Acid-Base Balance Workshop

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Objectives

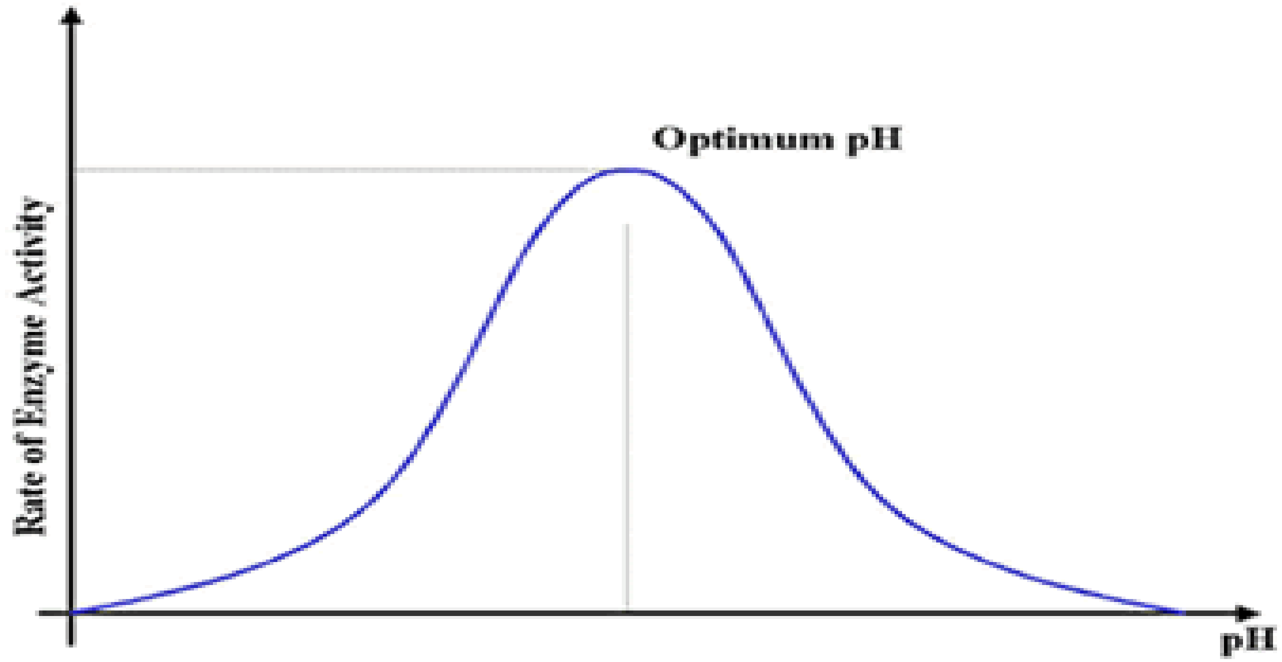
- Normal Acid-Base Physiology
- Simple Acid-Base Disorders
- Compensations and Disorders
- The Anion Gap
- Mixed Acid-Base disorders
- The General Approach
- Common pitfalls and Practical Issues

Don’t forget about the patients

Mastering ABG interpretation will happen only if you practice

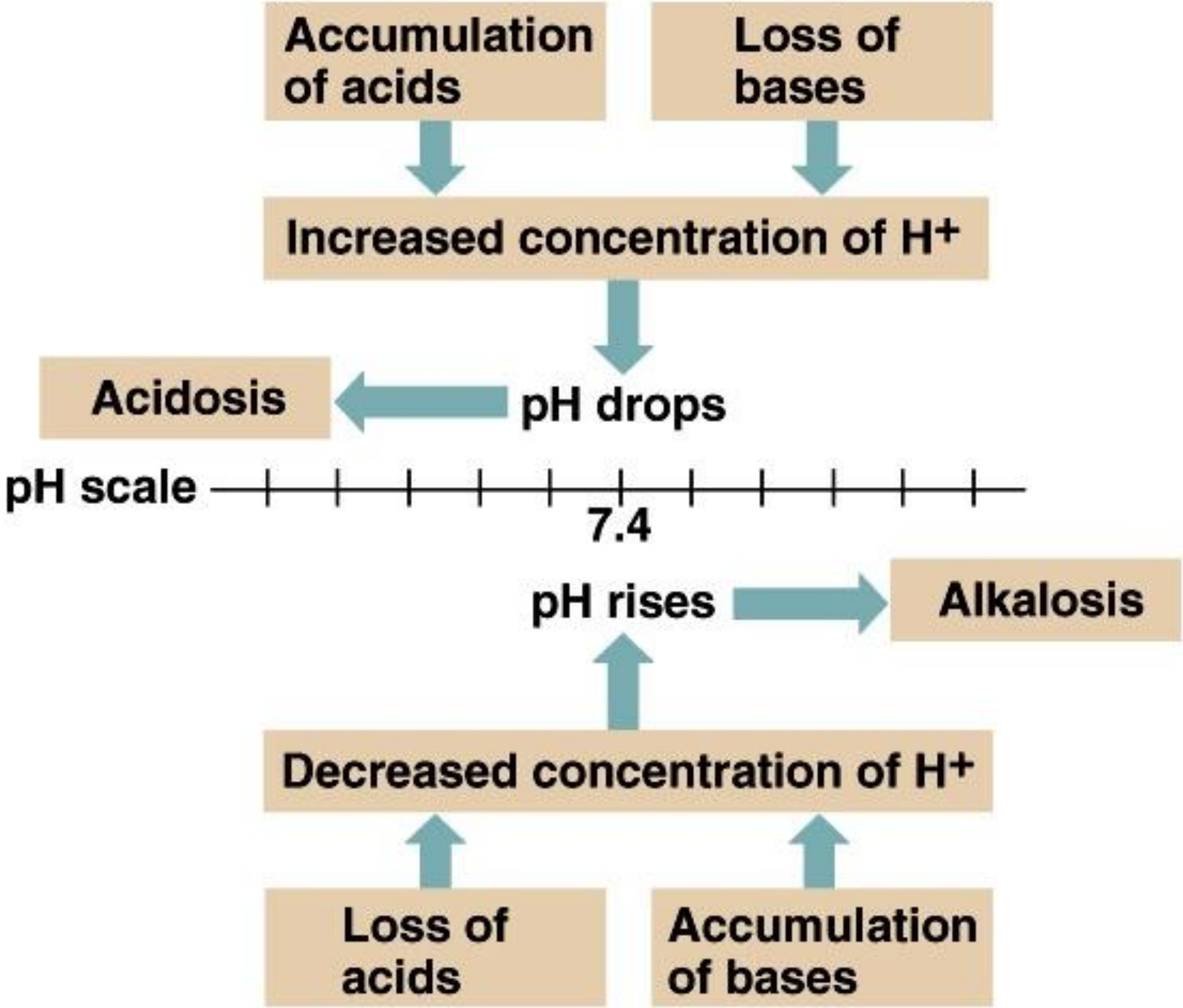
Role of Acid-Base Balance

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



Role of Acid-Base Balance

- Clinical consequences of deregulation of acid-base balance:
  - Poor vascular tone
  - Myocardial pump failure
  - Increased risk of arrhythmias
  - Skeletal muscle weakness
  - Electrolyte abnormalities
  - Delirium/Coma
  - Impaired cellular respiration


