Acid and Base Balance and Imbalance

pH Review

- $pH = - \log [H^+]$
- H^+ is really a proton
- Range is from 0 - 14
- If $[H^+]$ is high, the solution is acidic; $pH < 7$
- If $[H^+]$ is low, the solution is basic or alkaline ; $pH > 7$

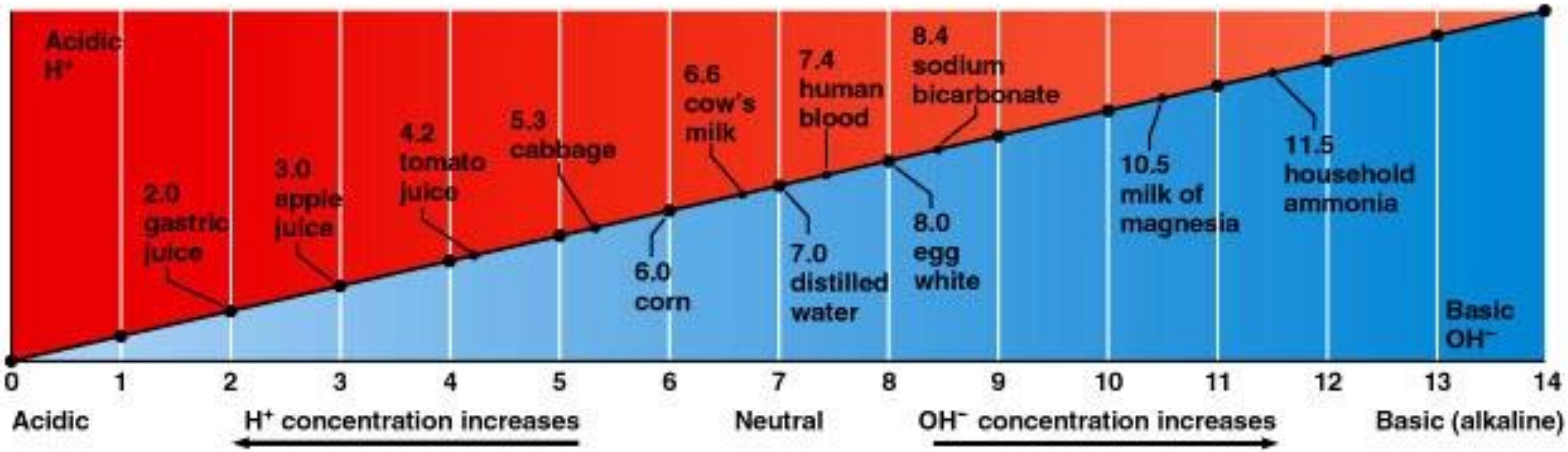


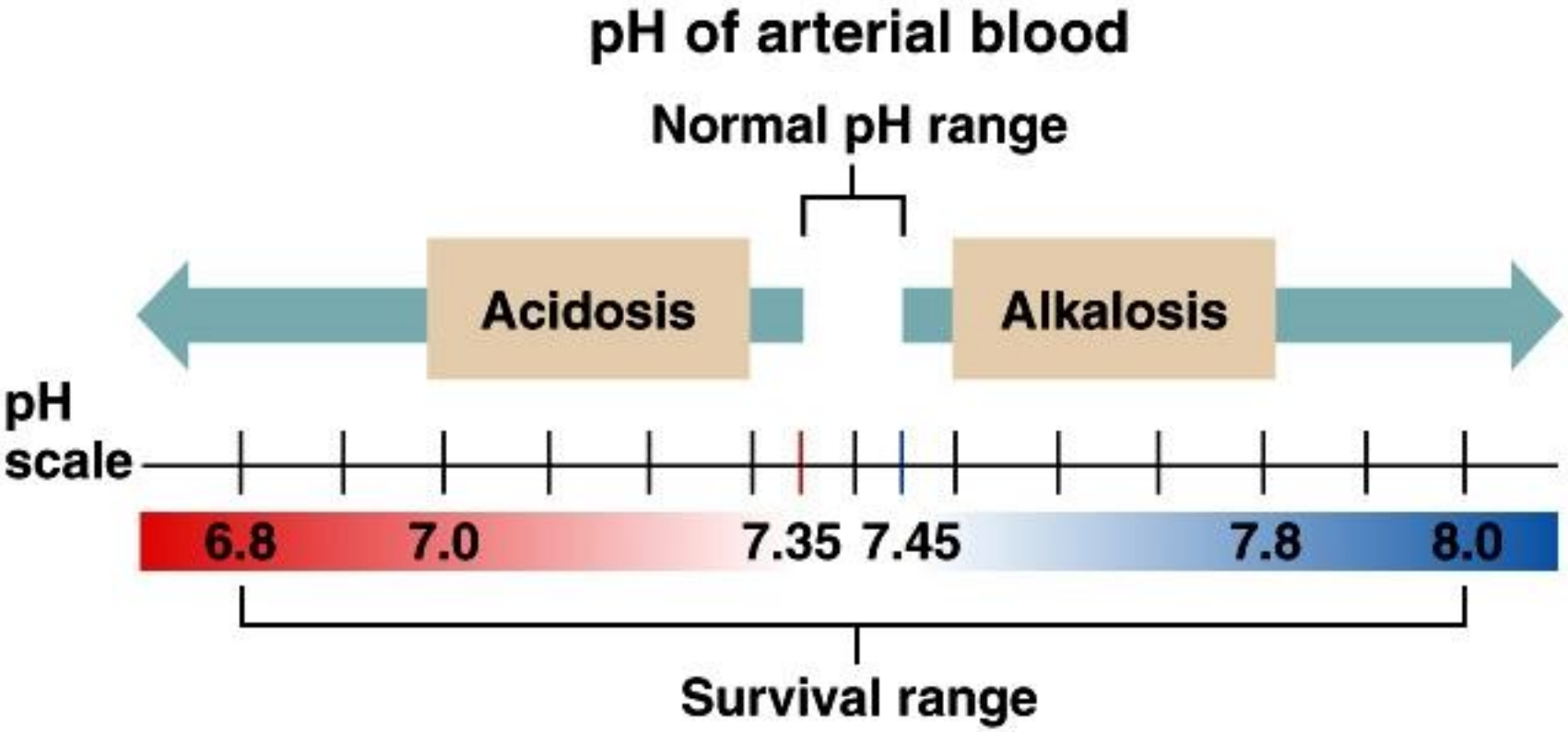
table 2.5 Hydrogen Ion Concentrations and pH

