

ACID-BASE DISORDERS

DR KUBO-MAINA

PHYSICIAN/LECTURER/NEPHROLOGY FELLOW

19/02/2021

Terms

- **Acid**

- Any substance that can yield a hydrogen ion (H^+) when dissolved in water
- Release of proton or H^+

- **Base**

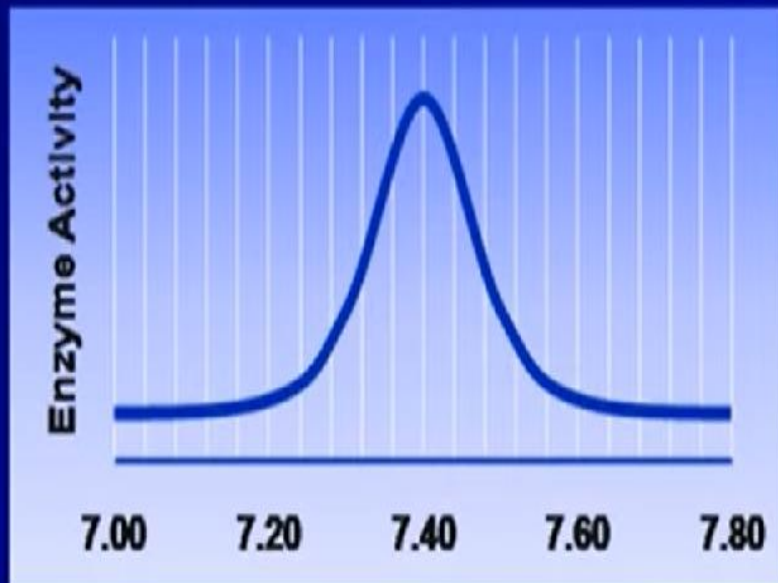
- Substance that can yield hydroxyl ions (OH^-)
- Accept protons or H^+

- **pH**

- Negative log of the hydrogen ion concentration
- $\text{pH} = \text{pK} + \log([\text{base}]/[\text{acid}])$
- Represents the hydrogen concentration

Role of Acid-Base Balance

- Maintains stable pH at 7.40 (7.35 - 7.45).
- "Physiologic pH" necessary to prevent enzyme inactivation and denaturing.

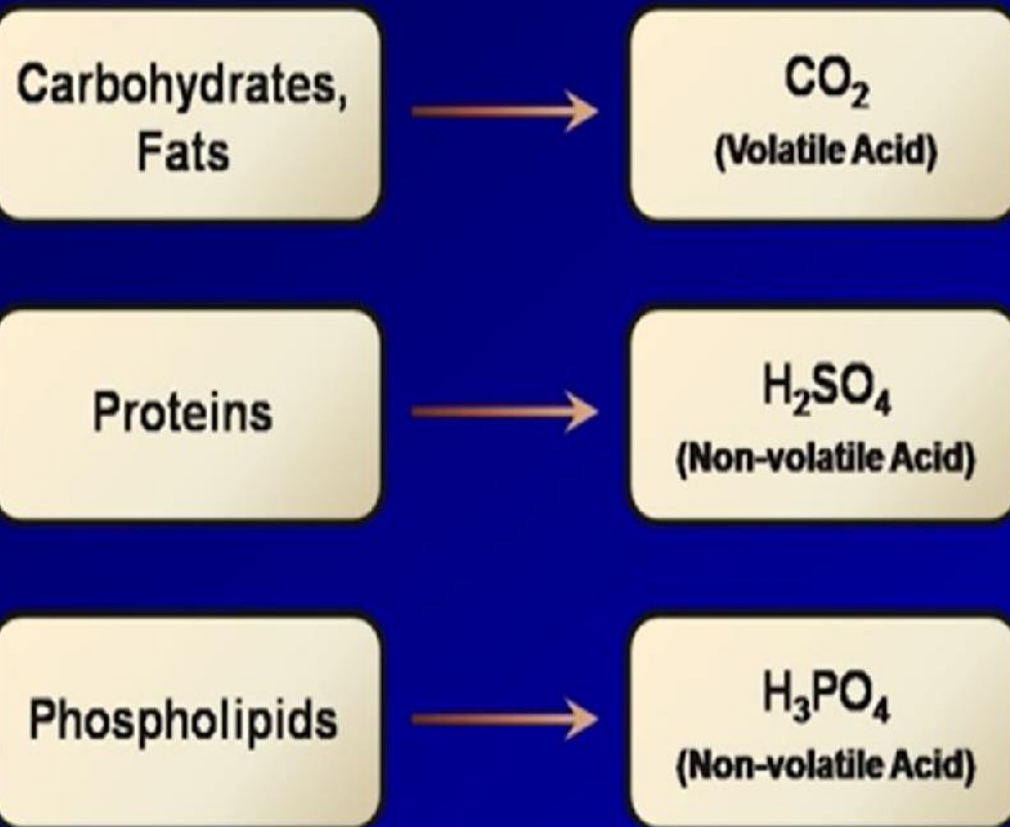


Clinical consequences of dysregulation of acid-base balance:

- Poor vascular tone
- Myocardial pump failure
- Increased risk of arrhythmias
- Skeletal muscle weakness
- Electrolyte abnormalities
- Delirium / Coma
- Impaired cellular respiration

Where is the acid coming from anyway?

Production of Acid (Physiologic)



Net Acid Production = Net Acid Elimination

Three Stages

1. Acid is produced as a consequence of normal metabolism.
2. Acid is transported via blood.
3. Acid is eliminated via lungs and kidneys.

Normal pH

- pH of the arterial plasma ~7.40
- ✓ Corresponds to a H⁺ concn of 40 nmol/L
- ↑ in H⁺ concn → ↓ in pH.
- pH < 7.35 : Acidosis
- pH > 7.45 : Alkalosis

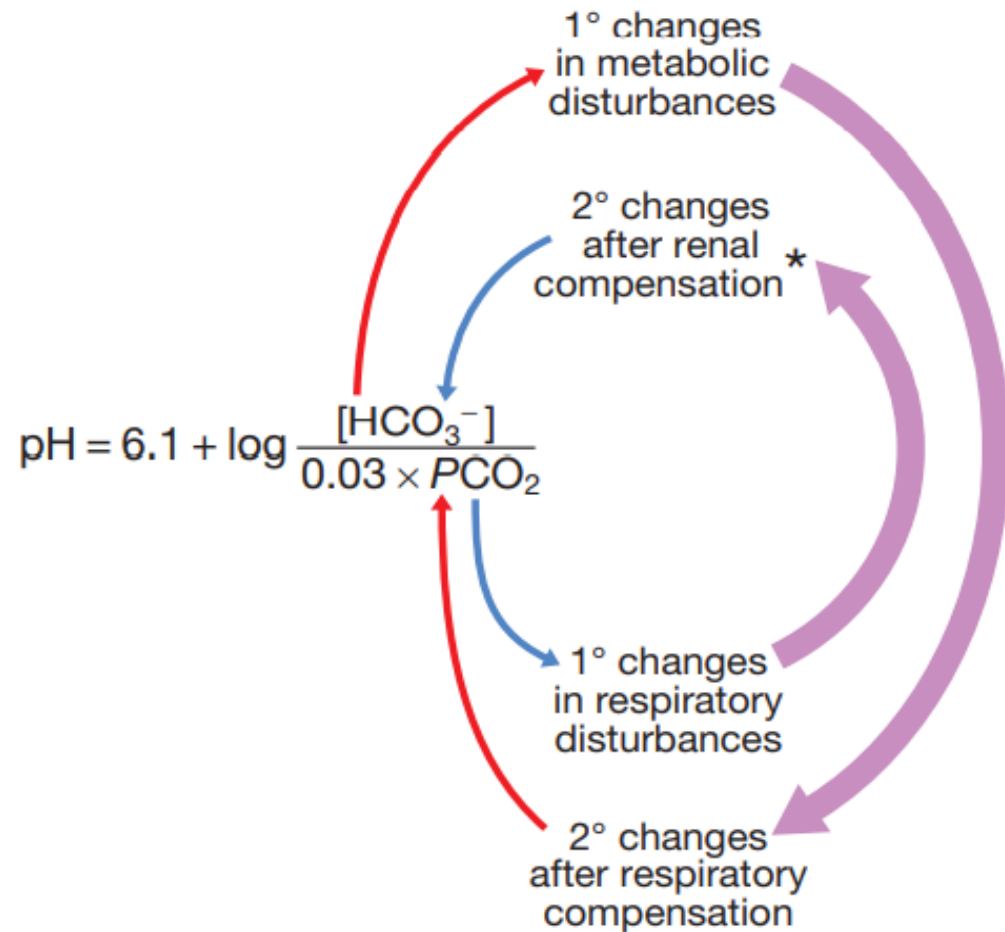
$$\text{pH} = \text{pK}_a + \log \frac{[\text{HCO}_3^-]}{[\text{CO}_2]}$$