Accumulation of acids
Loss of bases
Increased concentration of H+
Acidosis
pH drops
pH scale
7.4
pH rises
Alkalosis
Decreased concentration of H+
Loss of acids
Accumulation of bases

Role of Acid-Base Balance

- Net Acid production = Net Acid Elimination

Three Stages

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

1. Acid Production (Physiologic)

Carbohydrates, Fats	→	CO_2 (Volatile Acid)
Proteins	→	H_2SO_2 (Non-volatile Acid)
Phospholipids	→	H_3SO_4 (Non-volatile Acid)

1. Acid Production (Pathological)

Accumulated Acids

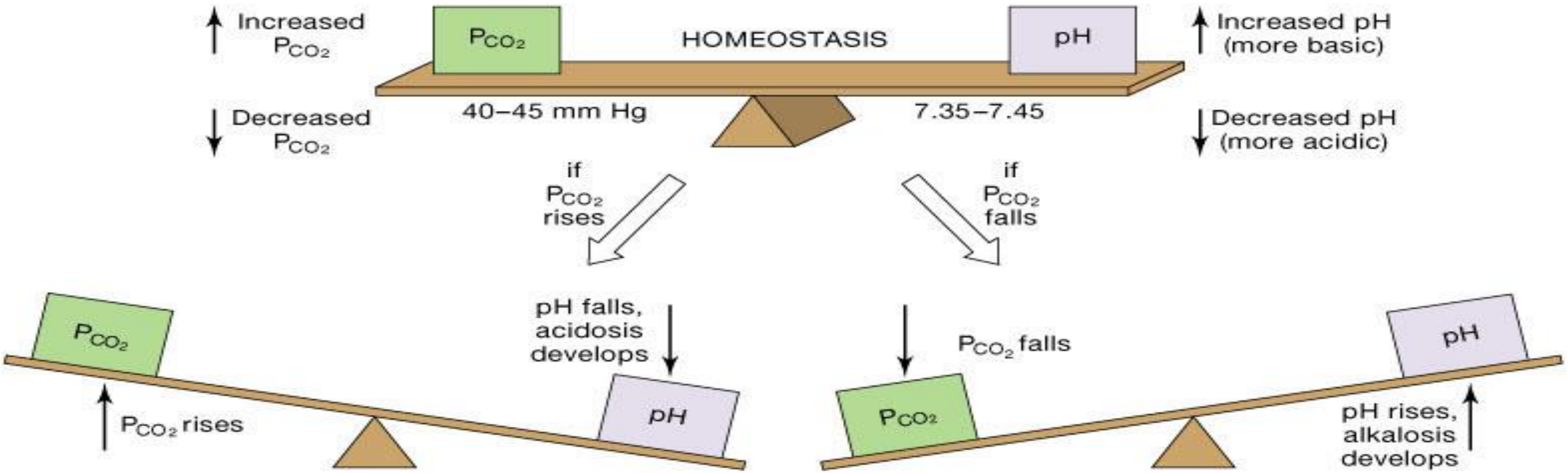
Cause		Accumulated Acids
Uncontrolled diabetes, Starvation	→	Acetoacetate
Hypotension Hypoxia CO poisoning Drugs (ASA)	→	Lactic acid
Ethylene Glycol poisoning	→	Glycolic acid Oxalic acid

2. Intravascular Transport of Acid

- To prevent sudden and large swings in pH, buffers are necessary
- Buffers have two major characteristics:
  - Consists of a weak acid and its anion
  - Resists changes in pH

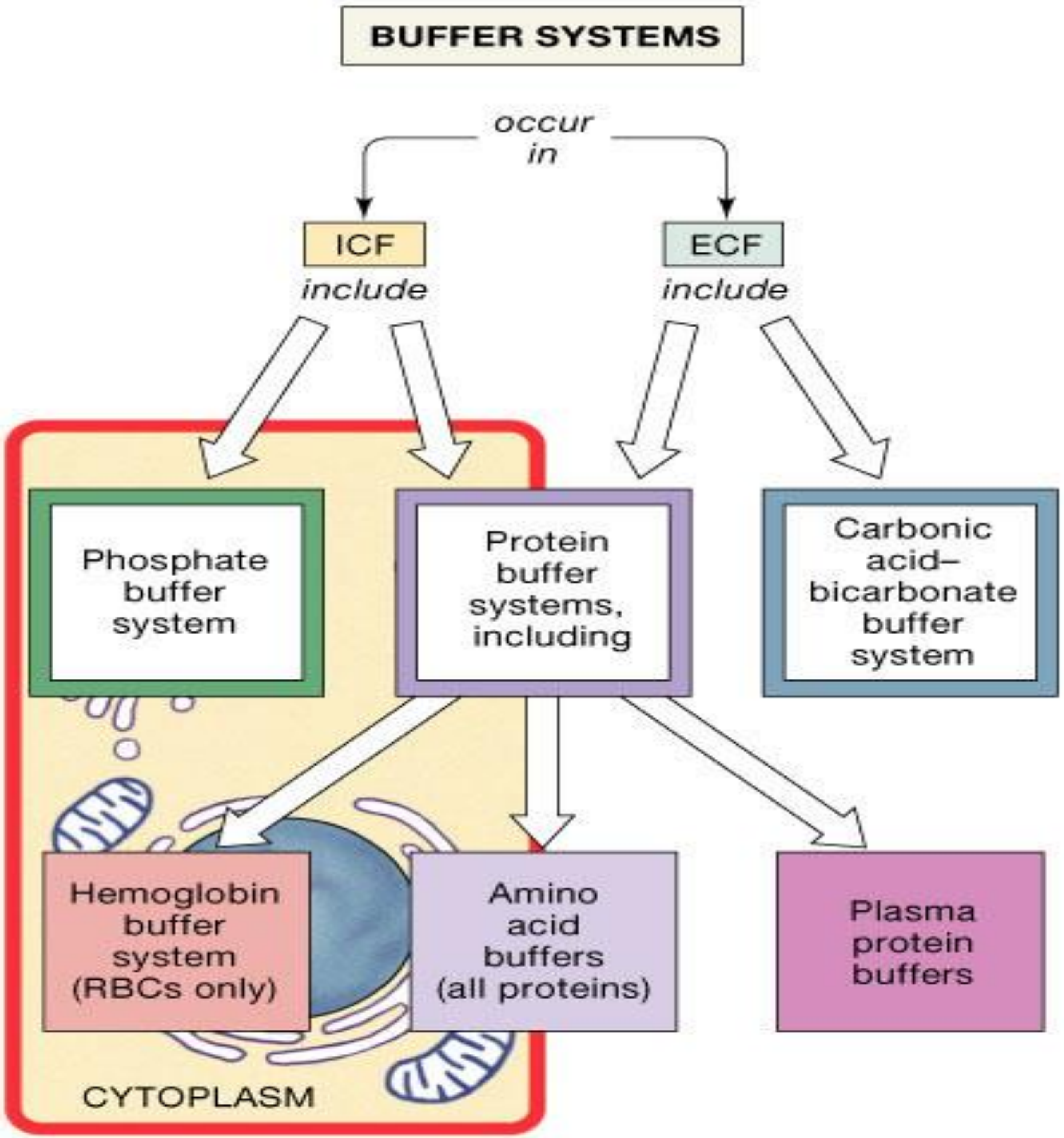
- Three major buffering systems:
  - Protein buffer system
    - Amino acid
  - Hemoglobin buffer system
    - H^+ are buffered by hemoglobin
    - Carbonic acid-bicarbonate
      - Buffers changes caused by organic and fixed acids
  - Minor buffering system
    - Phosphate
      - Buffer pH in the ICF