Grams of H^+ per Liter	pH	
0.00000000000001	14	↑
0.0000000000001	13	
0.000000000001	12	Increasingly basic
0.00000000001	11	
0.0000000001	10	
0.000000001	9	
0.00000001	8	
0.0000001	7	Neutral–neither acidic nor basic
0.000001	6	
0.00001	5	
0.0001	4	
0.001	3	
0.01	2	Increasingly acidic
0.1	1	
1.0	0	↓

- Acids are H^+ donors.
- Bases are H^+ acceptors, or give up OH^- in solution.
- Acids and bases can be:
  - Strong – dissociate completely in solution
    - HCl, NaOH
  - Weak – dissociate only partially in solution
    - Lactic acid, carbonic acid

The Body and pH

- Homeostasis of pH is tightly controlled
- Extracellular fluid = 7.4
- Blood = 7.35 – 7.45
- < 6.8 or > 8.0 death occurs
- Acidosis (acidemia) below 7.35
- Alkalosis (alkalemia) above 7.45



Small changes in pH can produce major disturbances

- Most enzymes function only with narrow pH ranges
- Acid-base balance can also affect electrolytes (Na^+, K^+, Cl^-)
- Can also affect hormones

The body produces more acids than bases

- Acids take in with foods
- Acids produced by metabolism of lipids and proteins
- Cellular metabolism produces CO_2.
- $CO_2 + H_20 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

Control of Acids

1. Buffer systems

   Take up H+ or release H+ as conditions change

   Buffer pairs – weak acid and a base

   Exchange a strong acid or base for a weak one

   Results in a much smaller pH change

Bicarbonate buffer

- Sodium Bicarbonate ($NaHCO_3$) and carbonic acid (H_2CO_3)
- Maintain a 20:1 ratio : HCO_3^- : H_2CO_3

$$HCl + NaHCO_3 \leftrightarrow H_2CO_3 + NaCl$$

$$NaOH + H_2CO_3 \leftrightarrow NaHCO_3 + H_2O$$

Phosphate buffer

- Major intracellular buffer
- $H^+ + HPO_4^{2-} \leftrightarrow H_2PO4^-$
- $OH^- + H_2PO_4^- \leftrightarrow H_2O + H_2PO_4^{2-}$

Protein Buffers

- Includes hemoglobin, work in blood and ISF
- Carboxyl group gives up H^+
- Amino Group accepts H^+
- Side chains that can buffer H^+ are present on 27 amino acids.