$$\text{pH} \propto \frac{[\text{HCO}_3^-]}{[\text{CO}_2]}$$

$$\text{Acidity} = \frac{\text{Bicarbonate}}{\text{Carbon Dioxide}}$$

$$A = B / CD$$

Relationship between pH, PCO₂ and HCO₃⁻



$$\text{pH} = \text{pKa} + \log \frac{[\text{HCO}_3^-]}{[\text{CO}_2]}$$

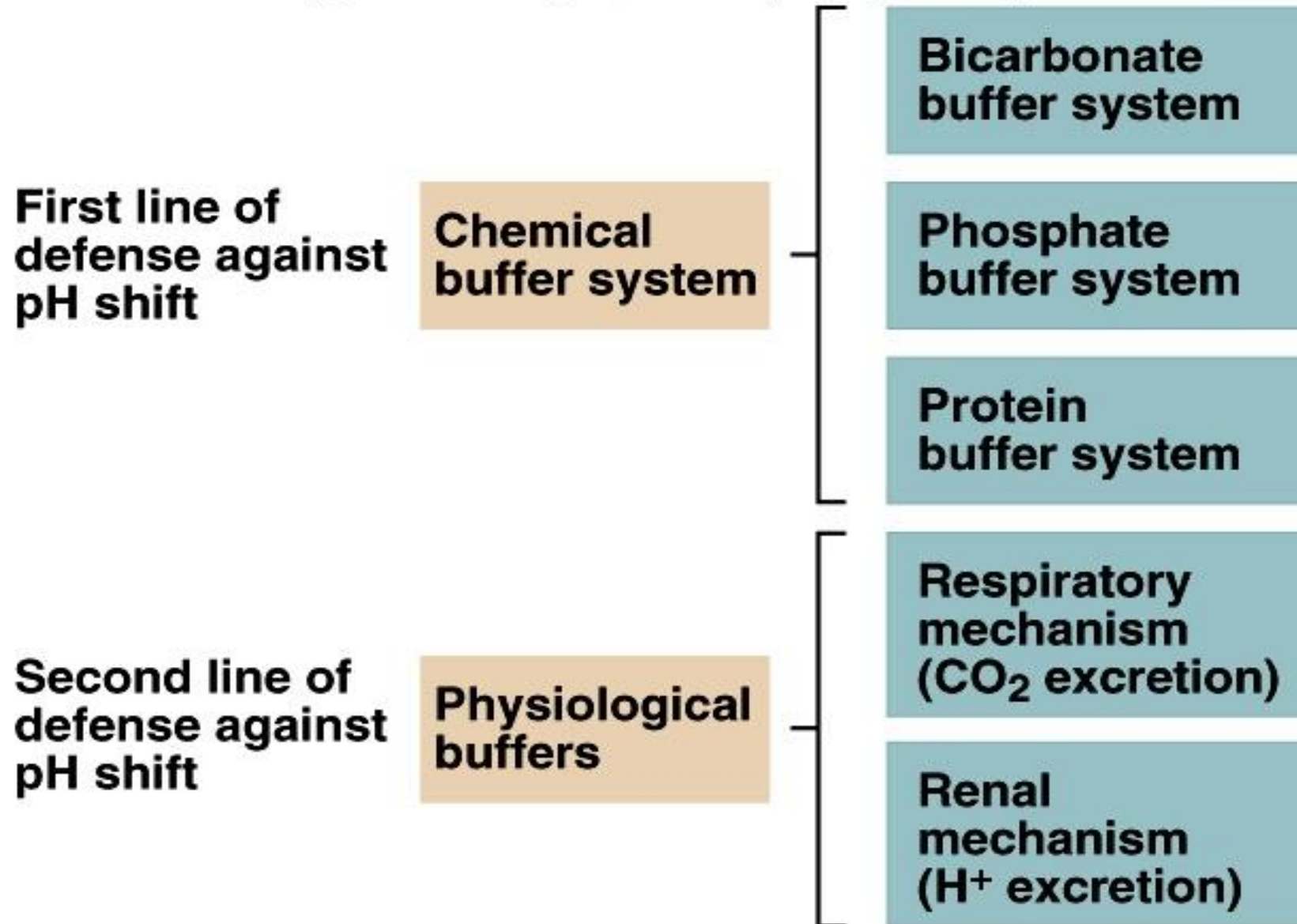
$$\text{pH} \propto \frac{[\text{HCO}_3^-]}{[\text{CO}_2]}$$

$$\text{Acidity} = \frac{\text{Bicarbonate}}{\text{Carbon Dioxide}}$$

$$A = B / CD$$

Regulation of pH

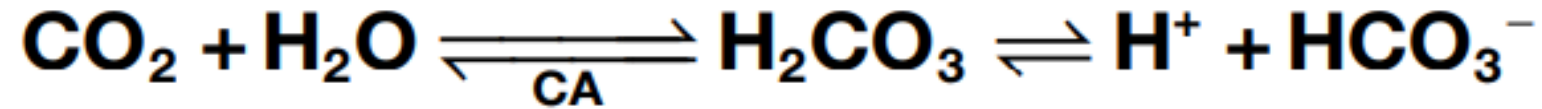
Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



ACID BASE HOMEOSTASIS

- Mechanisms that maintain pH of the ECF within narrow limits:

1. Blood and tissue buffers eg.



➤ Important buffer system because:

- ✓ Relatively high concn of bicarbonate available in the ECF (21-28mmol/l)
- ✓ Its key components are under physiologic control:
 - ☐ CO₂ by the lungs
 - ☐ HCO₃⁻ by the kidneys

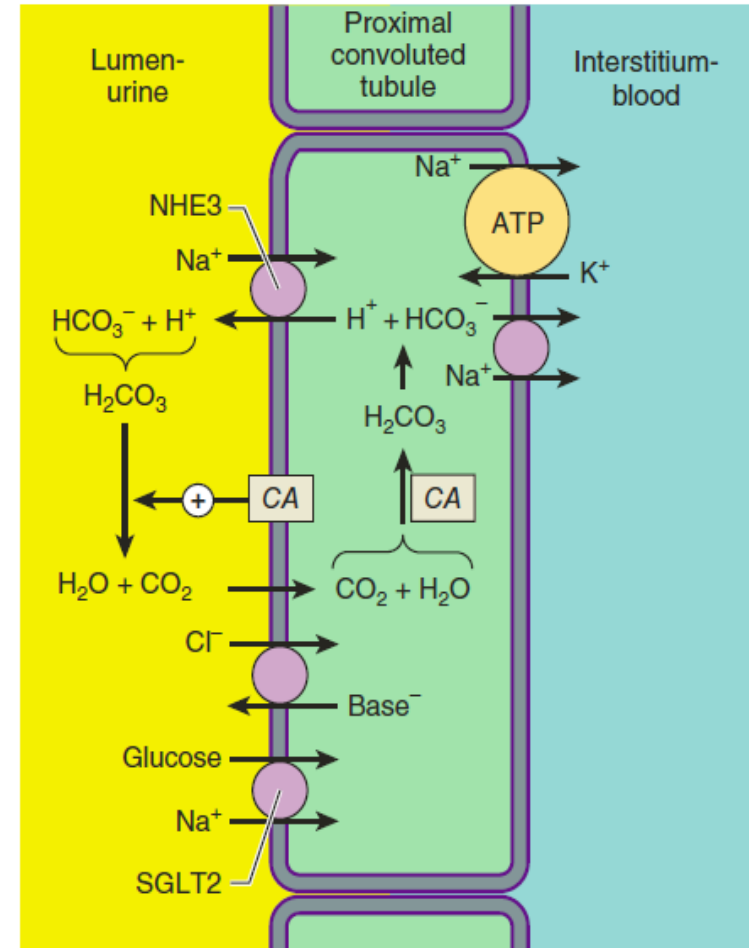
2. Respiratory Compensation for Acid-Base Disturbances

- Can occur rapidly
- Acid accumulation → pH changes in the brainstem → stimulate ventilatory drive → ↓s PCO₂ and ↑s pH.
- Systemic alkalosis → inhibition of ventilation → ↑s PCO₂ and ↓s pH.
 - Limited capacity to change pH though, as hypoxia provides an alternative stimulus to drive ventilation.

