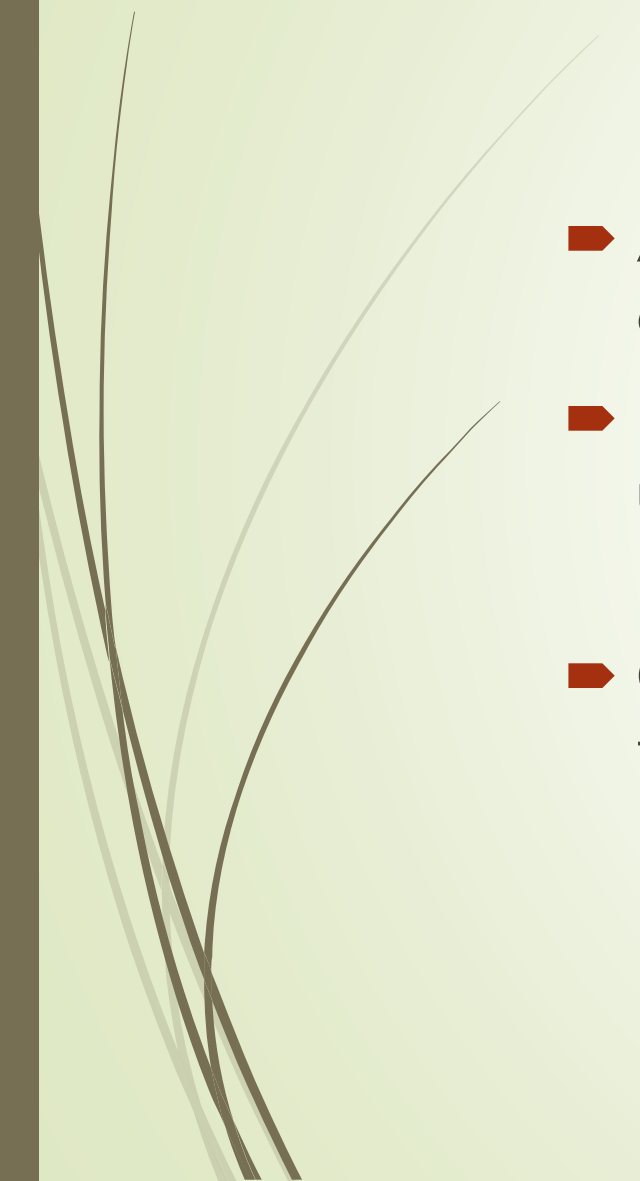
- ▶ Respiratory acidosis is characterized by an elevation in the  $p\text{CO}_2$  and a decrease in blood pH due most commonly to hypoventilation.
  - ▶ It results from conditions that decrease the ability of the lungs to excrete carbon dioxide at a rate to keep up with the body's production.
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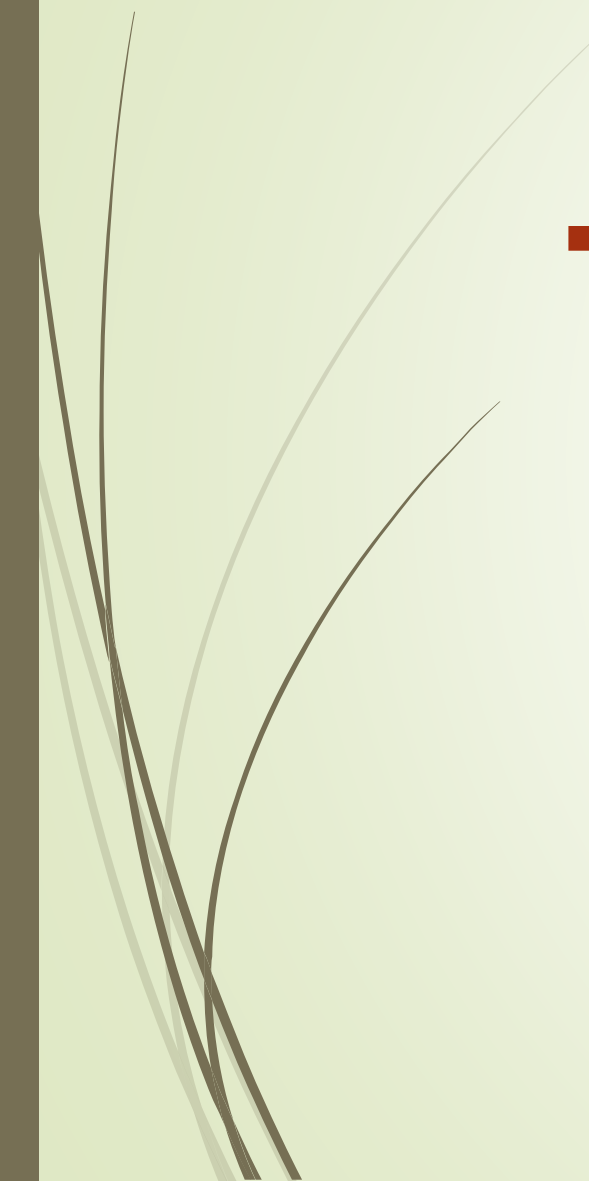



