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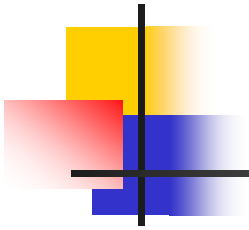

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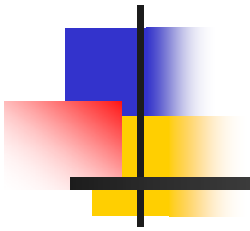


Introduction

Introduction

- Acid-base homeostasis critically affects tissue and organ performance
- Both acidosis and alkalosis can have severe and life threatening consequences

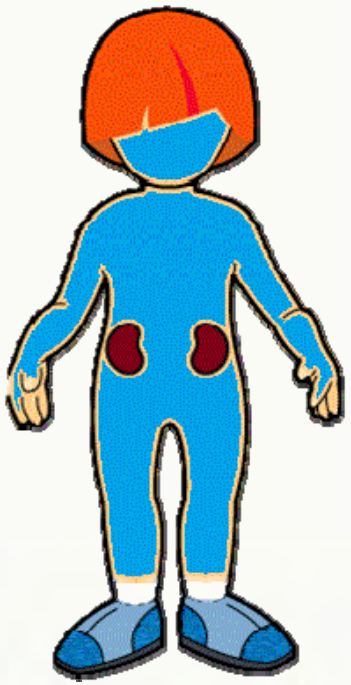
Introduction

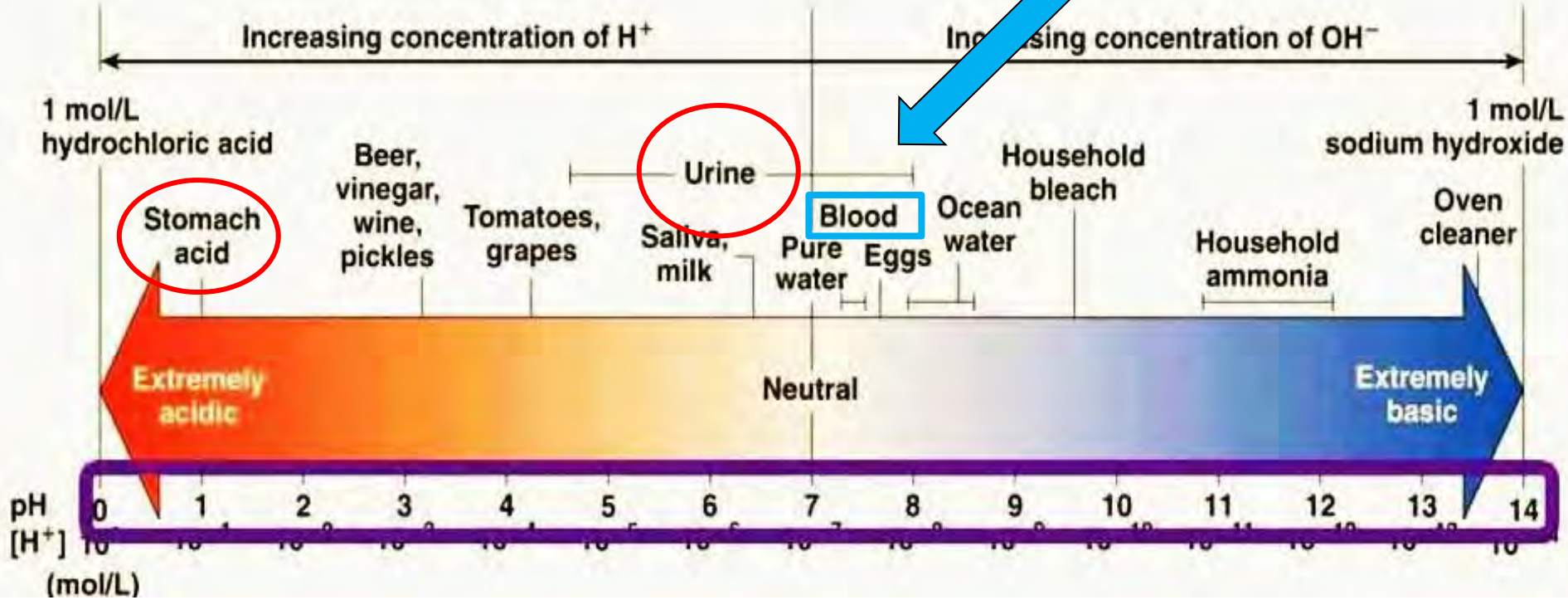
Small changes in pH can produce major disturbances:

- Enzymes
- Electrolytes
- Hormones

pH Scale

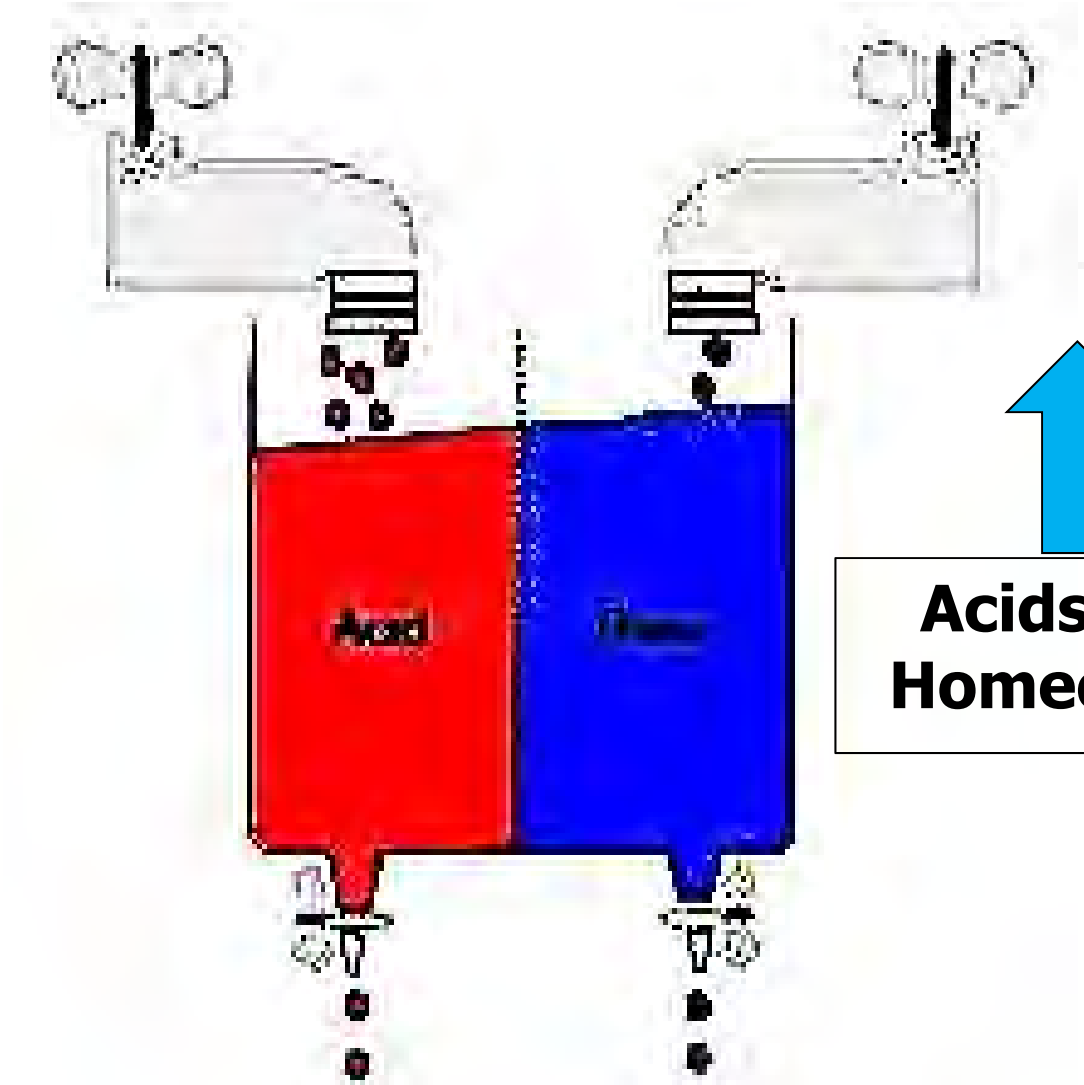
- Scale run from 0 to 14
- Acid range = Base range =





You get acidotic every day !

- **Food**
- **Drinks**
- **Metabolism**



Acids-base Homeostasis

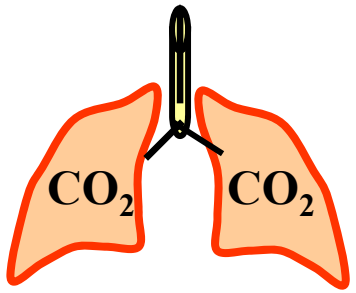
- While living, eating and drinking….there is..
- Production of 1 mmol of fixed acid/kg/day

The body produces more acids than bases

- Cellular metabolism produces CO_2.
- Metabolism of lipids and proteins produces acids.