The Basic Relationship between P_{CO2} and Plasma pH

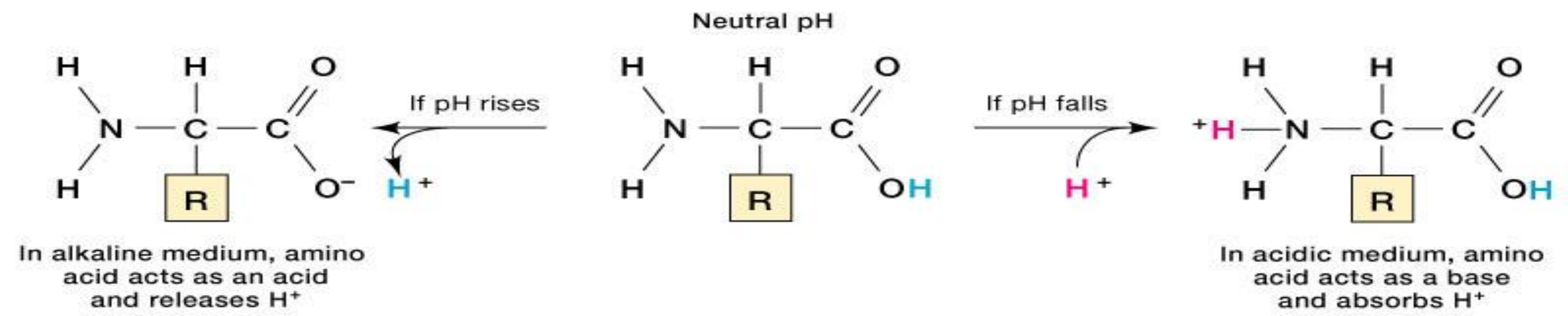


Relationship Between P_{CO2} and Plasma pH

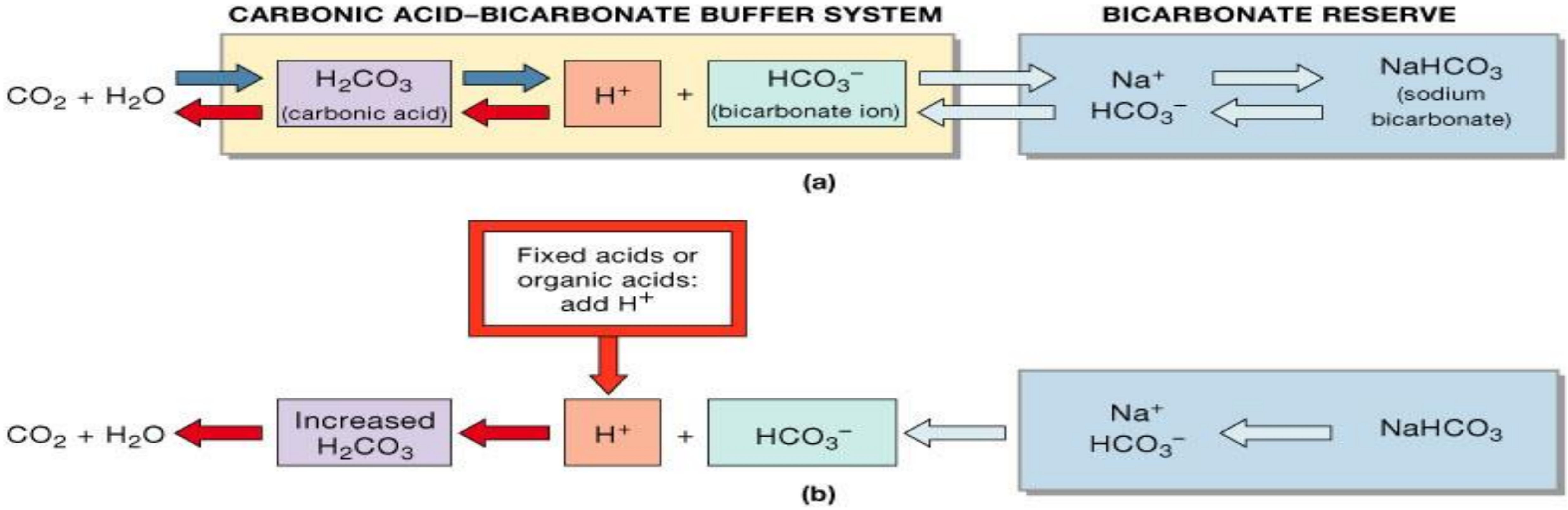
Buffer Systems in Body Fluids



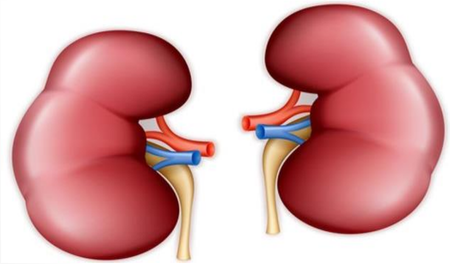
Amino Acid Buffers



The Carbonic Acid-Bicarbonate Buffer System

