Regulation of blood pH, role of buffers, concept of acidosis and alkalosis

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Objectives

- What is pH?- Definition
- Why is it necessary to maintain blood pH in narrow range?- Function
- How is it regulated?- Physiology
- What happens if regulation fails?- Diseases

Introduction

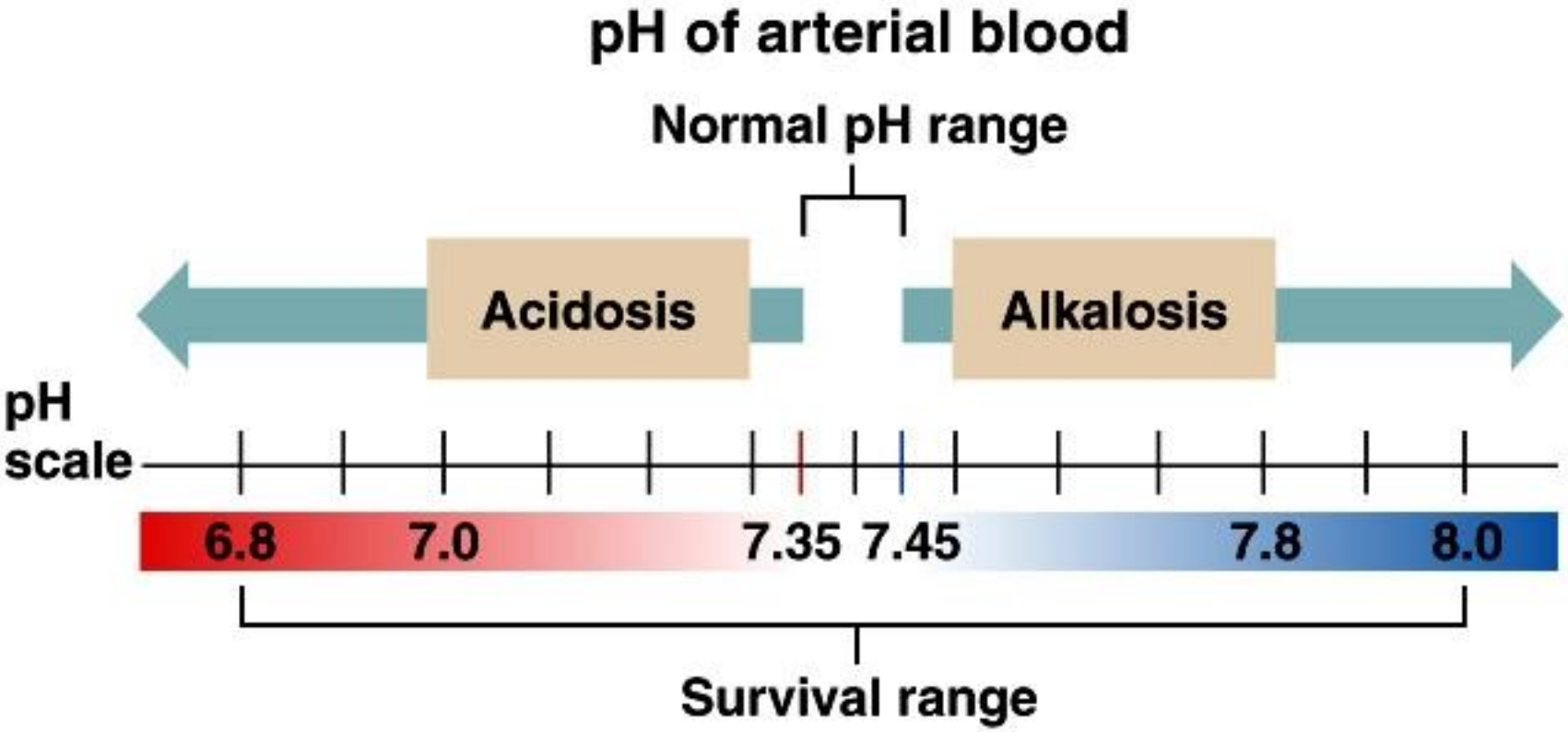
- pH = - log [H^+]
- H^+ is really a proton
- Range is from 0 – 14
- Acids are H^+ donors.
- Bases are H^+ acceptors, or give up OH^- in solution.
- Strong & weak.

$$HCl \longrightarrow H^+ + Cl^-$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

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



Why is it necessary to maintain blood pH in narrow range

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

Why Blood pH Tends to Change?

- Foods
- Acids produced by metabolism
- Cellular metabolism produces CO_2.

$$CO_2 + H_20 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

- Pathological conditions- increase organic acid production

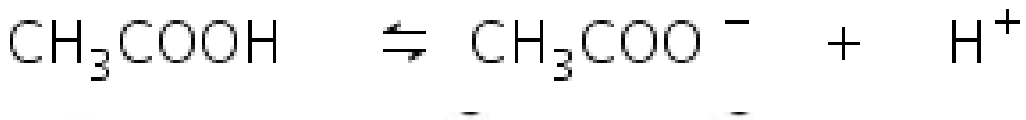
How is it regulated?