3. Renal Regulation of Acid-Base balance

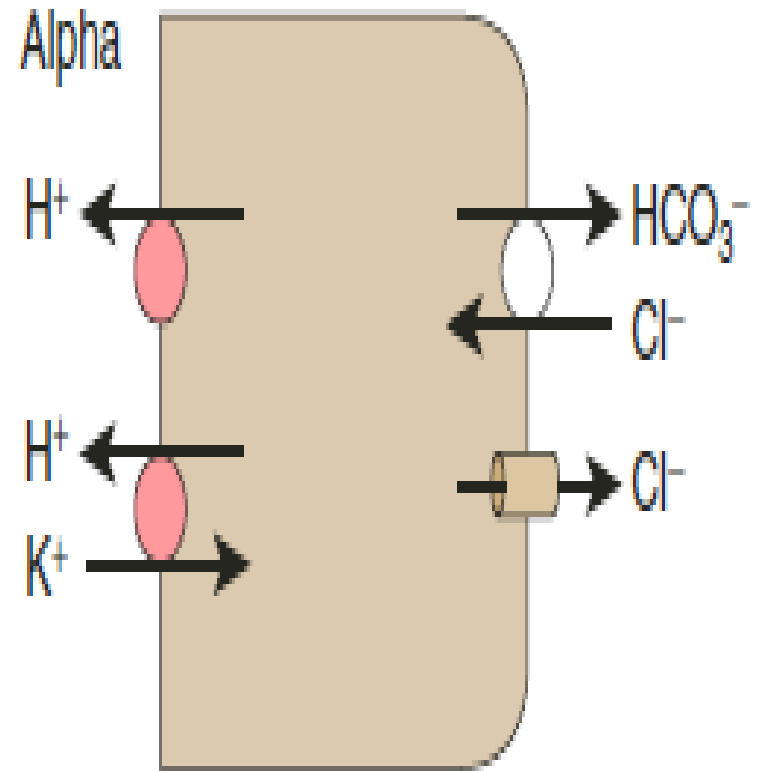
a. Proximal tubule

- The proximal tubule reabsorbs 85% of the filtered bicarbonate ions.
- Dependent on carbonic anhydrase.



b. Distal nephron segments

- Determine net acid excretion by the kidney.
- Acid is secreted into the lumen by a H^+ -ATPase in the intercalated cells of the collecting duct.
- The secreted H^+ ions contribute to net acid removal from the body



Urinary buffers

i. Phosphate

- $\text{HPO}_4^{2-} + \text{H}^+ \rightarrow \text{H}_2\text{PO}_4^-$
- Excreted in the urine with sodium.

ii. Ammonia

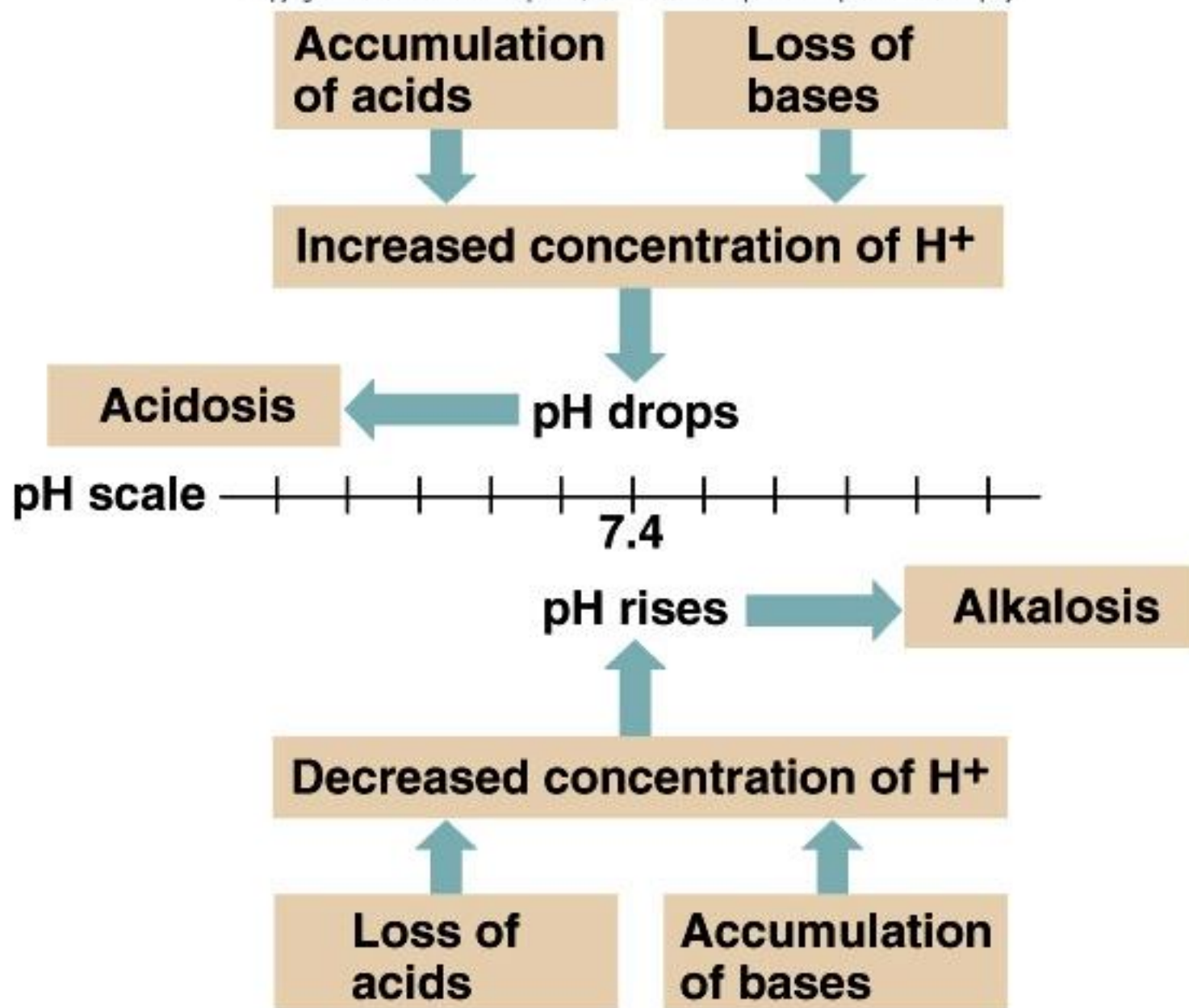
- $\text{NH}_3 + \text{H}^+ \rightarrow \text{NH}_4^+$
- Becomes trapped in the luminal fluid and is excreted with chloride ions.

- Importance:

- These two mechanisms remove approximately 1 mmol/kg of H^+ from the body per day
- Equal to the non-volatile acid load arising from the metabolism of dietary protein
- The plasma pH of 7.4 can be accounted for by the kidney's ability to generate an acidic urine (**pH typically 5–6**), in which the net daily excess of metabolic acid produced by the body can be excreted.

ACID-BASE DISTURBANCES

.