➤ **A differential diagnosis includes:**


- Central nervous system depression (sedatives, CNS disease, sleep apnea)
- Pleural disease (large pneumothorax or pleural effusion)
- Lung disease (ARDS, COPD, pulmonary edema, severe pneumonia)
- Acute airway obstruction (laryngospasm, sleep apnea)
- Neuromuscular disorders (GBS, myasthenia gravis, botulism)
- Thoracic cage injury (flail chest)
- Ventilator dysfunction

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- ▶ The kidney compensates for primary respiratory acidosis by retaining bicarbonate.
  - ▶ This compensation occurs over hours to days and is generally at a maximum within four days.
  - ▶ The rate of onset of respiratory acidosis can be determined by the degree of renal compensation (increase in  $\text{HCO}_3^-$ ) as listed above in step 3.

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- Alternatively, the chronicity of the respiratory acidosis can be predicted by the change in the pH.
  - In acute respiratory acidosis, the pH decreases by 0.08 units for each increase of 10 mmHg in the pCO<sub>2</sub> from its baseline of 40 mmHg.
  - Chronic respiratory acidosis is marked by a decrease in the pH of 0.03 units for every increase of 10 mmHg in the pCO<sub>2</sub>.

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- ▶ Differentiating acute from chronic respiratory conditions can have important clinical implications that may alert the clinician to a patient that is rapidly spiraling downward and might require emergent intubation, from a patient who has chronic disease, but is in less danger of imminent decompensation

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- ***A 70 year-old smoker presents with an acute onset of shortness of breath.***
  - ABG: pH 7.30, pCO<sub>2</sub> = 60 mmHg, pO<sub>2</sub> 60 mmHg
  - Metabolic panel: Na 135, Cl 100, HCO<sub>3</sub> 30