2. Respiratory mechanisms

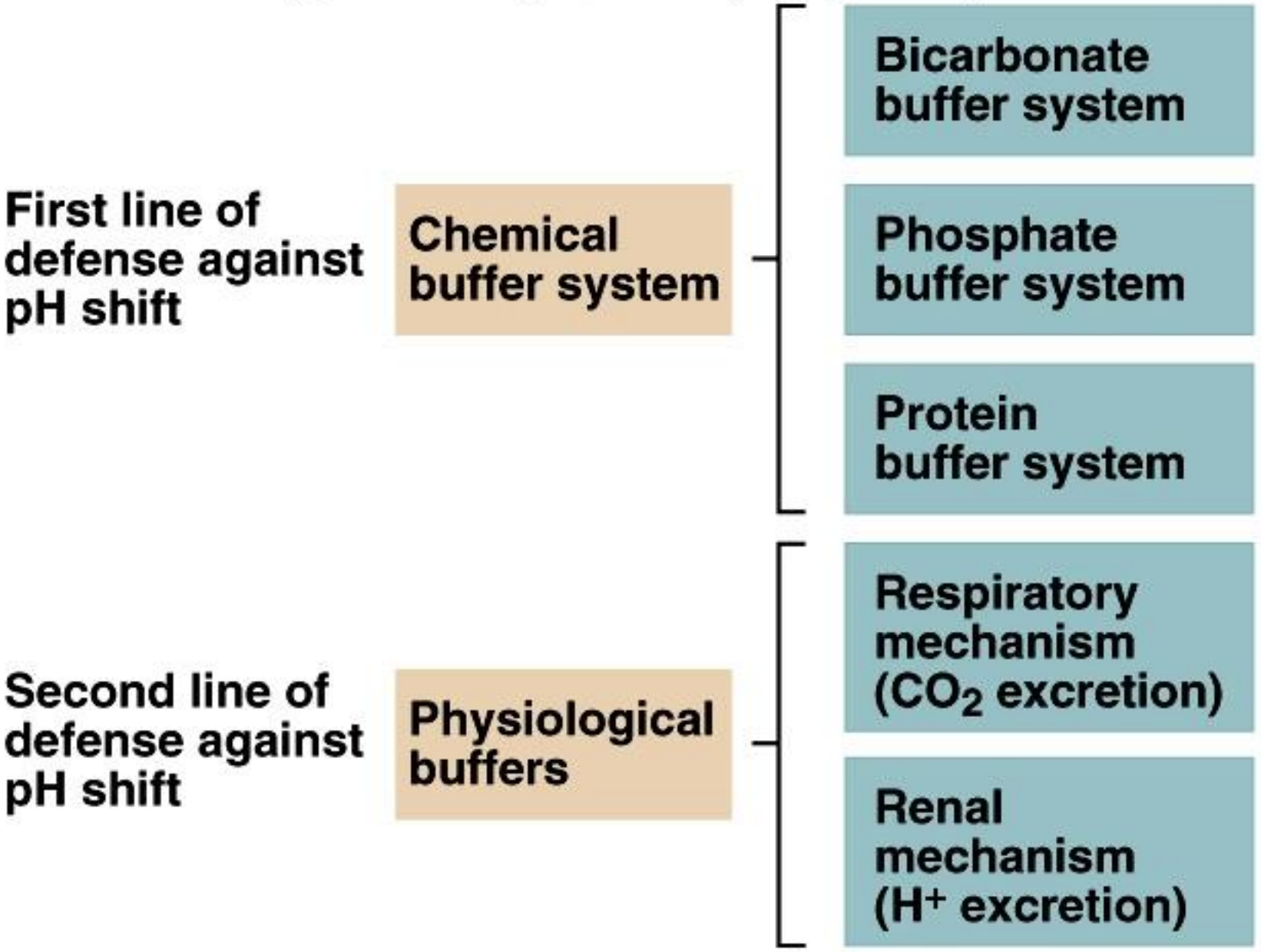
- Exhalation of carbon dioxide
- Powerful, but only works with **volatile acids**
- Doesn't affect **fixed acids** like lactic acid
- $CO_2 + H_20 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
- Body pH can be adjusted by changing rate and depth of breathing

