Understanding and Interpreting Acid:Base Disorders

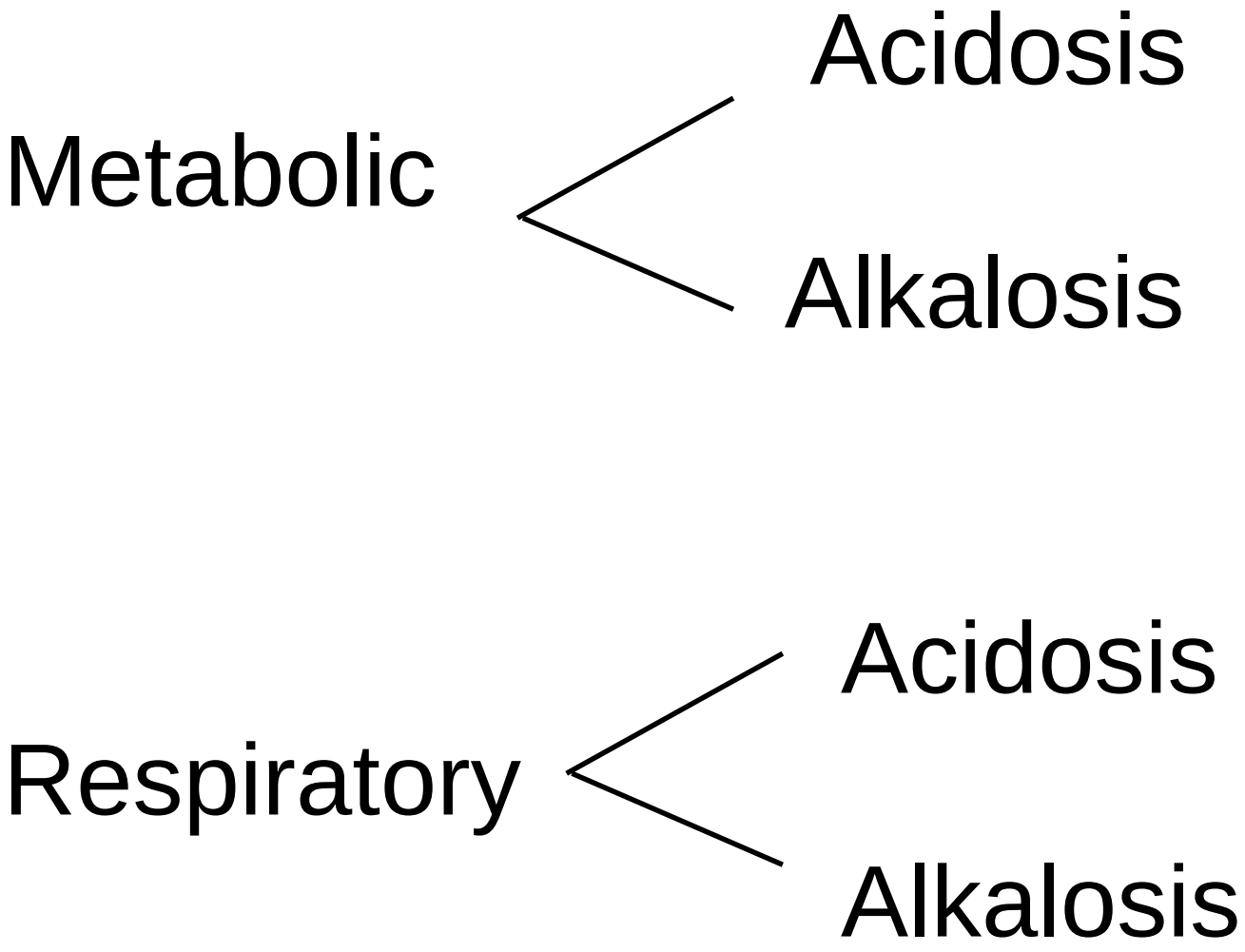
Reference Intervals

- pH 7.35-7.45 7.40
- $[H^+]$ 35-45 nmol/L 40
- $[HCO_3^-]$ 22-28 mmol/L 24
- pCO_2 35-45 mm Hg 40

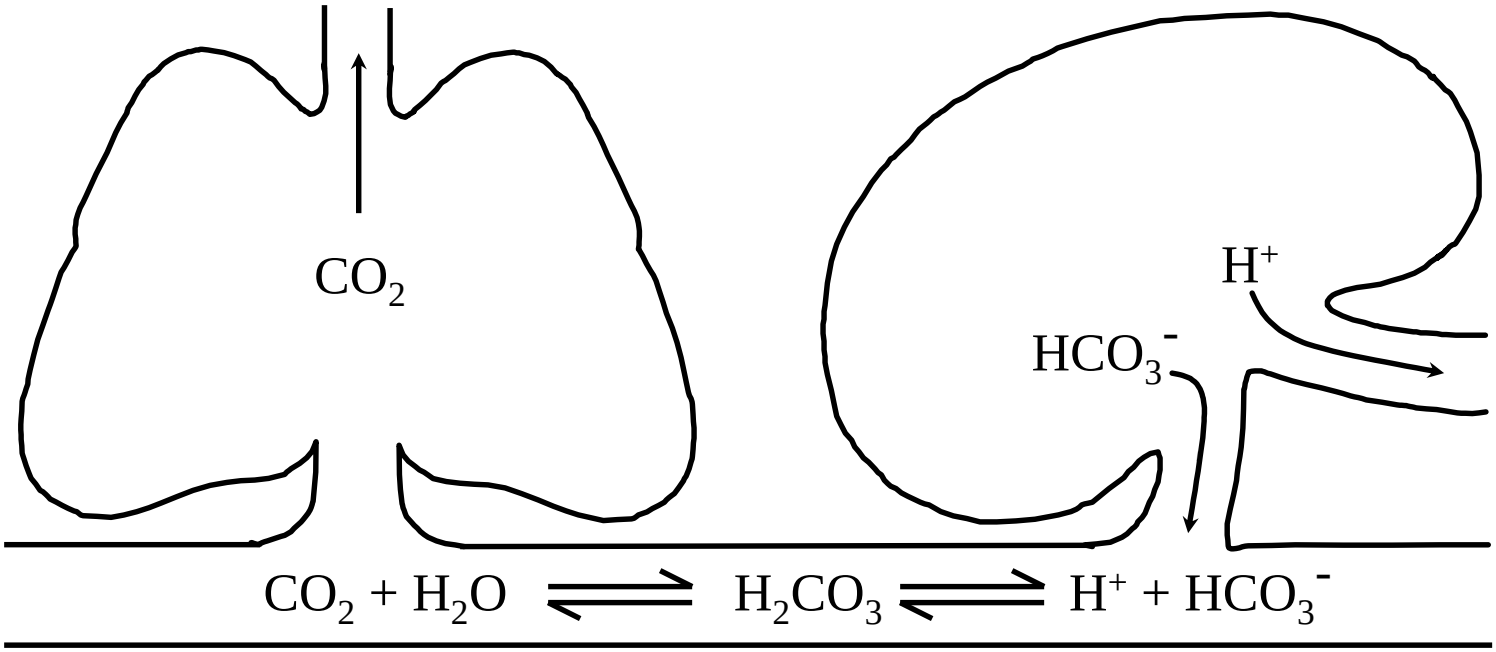
- pH = -log [H^+]
- Decrease of 1 pH unit = tenfold increase in [H^+]
- Most clinical measurements use pH – not intuitive

[H+] nmol/L	pH
20	7.70
25	7.60
30	7.52
35	7.45
40	7.40
45	7.35
50	7.30
55	7.26
60	7.22
65	7.19
70	7.15
75	7.12
80	7.10
85	7.07
90	7.05
95	7.02
100	7.00
126	6.90
158	6.80