Clinical terminology	Criteria
Normal pH	7.4 (7.35-7.45)
Acidemia	pH < 7.35
Alkalemia	pH > 7.45
Normal PaCO₂	40 (35- 45) mm of Hg
Respiratory acidosis (failure)	PaCO ₂ > 45 mm Hg and low pH
Respiratory alkalosis (hyperventilation)	PaCO ₂ < 35 mm Hg and high pH
Normal HCO₃	24 (22- 26) mEq/L
Metabolic Acidosis	HCO ₃ < 22 mEq/L and low pH
Metabolic Alkalosis	HCO ₃ > 26 mEq/L and high pH

Acid-Base Imbalances

- The body response to acid-base imbalance is called **compensation**
- May be **complete** if brought back within normal limits
- **Partial compensation** if range is still outside normal.

Compensation

Control of pH

Controlled by kidney
Altered by metabolic disorders

$$\text{pH} \propto \frac{[\text{HCO}_3^-]}{\text{PaCO}_2}$$

Controlled by respiration
Altered in respiratory disorders

	Primary Change	Compensation	Compensatory change
Metabolic acidosis	$\text{pH} \downarrow \leftarrow \frac{\text{HCO}_3^- \downarrow}{\text{PaCO}_2}$	Respiratory	$\text{pH} \downarrow \uparrow \leftarrow \frac{\text{HCO}_3^- \downarrow}{\text{PaCO}_2 \downarrow}$
Metabolic alkalosis	$\text{pH} \uparrow \leftarrow \frac{\text{HCO}_3^- \uparrow}{\text{PaCO}_2}$	Respiratory	$\text{pH} \uparrow \downarrow \leftarrow \frac{\text{HCO}_3^- \uparrow}{\text{PaCO}_2 \uparrow}$
Respiratory acidosis	$\text{pH} \downarrow \leftarrow \frac{\text{HCO}_3^-}{\text{PaCO}_2 \uparrow}$	Metabolic	$\text{pH} \downarrow \uparrow \leftarrow \frac{\text{HCO}_3^- \uparrow}{\text{PaCO}_2 \uparrow}$
Respiratory alkalosis	$\text{pH} \uparrow \leftarrow \frac{\text{HCO}_3^-}{\text{PaCO}_2 \downarrow}$	Metabolic	$\text{pH} \uparrow \downarrow \leftarrow \frac{\text{HCO}_3^- \downarrow}{\text{PaCO}_2 \downarrow}$

↑ or ↓ Primary change; ↑↑ or ↓↓, compensation

ACIDOSIS

- Principal effect of acidosis is depression of the CNS through ↓ in synaptic transmission.
- Generalized weakness
- Deranged CNS function the greatest threat
- Severe acidosis causes
 - Disorientation
 - coma
 - death

METABOLIC ACIDOSIS

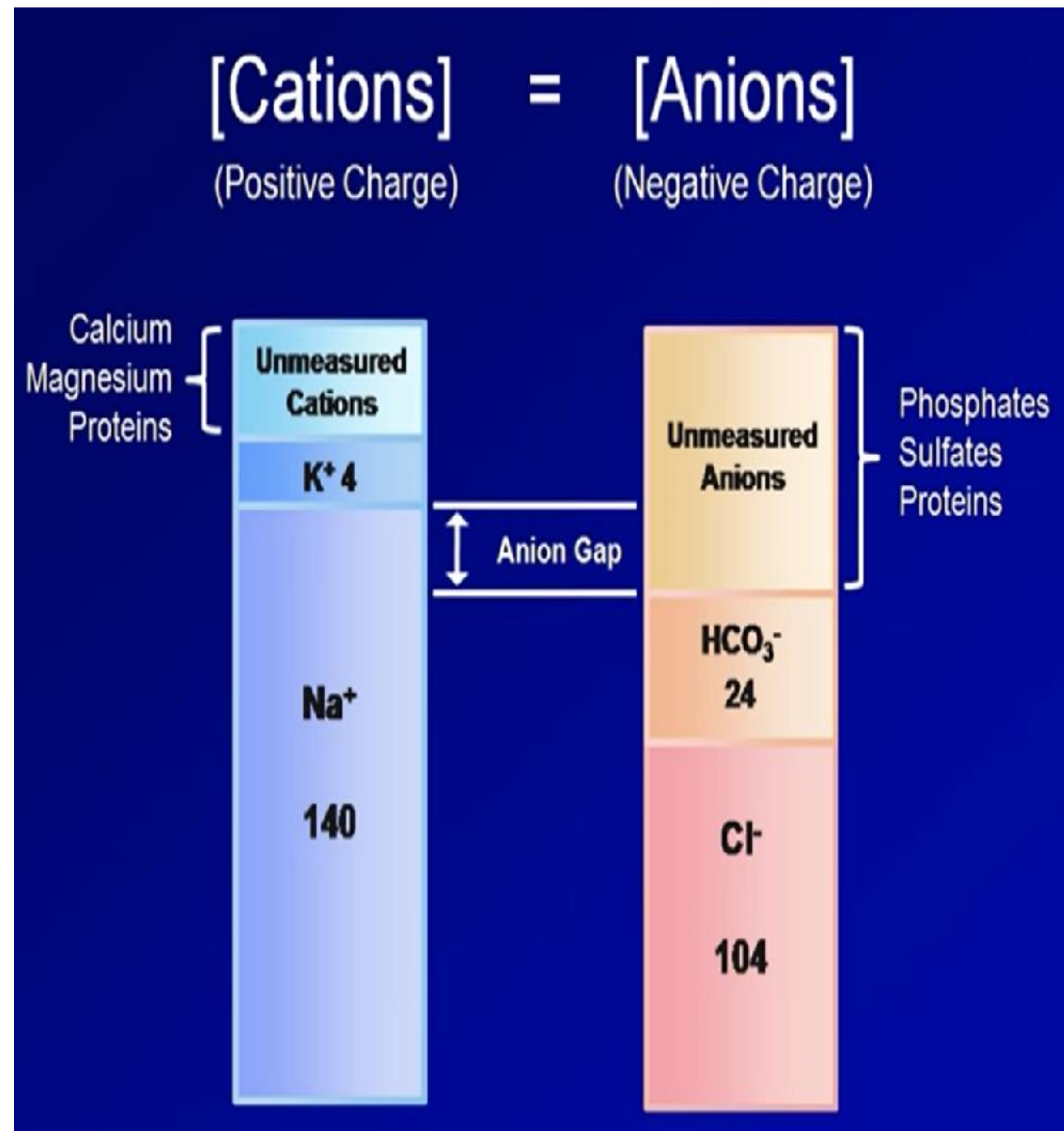
.

Metabolic Acidosis

- **Bicarbonate deficit** - blood concentrations of bicarbonate drop below 22mEq/L
- **Causes:**
 - **Loss of bicarbonate through diarrhea or renal dysfunction**
 - **Accumulation of acids (lactic acid or ketones)**
 - **Failure of kidneys to excrete H⁺**
 - **Can be High Anion Gap or Normal Anion Gap.**

The Anion Gap...

- The difference between cations and anions
- $AG = [Na^+ + K^+] - [HCO_3^- + Cl^-]$
- Normal: 12-16mmol/L
 - Made up of anions such as phosphate, sulphate & negatively charged plasma proteins
- An elevated anion gap usually indicates the presence of a pathologic acid



NB!