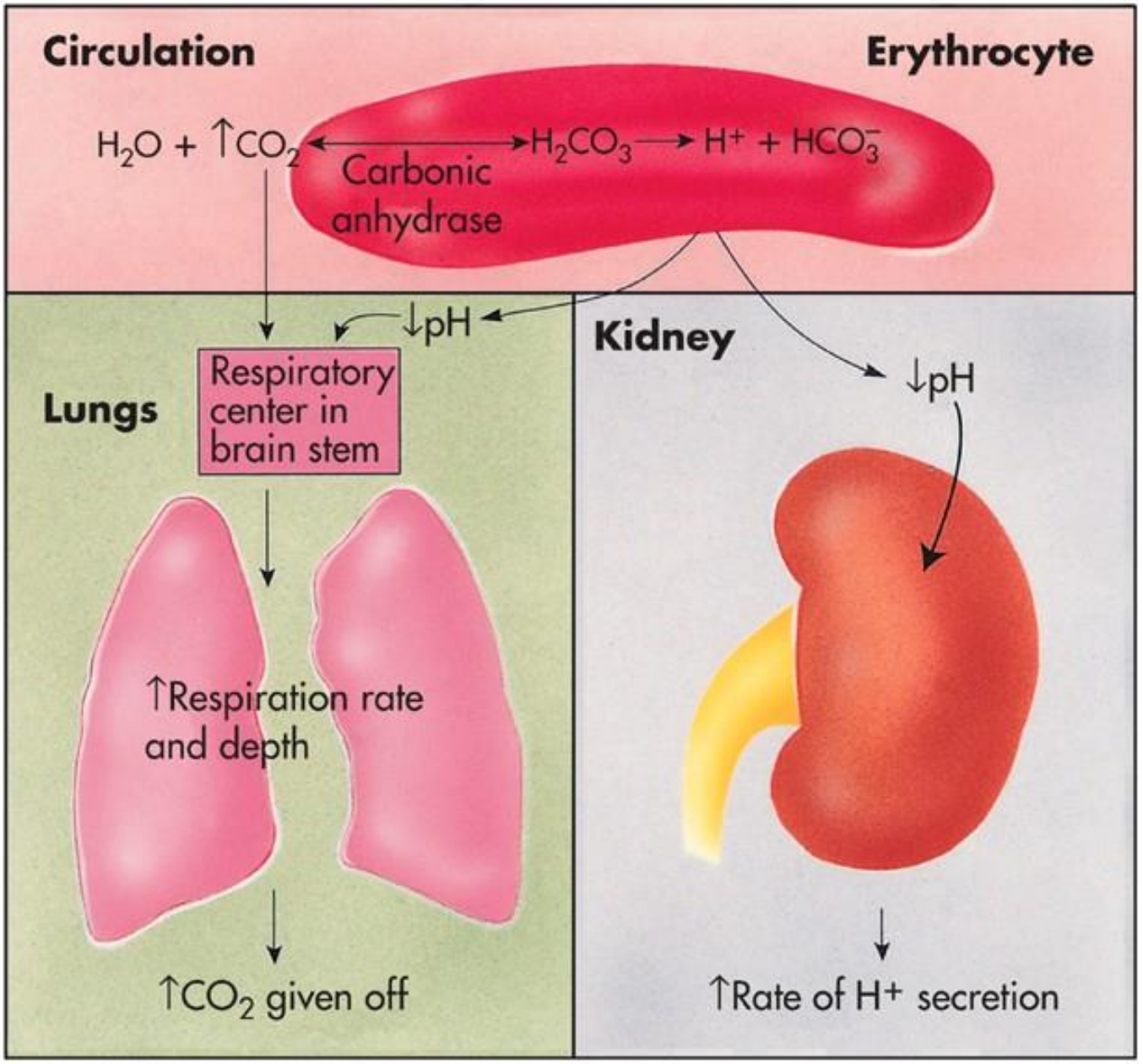
3. Kidney excretion

- Can eliminate large amounts of acid
- Can also excrete base
- Can conserve and produce bicarb ions
- Most effective regulator of pH
- If kidneys fail, pH balance fails

Rates of correction

- Buffers function almost instantaneously
- Respiratory mechanisms take several minutes to hours
- Renal mechanisms may take several hours to days





From Thibodeau GA, Patton KT: *Anatomy & physiology,* ed 5, St Louis, 2003, Mosby.

Acid-Base Imbalances

- pH< 7.35 acidosis
- pH > 7.45 alkalosis
- 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 norms.

Compensation

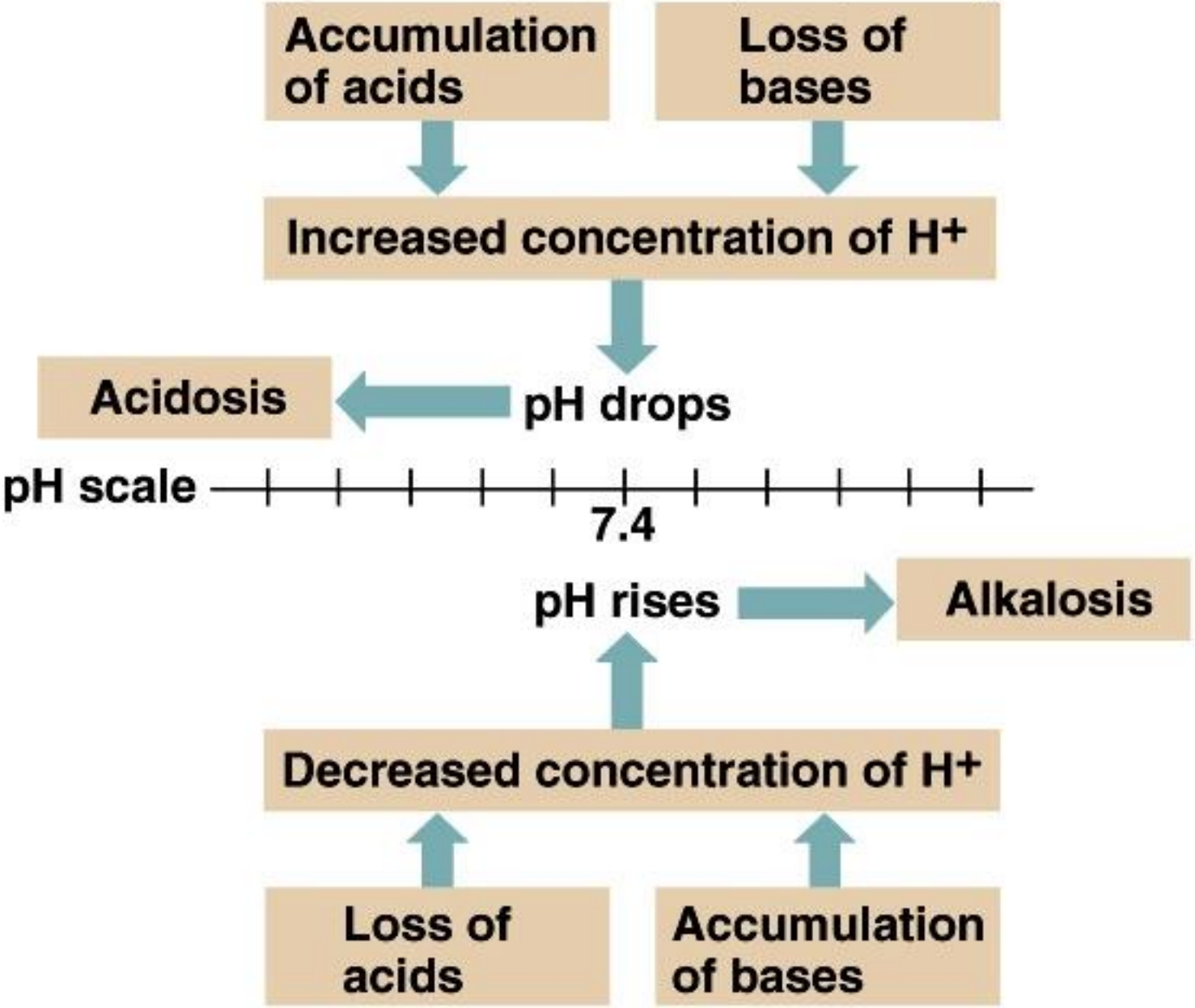
- If underlying problem is metabolic, hyperventilation or hypoventilation can help : **respiratory compensation**.
- If problem is respiratory, renal mechanisms can bring about **metabolic compensation.**