1. Buffers
2. Lung
3. Kidney

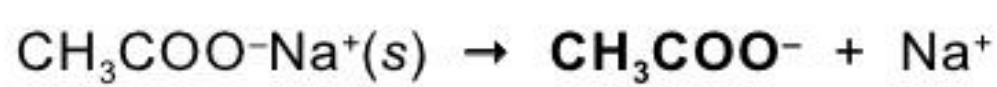
1. Buffer systems

General considerations:

- Resist change of pH
- Usually 1 weak acid and salt of its conjugate base
- eg. Acetate buffer



$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$



$$CH_3COO^-Na^+(s) \rightarrow \mathbf{CH_3COO^-} + Na^+$$

- pK of a buffer
- Buffer capacity

1a. Bicarbonate buffer

- Sodium Bicarbonate ($NaHCO_3$) and carbonic acid (H_2CO_3)

- Maintain a 20:1 ratio : HCO_3^- : H_2CO_3

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

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

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

1b. Phosphate buffer

- Major intracellular buffer

- $H^+ + HPO_4^{2-} \leftrightarrow H_2PO4^-$

- $OH^- + H_2PO_4^- \leftrightarrow H_2O + H_2PO_4^{2-}$

1c. Protein Buffers

- Includes hemoglobin, work in blood and ISF
- Carboxyl group gives up H^+
- Amino Group accepts H^+
- Side chains buffer H^+