Calculation of the Anion Gap

$$\text{Anion Gap} = [\text{Na}^+] - \left([\text{Cl}^-] + [\text{HCO}_3^-] \right)$$

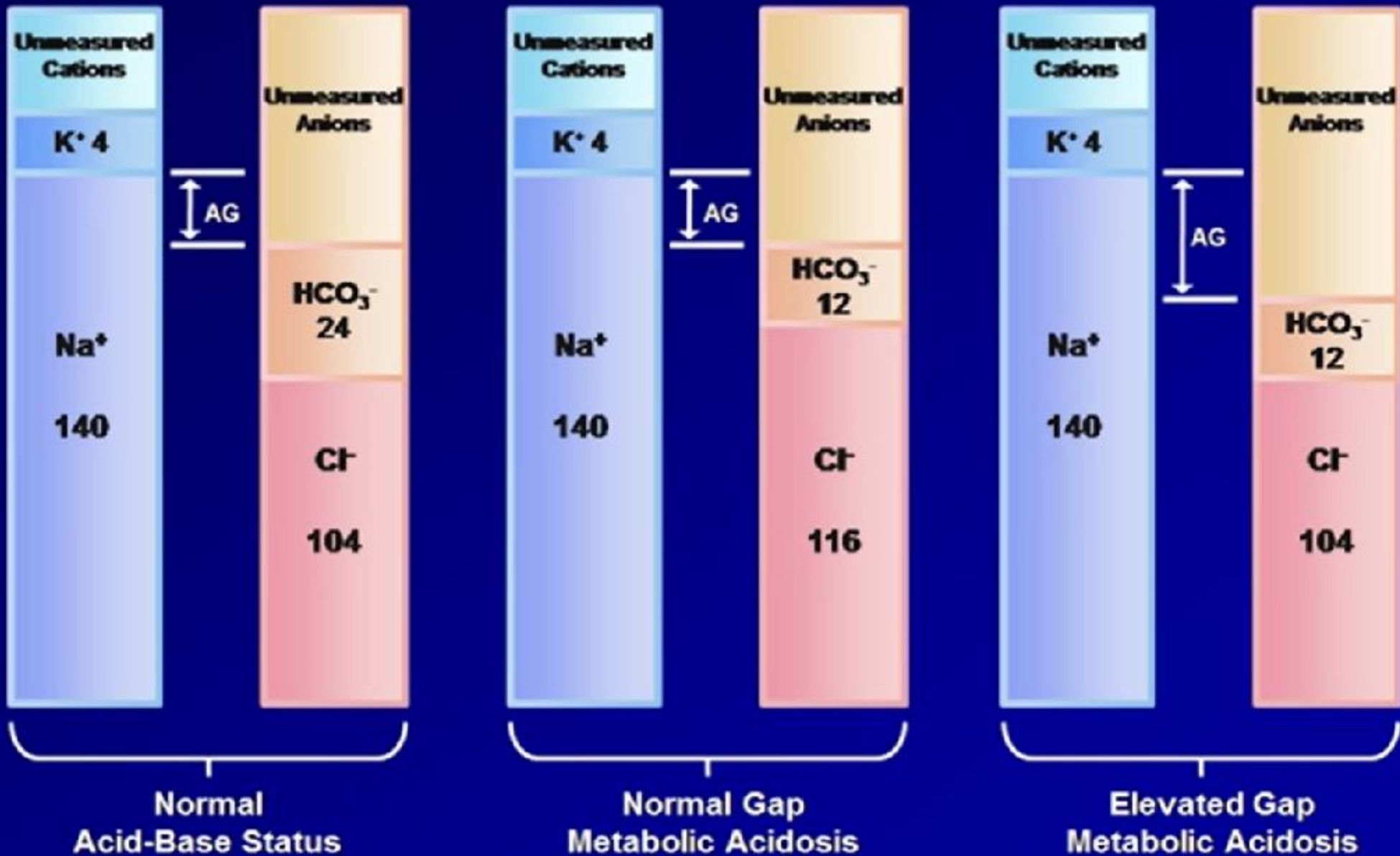
Normal Range: ~8-12 mEq/L (lab specific)

Uncommon Alternative

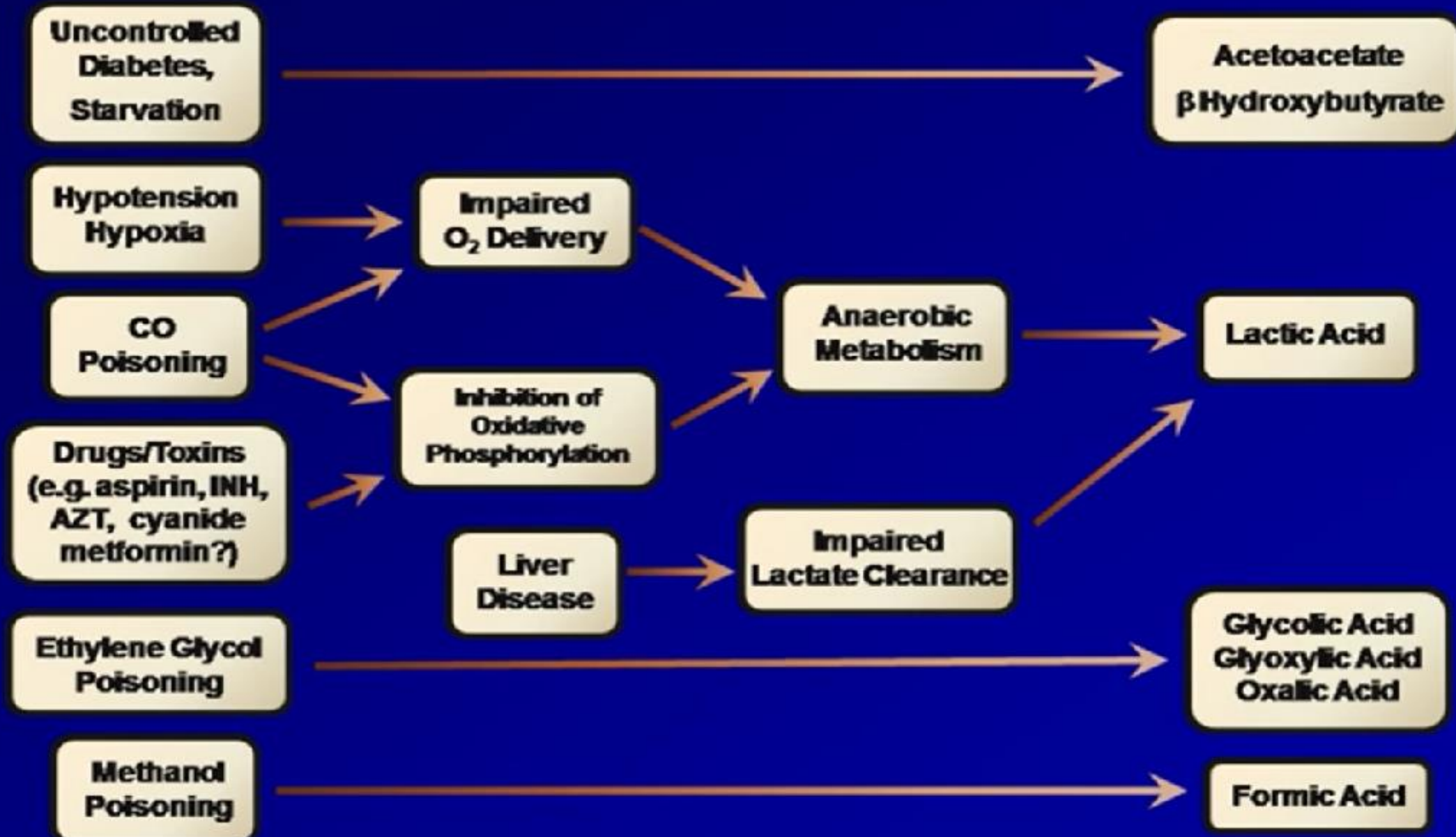
$$\text{Anion Gap} = \left([\text{Na}^+] + [\text{K}^+] \right) - \left([\text{Cl}^-] + [\text{HCO}_3^-] \right)$$

Normal range: 12-16 meq/L

Normal Gap vs. Elevated Gap Acidosis



Etiologies of an Elevated Gap Acidosis





16.19 Causes of metabolic acidosis

Disorder	Mechanism
A. Normal anion gap Ingestion or infusion of inorganic acid Gastrointestinal HCO_3 loss Renal tubular acidosis (RTA)	Therapeutic infusion of or poisoning with NH_4Cl , HCl Loss of HCO_3 in diarrhoea, small bowel fistula, urinary diversion procedure Urinary loss of HCO_3 in proximal RTA; impaired tubular acid secretion in distal RTA
B. Increased anion gap Endogenous acid load Diabetic ketoacidosis Starvation ketosis Lactic acidosis Renal failure Exogenous acid load Aspirin poisoning Methanol poisoning Ethylene glycol poisoning	Accumulation of ketones ¹ with hyperglycaemia (p. 811) Accumulation of ketones without hyperglycaemia (p. 800) Shock, liver disease, drugs Accumulation of organic acids Accumulation of salicylate ² Accumulation of formate Accumulation of glycolate, oxalate

Symptoms of Metabolic Acidosis

- Headache, lethargy
- Nausea, vomiting, diarrhea
- Coma
- Death

Compensation for Metabolic Acidosis

- Increased ventilation
- Renal excretion of hydrogen ions if possible
- K^+ exchanges with excess H^+ in ECF
 - (H^+ into cells, K^+ out of cells)

RESPIRATORY ACIDOSIS

.