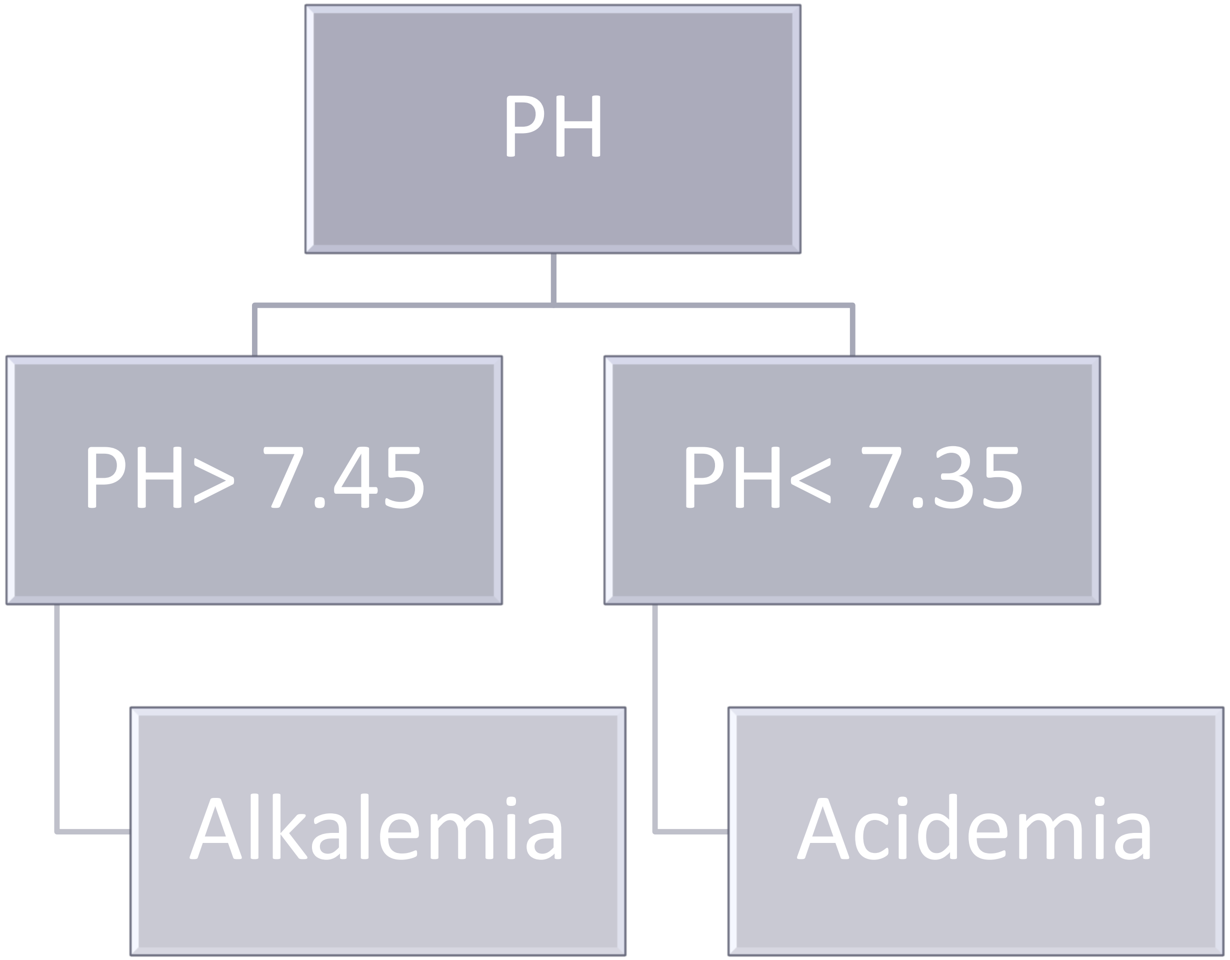


3. Elimination of Acid

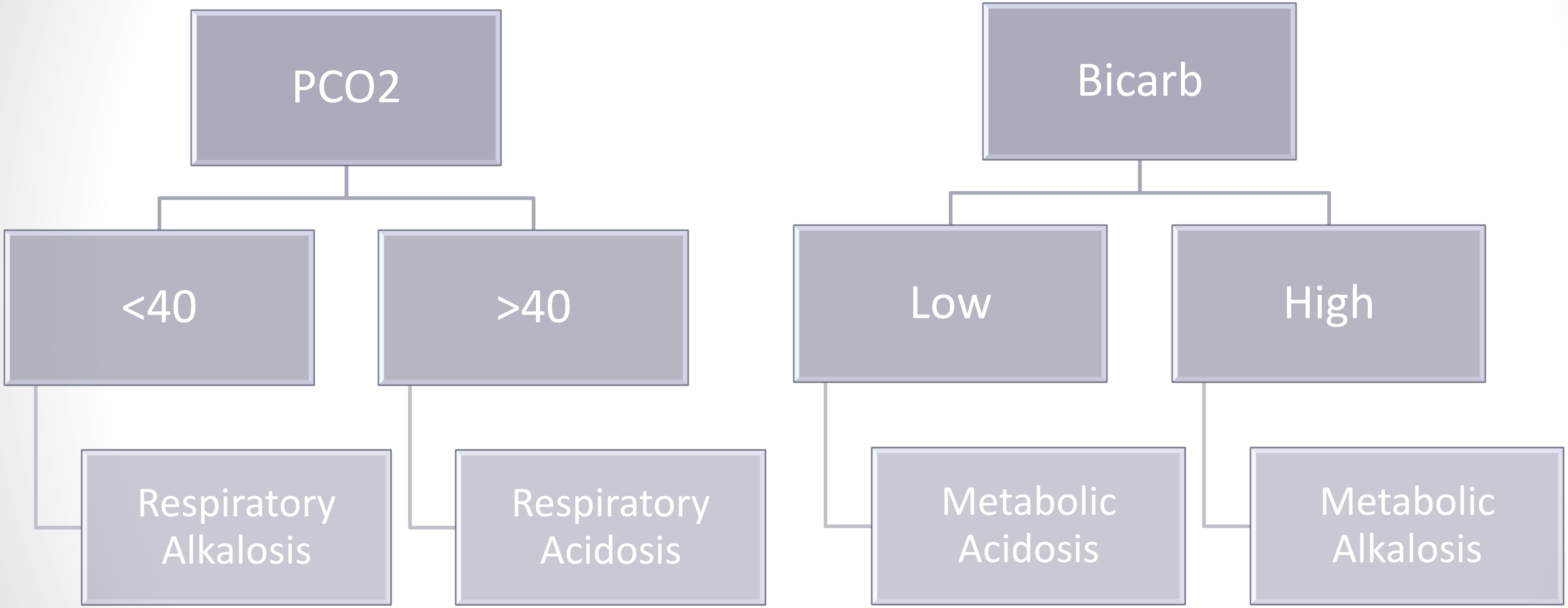
Site		**Mechanism**
Lungs 		Expiration of CO_2
Kidneys 	Proximal Tubule	Reabsorption of HCO_3
	Distal Tubule/Collecting ducts	Excretion of H^+ as titratable acid
		Excretion of NH_4^+