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

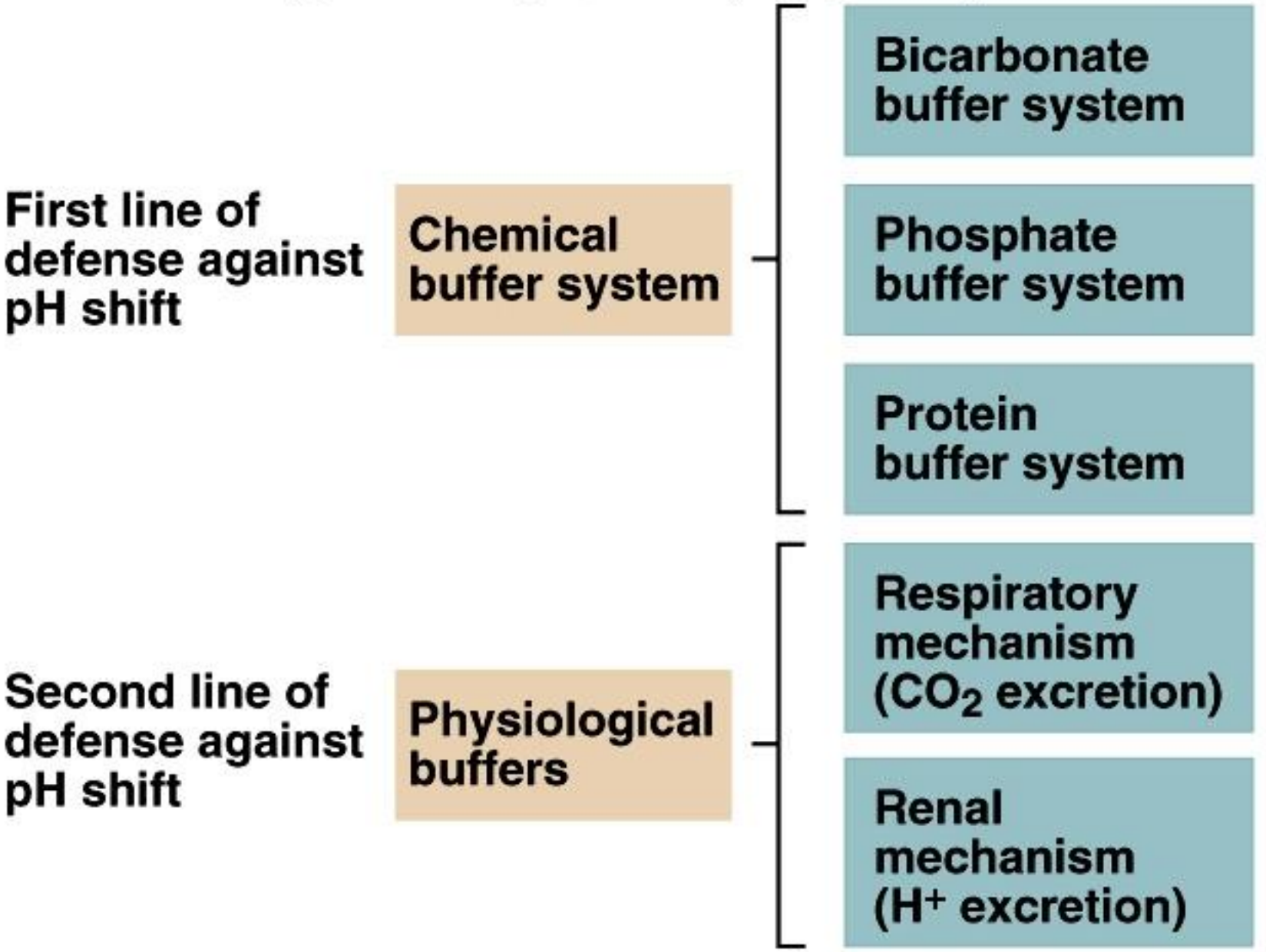
3. Role of Kidney

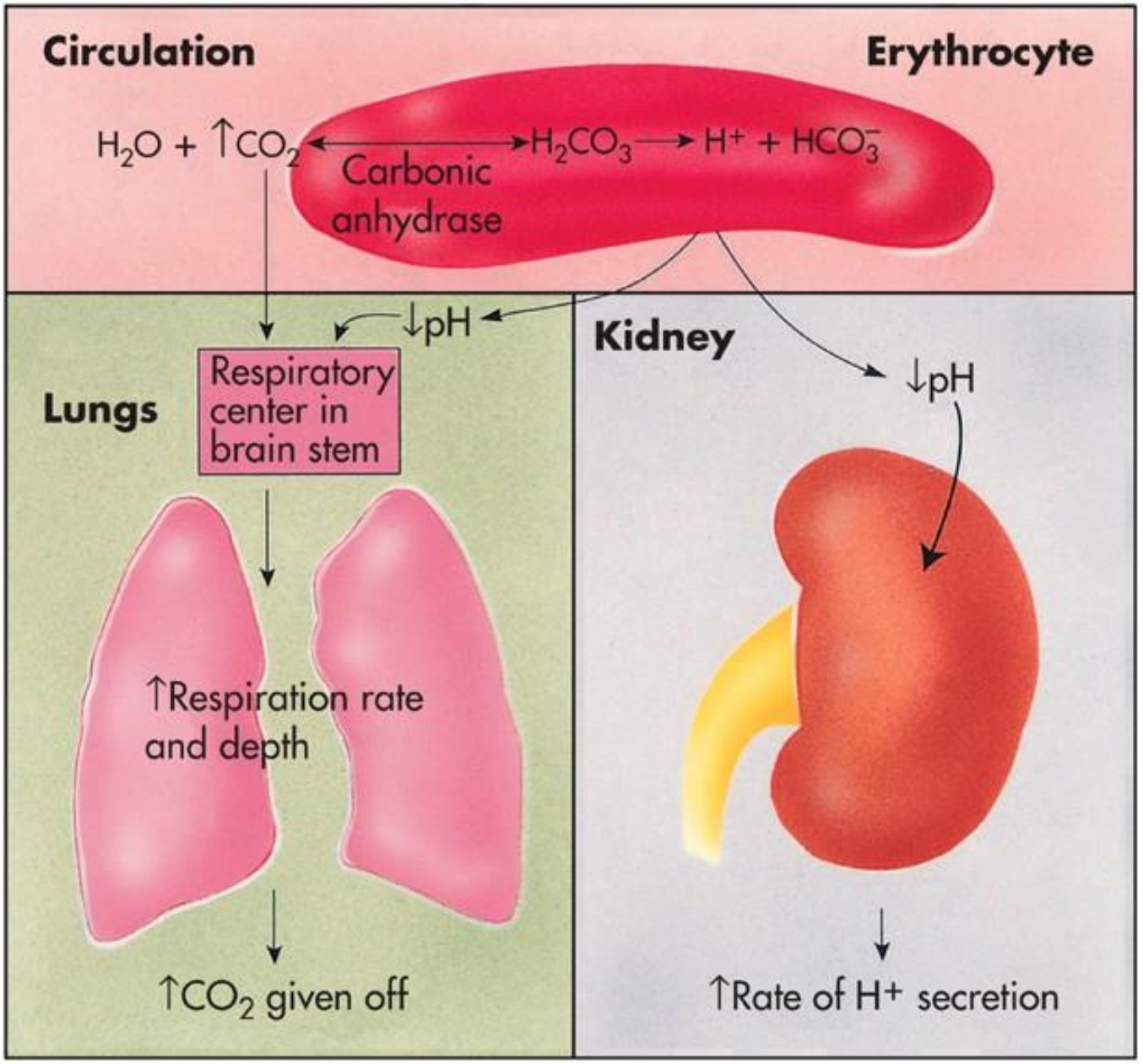
- Conserves bicarb ions
- Can eliminate large amounts of acid

- Can also excrete base
- Most effective regulator of pH

Rates of correction

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

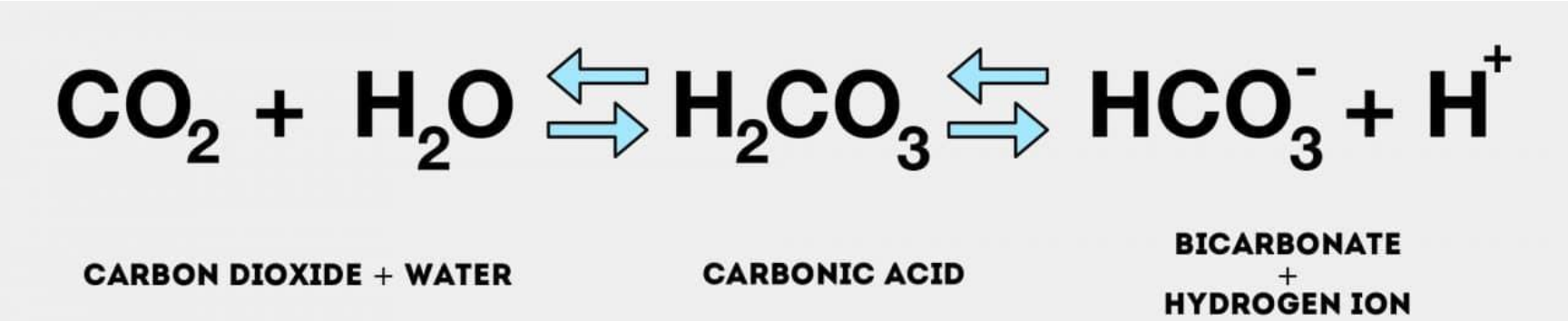




From Thibodeau GA, Patton KT: *Anatomy & physiology,* ed 5, St Louis, 2003, Mosby.