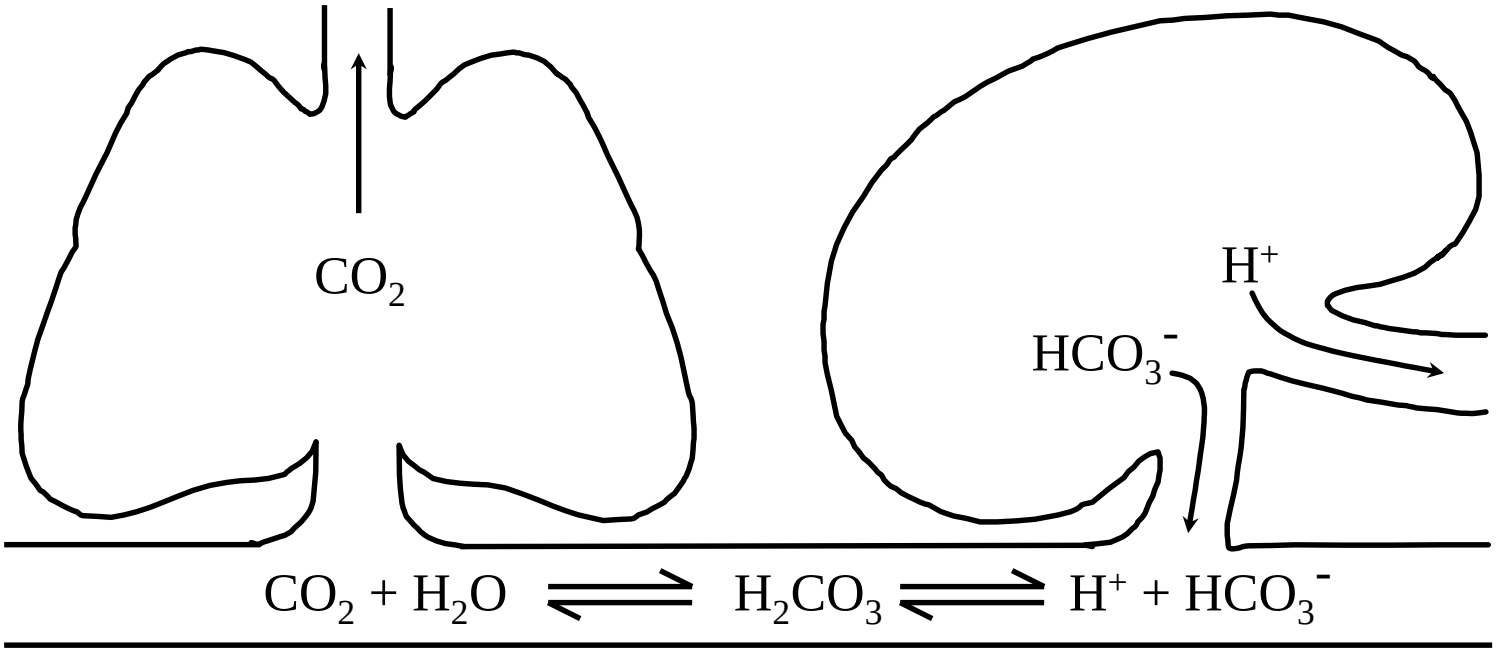
- pH < 7.40 ($[H^+]$ > 40 nmol/L) ACIDOSIS
- pH > 7.40 ($[H^+]$ < 40 nmol/L) ALKALOSIS
- Changes in $[H^+]$ can be due to changes in either the Respiratory or the Metabolic component of the Bicarbonate Buffering system
- Acidosis or Alkalosis – Respiratory or Metabolic


Metabolic
Acidosis
Alkalosis
Respiratory
Acidosis
Alkalosis

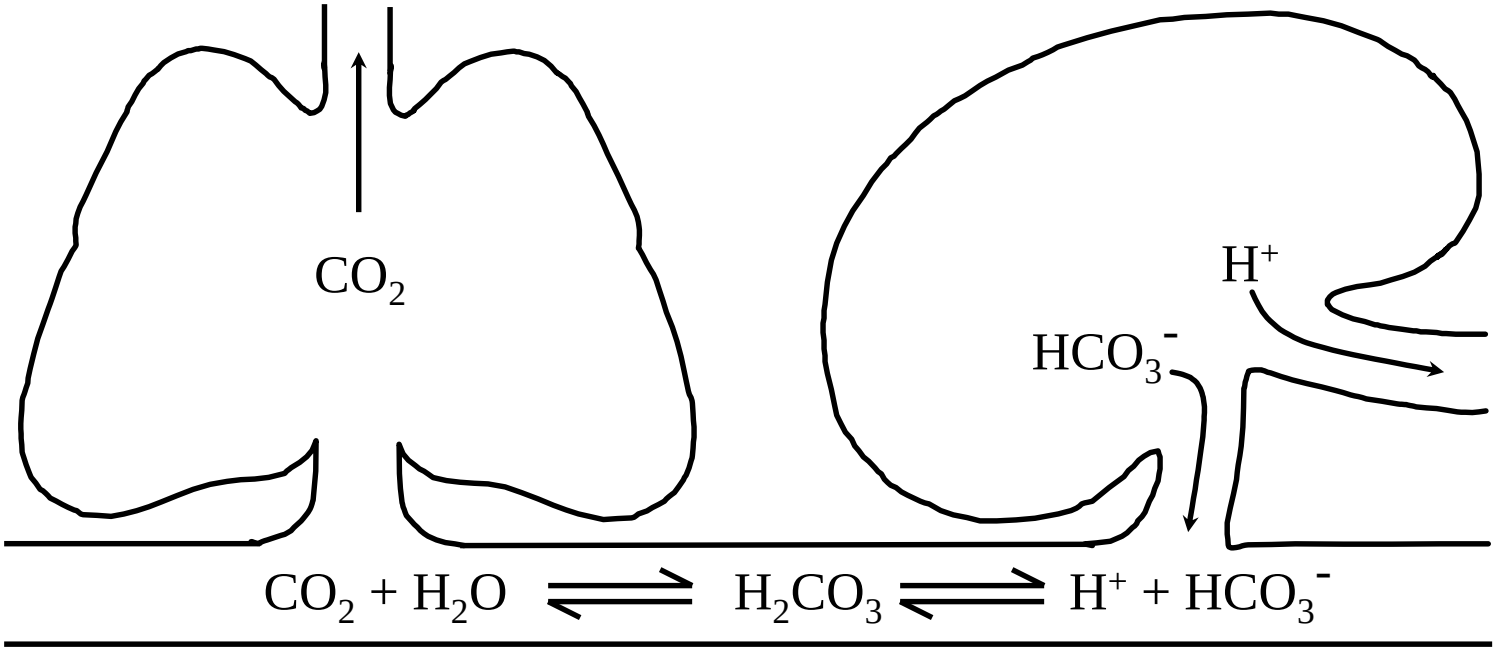
- CO_2 is the RESPIRATORY component
- Changes in lung function will increase or decrease the amount of CO_2 removed from the blood.



- H^+ is excreted by the kidney
- HCO_3^- is saved/regenerated by the kidney. This is the METABOLIC component
- Changes in kidney function will increase or decrease excretion and regeneration of these ions.



Metabolic Acidosis



Problem:
Excess $[H^+]$ ions.
Low $[HCO_3^-]$.