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

Alkalosis

- Alkalosis causes over excitability of the central and peripheral nervous systems.
- Numbness
- Lightheadedness
- It can cause :
  - Nervousness
  - muscle spasms or tetany
  - Convulsions
  - Loss of consciousness
  - Death



Respiratory Acidosis

- **Carbonic acid excess** caused by blood levels of CO_2 above 45 mm Hg.
- **Hypercapnia –** high levels of CO_2 in blood
- Chronic conditions:
  - Depression of respiratory center in brain that controls breathing rate – drugs or head trauma
  - Paralysis of respiratory or chest muscles
  - Emphysema

Respiratory Acidosis

- Acute conditons:
  - Adult Respiratory Distress Syndrome
  - Pulmonary edema
  - Pneumothorax

Compensation for Respiratory Acidosis

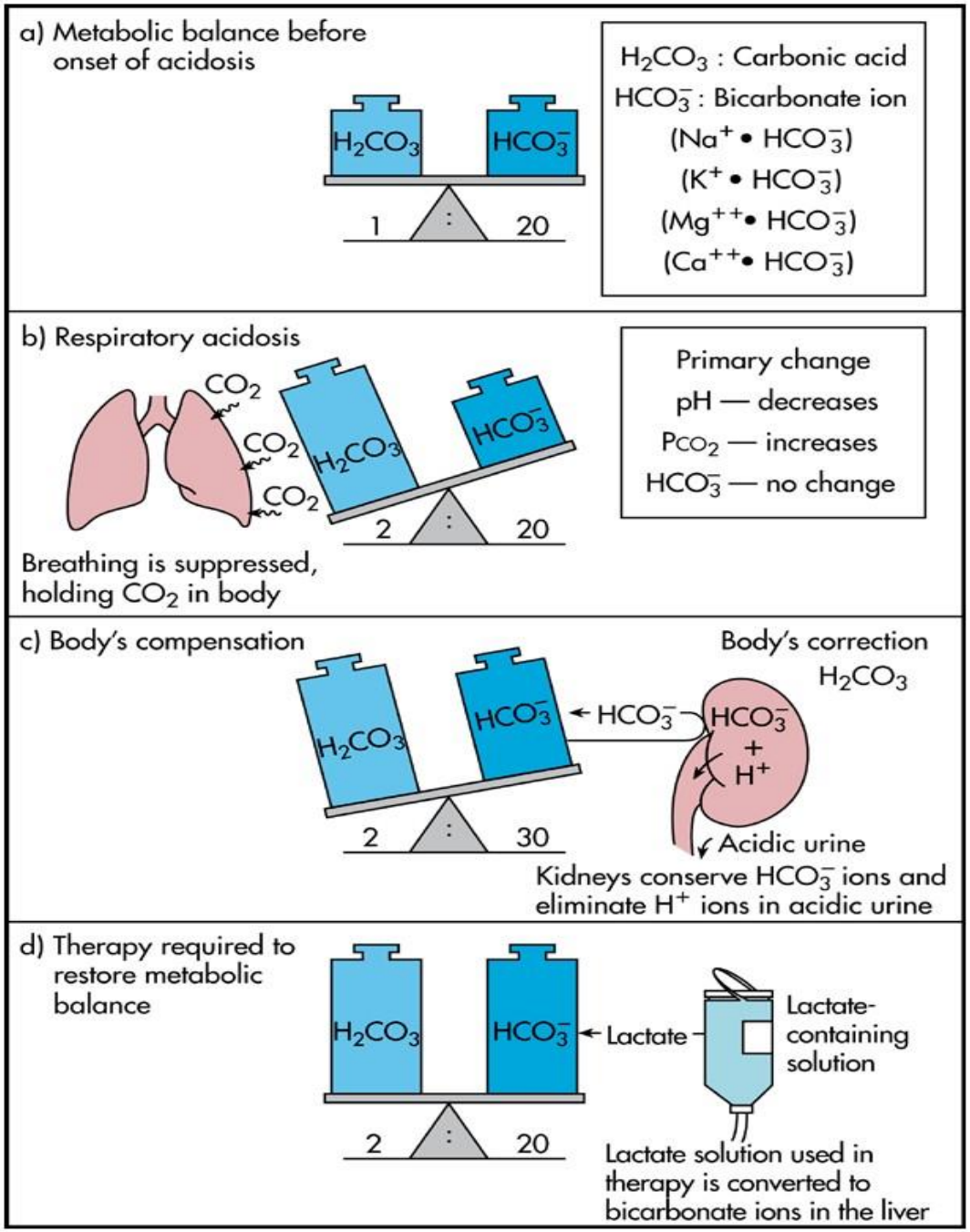
- Kidneys eliminate hydrogen ion and retain bicarbonate ion