What should be the pH of Blood?

$$pH = pK_a + \log\frac{[A^-]}{[HA]}$$



$$pH = 6.1 + \log\left(\frac{[HCO_3^-]}{0.03 \times pCO_2}\right)$$

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
  - eath

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

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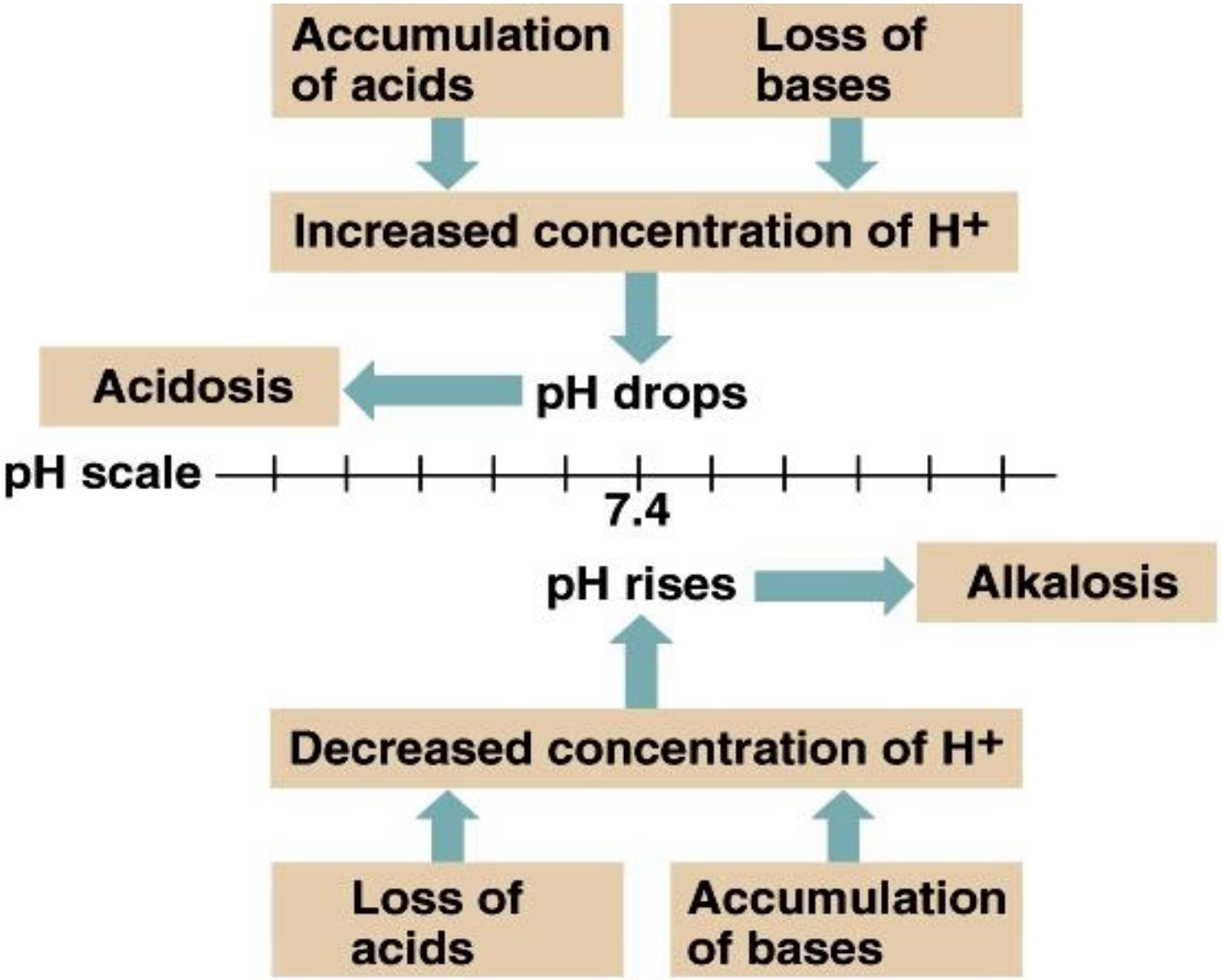