Metabolic Acidosis

- Increased production of hydrogen ions
  - due to metabolic production of acids or acid ingestion
    - Lactic acidosis, Diabetic Ketoacidosis, poisoning (methanol, ethylene glycol, salicylate)
- Decreased excretion of hydrogen ions
  - Renal failure – inability to excrete acids of metabolism
- Loss of bicarbonate

Lactic Acidosis

- Reduced delivery of O_2 to the cells means that oxidative metabolism is reduced
- Tissue hypoxia
- Pyruvate produced from glycolysis cannot enter Kreb's Cycle
- Pyruvic acid converted to lactic acid.
- Increased [lactic acid] results in lactic acidosis

Causes of lactic acidosis

Tissue hypoxia
decreased perfusion
reduced arterial PO_2

Drugs, etc.
ethanol, methanol
phenformin
fructose, sorbitol

Congenital
glucose 6-phosphatase deficiency
other inherited diseases with defective gluconeogenesis or pyruvate oxidation

Diabetic Ketoacidosis

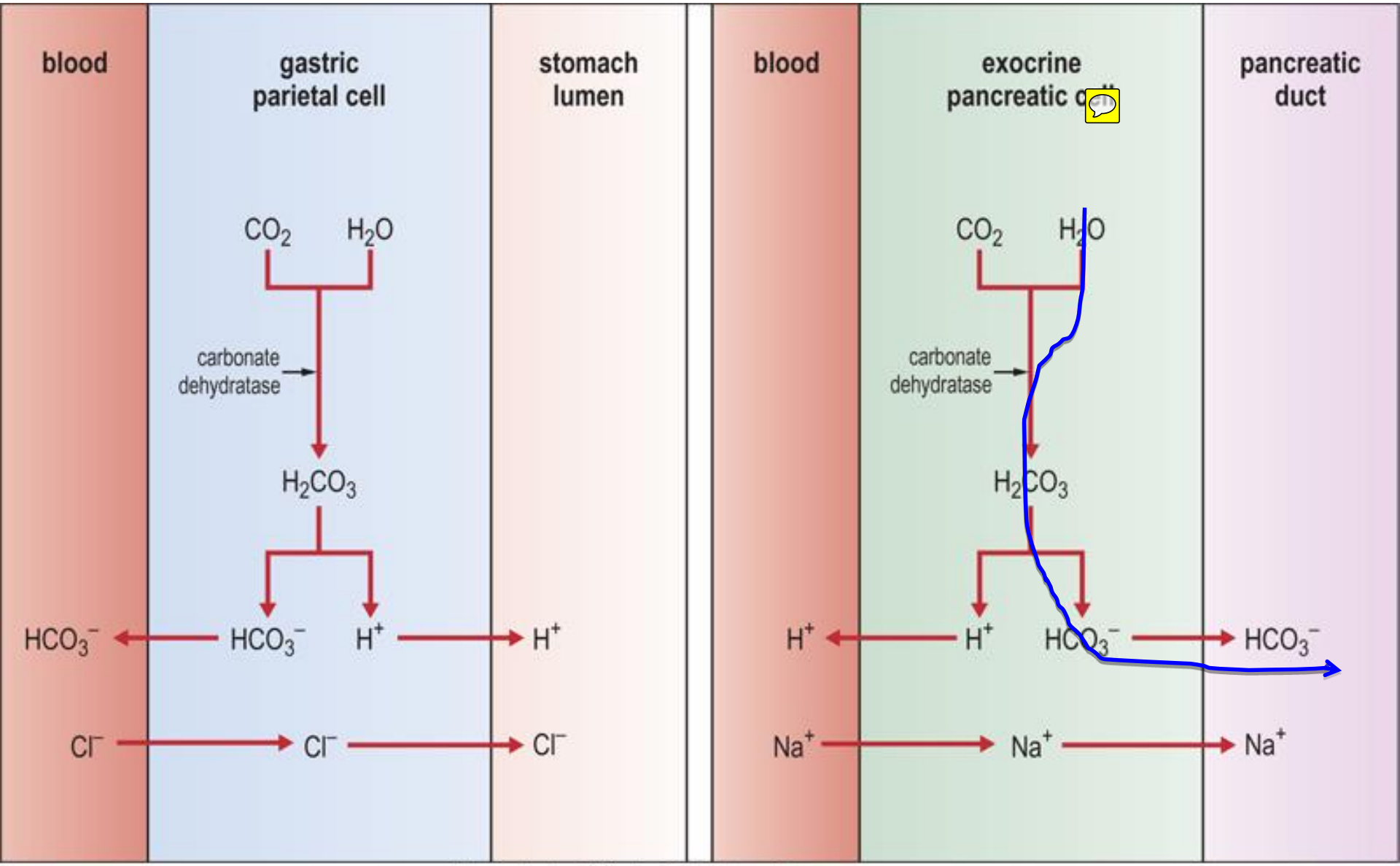
- In uncontrolled Type 1 diabetes – lack of insulin
- Extreme breakdown of Fatty Acids to Acetyl-CoA
- Acetyl CoA cannot enter Krebs Cycle
- Converted to Keto acids acetoacetic acid and β hydroxy butyric acid.
- Reestablishment of insulin metabolism will correct the problem

Poisoning

- Methanol metabolized to formaldehyde and formic acid
- Ethylene glycol metabolized to glycolic acid and oxalic acid
- Salicylate (Asprin) - an acid in itself, but major problem is uncoupling of glycolysis from oxidative phosphorylation. Leads to lactic acidosis

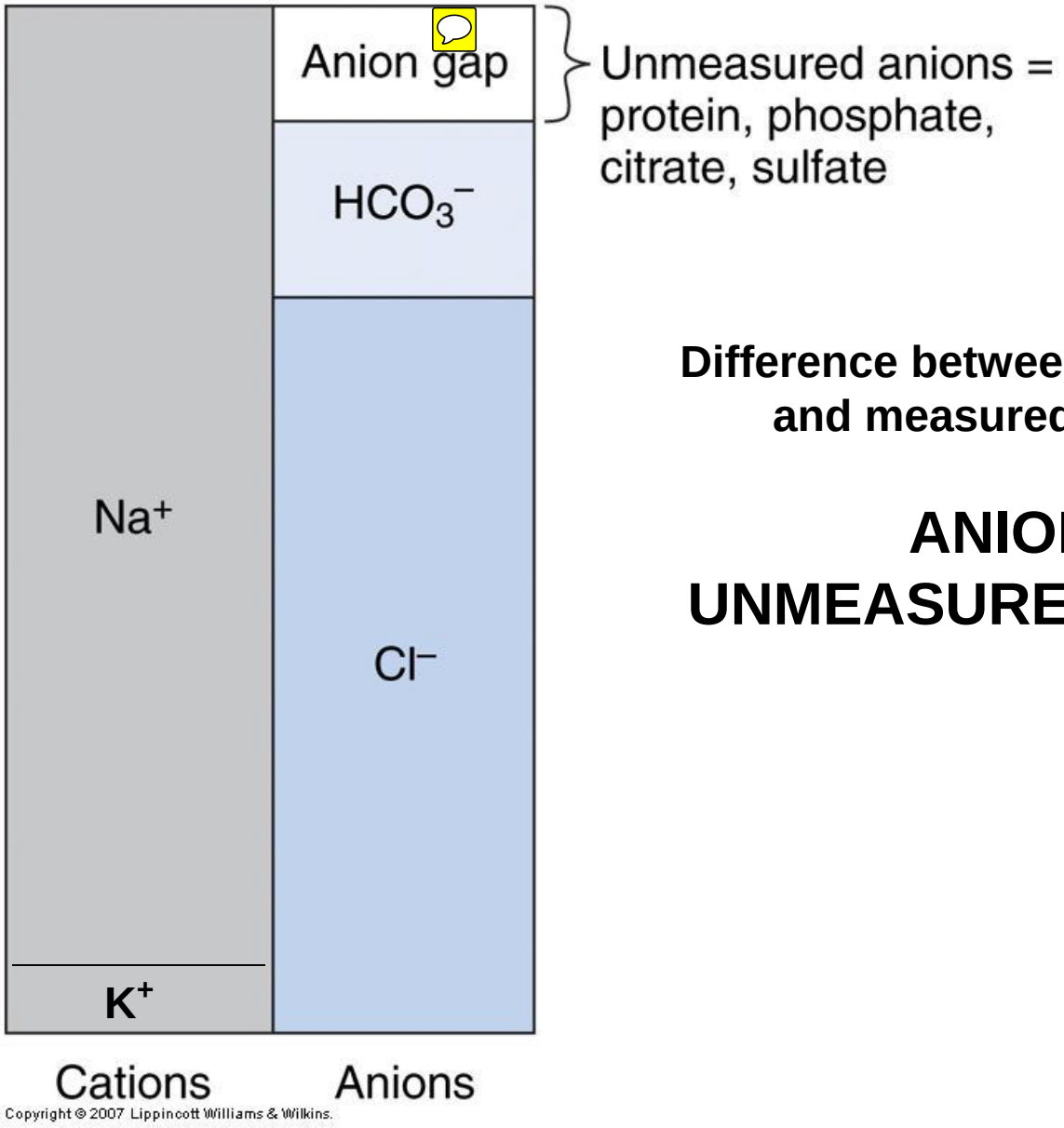
- Renal Failure -
  - loss of ability to excrete hydrogen ions due to glomerular failure
  - reduced Na in urine to exchange with H^+ and/or reduced phosphate in urine to buffer H^+
  - Reduced carbonic anhydrase activity

- Extreme diarrhea
  - Intestinal secretions are rich in bicarbonate. Excess loss of bicarb will result in metabolic acidosis.