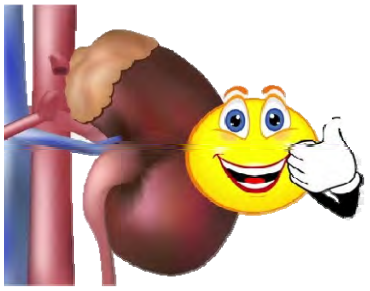
Volatile acid

$$H_2CO_3 \rightleftharpoons CO_2 + H_2O$$



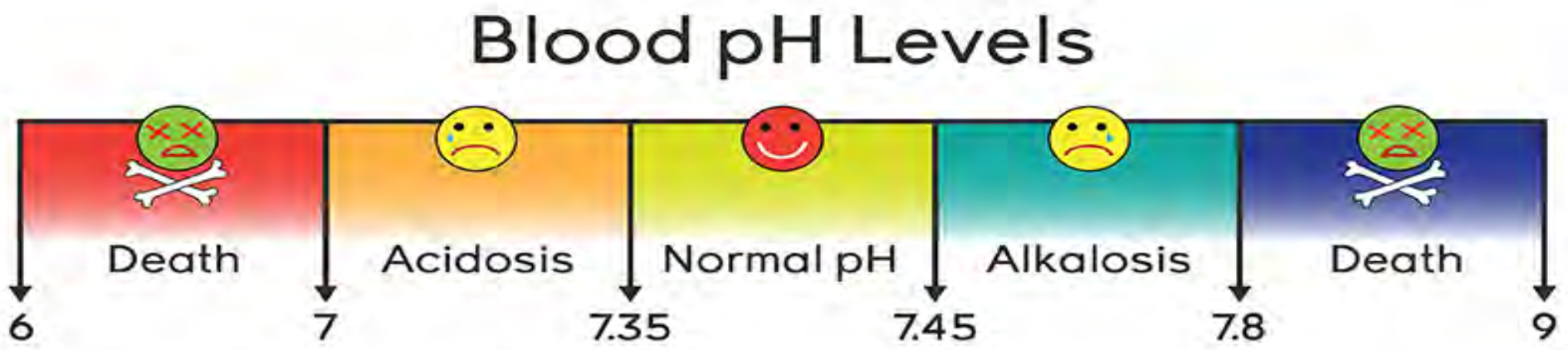
Fixed acid

H_2SO_4
H_3PO_4
Uric acid
Lactic acid
Ketone body



The Body and pH

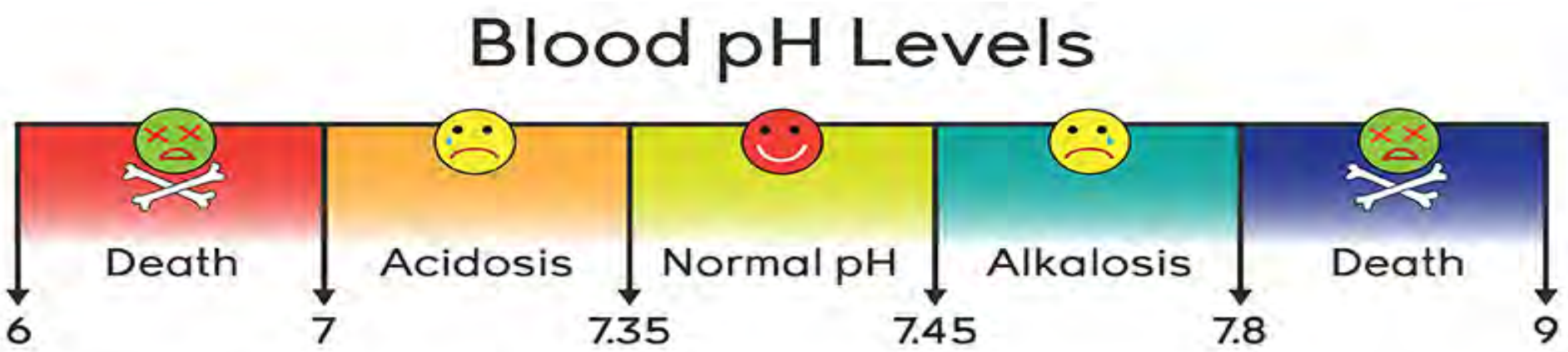
- Homeostasis of pH is tightly controlled
- Extracellular fluid = 7.4
- Blood = 7.35 – 7.45
- < 7.35: Acidosis (acidemia)
- > 7.45: Alkalosis (alkalemia)
- < 6.8 or > 8.0: death occurs



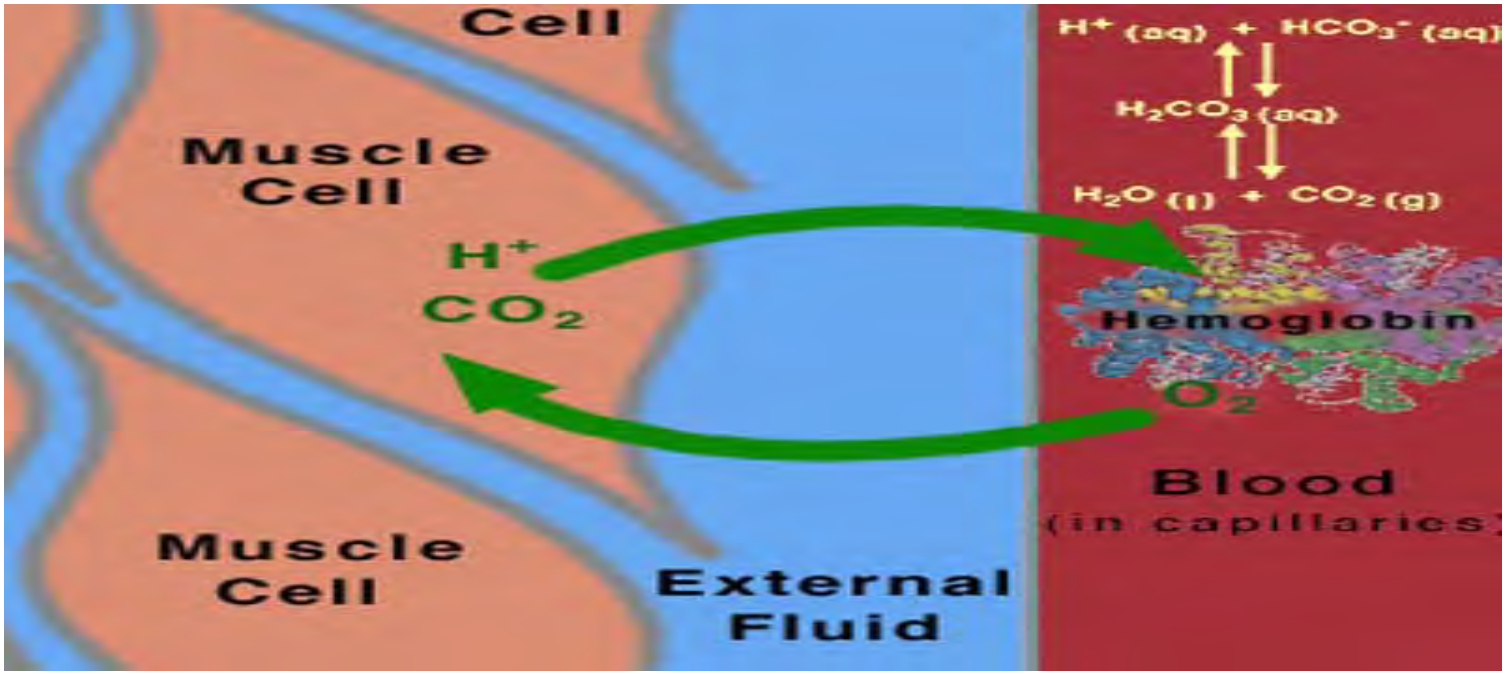
The Body and pH

The most important vital sign

RR, HR, BP



The most important pH for the body is the intracellular pH



The intracellular pH

Is maintained at about the pH of

Neutrality

(~6.8 at 37˚C)

because this is the pH at which metabolite intermediates are all

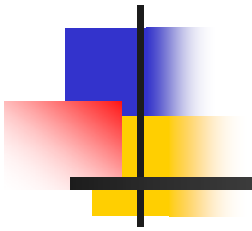
charged and trapped inside the cell

Extracellular pH is higher

- Fourfold gradient favouring exit of [H+] from the cell
- To avoid powerful effects of intracellular [H+] accumulation on metabolism

Stable intracellular pH by:

- 'Intracellular buffering'
- Adjustment of arterial pCO_2
- Loss of fixed acids from the cell into the ECF



Acid Base Physiology

pH Balance

- Blood buffers,
- Cells,
- Lungs,
- Kidneys.