Respiratory Acidosis

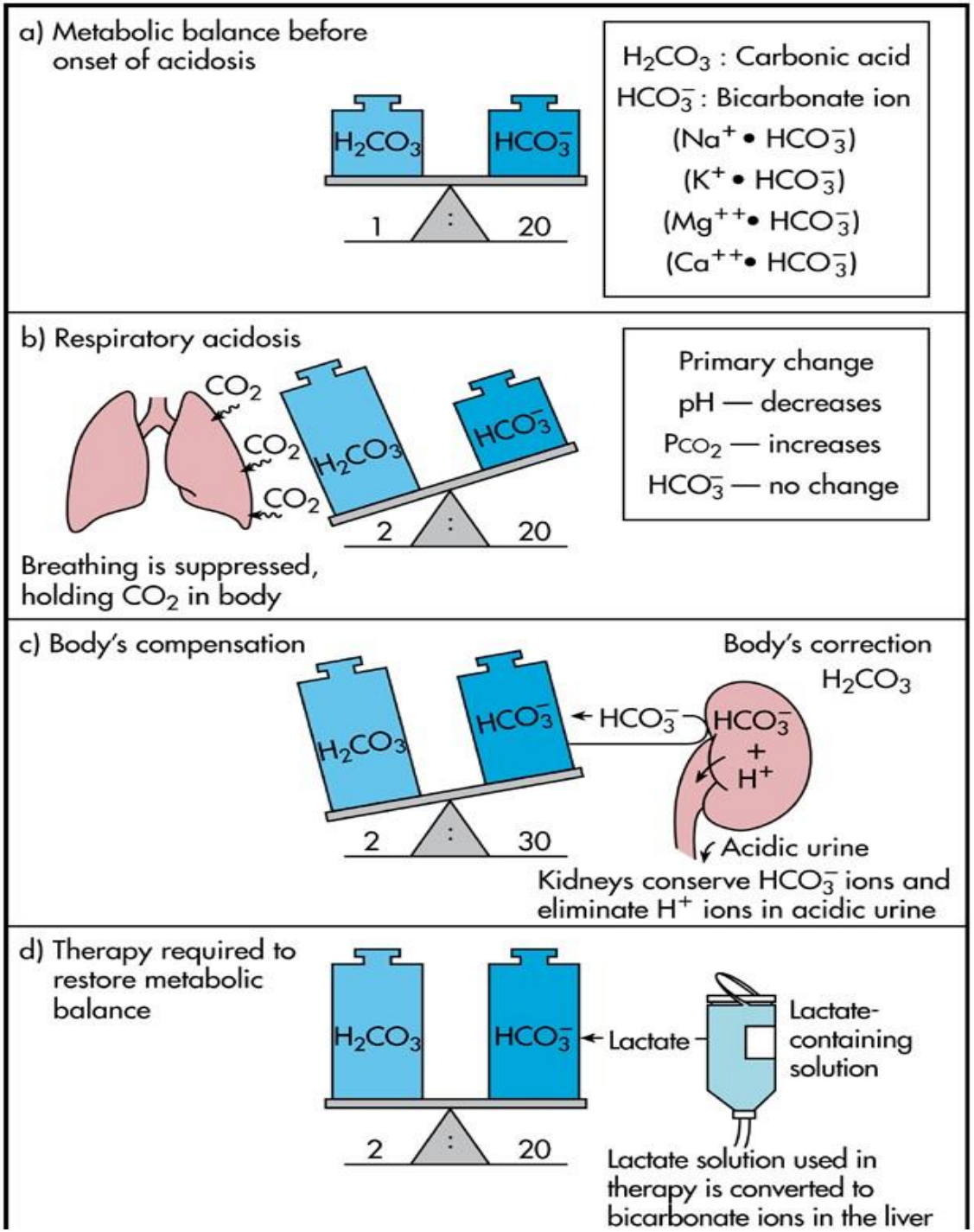
- **Carbonic acid excess** caused by blood levels of CO_2 above 45 mm Hg.
- **Hypercapnia –** high levels of CO_2 in blood
- Chronic conditions:
  - Depression of respiratory center in brain that controls breathing rate – drugs or head trauma
  - Paralysis of respiratory or chest muscles
  - Emphysema

Respiratory Acidosis

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

Compensation for Respiratory Acidosis

- Kidneys eliminate hydrogen ion and retain bicarbonate ion


a) Metabolic balance before onset of acidosis
H_2CO_3
HCO_3^-
1 : 20
H_2CO_3 : Carbonic acid
HCO_3^- : Bicarbonate ion
$(Na^+ \bullet HCO_3^-)$
$(K^+ \bullet HCO_3^-)$
$(Mg^{++} \bullet HCO_3^-)$
$(Ca^{++} \bullet HCO_3^-)$
b) Respiratory acidosis
CO_2
CO_2
CO_2
H_2CO_3
HCO_3^-
2 : 20
Primary change
pH — decreases
P_{CO_2} — increases
HCO_3^- — no change
Breathing is suppressed, holding CO_2 in body
c) Body's compensation
Body's correction
H_2CO_3
H_2CO_3
HCO_3^-
HCO_3^-
HCO_3^- + H^+
2 : 30
Acidic urine
Kidneys conserve HCO_3^- ions and eliminate H^+ ions in acidic urine
d) Therapy required to restore metabolic balance
H_2CO_3
HCO_3^-
Lactate
Lactate-containing solution
2 : 20
Lactate solution used in therapy is converted to bicarbonate ions in the liver