The Anion Gap

- Electrochemical neutrality must be maintained at all times
- Total [anions] must = total [cations]
- Major cations – Na^+, K^+
- Major anions – Cl^-, HCO_3, (and $protein^-$)
- We measure everything but the $protein^-$



Difference between measured Anions and measured Cations is the

ANION GAP
UNMEASURED ANION GAP

- Anion gap = ([Na] + [K]) – ([Cl] + [HCO_3])
- Normally equals 14-18 mmol/L.
- Represents mainly the net negative charge on proteins.
- When hydrogen ion production is increased, there is an accompanying anion produced. If this anion is not Chloride – then the anion gap will be increased.

- Lactic acidosis – anion is lactate
- Ketoacidosis – anions - β hydroxybutyrate and acetoacetate
- AN INCREASED ANION GAP IS DIAGNOSTIC OF METABOLIC ACIDOSIS

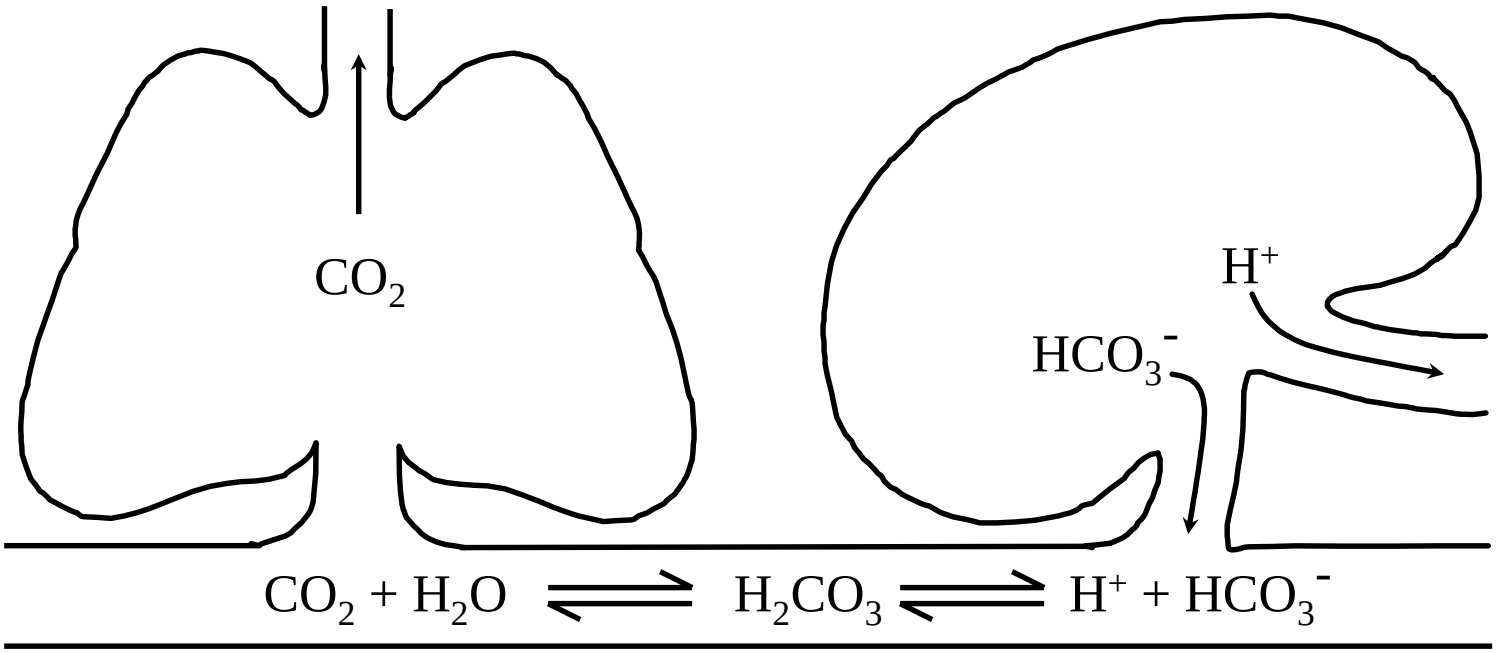
How does the body compensate for metabolic Acidosis?

- Increased [H^+] can be compensated for by reducing the pCO_2
- Hyperventilation will reduce the pCO_2 and pull the equilibrium in a direction to reduce [H^+]

Treatment

- Treat the underlying cause
- In extreme cases, bicarbonate may be given to try to buffer the H^+ and raise the pH

Metabolic Acidosis – Compensation



Response:
Hyperventilation
Decrease [CO_2]

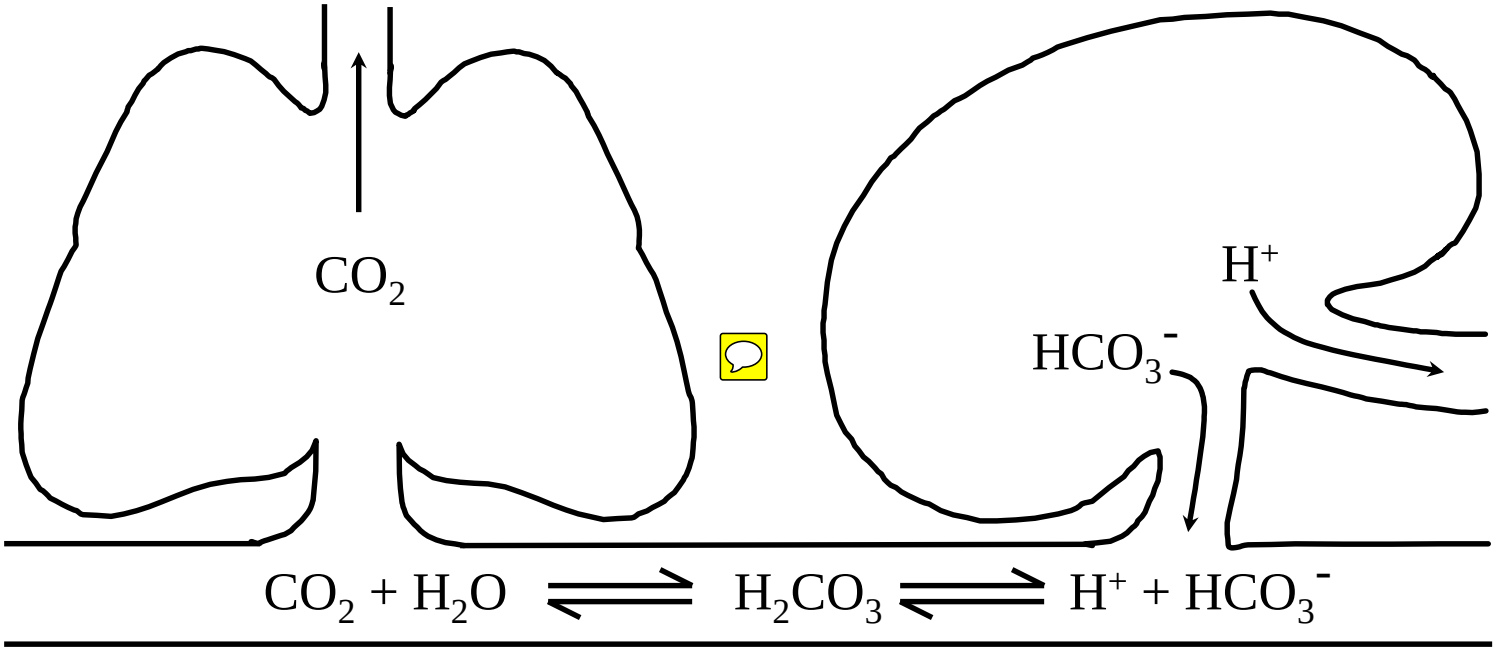
Problem:
Excess [H^+] ions.
Low [HCO_3^-].