Respiratory Acidosis

- **Carbonic acid excess** caused by blood levels of CO₂ above 45 mm Hg.
- Chronic conditions:
 - Depression of respiratory center in brain that controls breathing rate – drugs or head trauma
 - Paralysis of respiratory or chest muscles
 - Emphysema
- Acute conditons:
 - Adult Respiratory Distress Syndrome
 - Pulmonary edema
 - Pneumothorax

Compensation for Respiratory Acidosis

- Kidneys eliminate hydrogen ion and retain bicarbonate ion

Signs and Symptoms of Respiratory Acidosis

- Breathlessness
- Restlessness
- Lethargy and disorientation
- Tremors, convulsions, coma
- Skin warm and flushed due to vasodilation caused by excess CO₂

Treatment of Respiratory Acidosis

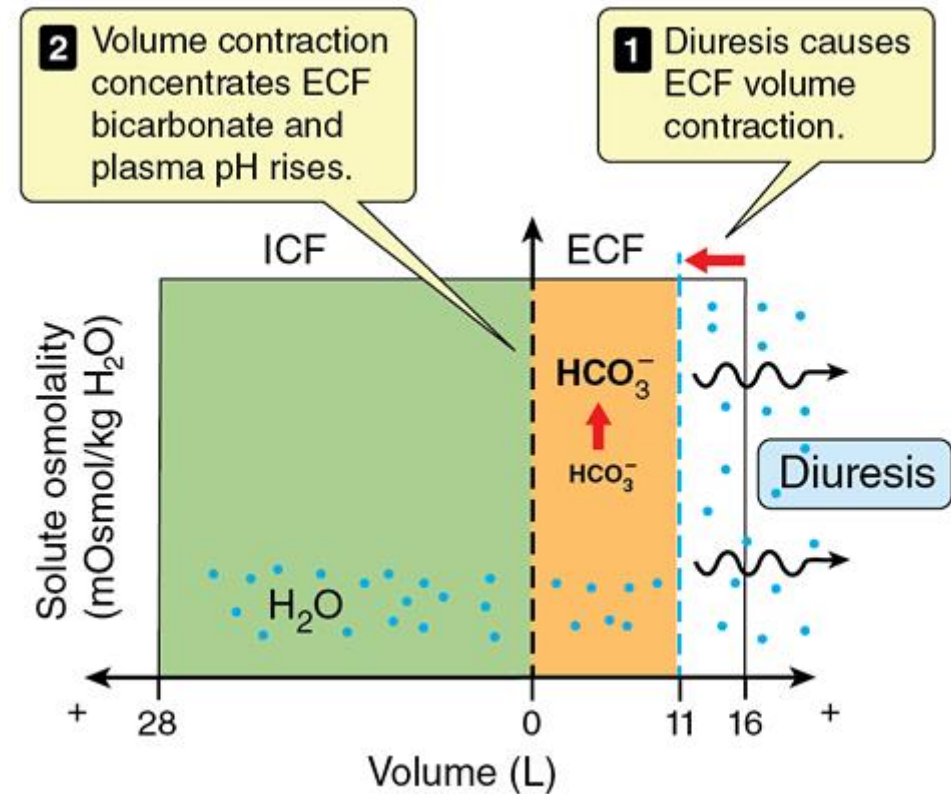
- Restore ventilation
- Treat underlying dysfunction or disease

ALKALOSIS

.

Metabolic Alkalosis

- **Bicarbonate excess** - concentration in blood is greater than 26 mEq/L
- Causes:
 - Excess vomiting = loss of stomach acid
 - Excessive use of alkaline drugs
 - Certain diuretics
 - Severe dehydration



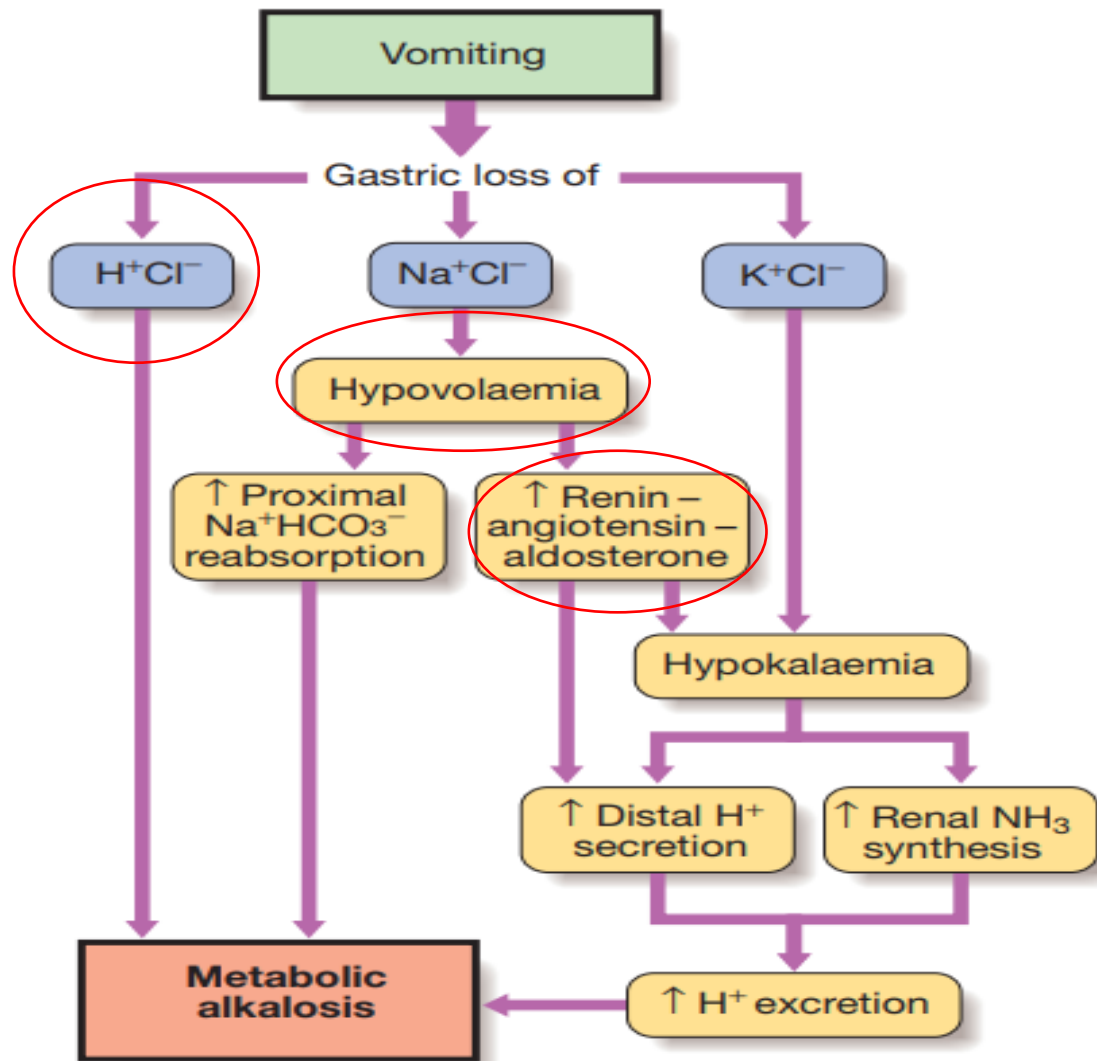
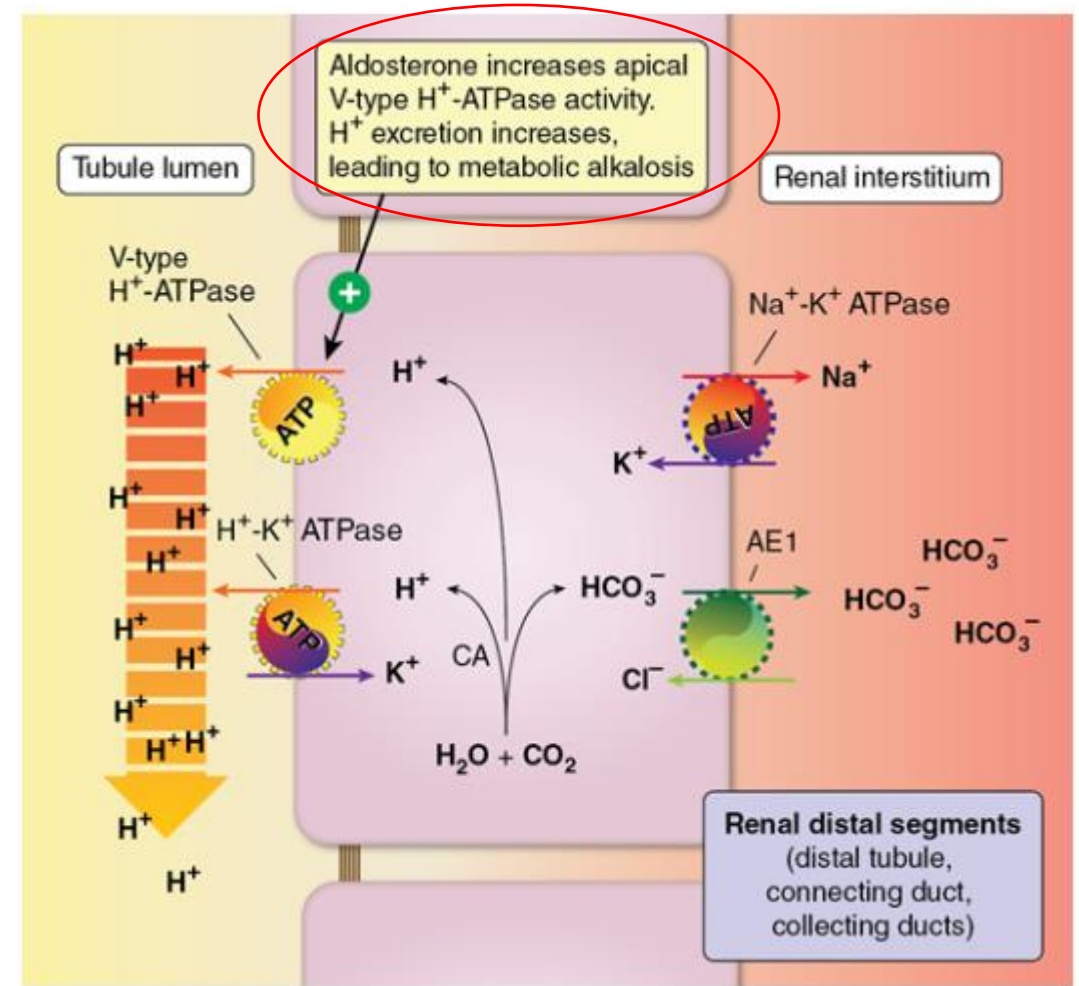