Respiratory Alkalosis

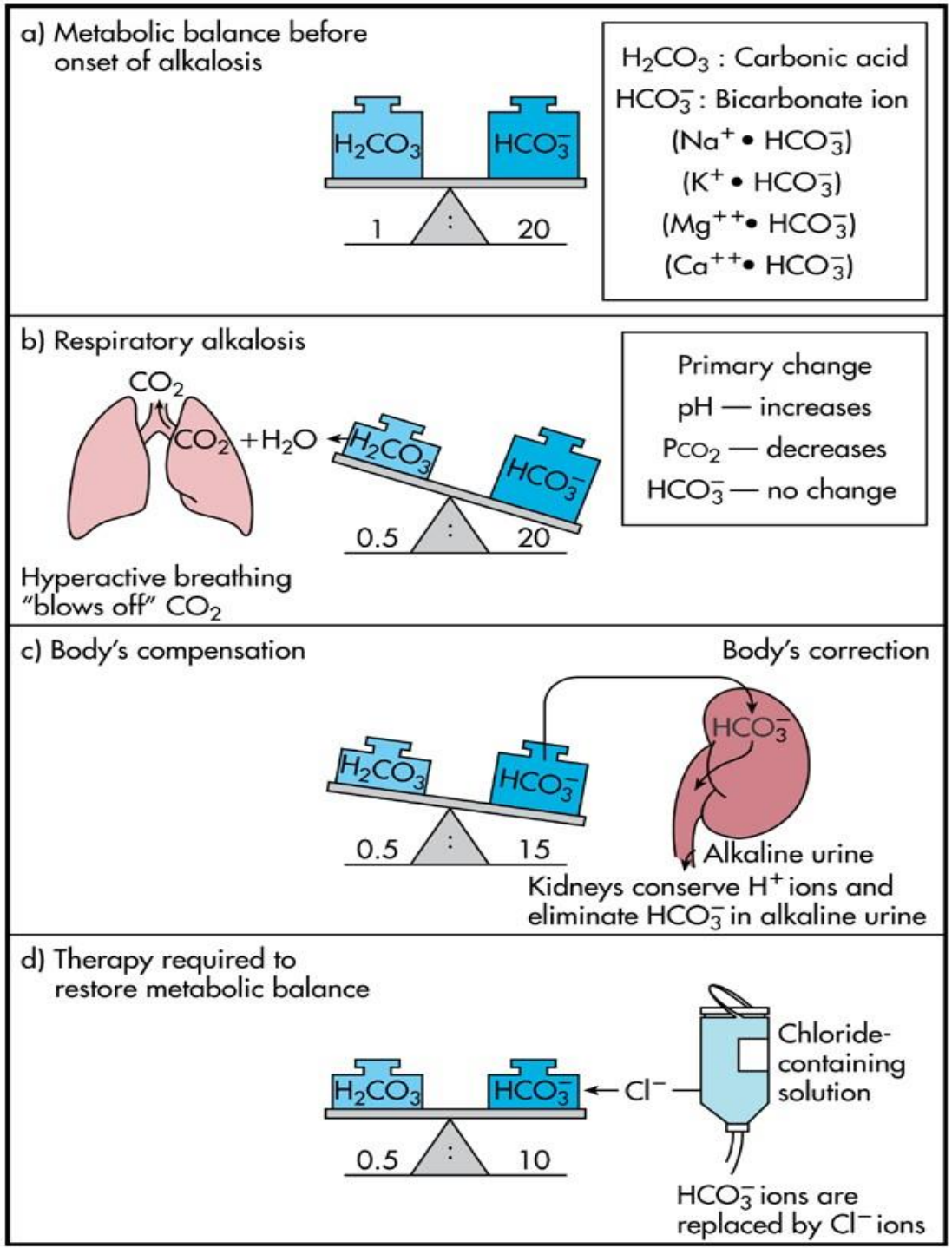
- Carbonic acid deficit
- pCO_2 less than 35 mm Hg (hypocapnea)
- Most common acid-base imbalance
- Primary cause is hyperventilation