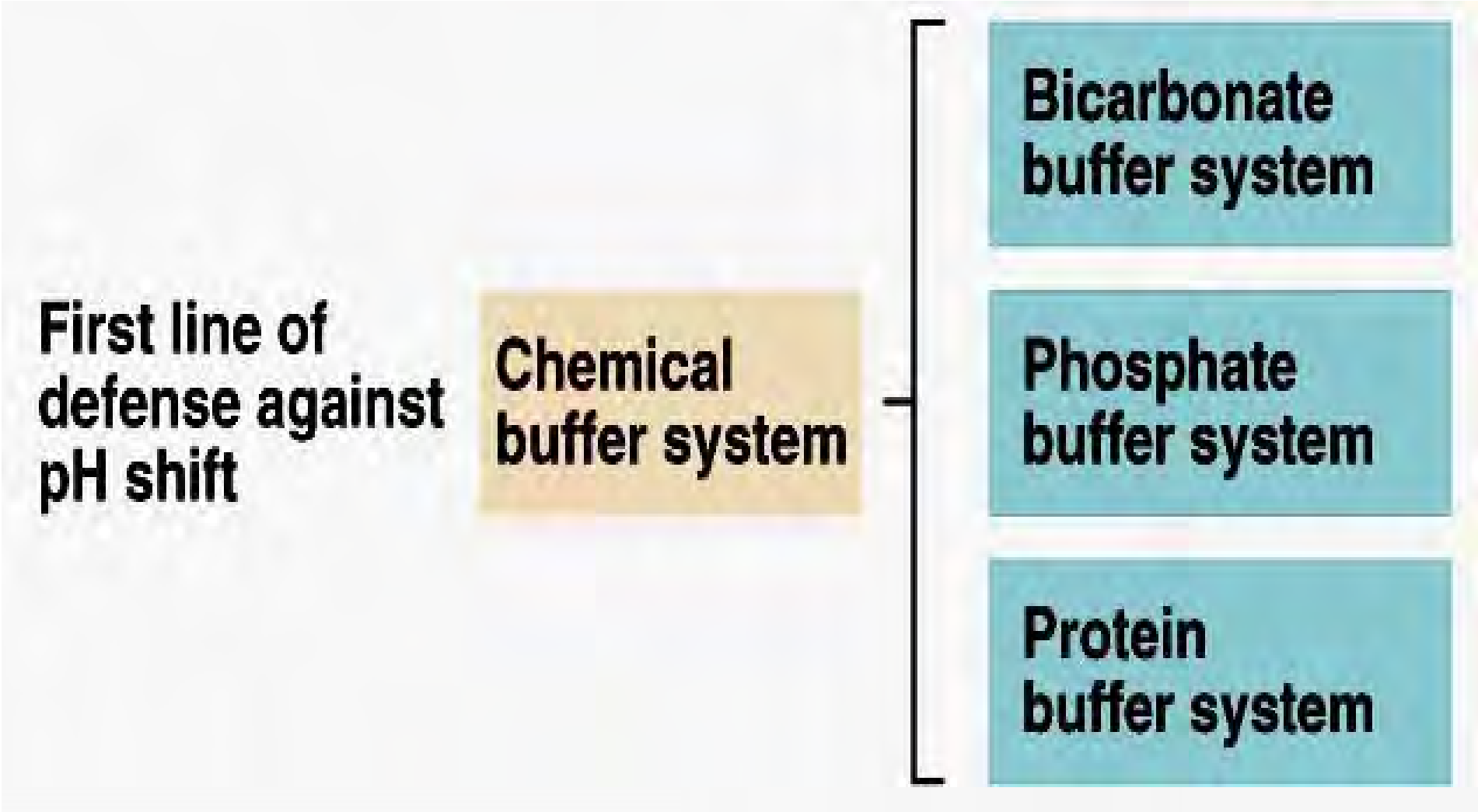
pH Balance

- **Buffering**

  occurs immediately
- **Respiratory regulation of CO_2**

  intermediate (12-24 hours)
- **Renal regulation of [H] and [HCO_3]**

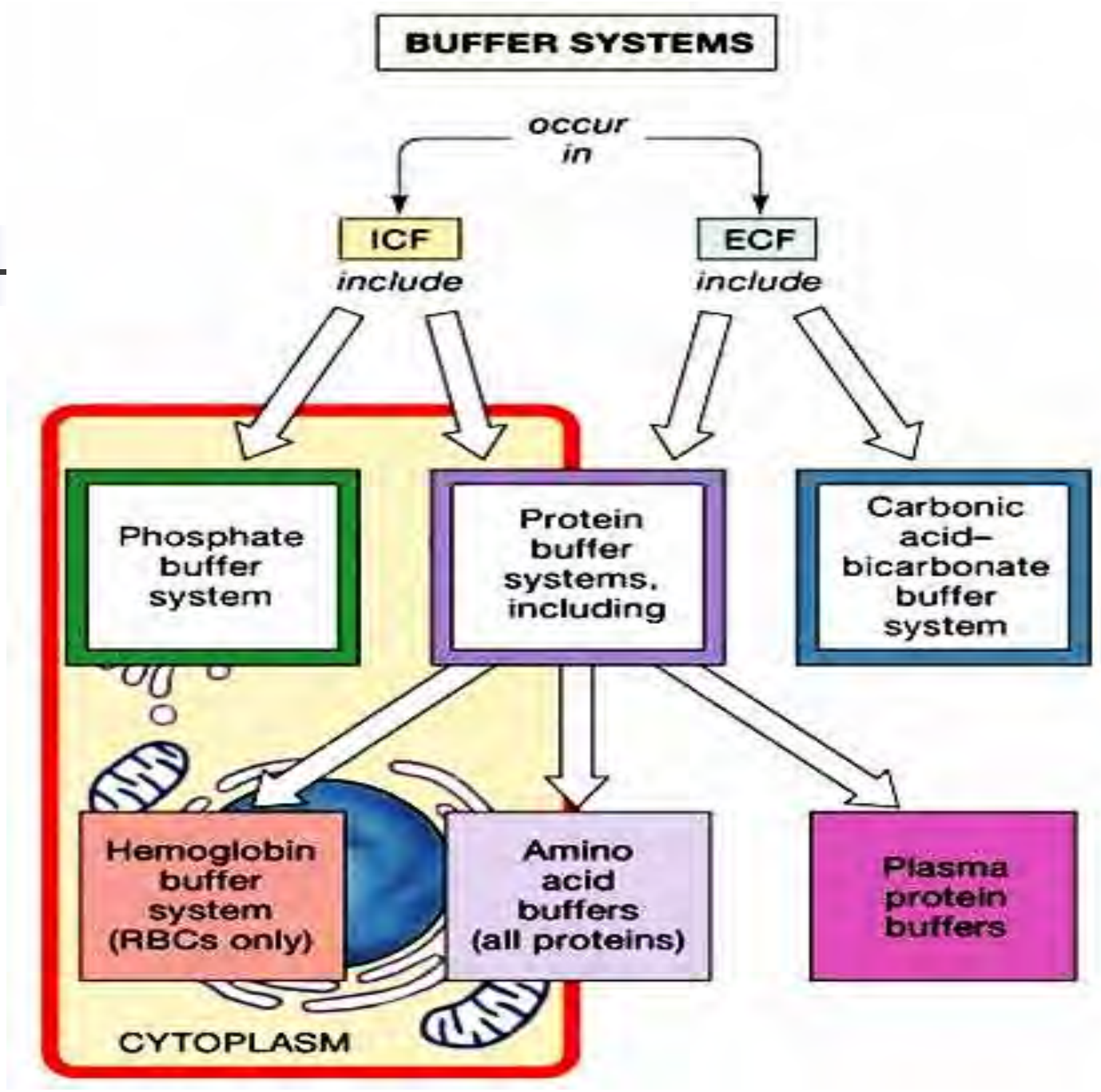
  occurs more slowly (24-72 hours)

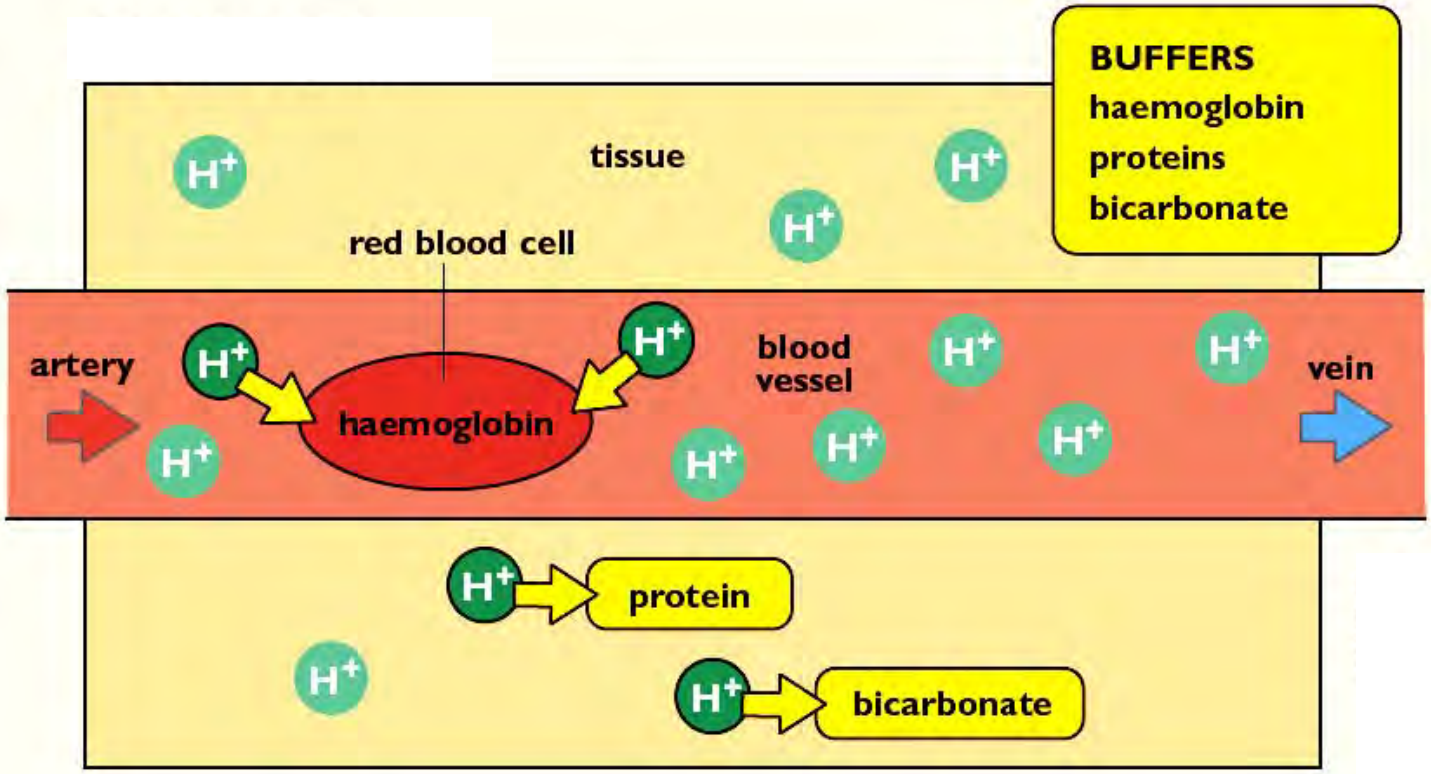

First line of defense against pH shift
Chemical buffer system
Bicarbonate buffer system
Phosphate buffer system
Protein buffer system

CARBON DIOXIDE + WATER

CARBONIC ACID

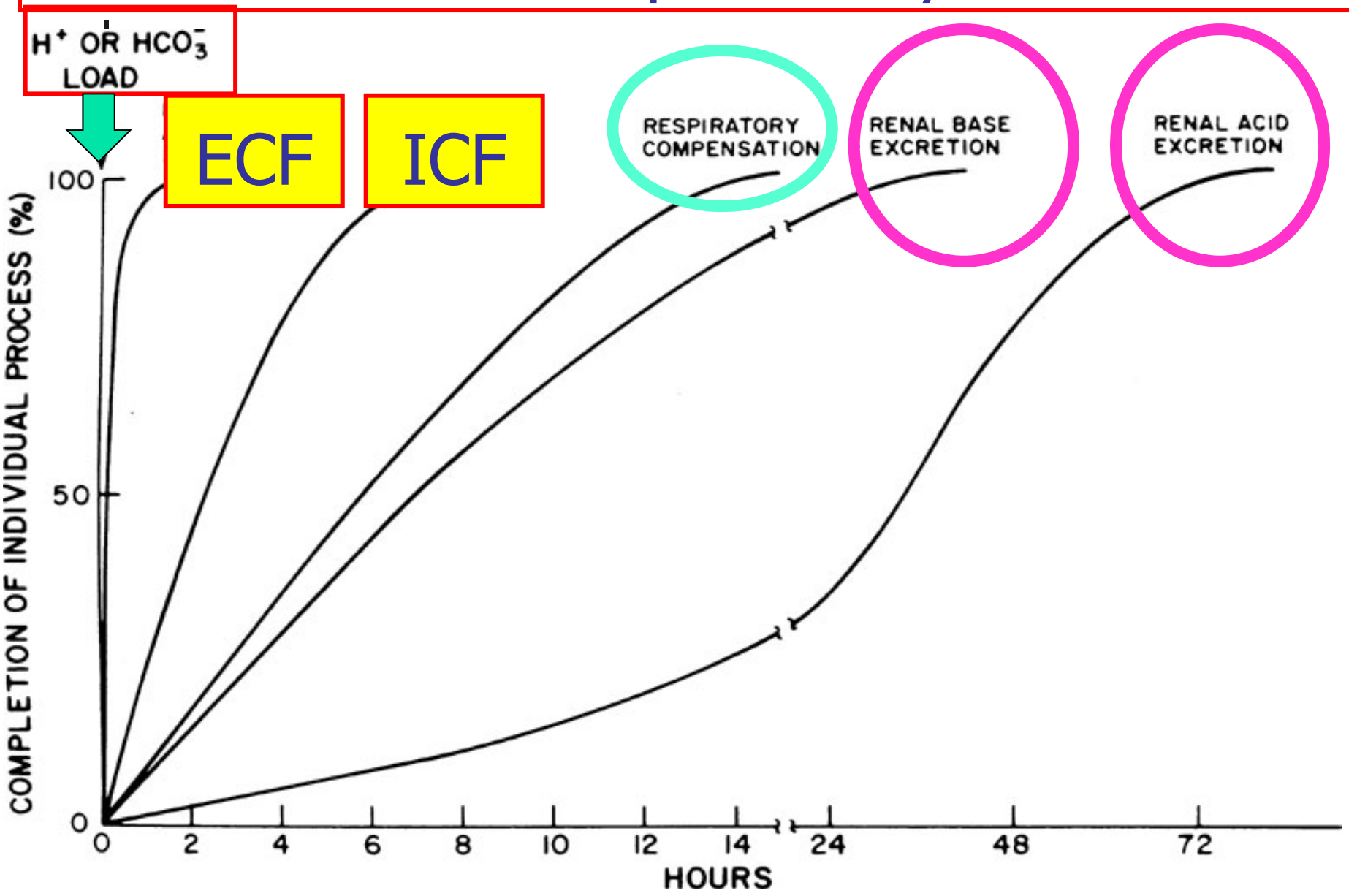
BICARBONATE
+
HYDROGEN ION


BUFFER SYSTEMS
occur in
ICF
include
ECF
include
Phosphate buffer system
Protein buffer systems, including
Carbonic acid–bicarbonate buffer system
Hemoglobin buffer system (RBCs only)
Amino acid buffers (all proteins)
Plasma protein buffers
CYTOPLASM