Signs and Symptoms of Respiratory Acidosis

- Breathlessness
- Restlessness
- Lethargy and disorientation
- Tremors, convulsions, coma
- Respiratory rate rapid, then gradually depressed
- Skin warm and flushed due to vasodilation caused by excess CO_2

Treatment of Respiratory Acidosis

- Restore ventilation
- IV lactate solution
- Treat underlying dysfunction or disease



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Respiratory Alkalosis

- Carbonic acid deficit
- pCO_2 less than 35 mm Hg (hypocapnea)
- Most common acid-base imbalance
- Primary cause is hyperventilation

Respiratory Alkalosis

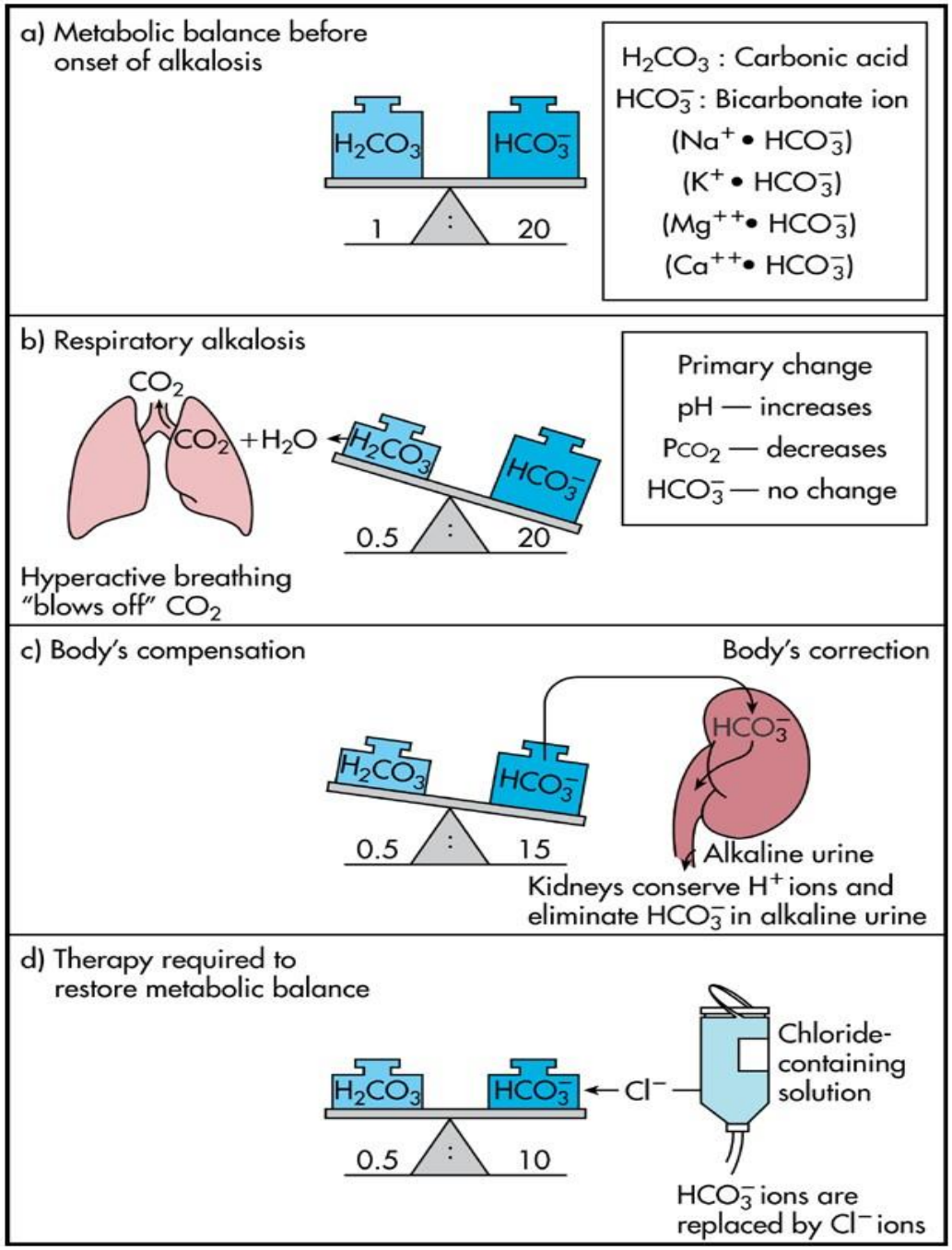
- Conditions that stimulate respiratory center:
  - Oxygen deficiency at high altitudes
  - Pulmonary disease and Congestive heart failure – caused by hypoxia
  - Acute anxiety
  - Fever, anemia
  - Early salicylate intoxication
  - Cirrhosis
  - Gram-negative sepsis