Decrease
[H^+]

Respiratory Acidosis

- Failure to remove CO_2 at the lungs results in increased pCO_2 and increased $[H^+]$
- Causes
  - Airway obstruction (can't breathe)
  - Failure of respiratory muscles (can't breathe)
  - Depressed respiratory drive (won't breathe)
    - Sedatives, anaesthetics, trauma
  - Pulmonary disease that limits gas exchange

Respiratory Acidosis



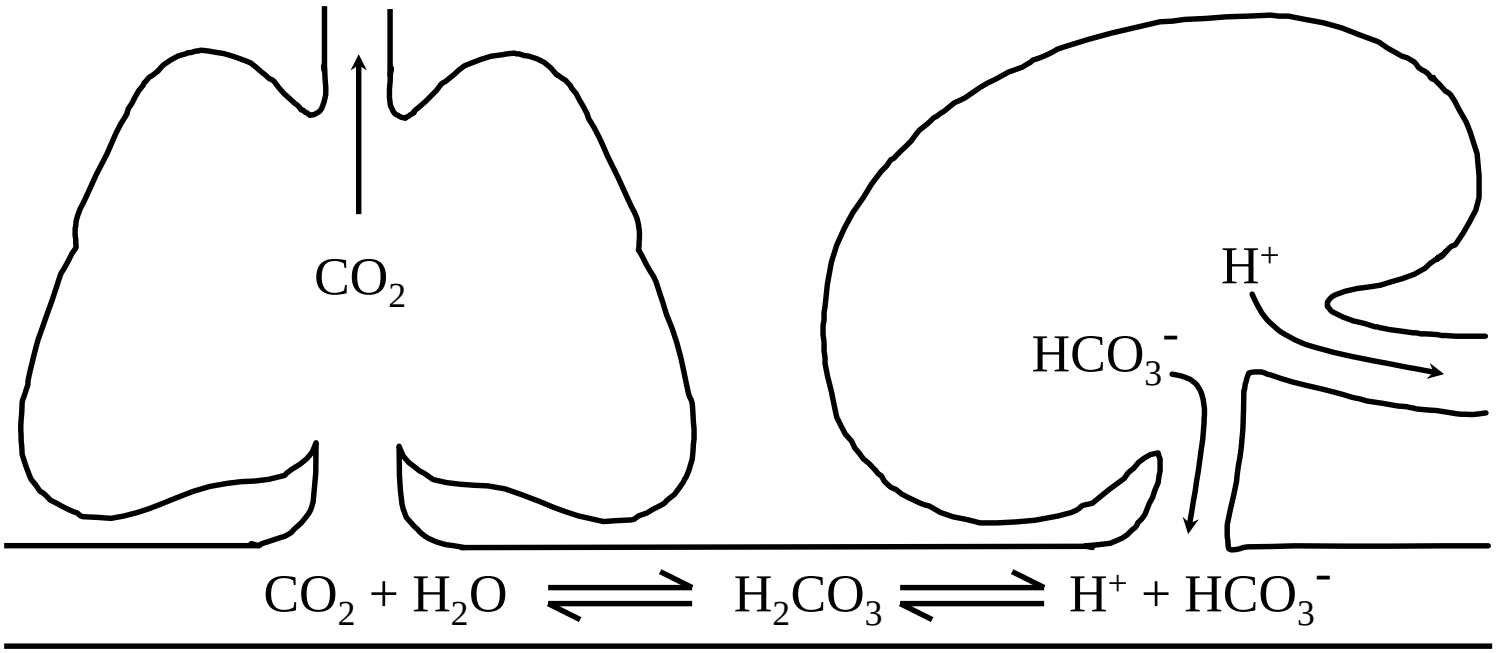
Problem:
Hypoventilation
High PCO_2
High $[H^+]$

Respiratory Acidosis Compensation and Treatment

- Increased pCO_2 can be compensated for by increasing bicarbonate production and increasing renal excretion of H^+
- Renal compensation for respiratory acidosis is slow (days to week)

- Treatment – improve gas exchange in the lungs

Respiratory Acidosis Compensation

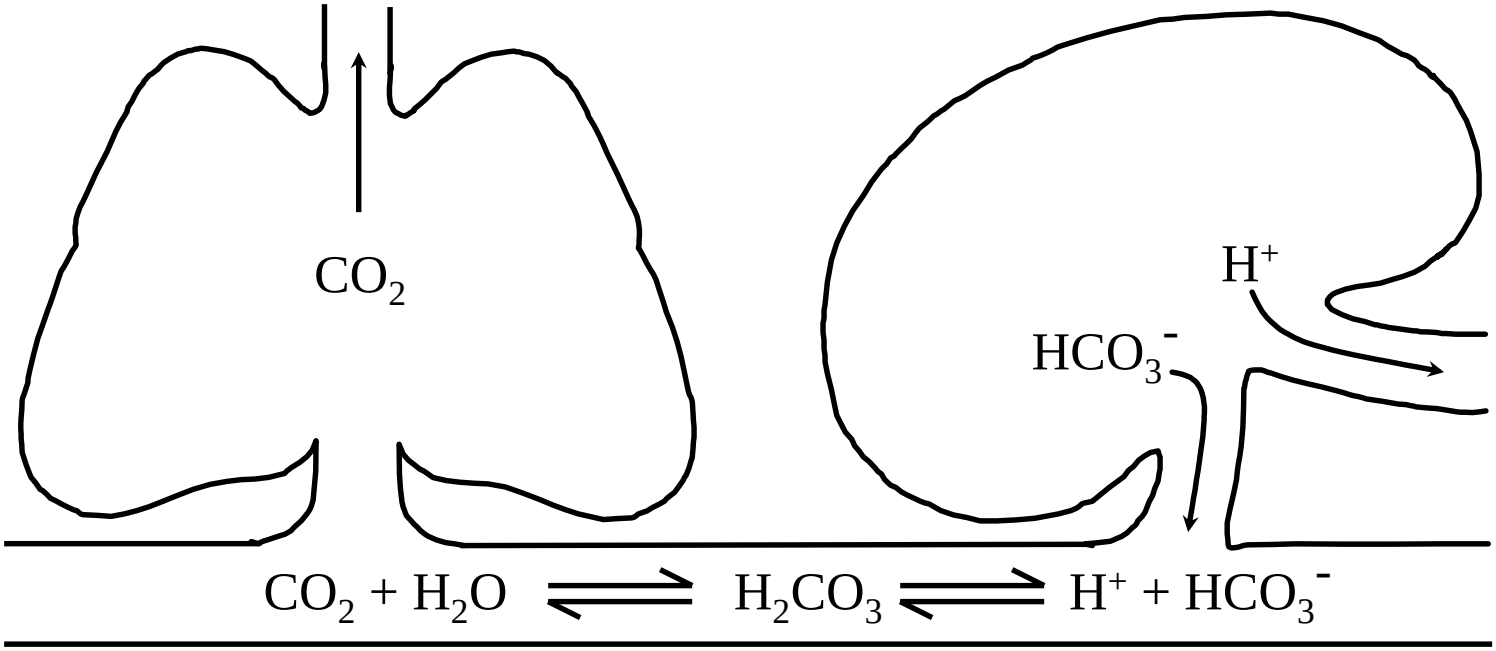


Problem:
Hypoventilation
High PCO_2
High $[H^+]$

Decrease $[H^+]$

Response:
Increase H^+ excretion.
Increase HCO_3^- production.