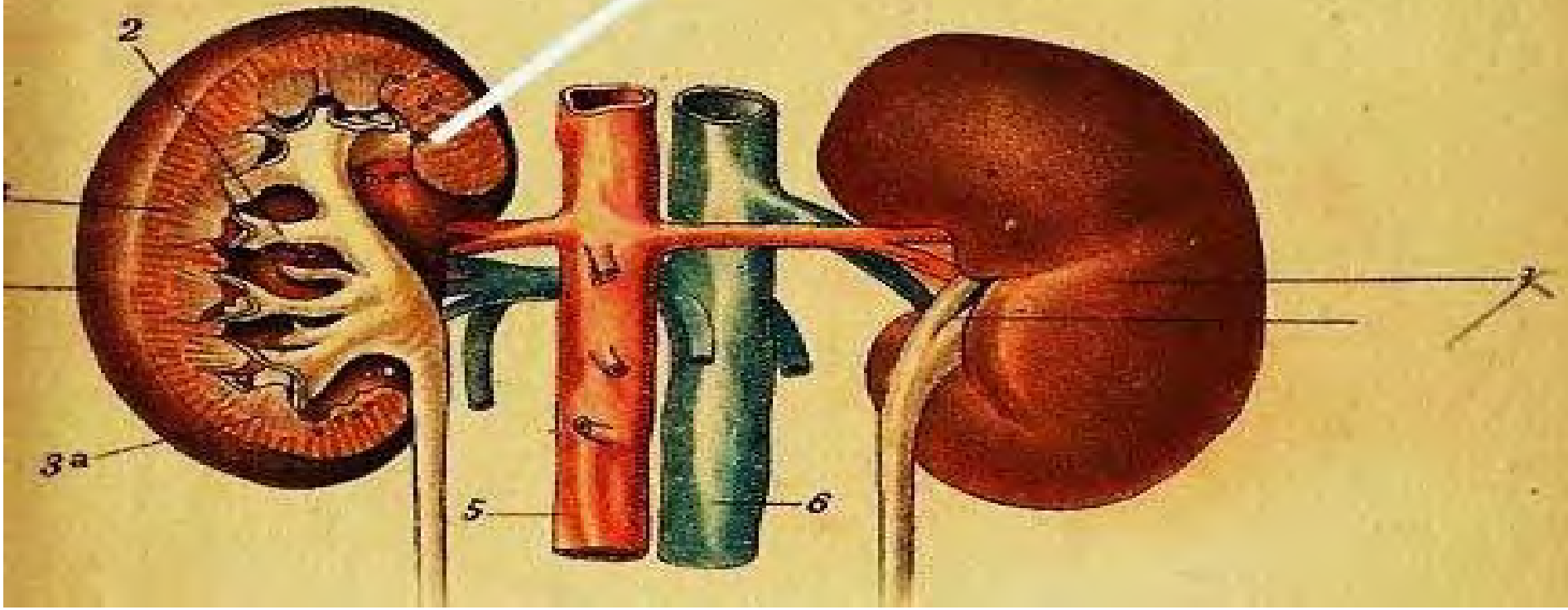


Buffers capture free [H+]

Time course of compensatory mechanisms



I deal with anything you put in me, so give me a break!



Renal system

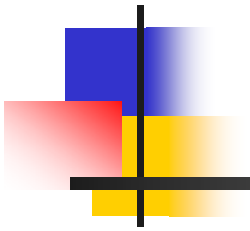
Proximal tubular mechanisms:

- Reabsorption of filtered HCO_3^-
- Production of NH_4^+

Renal system

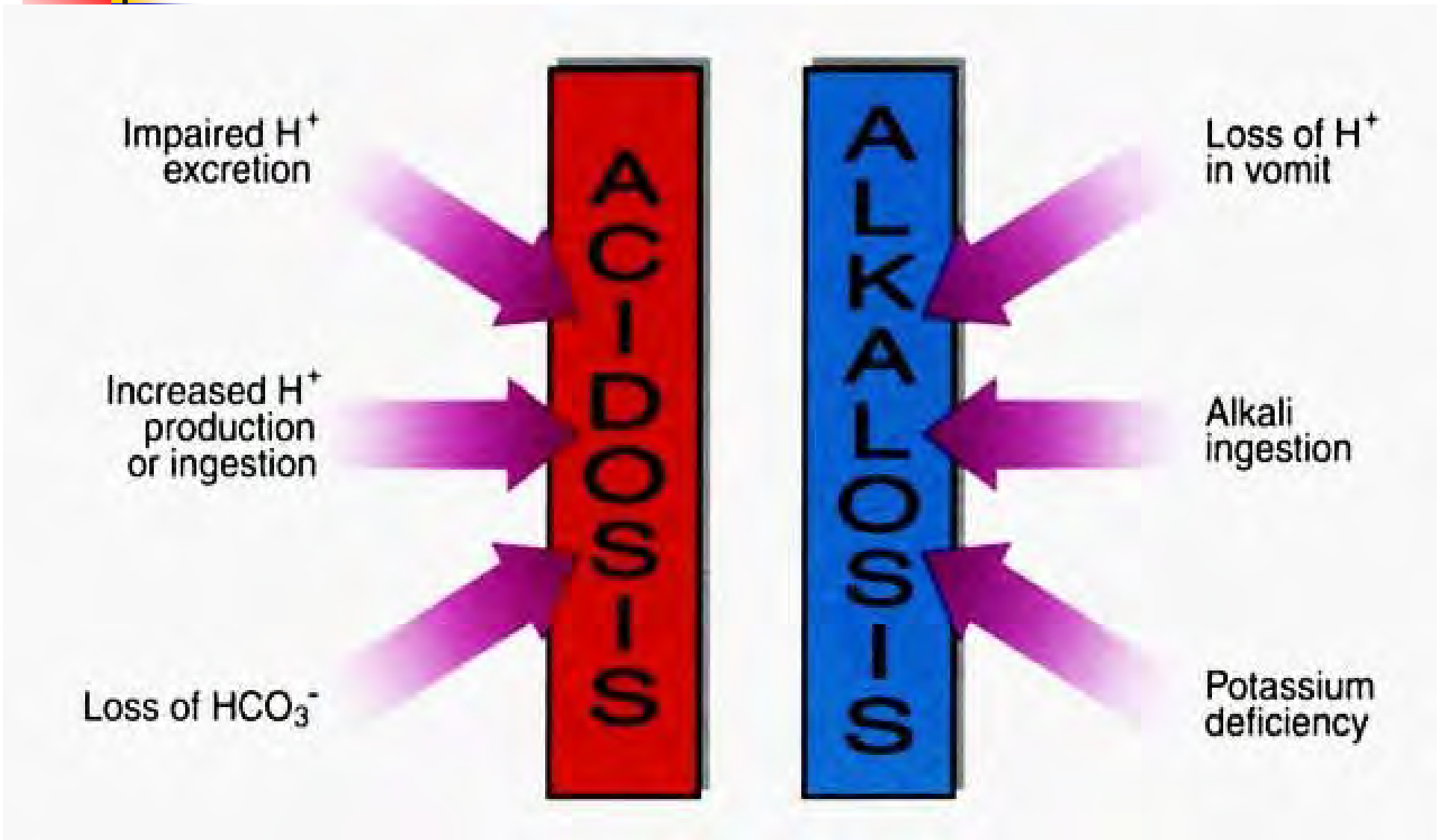
Distal tubular mechanisms

- Net excretion of H^+
- Addition of **NH_4^+** to luminal fluid
- Reabsorption of remaining **HCO_3^-**

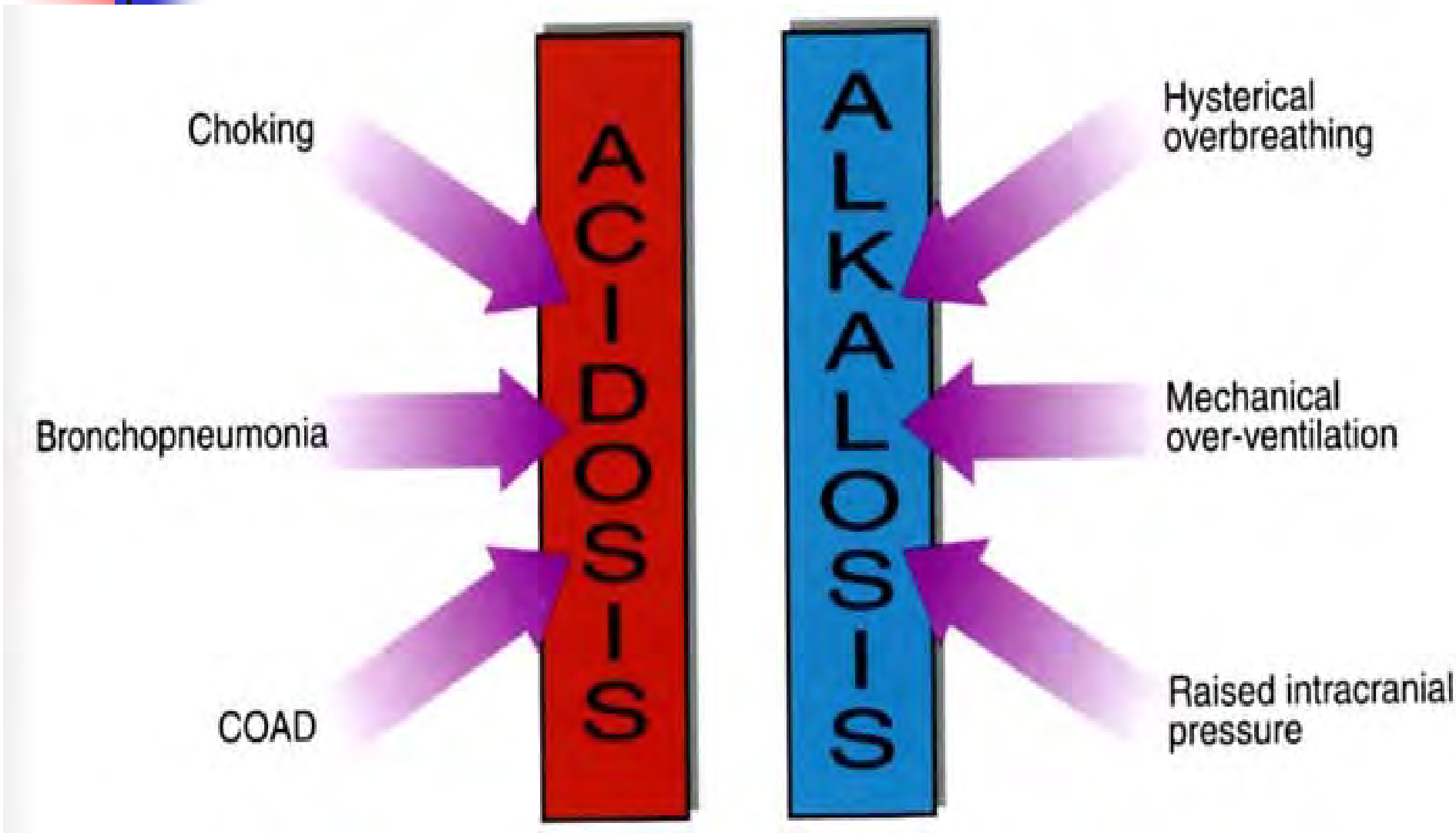


Acid Base Pathology

Causes of metabolic acid-base disorders



Causes of respiratory acid-base disorders



Pneumonics

for pneumonic lovers

- **MUD PILERS : AG Acidosis**
- **USED CAR : Non AG**
- **CLEVER PD : M. Alkalosis**
- **CHAMPS : Resp. Alkalosis**

Anion gap Acidosis
"MUD PILERS"

- **M ethanol**
- **Uremia**
- **DKA**

- **P araldehyde**
- **I ron, Isoniazid (INH)**
- **Lactic Acidosis**
- **E thanol, Ethylene glycol**
- **R habdomyolsis**
- **Salicylates, NSAID**

Causes of Non-AG Acidosis?
USED CAR

U reteral diversion,

S mall bowel fistula,

E xtra alimentation (hyperalimentation)

Diarrhea,

C arbonic anhydrase inhibitor,

A drenal insufficiency,

Renal tubular acidosis.