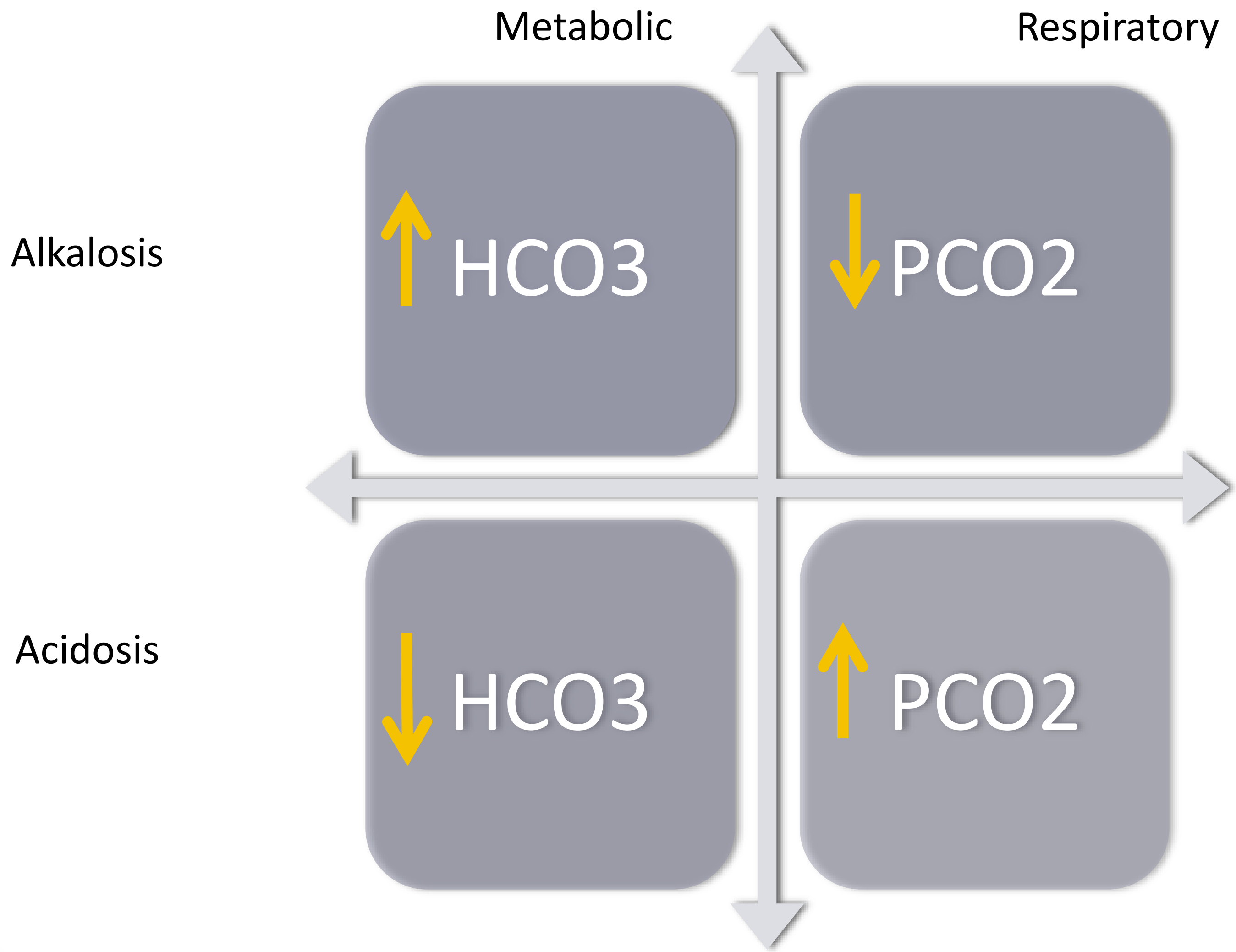
Primary Acid-Base Disorders

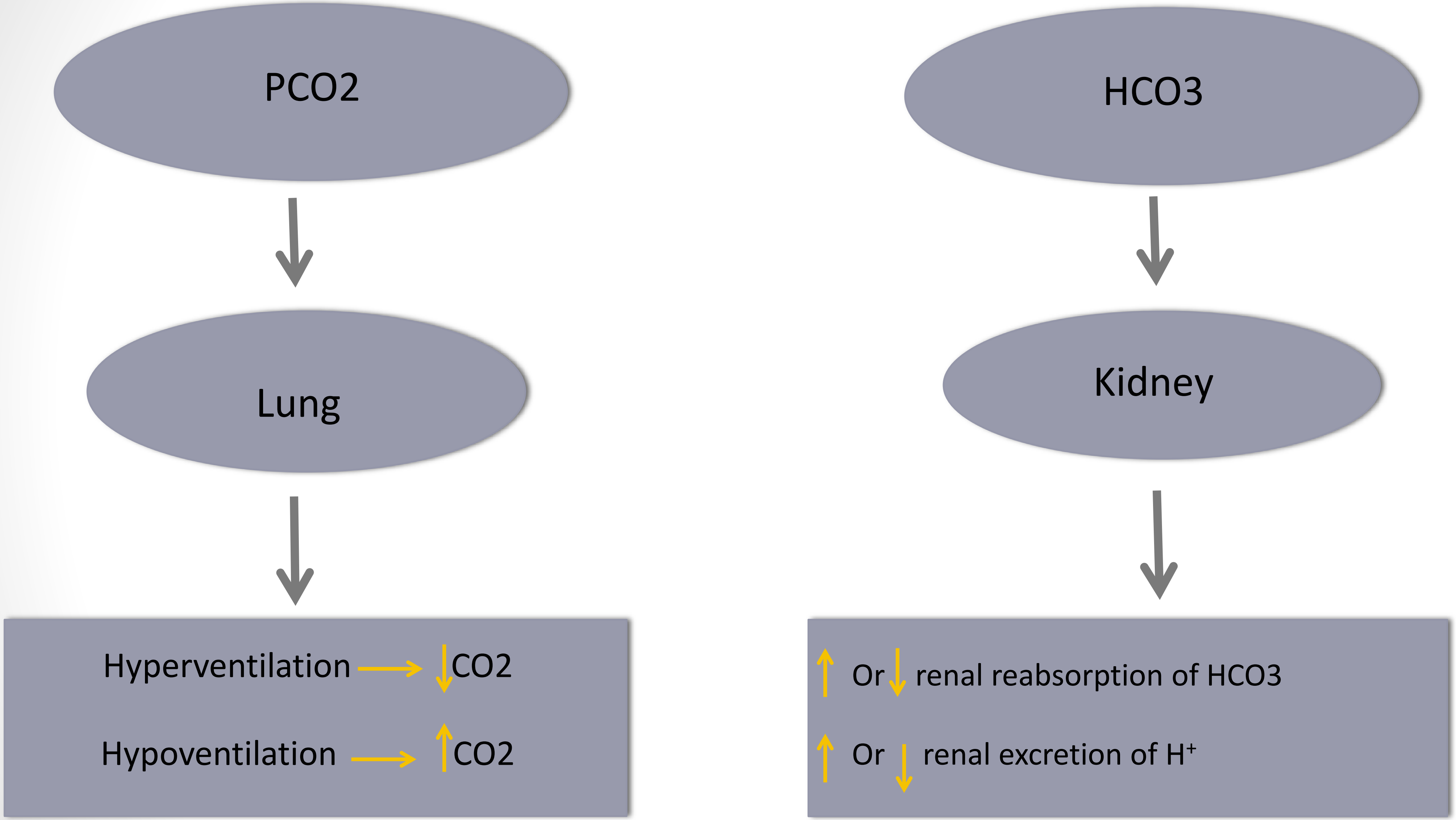
Acidemia vs Alkalemia



Respiratory vs Metabolic Disorders




Metabolic
Respiratory
Alkalosis
HCO3
PCO2
Acidosis
HCO3
PCO2


PCO2
Lung
Hyperventilation → ↓CO2
Hypoventilation → ↑CO2
HCO3
Kidney
↑ Or ↓ renal reabsorption of HCO3
↑ Or ↓ renal excretion of H+

Δ pH & PCO_2 → Same direction → Metabolic

- Low PH & Low PCO_2 → Metabolic acidosis
- High PH & High PCO_2 → Metabolic alkalosis

Δ pH & PCO_2 → Opposite direction → Respiratory

- Low PH & High PCO_2 → Respiratory acidosis
- High PH & Low PCO_2 → Respiratory alklalosis

The ABG

pH / P_aCO_2 / ~~P_aO_2~~ / HCO_3 / ~~O_2 Sat~~

Step 1: Always start with the pH

pH / P_aCO_2 / HCO_3

If pH <7.35 >> Acidemia

If pH >7.45 >> Alkalemia

Step 2: Check the PCO_2

pH 7.25 / P_aCO_2 60 / HCO_3 26

pH is ↓ than normal, while P_aCO_2 is than normal ↑

Since these are deranged is different directions the disorder is reparatory

<u>Respiratory Acidosis</u>

Compensation

- A primary metabolic disorder will result in respiratory compensation
- A primary respiratory disorder will result in metabolic compensation

Compensation

Compensation does not return the pH to normal

Patients never "overcompensate"

Compensation

Primary disorders	Compensation
Metabolic Acidosis	Hyperventilation → ↓ CO2
Metabolic Alkalosis	Hypoventilation → ↑ CO2
Respiratory Acidosis	Increased renal reabsorption of HCO3 Increased renal excretion of H^+
Respiratory Alkalosis	Decreased renal reabsorption of HCO3 Decreased renal excretion of H^+

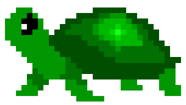
Remember…….