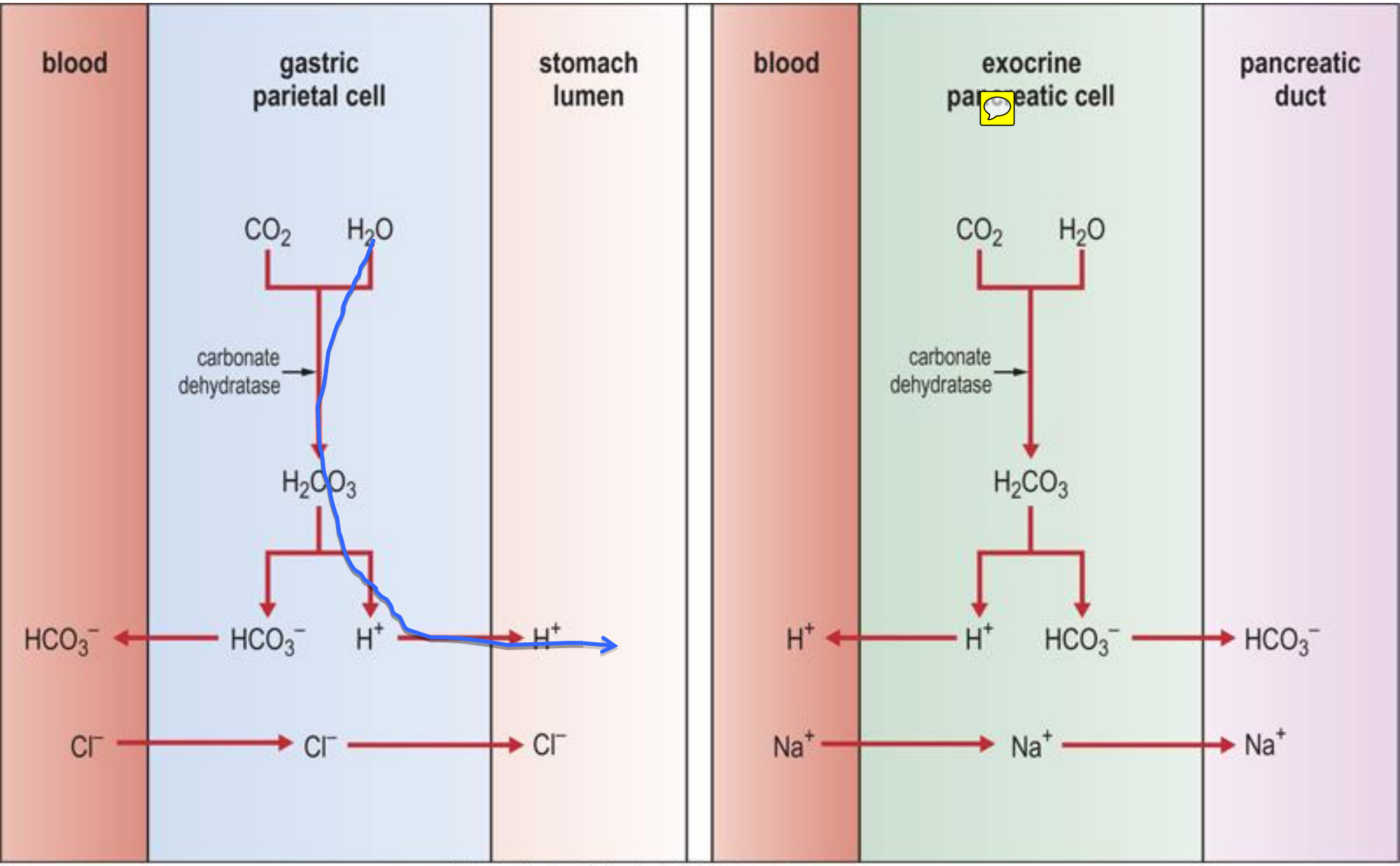
Metabolic Alkalosis



Problem:
Loss of H^+ ions.
High $[HCO_3^-]$.

Metabolic Alkalosis

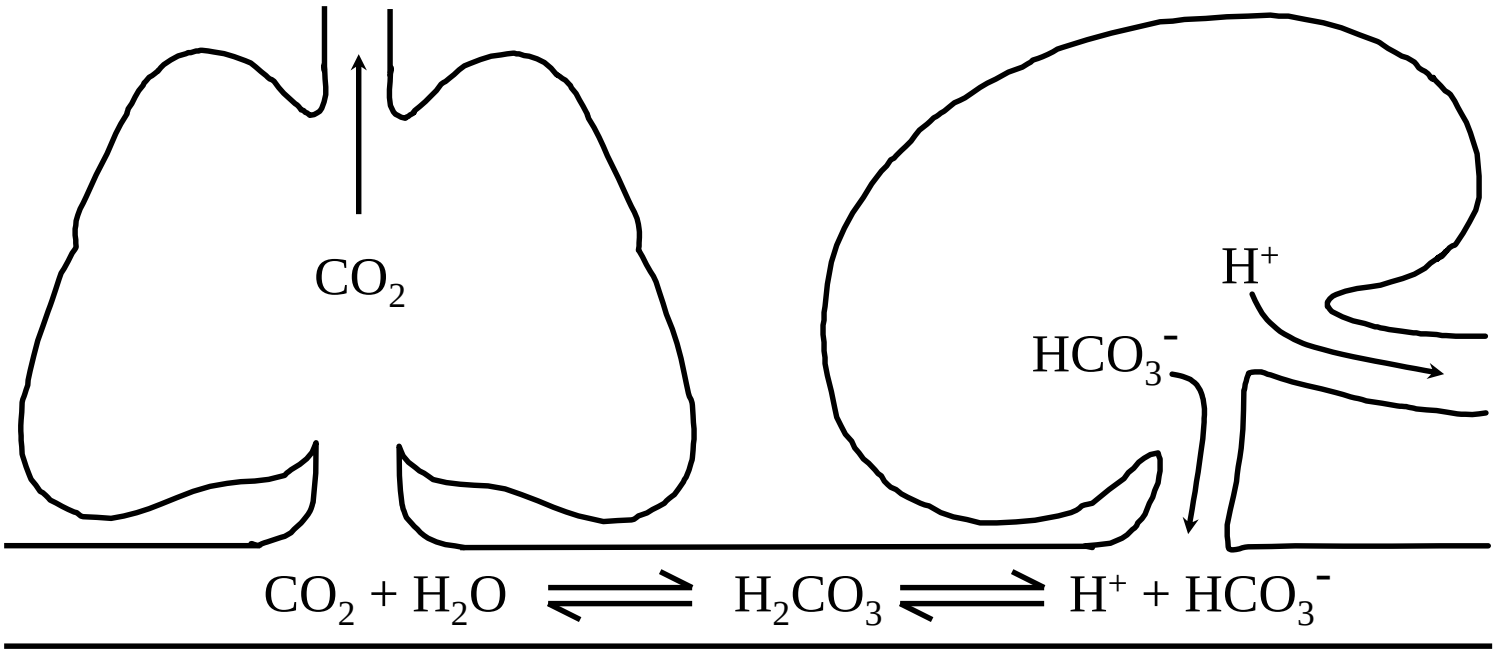
- Related to volume depletion and chloride loss
  - Loss of hydrogen ion through loss of gastric acid (HCl^-) – aspiration, vomiting
- Related to K^+ depletion
  - Loss of intracellular K^+, H^+ move into cells, extracellular alkalosis
  - Reduced K^+, H^+ exchanges for Na in distal tubule
    - Exacerbated by increased aldosterone



How does the Body Compensate for Metabolic Alkalosis?