Pathophysiology

- **Primary effect of a disease**
  - **CO2 ► Resp.**
  - **HCO3 ► Metabolic**
- **Compensatory effect:**
  1. **Rapid respiratory**
  2. **Slower renal**
- **Final Effect.**

Primary disorder	*Compensatory process*
HCO3 decrease	Hyperventilation (lower $PaCO_2$)
HCO3 increase	Hypoventilation (raise $PaCO_2$)
CO2 decrease	Renal HCO_3^- excretion
CO2 increase	Renal HCO_3^- retention

Pathophysiology

- Primary effect of a disease
  - CO2 ▶ Resp.
  - HCO3 ▶ Metabolic
- Compensatory effect:
  1. Rapid respiratory
  2. Slower renal

- Good
- Abnormal

- **Final Effect.**

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 the serum $[HCO_3^-]$**
Respiratory acidosis	
Acute 1	**$[HCO_3^-]$ increases by 1 for each 10 mm Hg increase in the PCO_2**
Chronic 3	**$[HCO_3^-]$ increases by 3.5 for each 10 mm Hg increase in the PCO_2**
Respiratory alkalosis	
Acute 2	**$[HCO_3^-]$ falls by 2 for each 10 mm Hg decrease in the PCO_2**
Chronic**** 4	**$[HCO_3^-]$ falls by 4 for each 10 mm Hg decrease in the PCO_2**

Compensatory process

- Not a primary acid base disorder
- Not termed acidosis or alkalosis.
- It is a change that follows a primary disorder.
- It attempts to restore the blood pH to normal
- Pathophysiologic principle: body does not fully compensate even for chronic acid-base disorders

Compensatory process

1. **Compensatory organ.**
2. **Mixed A-B disorder.**

Compensatory process

- **Determine whether the patient's compensation is appropriate?**

1. If appropriate, then a simple acid-base disorder is present.

2. If not appropriate, then a mixed disorder is present.

Compensatory process

The identity of the second disorder is determined by deciding whether the compensation is

too little or **too much**

compared with what was expected.

Compensatory process

If a mixed respiratory disturbance is occurring with the metabolic acidosis,

it would be defined by the direction

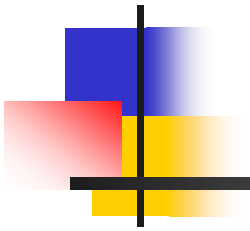
PCO_2 varies outside the range predicted by Winter's formula

not by

PCO_2 variation from the normal value of 40.

Example to illustrate how to use Winter's formula to assess respiratory response to metabolic acidosis.

- If HCO3 is 10 mEq/L,
- PCO2 should be between 21 and 25 according to Winter's formula.
- If PCO2 falls outside this range, then an additional respiratory disturbance must be occurring concurrently.
- If PCO2 < 21, respiratory alkalosis.
- If PCO2 > 25, respiratory acidosis.



Acid Base Anatomy

The anatomy of ABG

The Henderson-Hasselbalch equation

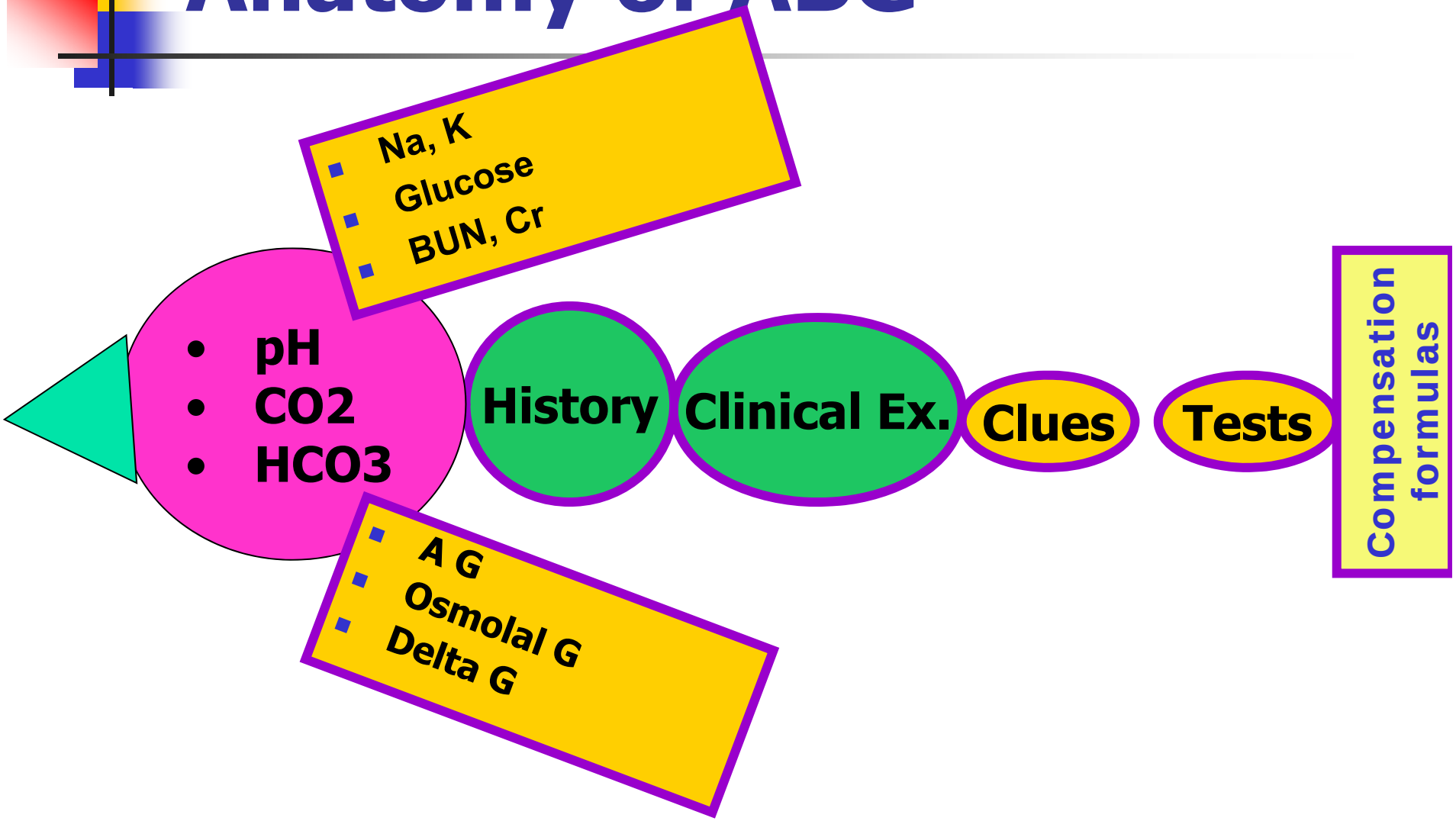
$$[H+] = 24 \times PCO2/HCO3$$

The anatomy of ABG

The Henderson-Hasselbalch equation

$$[H+] = 24 \times \frac{Lung}{Kidney}$$

Anatomy of ABG




clue

Common clinical states and associated acid-base disorders

Pulmonary embolus	Respiratory alkalosis
Cirrhosis	Respiratory alkalosis
Sepsis	Respiratory alkalosis, metabolic acidosis
Vomiting	Metabolic alkalosis
Diuretic use	Metabolic alkalosis
Severe diarrhea	Metabolic acidosis
Hypotension	Metabolic acidosis
Renal failure	Metabolic acidosis
COPD	Respiratory acidosis

Metabolic acidosis with hypoglycemia

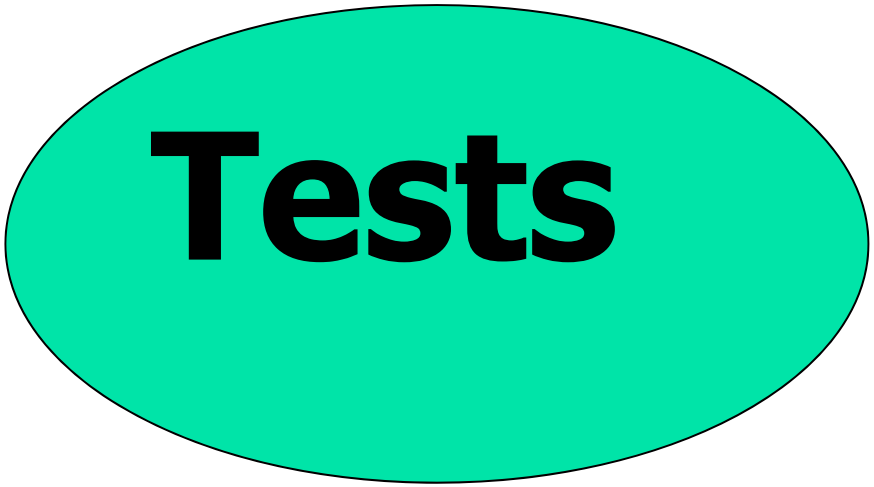
- Starvation
- Adrenal insufficiency
- Liver failure
- Reye Syndrome
- Inborn error of metabolism

Metabolic acidosis with glucosuria

- DKA
- Proximal RTA
- Inborn error of metabolism

Hyperkalemia & Acidosis

- Renal insufficiency
- Aldosterone deficiency
- Type IV RTA


Tests

Tests

- Urine analysis.
- Spot urine.
- Chemistries **(BUN, Cr, glucose).**
- **Renal US (Nephrocalcinosis, ESKD).**

Tools

1. Accuracy ruler
2. Gaps
3. Corrected HCO3

Tools

pH	6.9	7	7.1	7.2	7.3	7.4	7.5	7.6	7.7
H^+	125	100	80	60	50	40	30	25	20

- Anion Gap
- Osmolal Gap
- Delta Anion Gap

- Corrected HCO3

Anion Gap

What is an anion gap?