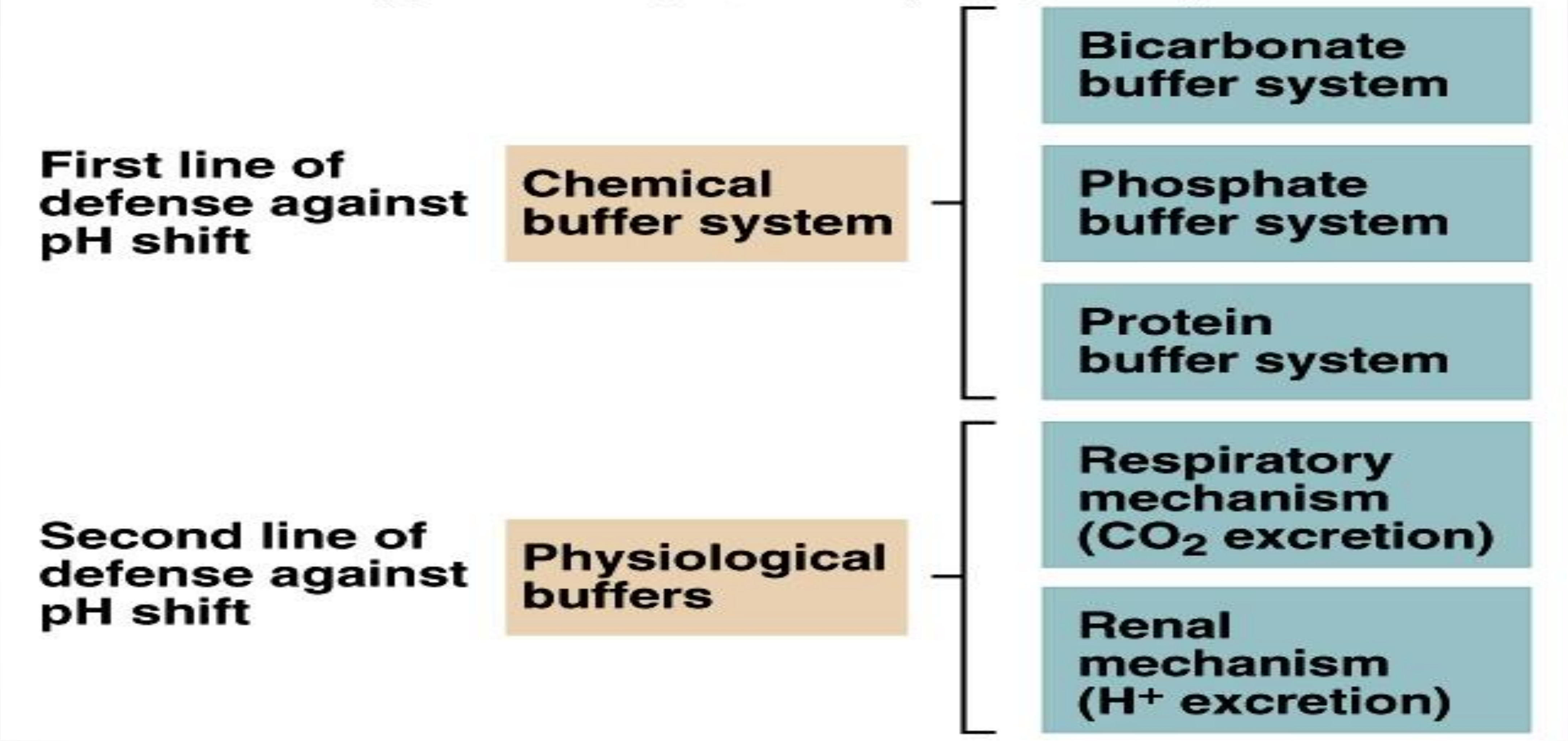
Respiratory compensation is always

FAST*…12-24 hrs*

Metabolic compensation always

SLOW*...5 -7 days*




First line of defense against pH shift
Chemical buffer system
Bicarbonate buffer system
Phosphate buffer system
Protein buffer system
Second line of defense against pH shift
Physiological buffers
Respiratory mechanism (CO_2 excretion)
Renal mechanism (H^+ excretion)

Acid-Base Disorders

Blood Gas Norms

	pH	pCO_2	pO_2	HCO_3	BE
Arterial	7.35-7.45	35-45	80-100	22-26	-2 to +2
Venous	7.30-7.40	43-50	~45	22-26	-2 to +2

Type of Disorder	pH	$PaCO_2$	$[HCO_3]$
Metabolic Acidosis	↓	↓	↓
Metabolic Alkalosis	↑	↑	↑
Acute Respiratory Acidosis	↓	↑	↑
Chronic Respiratory Acidosis	↓	↑	↑↑
Acute Respiratory Alkalosis	↑	↓	↓
Chronic Respiratory Alkalosis	↑	↓	↓↓

Note: if PaCO2, PH & HCO3 in same direction----→Metabolic
if opposite →Respiratory

Practical Approach

First:

- Detailed history/exam
- Medication
- Complementary lab test (Na/K/Cl , UEG,etc)

Second: Check if data consistence

$$\left[H^+\right] = 24 \times \frac{PaCO_2}{HCO_3^-}$$

pH	$[H^+]$	pH	$[H^+]$
7.80	16	7.30	50
7.75	18	7.25	56
7.70	20	7.20	63
7.65	22	7.15	71
7.60	25	7.10	79
7.55	28	7.00	89
7.50	32	6.95	100
7.45	35	6.90	112
7.40	40	6.85	141
7.35	45	6.80	159

Third: What does the patient has

Acidosis:
- PH<7.35

Alkalosis:
- PH>7.45

Fourth: Determine is it respiratory or metabolic ?

Acidosis:

- HCO_3<22= Metabolic
- CO_2>45= Respiratory

Alkalosis:

- HCO_3>28=Metabolic
- CO_2<35= Respiratory

Fifth- Evaluate Compensatory Response:

If there is primary metabolic:

Acidosis:

-Expected $PACO2=1.5X(HCO3)+8+/-2$

Alkalosis:

-$PaCO_2$ increase by 7mmhg for each 10meq/l increase in [HCO3]

If expected = measured --→fully compensated.

If expected > measured --→ respiratory Alkalosis

If expected < measured---→ respiratory acidosis

If there is respiratory :

Acidosis:

-[HCO_3^-] increases by 1 (acute) & 3.5-4 (chronic) for each 10-mm Hg increase in PCO_2.

Alkalosis:

-[HCO_3^-] falls by 2 (acute) & 4 (chronic) for each 10-mm Hg decrease in PCO_2

If measured = expected →simple, fully compensated.

If measured < expected→ metabolic acidosis.

If measured > expected →metabolic alkalosis.