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

Compensation of Respiratory Alkalosis

- Kidneys conserve hydrogen ion
- Excrete bicarbonate ion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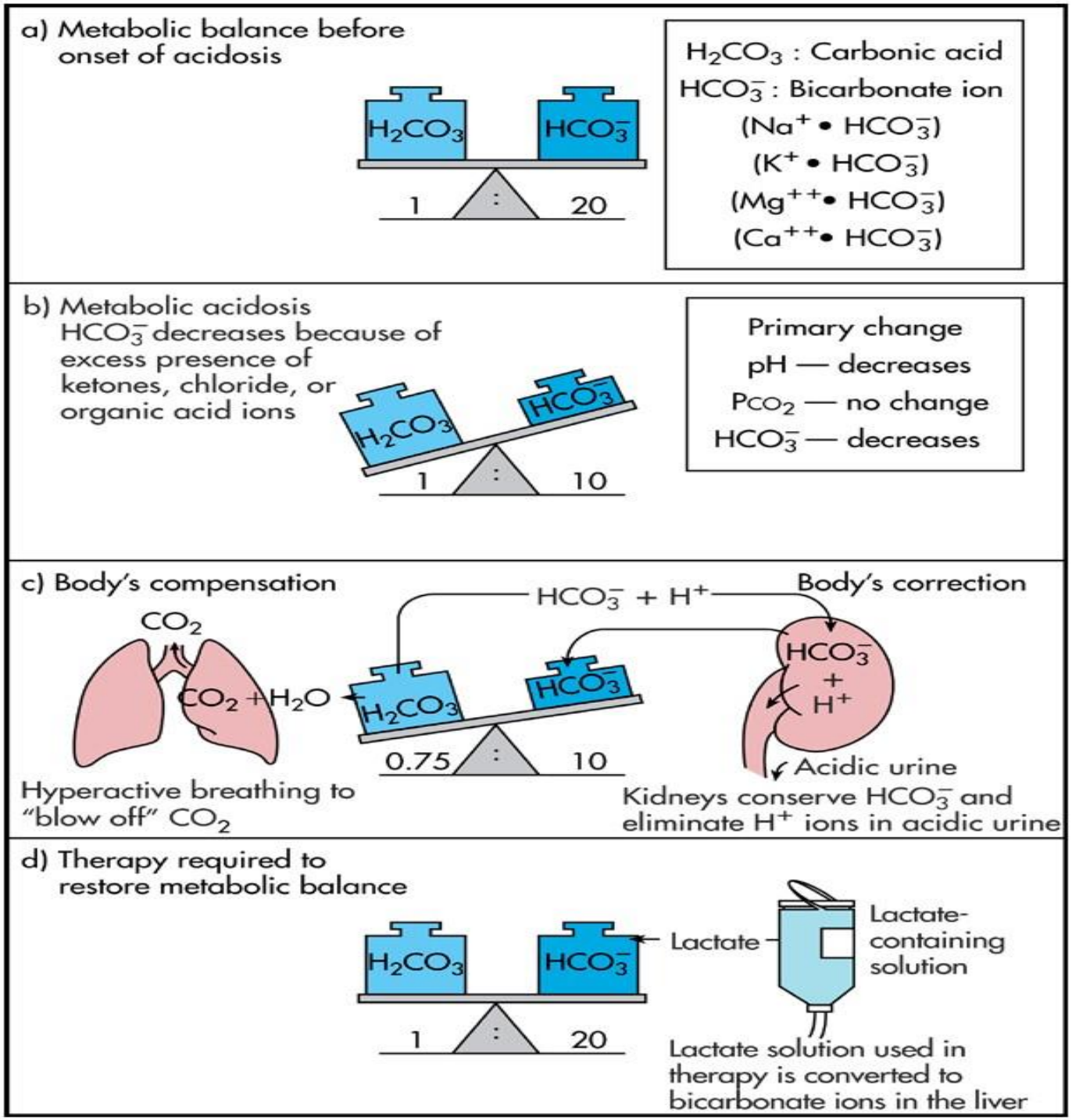
b) Respiratory alkalosis
CO_2
CO_2 + H_2O
H_2CO_3
HCO_3^-
0.5
20
Hyperactive breathing "blows off" CO_2
Primary change
pH — increases
P_{CO_2} — decreases
HCO_3^- — no change
c) Body's compensation
Body's correction
H_2CO_3
HCO_3^-
0.5
15
HCO_3^-
Alkaline urine
Kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine
d) Therapy required to restore metabolic balance
H_2CO_3
HCO_3^-
Cl^-
0.5
10
Chloride-containing solution
HCO_3^- ions are replaced by Cl^- ions