Excellent tool

for narrowing the D.D.

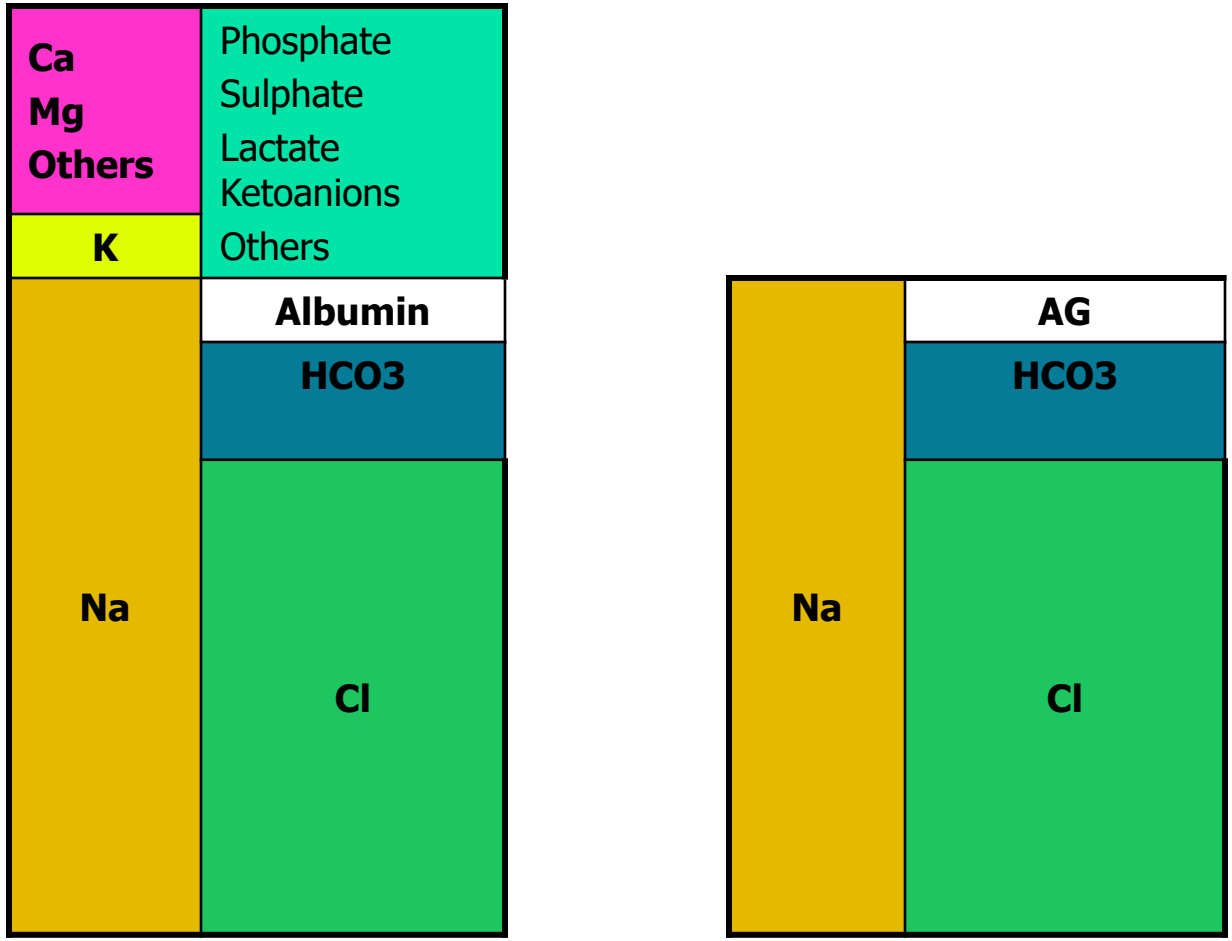
of

metabolic acidosis.

AG

- Is not real.
- It is apparent gap.
- Lab. does not measure all ionic components in serum
- It represents the difference between unmeasured cations & anions

AG represents anions other than bicarbonate & chloride required to balance the positive charge of Na



Causes of Non-AG Acidosis? (Hyperchloremic)

- **GIT loss of HCO3**
  (Diarrhea)
- **Renal loss of HCO3**
  (RTA)

Causes of AG Acidosis?

↓ **EXCRETION OF ACIDS**

1. RENAL FAILURE

↑ **PRODUCTION OF ACIDS**

1. LACTIC ACIDOSIS
2. KETOACIDOSIS (DKA, Alcoholic, Starvation)
3. INTOXICATIONS

***Inborn errors of metabolism

Intoxications Causing AG Acidosis?

Methanol

Ethylene glycol, Ethanol

Paraldehyde

Salicylate, NSAID

Osmolal Gap

Normal Osmolal Gap

- **Measured serum osmolality**
- **> calculated serum osmolality by**
- **= 10-15 mmol/L**

Measured — Calculated serum osmolality = 10-15

Osmolal Gap

Is very helpful to recognize the intoxications

Increased Osmolal Gap

> 25 mOsm/L

Ingestions Causing High Osmolal Gap

- Ethanol
- Methanol
- Ethylene glycol

Corrected HCO3

Delta HCO_3

- Calculate delta anion gap

  (Patient's AG - 12)

- Add it to the measured HCO3

  (Corrected HCO3)

Corrected HCO3

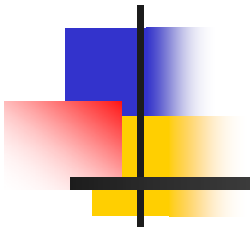
= measured HCO3 + (AG - 12)

Corrected HCO3

If varies significantly above or below 24 then a mixed metabolic disturbance exists.

Corrected HCO3

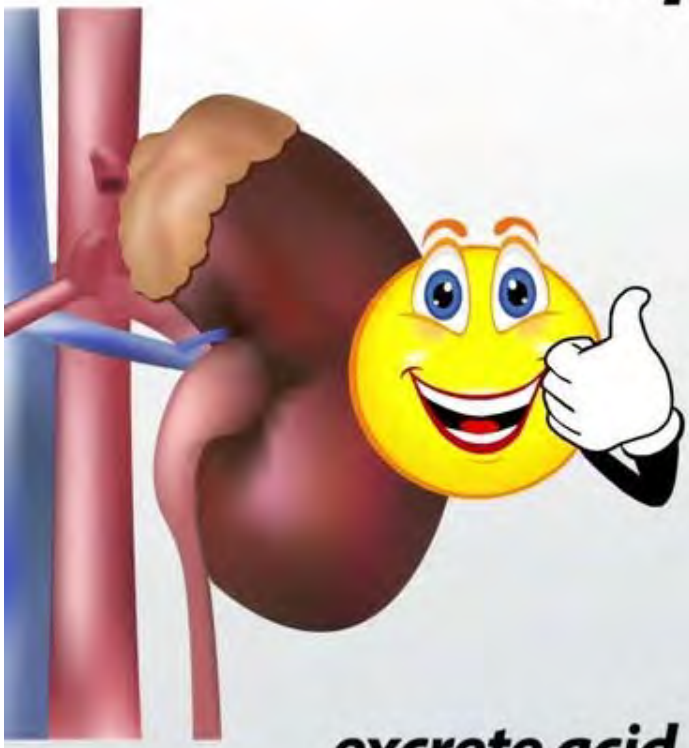
- **> 30** = metabolic alkalosis co-exists.
- **< 24** = non-gap acidosis co-exists.



Acid Base Disorders

HOW THE BODY TRIES TO COMPENSATE

respiratory acidosis



excrete acid
conserve bicarbonate

Hypoventilation

RESPIRATORY ACIDOSIS

- Respiratory acidosis is a primary rise in pCO2 with a compensatory rise in plasma [HCO3 -].
- Increased pCO2 occurs in clinical situations in which decreased alveolar ventilation occurs.

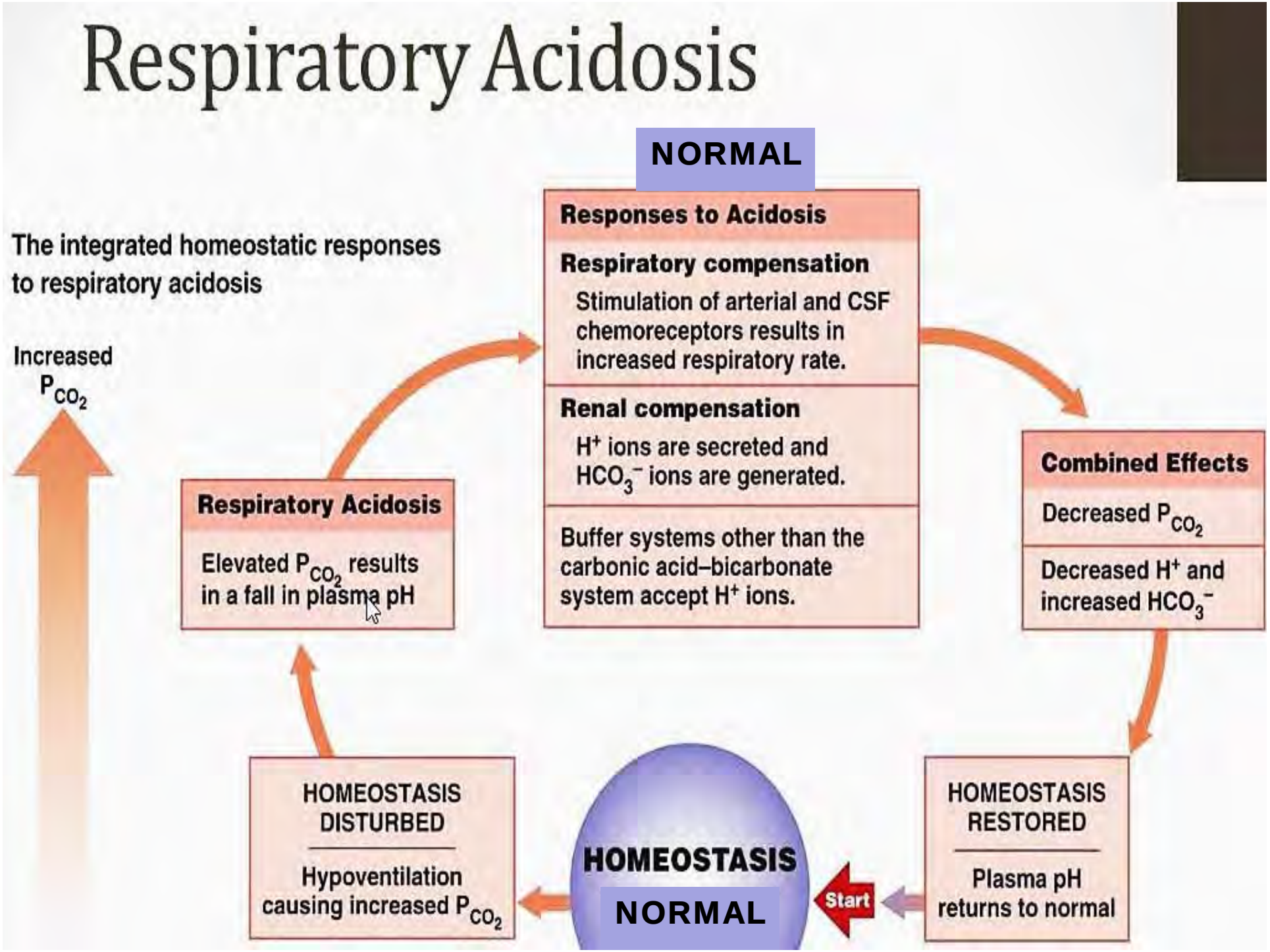
RESPIRATORY ACIDOSIS
Compensation

- **Acute RA - buffering only!**
  - **99% of this buffering occurs intracellular**
  - **bicarbonate system is not responsible for any buffering** of a respiratory acid-base disorder - system cannot buffer itself