Fig. 16.12 Generation and maintenance of metabolic alkalosis during prolonged vomiting. Loss of H^+Cl^- generates metabolic alkalosis, which is maintained by renal changes.



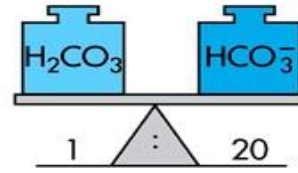
Compensation for Metabolic Alkalosis

- Alkalosis most commonly occurs with renal dysfunction, so can't count on kidneys
- Respiratory compensation difficult – hypoventilation limited by hypoxia

Symptoms of Metabolic Alkalosis

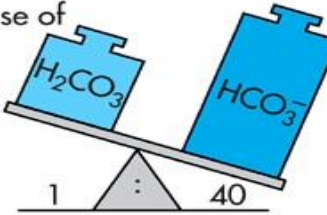
- Respiration slow and shallow
- Hyperactive reflexes ; tetany
- Often related to depletion of electrolytes
- Atrial tachycardia
- Dysrhythmias

a) Metabolic balance before onset of alkalosis



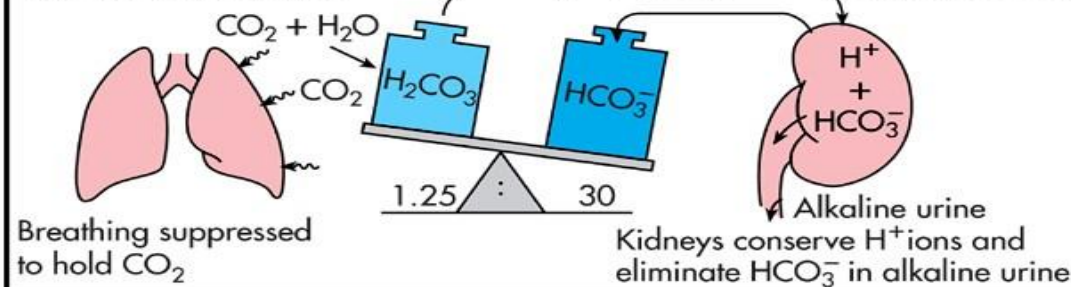
H_2CO_3 : Carbonic acid
 HCO_3^- : Bicarbonate ion
 $(\text{Na}^+ \bullet \text{HCO}_3^-)$
 $(\text{K}^+ \bullet \text{HCO}_3^-)$
 $(\text{Mg}^{++} \bullet \text{HCO}_3^-)$
 $(\text{Ca}^{++} \bullet \text{HCO}_3^-)$

b) Metabolic alkalosis
 HCO_3^- increases because of
 loss of chloride ions
 or excess ingestion
 of sodium bicarbonate

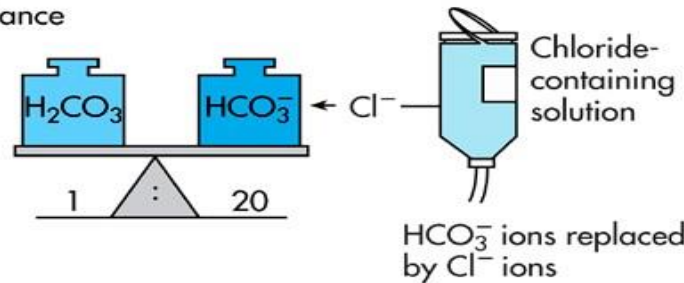


Primary change
 pH — increases
 PCO_2 — no change
 HCO_3^- — increases

c) Body's compensation



d) Therapy required to restore metabolic balance



RESPIRATORY ALKALOSIS

.

Respiratory Alkalosis

- Carbonic acid deficit
- $p\text{CO}_2$ less than 35 mm Hg (hypocapnea)
- Primary cause is hyperventilation

Respiratory Alkalosis

- Conditions that stimulate respiratory center:
 - Oxygen deficiency at high altitudes
 - Pulmonary disease and Congestive heart failure – caused by hypoxia
 - Acute anxiety
 - Fever, anemia
 - Cirrhosis
 - Gram-negative sepsis