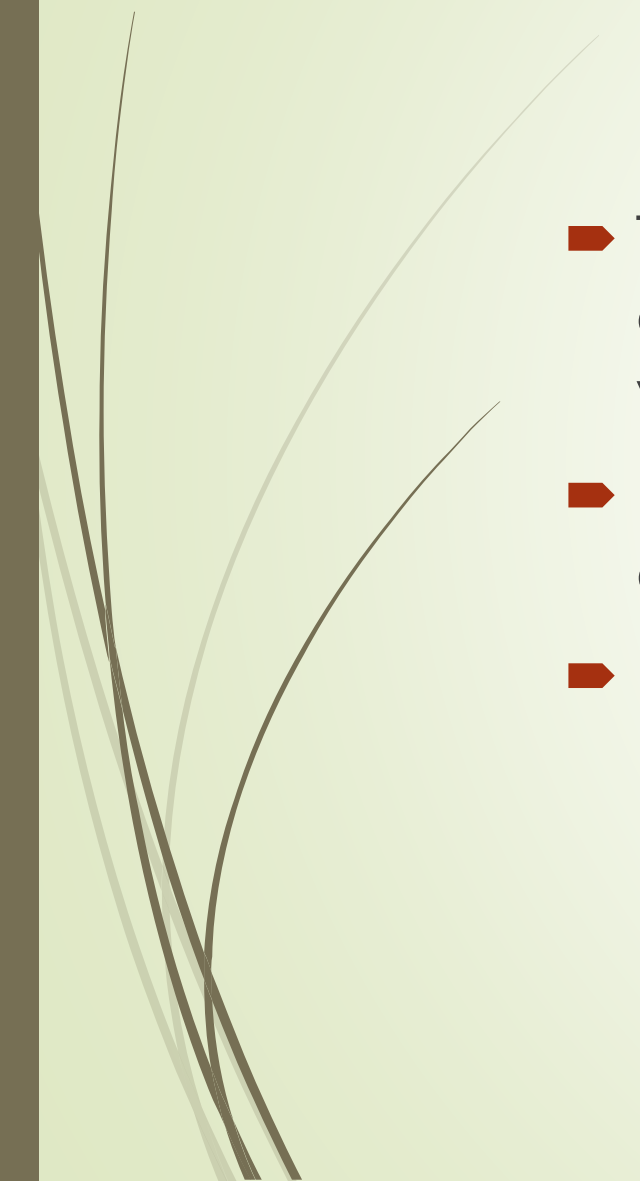
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- **Step 1:** Acidosis
  - **Step 2:** Respiratory
  - **Step 3:** Acute on chronic. pCO<sub>2</sub> increased by 20, therefore the HCO<sub>3</sub> should increase by 2 if acute and 8 if chronic. Because the HCO<sub>3</sub> increased from 24 to 30 (6), an acute on chronic respiratory acidosis is present.
  - **Step 4:**  $AG = 135 - (100 + 26) = 9$ . No anion gap metabolic acidosis
  - **Step 5:** XX
  - **Answer: Acute on chronic respiratory acidosis due to COPD exacerbation**









# Metabolic alkalosis

- Metabolic alkalosis is characterized by an increase in the serum bicarbonate concentration.
- **The causes of metabolic alkalosis are :**
- Volume contraction (vomiting, NG suction, loop or thiazide diuretics).
- Excess glucocorticoids or mineralocorticoids (eg, Cushing's syndrome).
- Hypokalemia
- Bartter's syndrome.
- Alkali ingestion/infusion.
- Post-hypercapnic alkalosis

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- To differentiate the most common cause of metabolic alkalosis which is volume depletion from other causes you need to measure urine chloride
  - If urine chloride less than 10 this due to volume depletion (saline response)
  - If urine chloride more than 10 this due to other causes (saline resistance)

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- **Example 4:**
  - ***A 20 year old student presents with excessive vomiting after binge drinking.***
  - ABG: pH 7.50, pCO<sub>2</sub> 44, pO<sub>2</sub> 100
  - Metabolic panel: Na 138, Cl 100, HCO<sub>3</sub> 30

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- **Step 1:** Alkalosis
  - **Step 2:** Metabolic
  - **Step 3:** Increase in pCO<sub>2</sub> should equal 0.6 multiplied by the elevation of the HCO<sub>3</sub> ±2.
  - The increase of the pCO<sub>2</sub> of 4 is within two of 6(0.6) or 3.6; therefore there is appropriate compensation.
  - **Step 4:**  $AG = 138 - (100 + 30) = 8$
  - **Step 5:** XX
  - **Answer: Metabolic alkalosis secondary to vomiting**