- Increasing pCO_2 will increase the hydrogen ion concentration
- Hypoventilation will reduce gas exchange and increase pCO_2
- Problem here – hypoventilation will also reduce oxygen availability

Metabolic Alkalosis - Compensation

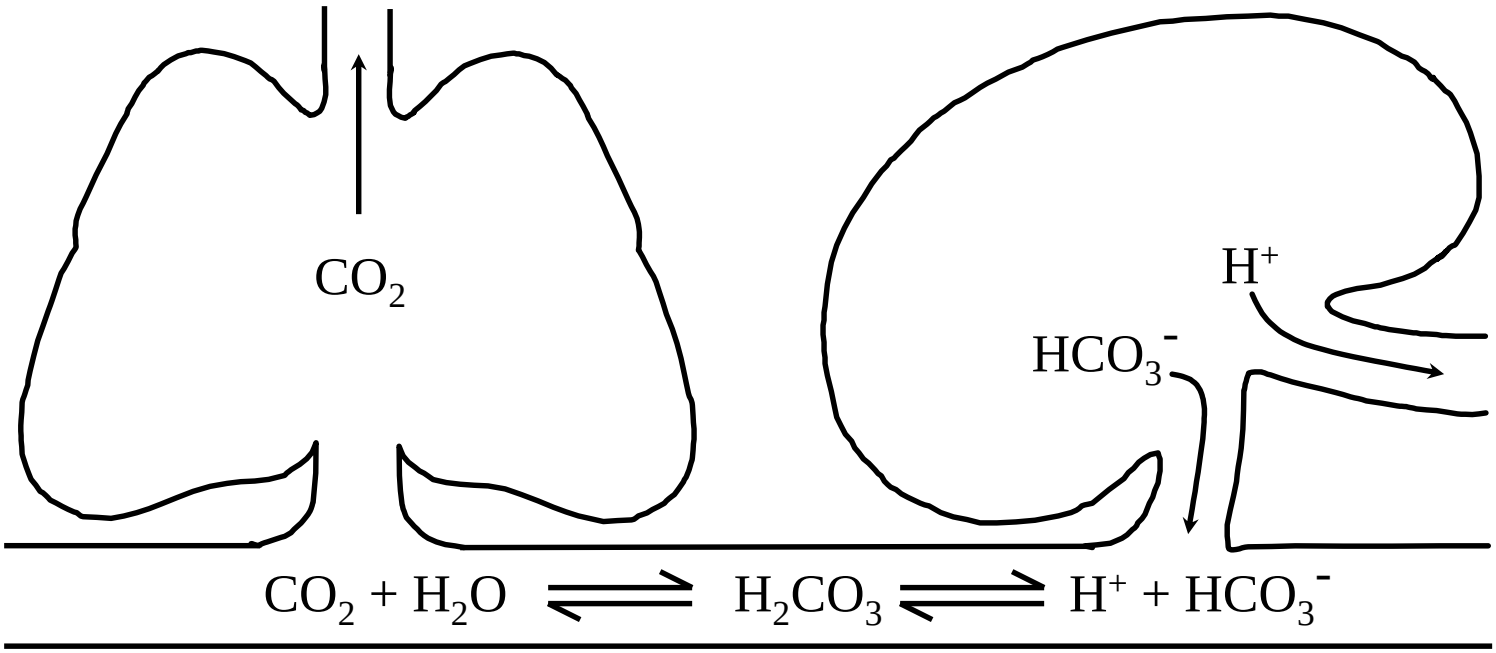


Response:
Hypoventilation
Increase [CO_2]

Problem:
Loss of H^+ ions.
High [HCO_3^-].

Increase
[H^+]

Respiratory Alkalosis



Problem:
Hyperventilation
Low PCO_2
Low $[H^+]$

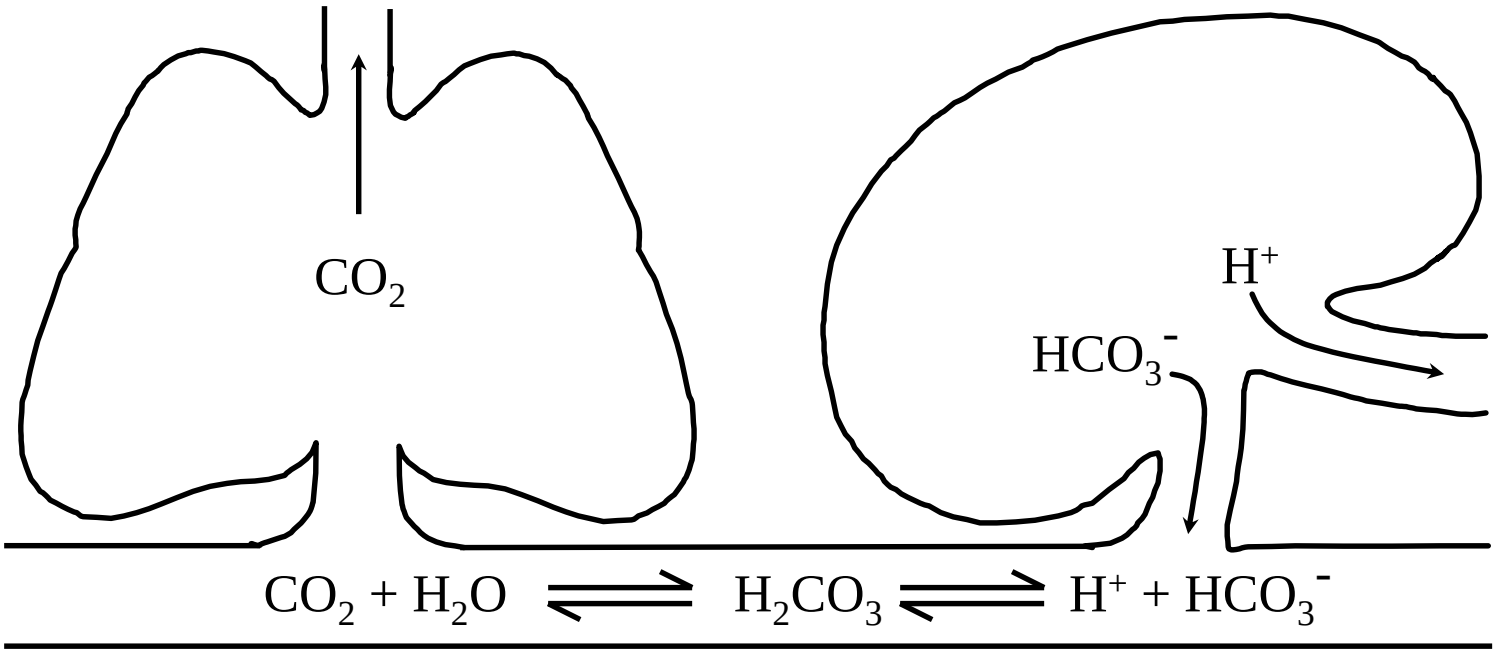
Respiratory Alkalosis

- Reduced pCO_2 leads to reduced $[H^+]$
- Increased respiratory drive due to hypoxia
  - High altitude
  - Severe anemia
  - Pulmonary disease
- Cerebral disturbances
- Respiratory Stimulants (salicylate)
- Voluntary hyperventilation
- Mechanical Hyperventilation

Respiratory Alkalosis - Compensation

- Decrease renal excretion of hydrogen ion and decrease renal production of bicarbonate