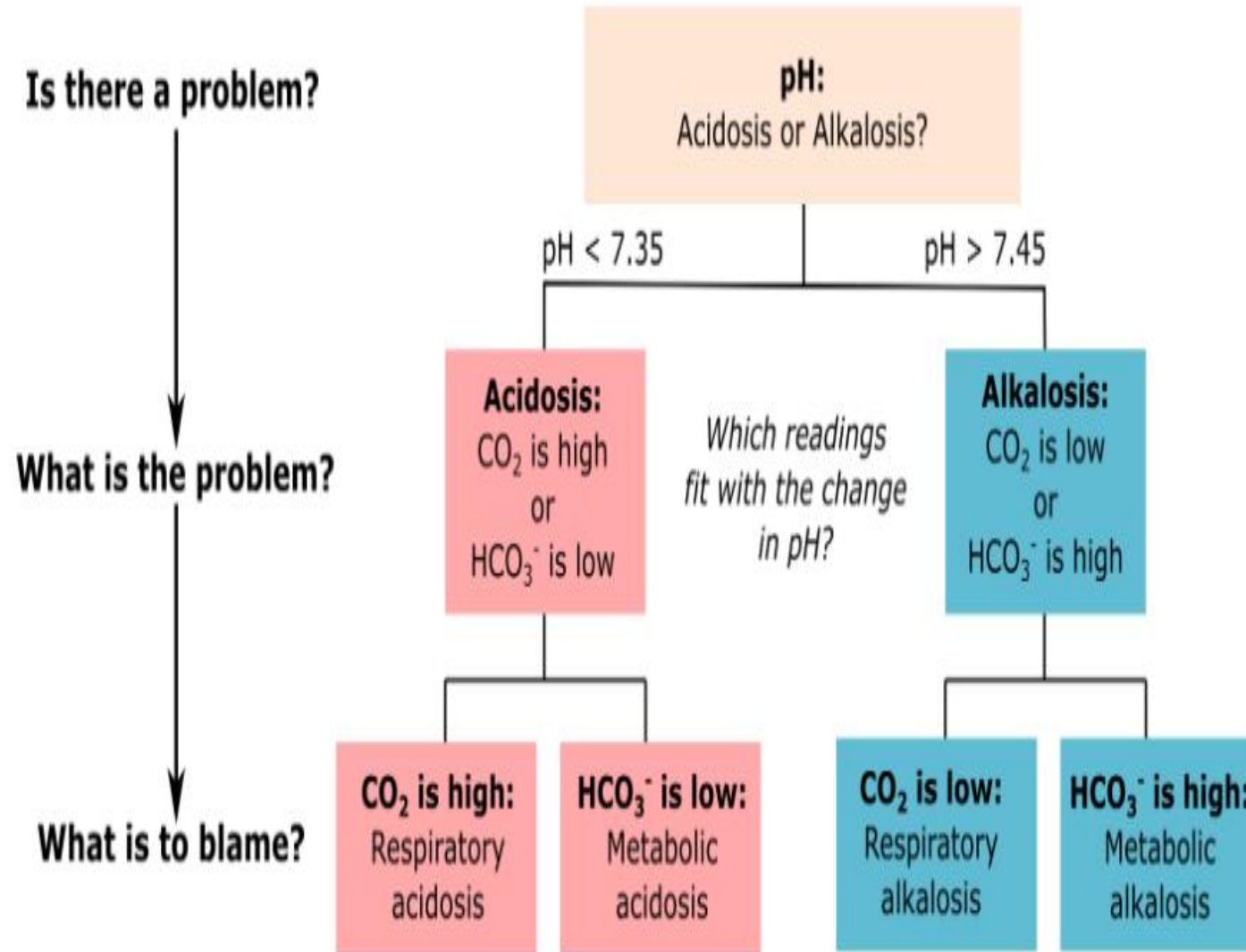
Compensation of Respiratory Alkalosis

- Kidneys conserve hydrogen ion
- Excrete bicarbonate ion

APPROACH TO THE BLOOD GAS ANALYSIS (BGA)

.

Steps in initial evaluation of the BGA



1. Check the pH
2. Look at the **PCO₂**
3. Check the **HCO₃⁻**
4. Check for any compensation

BGA Interpretation Examples..

Example 1

- pH= 7.31
- PCO₂= 40mmHg
- HCO₃⁻ = 18meq/L
- ??

• Example 2

- pH = 7.49
- PCO₂= 22mmHg
- HCO₃⁻= 25meq/L
- ??

One more.....

- **pH = 7.33**
- **PCO₂ = 20mmHg**
- **HCO₃⁻ = 19meq/L**
- **??**

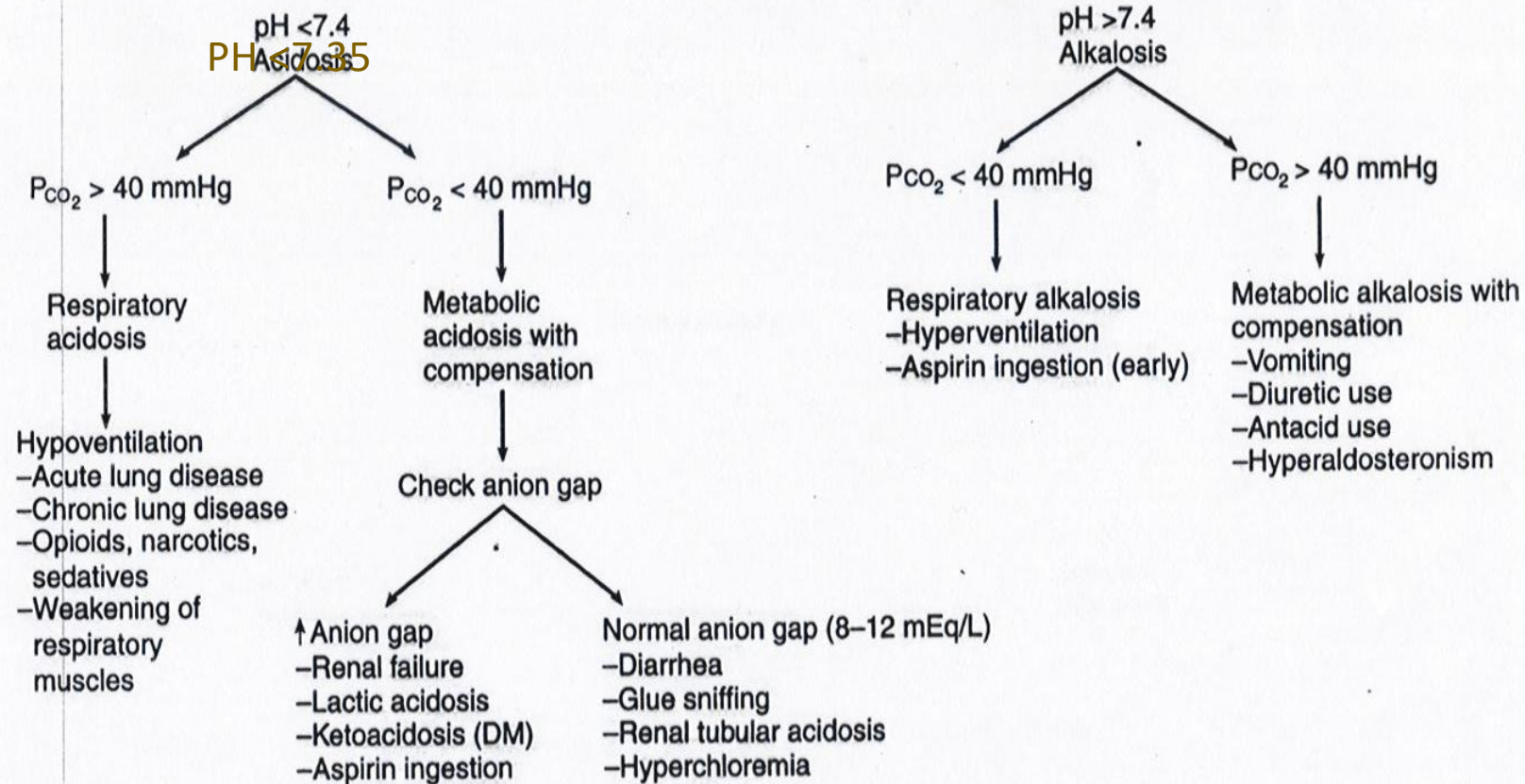
Diagnosis of Acid-Base Imbalances

1. Note whether the pH is low (acidosis) or high (alkalosis)
2. Decide which value, $p\text{CO}_2$ or HCO_3^- , is outside the normal range **and** could be the **cause** of the problem. If the cause is a change in $p\text{CO}_2$, the problem is respiratory. If the cause is HCO_3^- the problem is metabolic.

3. Look at the value that doesn't correspond to the observed pH change. If it is inside the normal range, there is no compensation occurring. If it is outside the normal range, the body is partially compensating for the problem.

Acidosis/alkalosis

Check arterial pH



THE END

.