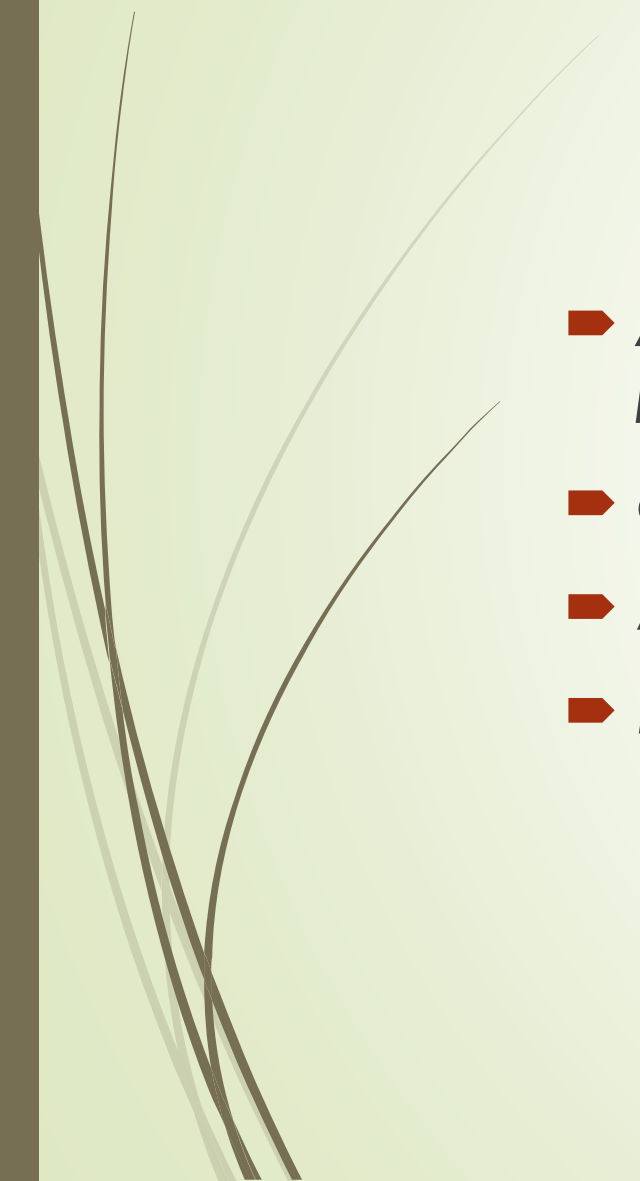
# Respiratory alkalosis

- ▶ Respiratory alkalosis is characterized by a decrease in the  $p\text{CO}_2$  and an elevation in the blood pH.
- ▶ The  $p\text{O}_2$  can be used to distinguish between disease of the lungs and other causes of hyperpnea (eg, fever)




➤ **The causes of a primary respiratory alkalosis include:**

- CNS disease (CVA) o Toxins (Salicylates)
- High altitude
- Severe anemia
- Pregnancy
- Lung disease/hypoxia (asthma, pneumonia, PE, pulmonary edema, pulmonary fibrosis)
- Anxiety o Cirrhosis of the liver
- Fever (Sepsis)
- Ventilator dysfunction

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- ***A 22 year-old woman presents with 4 hours of numbness in both hands typical***
  - of previous episodes of anxiety.
  - ABG: pH 7.48, pCO<sub>2</sub> 30 mmHg, pO<sub>2</sub> 86 mmHg
  - Metabolic panel: Na 140, Cl 110, HCO<sub>3</sub> 22



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- **Step 1:** Alkalosis
  - **Step 2:** Respiratory
  - **Step 3:** Acute. Drop in the pCO<sub>2</sub> by 10 corresponds to a drop in the HCO<sub>3</sub> by 2 if acute and 5 if chronic. 24-22 = 2 and therefore, as would be expected by the clinical history, an acute disorder is diagnosed.
  - **Step 4:** AG 140-(110+22) = 8
  - **Step 5:** XX
  - **Answer: Acute respiratory alkalosis secondary to a panic attack**



# Practice Cases

## ▶ **CASE 1**

- ▶ A diabetic presents with diarrhea and cough.
- ▶ CXR reveals an infiltrate.
- ▶ pH 7.31; pCO<sub>2</sub> 10
- ▶ Na 123; Cl 99; HCO<sub>3</sub> 5

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- ▶ **Primary AGMA (DKA), respiratory alkalosis (pneumonia), NAGMA (diarrhea)**



➤ **CASE 2**

➤ An alcoholic presents with vomiting.