DISORDER	EXPECTED COMPENSATION
Metabolic acidosis	$PCO_2 = 1.5 \times [HCO_3^-] + 8 \pm 2$
Metabolic alkalosis	PCO_2 increases by 7 mm Hg for each 10 mEq/L increase in s. $[HCO_3^-]$ or $PaCO_2 = 0.7 \times (HCO3^-) + 20 \pm 5$
Respiratory acidosis	
Acute	$[HCO_3^-]$ increases by 1 for each 10-mm Hg increase in PCO_2
Chronic	$[HCO_3^-]$ increases by 3.5 for each 10-mm Hg increase in PCO_2
Respiratory alkalosis	
Acute	$[HCO_3^-]$ falls by 2 for each 10-mm Hg decrease in PCO_2
Chronic	$[HCO_3^-]$ falls by 4 for each 10-mm Hg decrease in PCO_2

Sixth: Calculate Anion Gap

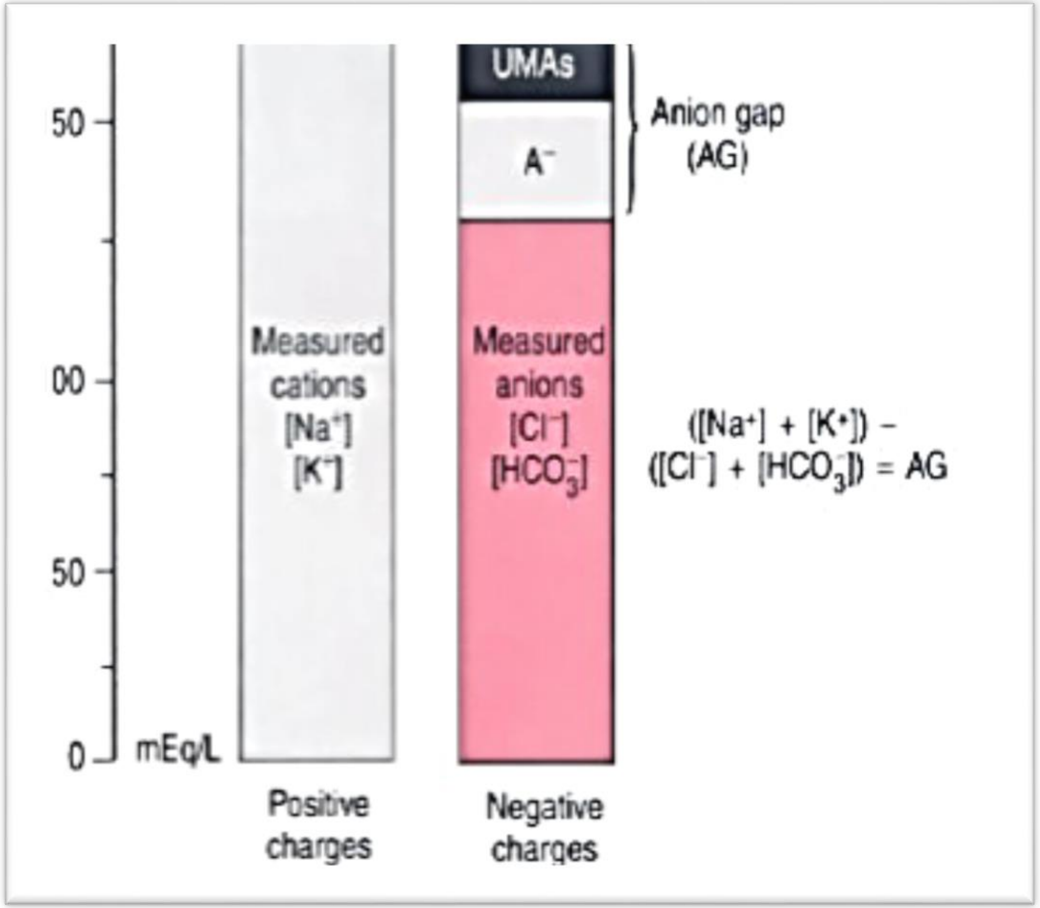
- SAG-Represents the level of unmeasured anions in extracellular fluid
- Helps differentiate acidotic conditions

UA-UC=Na-(Cl+HCO3)

- SAG=Na-(Cl+HCO3)

Normal=10+/-2

- Corrected SAG for Hypoalbumenia = measured SAG+2.5(4-Albumin {g/dl})



Urine & Osmolar gap

- **UAG=Na + K- Cl**
- **NeGUTive----GUT loss**
- **Positive----RTA**

  -Type 1-(urine PH>5.5 & S.K low)

  -Type 2-(urine PH <5.5 & S.K low)

  -Type 4-(urine PH <5.5 & S.K high)

- **For high osmolar gap calculate:**

Osmolar Gap=measured serum osmollarity – calculated serum osmolality .

(Normal < 15mosmol/kg)

- **If high consider :ME DIE**

-Methanol

-Ethanol

-Diuretic

-Isopropyl Alcohol

-Ethylene glycol

Seventh: Calculate the excess anion gap

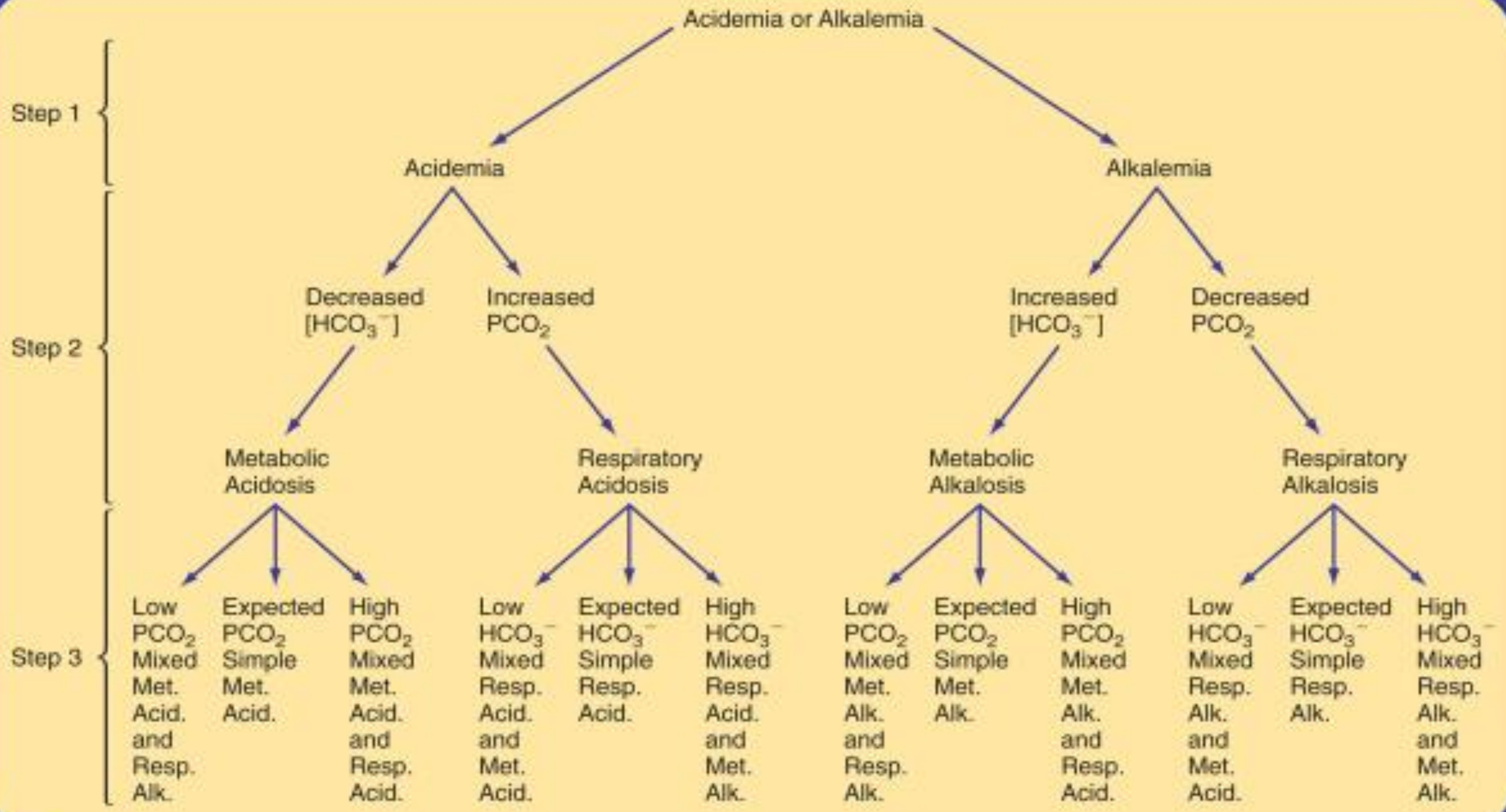
- Compare change of AG to change in HCO3