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+**

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)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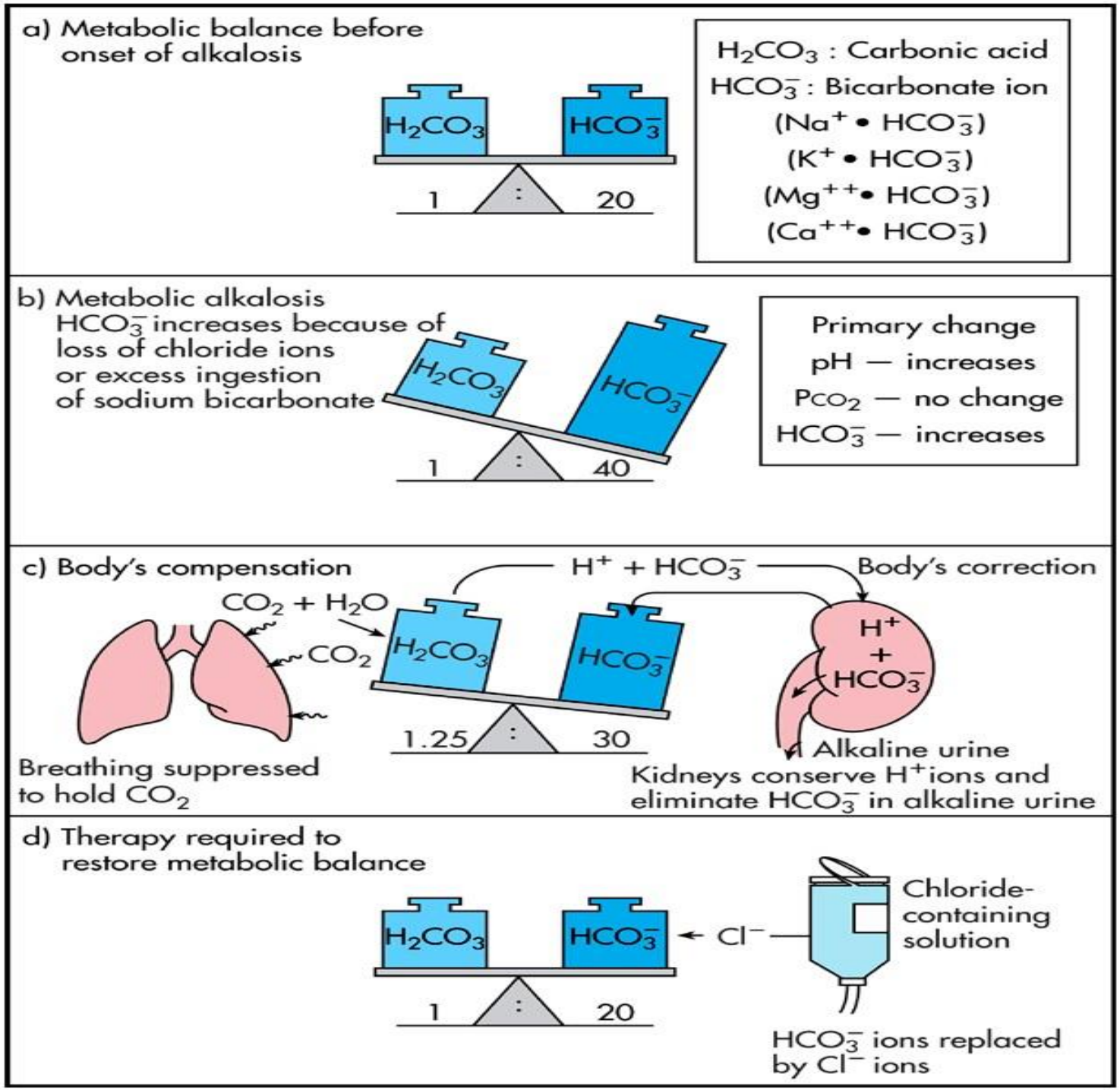
$(Mg^{++} \bullet HCO_3^-)$
$(Ca^{++} \bullet HCO_3^-)$
b) Metabolic acidosis HCO_3^- decreases because of excess presence of ketones, chloride, or organic acid ions
1 : 10
Primary change
pH — decreases
P_{CO_2} — no change
HCO_3^- — decreases
c) Body's compensation
CO_2
$CO_2 + H_2O$
$HCO_3^- + H^+$
Body's correction
$HCO_3^- + H^+$
0.75 : 10
Acidic urine
Hyperactive breathing to "blow off" CO_2
Kidneys conserve HCO_3^- and eliminate H^+ ions in acidic urine
d) Therapy required to restore metabolic balance
1 : 20
Lactate
Lactate-containing solution
Lactate solution used in therapy is converted to bicarbonate ions in the liver

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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$(Ca^{++} \bullet HCO_3^-)$
b) Metabolic alkalosis
HCO_3^- increases because of loss of chloride ions or excess ingestion of sodium bicarbonate
H_2CO_3
HCO_3^-
1 : 40
Primary change
pH — increases
P_{CO_2} — no change
HCO_3^- — increases
c) Body's compensation
$H^+ + HCO_3^-$
Body's correction
$CO_2 + H_2O$
CO_2
H_2CO_3
HCO_3^-
1.25 : 30
$H^+ + HCO_3^-$
Alkaline urine
Breathing suppressed to hold CO_2
Kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine
d) Therapy required to restore metabolic balance
H_2CO_3
HCO_3^-
1 : 20
Cl^-
Chloride-containing solution
HCO_3^- ions replaced by Cl^- ions

Diagnosis of Acid-Base Imbalances

- What is the primary disorder?
- Compensatory mechanism?
- Complete or incomplete?
- Investigation- ABG
- Essential parameters in an ABG-

TABLE 4–1 Normal Blood Gas Values

Blood Gas Value*	Arterial
pH	7.35 to 7.45
Pco_2	35 to 45 mm Hg
HCO_3	22 to 28 mEq/L
Po_2	80 to 100 mm Hg

Diagnosis of Acid-Base Imbalances

1. Note whether the pH is low (acidosis) or high (alkalosis) or normal (normal/ compensated).
2. Identify individual changes in pCO_2 or HCO_3^-
3. Change correspond to the pH finding would be primary pathology.
4. Change in other one refers to compensation.

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
  - PCO_2 = 32 mm Hg

Metabolic Acidosis with
compensatory Respiratory Alkalosis

ABG no.	pH	PCO_2	HCO_3^-	Primary	Compensatory
1	7.28	36	20	Met Acidosis	Nil
2	7.3	32	20	Met Acidosis	Resp Alkalosis (Incomplete)
3	7.36	30	20	Met Acidosis	Resp Alkalosis (Complete)

Diagnose

pH =7.5

HCO_3^- = 31 mEq / L (22 - 26)

PCO_2 = 49 mm Hg (35 - 45)

Diagnose

pH =7.37

HCO_3^- = 36 mEq / L (22 - 26)

PCO_2 = 62 mm Hg (35 - 45)

PO_2 = 65 mm Hg (80-100)

THANK YOU