➤ pH 7.20; pCO<sub>2</sub> 25

➤ Na 130; Cl 80; HCO<sub>3</sub> 10

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- ▶ **Primary AGMA (alcoholic ketoacidosis), metabolic alkalosis (vomiting)**
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➤ **CASE 3**

- A man with arthritis presents with confusion, shortness of breath, and diaphoresis.
- pH 7.30; pCO<sub>2</sub> 18
- Na 147; Cl 108; HCO<sub>3</sub> 16

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- ▶ **Primary AGMA and respiratory alkalosis (Salicylate toxicity—107 mg/dl)**





➤ **CASE 4**

➤ A patient with COPD presents with shortness of breath.

➤ pH 7.18; pCO<sub>2</sub> 80

➤ Na 135; Cl 93; HCO<sub>3</sub> 30

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- ▶ **Primary respiratory acidosis—acute-on-chronic (COPD exacerbation)**



➤ **CASE 5**

- A woman with Crohn's disease presents with fever, vomiting, and diarrhea.
- pH 7.36; pCO<sub>2</sub> 22
- Na 147; Cl 121; HCO<sub>3</sub> 14

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- ▶ **Primary NAGMA (diarrhea), respiratory alkalosis (fever), metabolic alkalosis (vomiting)**



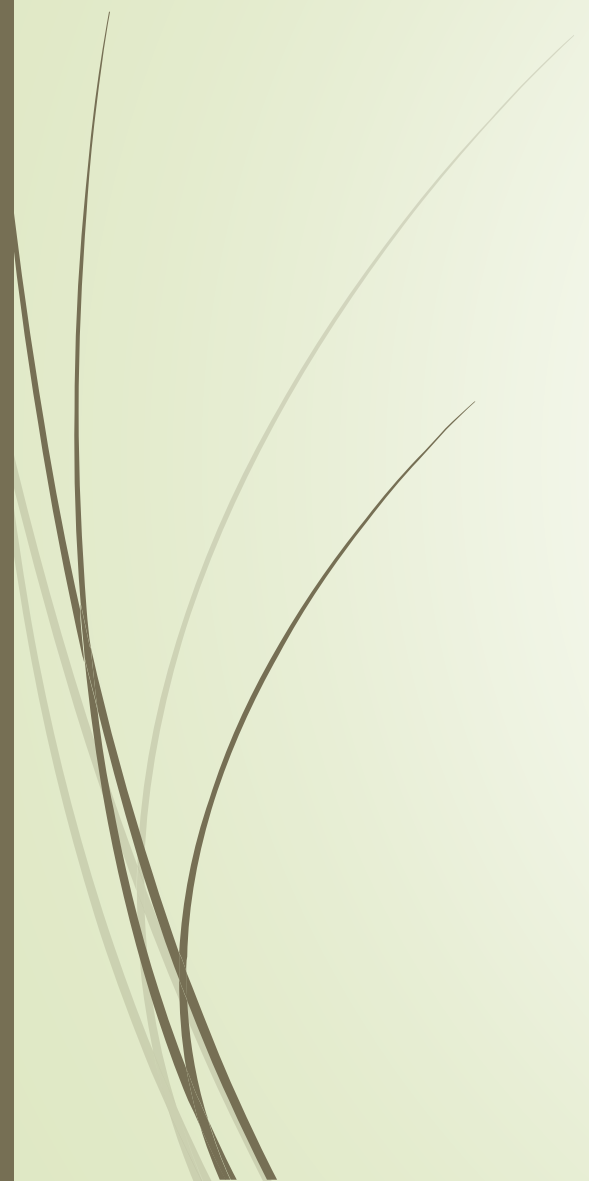
➤ **CASE 6**

➤ A noncompliant patient with diabetes and cirrhosis presents with vomiting.

➤ pH 7.46; pCO<sub>2</sub> 17

➤ Na 133; Cl 84; HCO<sub>3</sub> 15

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- ▶ **Primary chronic respiratory alkalosis (cirrhosis), AGMA (DKA), metabolic alkalosis**



QUESTION