Compensation of Respiratory Alkalosis

- Kidneys conserve hydrogen ion
- Excrete bicarbonate ion

Treatment of Respiratory Alkalosis

- Treat underlying cause
- Breathe into a paper bag
- IV Chloride containing solution – Cl^- ions replace lost bicarbonate ions



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Metabolic Acidosis

- **Bicarbonate deficit** - blood concentrations of bicarb 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+**

Symptoms of Metabolic Acidosis

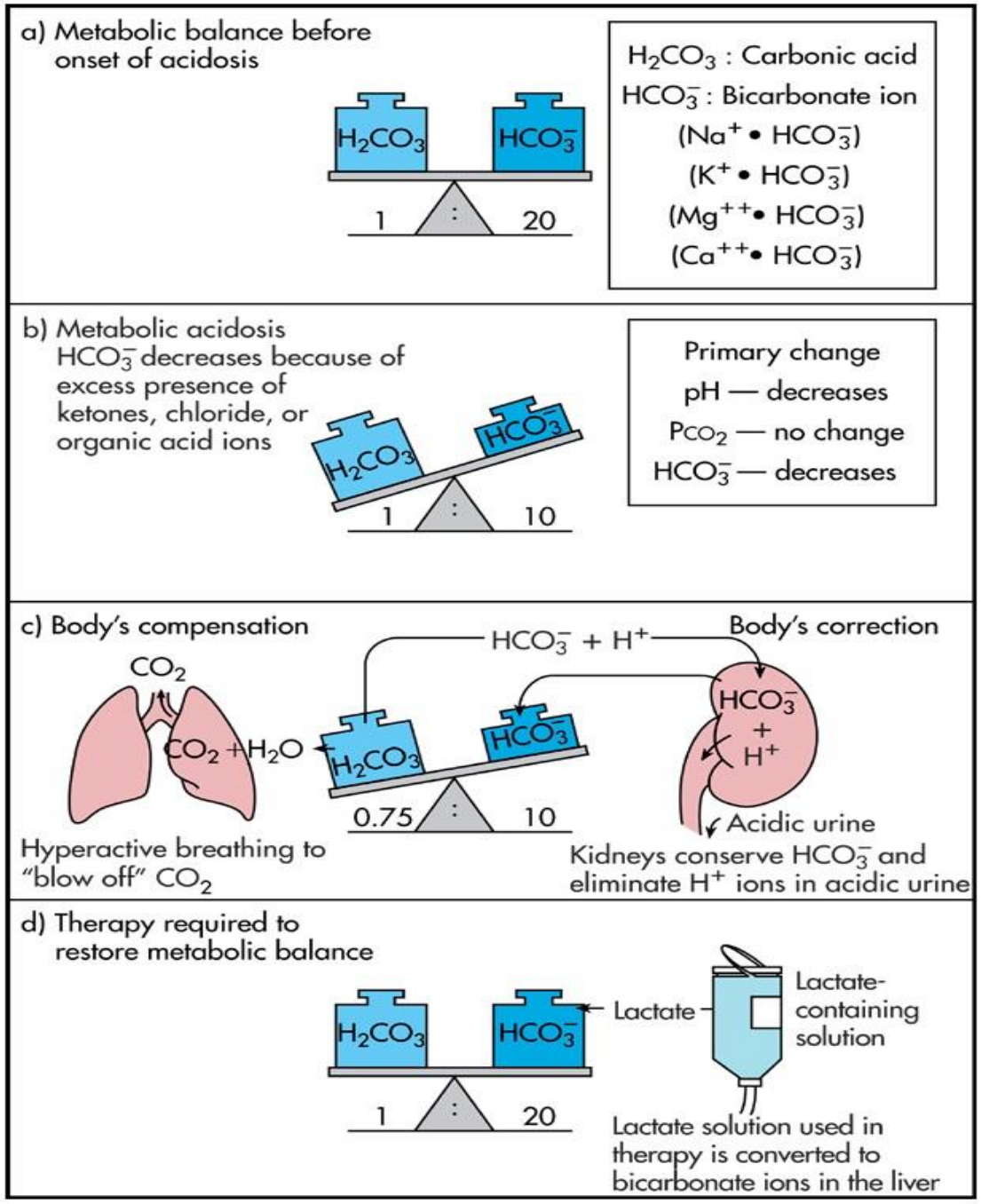
- Headache, lethargy
- Nausea, vomiting, diarrhea
- Coma
- Death