RESPIRATORY ACIDOSIS
Compensation

- **Chronic RA - renal bicarbonate retention**
  - 3 or 4 days to reach its maximum

Respiratory Acidosis



A rise in arterial pCO_2
is a potent stimulus
to ventilation
so a respiratory acidosis will
rapidly correct
unless some abnormal factor
is maintaining the hypoventilation

RESPIRATORY ACIDOSIS

Etiology

- **Airway Obstruction**
  - **a.** Chronic (COPD)
  - **b.** Acute (asthma)
  - **c.** Upper airway obstruction
  - **d.** Obstructive sleep apnea
- **Thoracic/Pulmonary Disorders**
  - **a.** Bony thoracic cage: Flail chest, kyphoscoliosis
  - **b.** Parenchymal lesions: Pneumothorax, pulmonary edema.
  - **c.** Large pleural effusions
  - **d.** Scleroderma
  - **e.** Marked obesity (Pickwickian syndrome)
- **Central Nervous System** Drugs, Sedative, Central sleep apnea
- **Neuromuscular Abnormalities with Ventilatory Failure**

RESPIRATORY ACIDOSIS
metabolic effects (hypercapnia!)

- Depression of intracellular metabolism
- Cerebral effects
- CVS effects
- hypoxemia

RESPIRATORY ACIDOSIS
Signs and Symptoms

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

RESPIRATORY ACIDOSIS
Treatment

The pCO_2 rapidly returns to normal with restoration of adequate alveolar ventilation

RESPIRATORY ACIDOSIS
Treatment

- ***Correct underlying etiology***
  1. *Reverse narcotic sedation with naloxone (Narcan), etc..*
  2. *Reverse Hypokalemia.*
  3. *Remove airway obstruction e.g. Adenoid……*
  4. *Treat pulmonary infection, edema, effusion…*
- ***Improve Ventilation:***
  1. *O2.*
  2. *Intubation.*
  3. *Ventilatory support.*

RESPIRATORY ACIDOSIS
Treatment

Rapid fall in pCO_2 (especially if the RA has been present for some time) can result in:

- **severe hypotension**
- **'post hypercapnic alkalosis'**

Metabolic acidosis

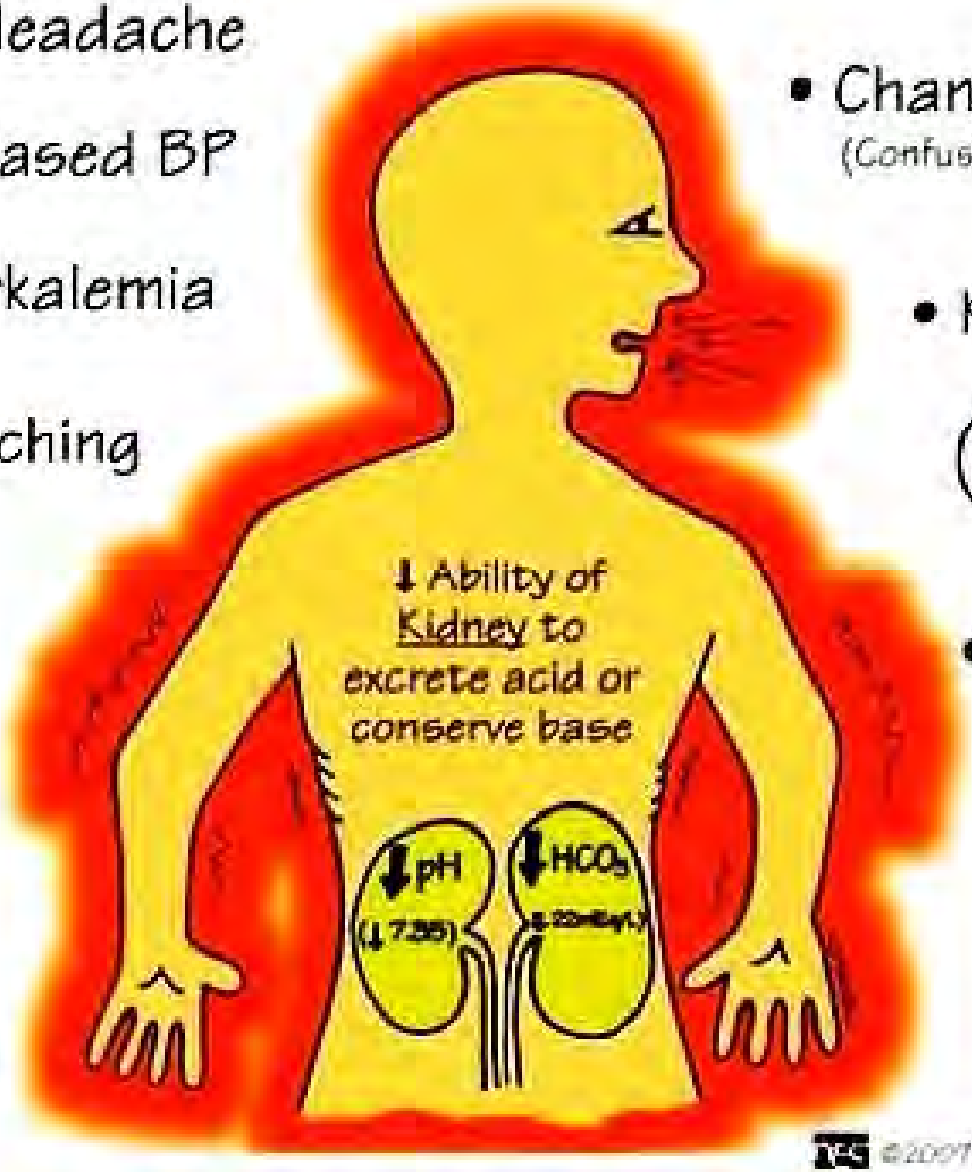
- primary disorder is ↓$\mathbf{HCO_3^-}$:
  - ↑ fixed [H^+] = high AG
  - loss or ↓ reabsorption of HCO_3^- = normal AG

Metabolic Acidosis

- Causes:
  - Loss of bicarbonate through diarrhea or renal dysfunction
  - Accumulation of acids (lactic acid or ketones)
  - Failure of kidneys to excrete H+

METABOLIC ACIDOSIS

- Headache
- Decreased BP
- Hyperkalemia
- Muscle Twitching
- Warm, Flushed Skin (Vasodilation)
- Nausea, Vomiting Diarrhea



- Changes in LOC (Confusion, ↑drowsiness)
- Kussmaul Respirations (Compensatory Hyperventilation)
- Causes:
  - DKA
  - Severe Diarrhea
  - Renal Failure
  - Shock

Symptoms of Metabolic Acidosis

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

Acidosis

Clinical effects of severe acidosis: pH <7.2

1. Decreased myocardial contractility & COP,
2. Heart failure,
3. Hypotension,
4. Decreased hepatic & renal blood flow,
5. Tissue hypoxia,
6. Pulmonary edema.

POTASSIUM LEVELS IN ACIDOSIS

Potassium Goes Up
In Acidosis

Treatment of Metabolic Acidosis

1. Correct any underlying disorder (diarrhea, etc).

2. Treatment with bicarbonate should be reserved for severe metabolic acidosis.

If the pH <7.20, correct with sodium bicarbonate.

3. Replace with one-half the total amount of bicarbonate over 8-12 h and reevaluate.

- Be aware of sodium & volume overload during replacement.
- Isotonic bicarbonate drip.

RESPIRATORY ALKALOSIS

- Respiratory alkalosis is a primary fall in pCO2 with a compensatory decrease in plasma [HCO3 -].
- Respiratory alkalosis occurs with hyperventilation.
- Most common acid-base imbalance

RESPIRATORY ALKALOSIS

Etiology "Hyperventilation"

1. Central stimulation

- Anxiety, pain
- Head trauma
- Tumors
- Salicylate overdose
- Fever, early sepsis

2. Peripheral stimulation

- CHF (mild)
- Interstitial lung disease
- Early Pneumonia
- High Altitude
- Hypoxemia

3. Miscellaneous

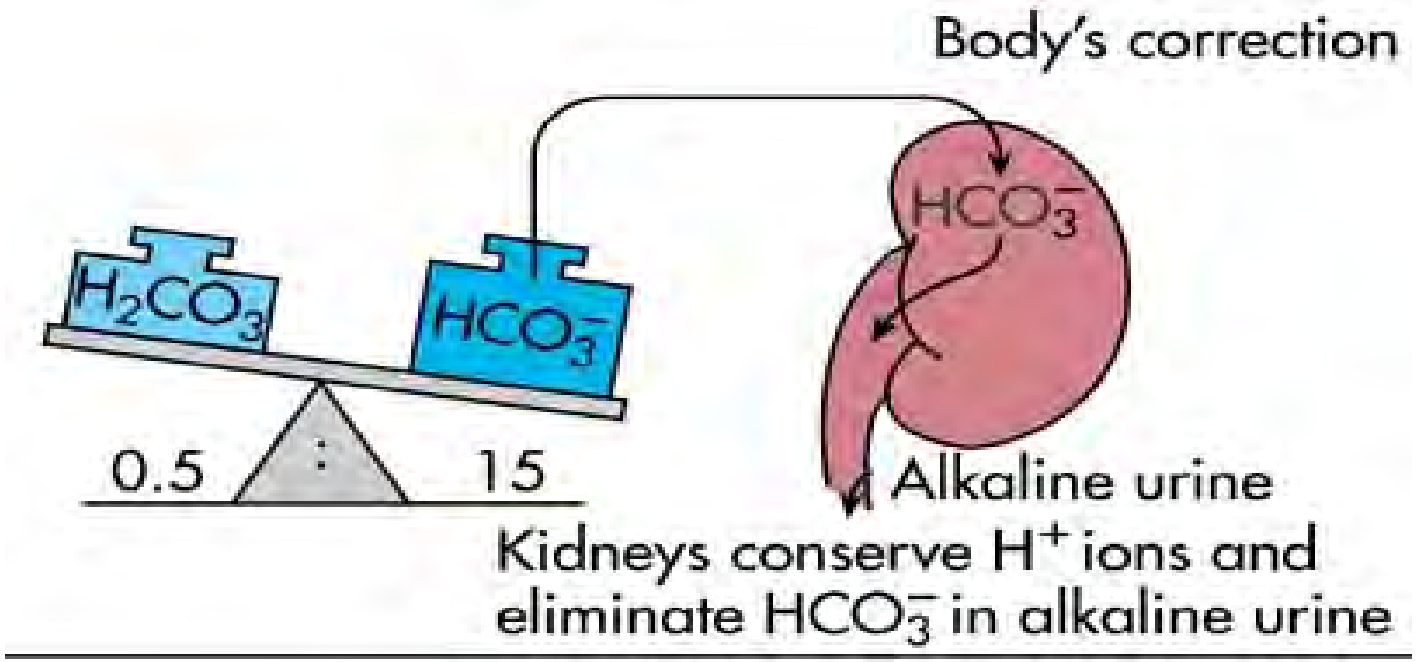
- Hepatic insufficiency
- Pregnancy
- Progesterone
- Hyperthyroidism
- Iatrogenic mechanical overventilation