Can uncover mixed metabolic disorder (Metabolic acidosis & Metabolic Alkalosis).

Excess AG(G-G ratio)= {Calculated AG-12}+measured HCO3

If the Sum > 30----Concomitant Metabolic Alkalosis.

If the Sum < 23----concomitant non Anion Gap Metabolic Acidosis



Acidemia or Alkalemia
Step 1
Acidemia
Alkalemia
Step 2
Decreased [HCO_3^-]
Increased PCO_2
Increased [HCO_3^-]
Decreased PCO_2
Metabolic Acidosis
Respiratory Acidosis
Metabolic Alkalosis
Respiratory Alkalosis
Step 3
Low PCO_2 Mixed Met. Acid. and Resp. Alk.
Expected PCO_2 Simple Met. Acid.
High PCO_2 Mixed Met. Acid. and Resp. Acid.
Low HCO_3^- Mixed Resp. Acid. and Met. Acid.
Expected HCO_3^- Simple Resp. Acid.
High HCO_3^- Mixed Resp. Acid. and Met. Alk.
Low PCO_2 Mixed Met. Alk. and Resp. Alk.
Expected PCO_2 Simple Met. Alk.
High PCO_2 Mixed Met. Alk. and Resp. Acid.
Low HCO_3^- Mixed Resp. Alk. and Met. Acid.
Expected HCO_3^- Simple Resp. Alk.
High HCO_3^- Mixed Resp. Alk. and Met. Alk.

Case

3 yo boy with diarrhea i... s:

ph – 7.23

HCO3 – 10

pCO2 – 23

AG - 13

?

...abolic?
...sis

...tion

...tion?
(Use Winter's formula)

Expected pCO2 = (1.5 * HCO3) + 8 +/-2
So,
Expected pCO2 = (1.5 * 10) + 8 +/-2
=(15) + 8 +/-2
=23 +/- 2

So, we have a metabolic acidosis with respiratory compensation

5 yo boy presents to ED with dyspnea for 3 days. ABG shows the following:

- pH – 7.33
- paCO2 – 60
- paO2 – 57
- HCO3 - 31

Acidemia or alkalemia?
Low pH = Acidemia

Primary Resp. or Metabolic disturbance?
Respiratory

Is there metabolic compensation?

Case study

15 years; old; Female pregnant with insulin dependent diabetes is admitted to the ICU after stopping insulin . She has had severe nausea and vomiting for several days & she start to be tachypnea.

ABG - PH 7.55/ $PaCO_2$- 21/ HCO_3 18/ PaO_2-70

Na-136 BUN-32

Cr-1.2 K - 3.5

Cl-70 CO_2-19

-What is/are the Acid – base imbalance she had?

Case 1

A 4 year old moderately dehydrated was admitted with a two day history of acute severe diarrhea.

Electrolyte results: Na^+ 134, K^+ 2.9, Cl^- 108, HCO_3^- 16, BUN 31,

Cr 1.5.

-ABG: pH 7.31 pCO_2 33

HCO_3 16 pO_2 93 mmHg

What is the acid base disorder

Case 2

A 12 year old female with type I DM, presents to ER with a 1 day history of nausea, vomiting, polyuria, polydypsia and vague abdominal pain. P.E. noted for deep sighing breathing, orthostatic hypotension, and dry mucous membranes.

Labs:

Na 132 , K 6.0, Cl 93, HCO_3^- 11, glucose 720, BUN 38, Cr 2.6.
UA: pH 5, SG 1.010, ketones negative, glucose positive . Plasma ketones trace.
ABG: pH 7.27 HCO_3^- 10 PCO_2 23

-What is the acid base disorder?

Case 3

A previously well 5 year old male is admitted with a complaint of severe vomiting for 5 days. Physical examination reveals postural hypotension, tachycardia, and diminished skin turgor. The laboratory finding include the following:

Na=140,K=3.4,Cl=77,HCO3-=9,Cr=2.1

ABG: pH=7.23 , PCO2= 22mmHg

Case 4

A 16 year old women with history of CHF presents with increased shortness of breath and leg swelling.

ABG: pH 7.24, PCO_2 60 mmHg, PO_2 52 HCO_3^- 27

-What is the acid base disorder?

Case 5

A 20 year old female presents with nausea, vomiting and poor oral intake 2 days prior to admission. The patient reports a 3 day history of binge drinking prior to symptoms.

Labs : Serum chemistry: Na 132, K 5.0, Cl 104, HCO_3^- 16 , BUN 25, Cr 1.3, Glu 75

ABG: pH 7.30, PCO_2 29, HCO_3^- 16, PO_2 92

Serum albumin 1.0

Case 6

6years old with Muscle dystrophy & progressive distress

ABG-PH-7.30/PaCO275/PaO2-45 &SPO2 80%

Case 7

1 month old male presents with projectile emesis .
ABG - 7.49 / 40 / 98 / 30
Na- 140 / K- 2.9 / Cl- 92 / HCO3- 32.

Case 8

A 3 year old brought to the ER at 3 am after being found unarousable on his bedroom floor, with urinary incontinence. EMS monitoring at the scene revealed sinus bradycardia. One amp of D50W and 5 mg of naloxone were given IV without response. Vital signs are stable; respiratory effort is regular, but tachypneic. He is acyanotic

- Na+=154, K=5.6, Cl=106, HCO3=5, BUN=6 creatinine=1.7, glucose=804, PO4=12.3, Ca++=9.8, NH4=160, serum osms=517
- PH=6.80, PaCO2=33, PaO2=298.

Case 9

15 years; old; Female pregnant with insulin dependent diabetes is admitted to the ICU after stopping insulin . She has had severe nausea and vomiting for several days & she start to be tachypnic.

ABG - PH 7.55/ $PaCO_2$- 21/ HCO_3 18/ PaO_2-70

Na-136 BUN-32

Cr-1.2 K - 3.5

Cl-70 CO_2-19

-What is/are the Acid – base imbalance she had?