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)

Treatment of Metabolic Acidosis

- IV lactate solution



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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
  - Endocrine disorders
  - Heavy ingestion of antacids
  - Severe dehydration

Compensation for Metabolic Alkalosis

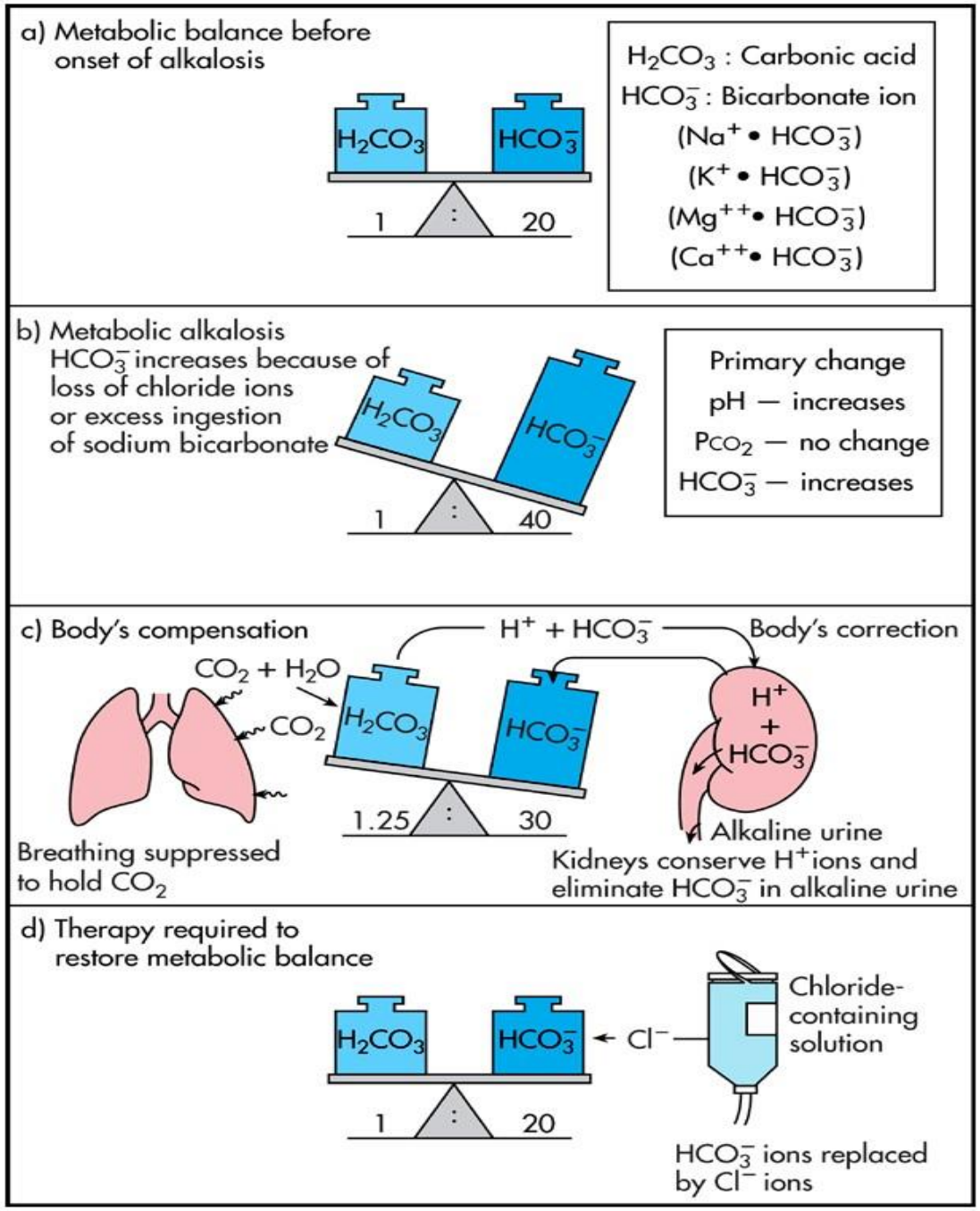
- Alkalosis most commonly occurs with renal dysfunction, so can’t count on kidneys
- Respiratory compensation difficult – hypoventilation limited by hypoxia

Symptoms of Metabolic Alkalosis

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

Treatment of Metabolic Alkalosis

- Electrolytes to replace those lost
- IV chloride containing solution
- Treat underlying disorder



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Diagnosis of Acid-Base Imbalances

1. Note whether the pH is low (acidosis) or high (alkalosis)
2. Decide which value, pCO_2 or HCO_3^- , is outside the normal range **and** could be the **cause** of the problem. If the cause is a change in pCO_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.

Example

- A patient is in intensive care because he suffered a severe myocardial infarction 3 days ago. The lab reports the following values from an arterial blood sample:
  - pH 7.3
  - HCO_3^- = 20 mEq / L (22 - 26)
  - pCO_2 = 32 mm Hg (35 - 45)

Diagnosis

- Metabolic acidosis
- With compensation