RESPIRATORY ALKALOSIS
Treatment

- **Correct the underlying disorder.**
- *Hyperventilation Syndrome: Best treated by having the patient rebreathe into a paper bag to increase pCO2.*

Compensation of Respiratory Alkalosis

- **Kidneys conserve hydrogen ion**
- **Excrete bicarbonate ion**



General rule for the respiratory response to a metabolic alkalosis:

A patient will increase PCO_2 above 40 but not greater than

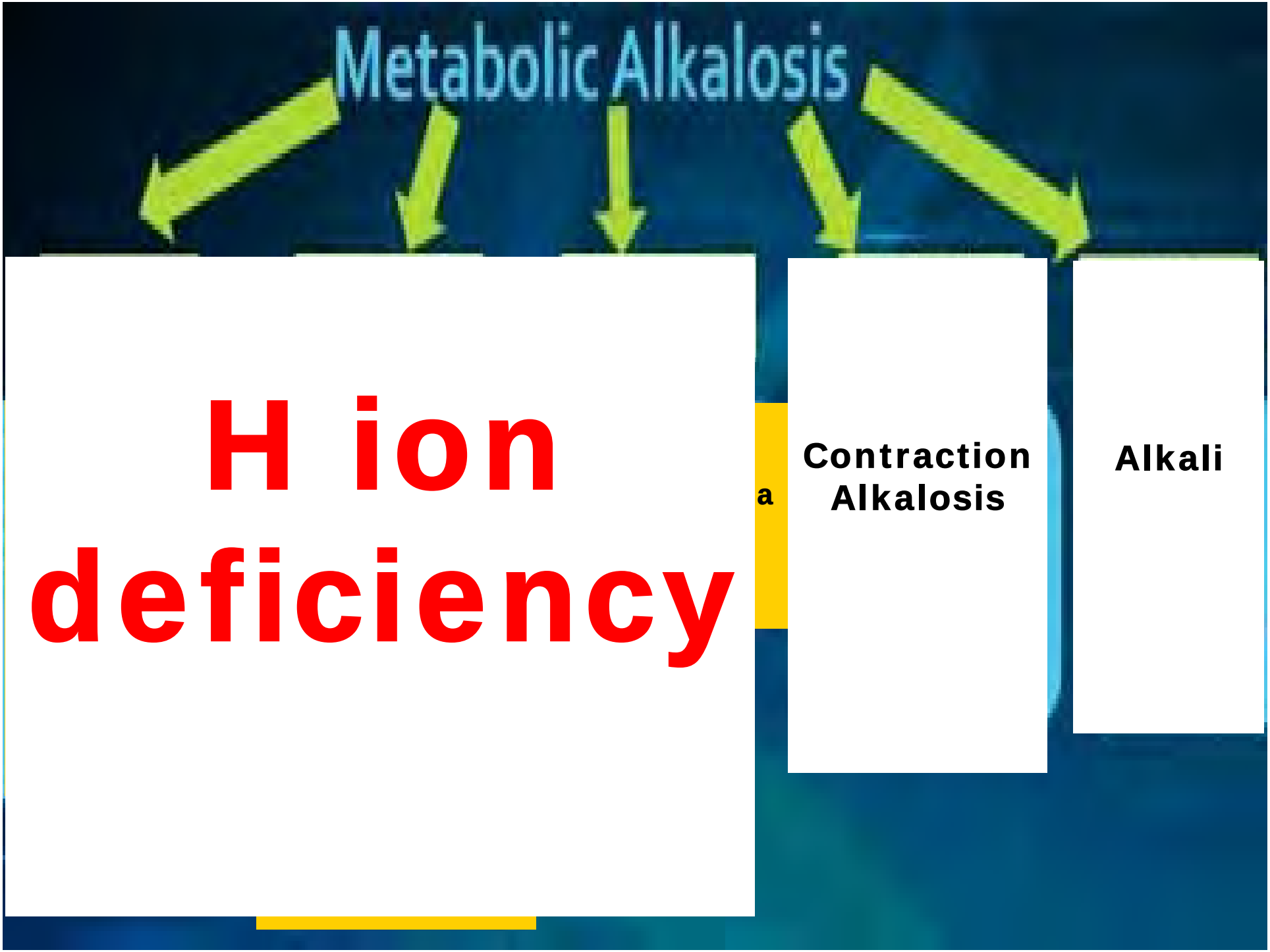
50-55

to compensate for a

metabolic alkalosis

Metabolic Alkalosis

- **Bicarbonate excess** -
- concentration in blood is greater than 26 mEq/L


Metabolic Alkalosis
H ion deficiency
a
Contraction Alkalosis
Alkali

Causes of Metabolic Alkalosis

- Vomiting
- Diuretics.
- Severe dehydration.
- Excess alkali administration.
- Cushing’s syndrome.
- Conn’s syndrome.
- Bartter syndrome.

Metabolic Alkalosis

Metabolic alkalosis in children is most commonly secondary to emesis

or

diuretic use.

Alkalosis

- Alkalosis causes over excitability of the central and peripheral nervous systems.

- It can cause :
  - Nervousness, numbness, lightheadedness
  - muscle spasms or tetany
  - Convulsions
  - Loss of consciousness
  - Death

Urinary Chloride

Spot urine Cl^- less than 10 mEq/L

- ✓ often associated with volume depletion
- ✓ respond to saline infusion
- ✓ common causes - previous thiazide diuretic therapy, vomiting (90% of cases)

Urinary Chloride

Spot urine Cl^- greater than 20 mEq/L

- ✓ often associated with volume expansion & hypokalemia
- ✓ resistant to therapy with saline infusion
- ✓ causes:
  1) **excess aldosterone,**
  2) **severe K^+ deficiency,**
  3) **current diuretic therapy,**
  4) **Bartter syndrome**

Hypokalemia

Clue

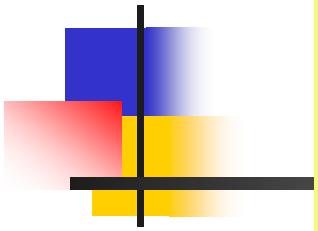
knowmedge

Metabolic Acidosis

Diarrhea
RTA I, II

Treatment of Metabolic Alkalosis

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



Stepwise Approach to Acid-Base Disorders

First question

- **Is there a lab error?**

Stepwise approach to acid-base disorders

- **Step 1:** Acidemic or Alkalemic?
- **Step 2:** Respiratory or metabolic?
- **Step 3:** Respiratory, acute or chronic?
- **Step 4:** Metabolic acidosis, AG, Osmolal G?
- **Step 5:** AG acidosis, mixed? Corrected HCO3!!!
- **Step 6:** Assess the normal compensation.

Patient

- **pH 7.1**
- **Pco2 40**
- **Hco3 12**
- **AG 12**

$(H^+) = 24 \times pCO_2 / HCO_3 = 80$

pH	7	7.1	7.2	7.3	7.4	7.5	7.6
H^+	100	80	60	50	40	30	25

What are the abnormalities?

1) **Metabolic acidosis**
2) **Normal AG**

Hypoventilation (expected 24-28)

How would your Dx produce hypoventilation?

1) **Hypokalemia**

The Rules

- Look at the pH:
- Whichever side of 7.40 the pH is on, the process that caused it to shift to that side is the primary abnormality
- Principle: the body doesn't fully compensate for primary acid-base disorders

The Rules

- Calculate the anion gap: Na – (Cl + HCO3)
- if AG is **>20**,
  - ✓ there is a primary metabolic acidosis
  - ✓ **regardless of pH or HCO3**
- Principle: the body doesn't generate a large anion gap to compensate for a primary disorder

The Rules

- Calculate the delta AG,
- Add to measured HCO3,
- if **>30**, there is metabolic alkalosis;
- if **<24**, there is non-gap metabolic acidosis

Examples

Case 1

- 3 yrs. boy with diarrhea is evaluated in the ER. Initial ABG

ph – 7.23

HCO3 – 10

pCO2 – 23

AG - 13

Is

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

So, we have a non gap metabolic acidosis with respiratory compensation

Case 2

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

pH – 7.35

paCO2 – 60

paO2 – 57

HCO3 - 31

So, this is

1. Chronic resp. acidosis with appropriate compansation

2. Mixed acute resp. acidosis with metabolic alkalosis

HISTORY

EXAMINATION

History

- Always useful in evaluating patients with respiratory acid-base disturbances.
- The expected metabolic compensation for a respiratory process changes based on whether the process is **acute** or **chronic**.
- This can only be deduced by the history.

Case 3

- 15 yrs. with 4 days of vomiting and fever.

pH- 7.50

pCO2- 42

HCO3- 34

So, this is
Mixed
metabolic alkalosis
with
respiratory acidosis

MCQ 1

5 yrs. boy presented to ER with vomiting, hypertension, convulsions, then coma.

pH	7.40
pCO2	40
HCO3	24
Na	145
Cl	98

1. Normal ABG
2. Anion Gap Metabolic Acidosis & Metabolic Alkalosis
3. Non anion Gap Metabolic Acidosis & Metabolic Alkalosis
4. Anion Gap Metabolic Acidosis & Resp. Alkalosis
5. Metabolic Alkalosis & Resp. Acidosis

MCQ 2

5 yrs. boy presented to ER with vomiting, hypertension, convulsions, then coma.

pH	7.40
pCO2	40
HCO3	24
Na	145
Cl	98

1. DKA.
2. Uremia.
3. Conn's disease.
4. Cushing disease.
5. None of the above.

Acid Base Disorders

MCQ 3

16 years old boy , a case of FSGS on diuretics and Steroids presented with BP 70/40 mmHg

pH	7.4
PCO_2	40 mmHg
HCO_3	24 meq/l
Na^+	143 meq/l
Cl^-	95 meq/l
K^+	3.6 meq/l
S. Albumin	1 gram/dl

A. no acid base disorder
B. Respiratory acidosis
C. Metabolic alkalosis + resp acidosis
D. Metabolic acidosis + resp alkalosis
E, None of the above

Conclusions

Acid-base disturbances
are easy to analyze
if
approached systematically

Conclusions

- Calculate AG
- Calculate delta AG
- Add to measured HCO3
- Calculate AG on EVERY chemistry you see

”اللهم انفعنا بما علمتنا,
وعلمنا ماينفعنا,
وزدنا علما“

Thank You!!!!