Respiratory Alkalosis



Problem:
Hyperventilation
Low PCO_2
Low $[H^+]$

Increase
$[H^+]$

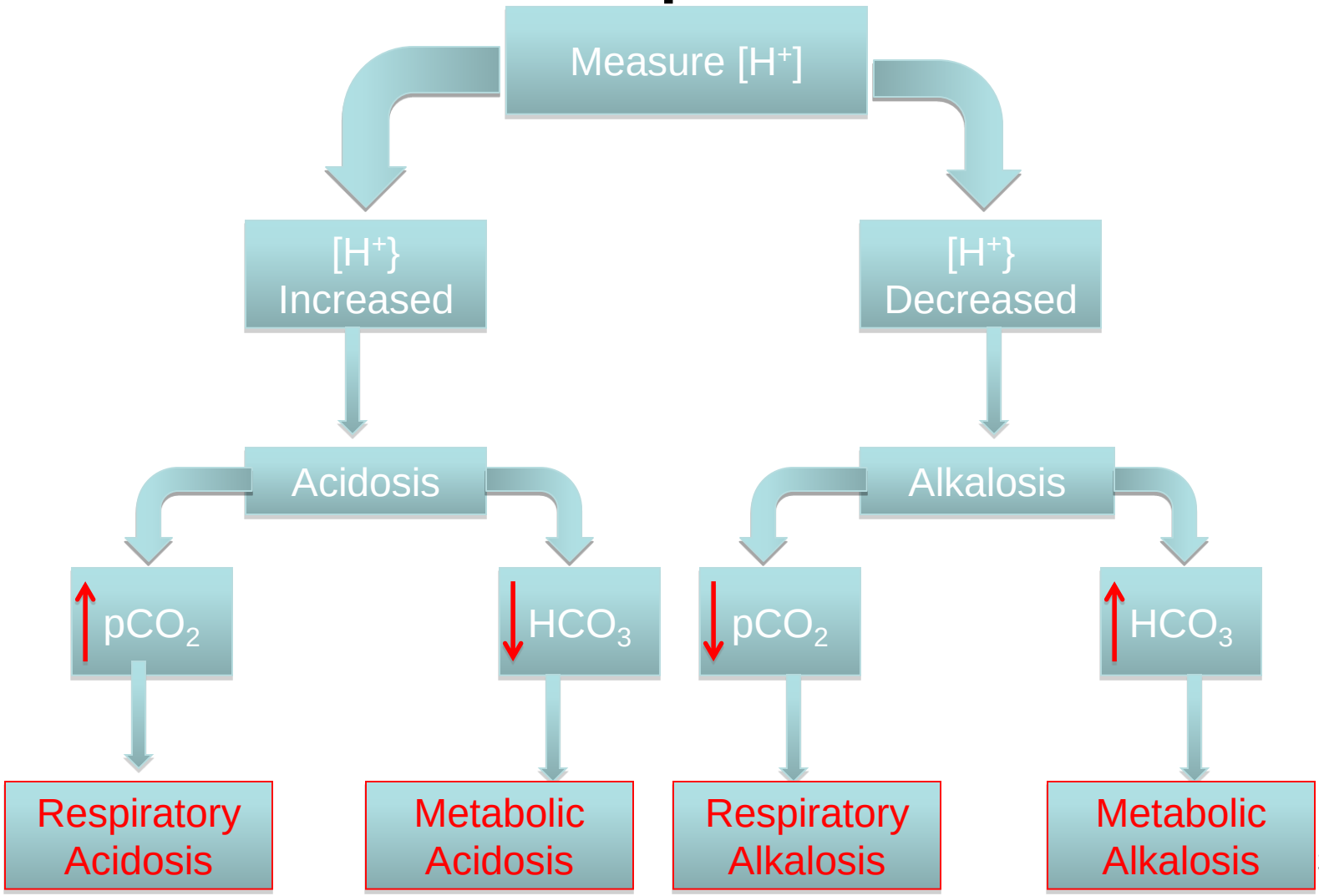
Response:
Decrease H^+
excretion.
Decrease HCO_3^-
production.

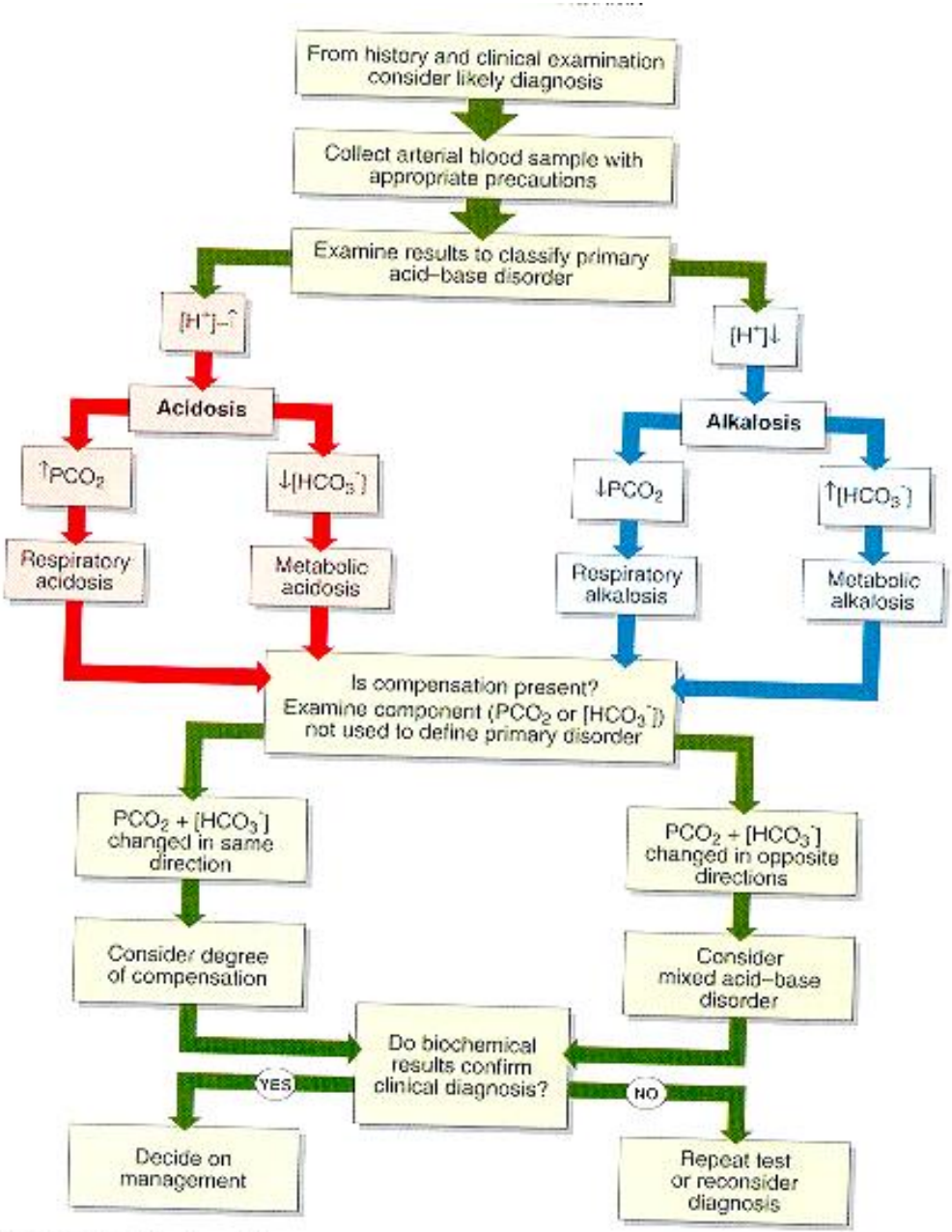
Summary

- Metabolic Acidosis is compensated for by respiratory alkalosis
- Respiratory Acidosis is compensated for by metabolic alkalosis
- Metabolic Alkalosis is compensated for by respiratory acidosis
- Respiratory Alkalosis is compensated for by metabolic acidosis

- Respiratory compensation is quick (hours) but can seldom completely compensate
  - pH does not return all the way to 7.40
- Metabolic compensation is slow (days) but given enough time will compensate almost all the way back to pH 7.40

Simplified Algorithm for Blood Gas Interpretation





2 Acid–base disorders: diagnosis and management.