The Henderson-Hasselbalch Formula

The Mantra

$$pH = pKa + \log \frac{[HCO_3^-]}{[CO_2]}$$

$$pH \propto \frac{[HCO_3^-]}{[CO_2]}$$

$$\text{Acidity} = \frac{\text{Bicarbonate}}{\text{Carbon Dioxide}}$$

$$A = {}^{B}/_{CD}$$

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Arterial Blood Gas

pH / $PaCO_2$ / PaO_2 / HCO_3 / Base

7.40 / 40 / 100 / 24 / 0

	"Normal"	Range
pH	7.40	7.35 - 7.45
$PaCO_2$ (mmHg)	40	35 – 45
PaO_2 (mmHg)	100	80 – 100
HCO_3^- (mEq/L)	24	22 – 26
Base Excess/Deficit (mEq/L)	0	± 2

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STEP #1

Look at the pH

pH / $PaCO_2$ / PaO_2 / HCO_3 / Base

7.35 – 7.45

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4 Main Ways pH Can Change

<u>Metabolic Alkalosis</u>

Increase in HCO_3, increases pH

$$\uparrow pH \propto \frac{\uparrow [HCO_3^-]}{[CO_2]}$$

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4 Main Ways pH Can Change

Metabolic Alkalosis

Increase in HCO_3, increases pH

Metabolic Acidosis

Decrease in HCO_3, decreases pH

$$\downarrow pH \propto \frac{\downarrow [HCO_3^-]}{[CO_2]}$$

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4 Main Ways pH Can Change

Metabolic Alkalosis

Increase in HCO_3, increases pH.

Metabolic Acidosis

Decrease in HCO_3, decreases pH.

Respiratory Acidosis

Increase in pCO_2, decreases pH

$$\downarrow pH \propto \frac{[HCO_3^-]}{\uparrow [CO_2]}$$

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4 Main Ways pH Can Change

Metabolic Alkalosis

Increase in HCO_3, increases pH.

Metabolic Acidosis

Decrease in HCO_3, decreases pH.

Respiratory Acidosis

Increase in pCO_2, decreases pH.

Respiratory Alkalosis

Decrease in pCO_2, increases pH

$$\uparrow pH \propto \frac{[HCO_3^-]}{\downarrow [CO_2]}$$

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STEP #2

Respiratory or Metabolic?

*pH / **$PaCO_2$** / PaO_2 / **HCO_3** / Base*

35 - 45 *22-26*

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STEP #3

Is there compensation and is it adequate?

- Acute
- Chronic

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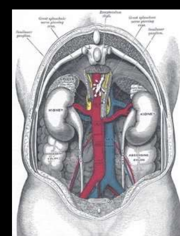
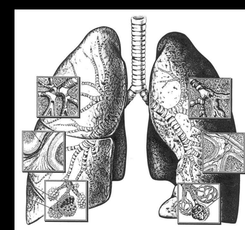
Acid/Base Homeostasis

BEANS VS BALLOONS





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Compensation Direction

	pH	Primary	Compensation
Metabolic acidosis	↓	↓ HCO_3	↓ pCO_2
Metabolic alkalosis	↑	↑ HCO_3	↑ pCO_2
Respiratory acidosis	↓	↑ pCO_2	↑ HCO_3
Respiratory alkalosis	↑	↓ pCO_2	↓ HCO_3

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Respiratory Acidosis

$$\downarrow pH \propto \frac{[HCO_3^-]}{\uparrow [CO_2]}$$

↓ MINUTE VENTILATION

TIDAL VOLUME x RESPIRATORY RATE

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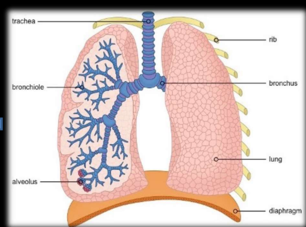
Respiratory Acidosis



Normal

CNS Depression
Neuromuscular Impairment
Thoracic restriction

Abnormal

Obstruction (late)
Alveoli dysfunction
Perfusion defect

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Respiratory Acidosis

Metabolic Compensation

Acute: 10:1

Chronic: 10:3

For every 10 mmHg increase of PaCO2, serum HCO_3^- increase by 1 *(acute)* or 3 (chronic) mEq/L

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Respiratory Alkalosis

$$\uparrow pH \propto \frac{[HCO_3^-]}{\downarrow [CO_2]}$$

↑ **Minute Ventilation**

Tidal volume x **Respiratory Rate**

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Respiratory Alkalosis

- **C** *ardiac*
- **H** *ypoxemia*
- **A** *nemia*
- **M** *edications*
- **P** *regnancy*
- **I** *atrogenic*
- **O** *bstruction (early)*
- **N** *eurologic*
- **S** *tress*

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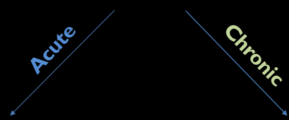
Respiratory Alkalosis

Metabolic Compensation



10:2 10:4

For every 10 mmHg decrease of PaCO2, serum HCO_3^- decreases by 2 *(acute)* or 4 (chronic) mEq/L

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A Little Trick

pH will change ***0.08*** for every ***10 mmHg*** change in $PaCO_2$

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STEP #4

If metabolic acidosis, calculate anion gap

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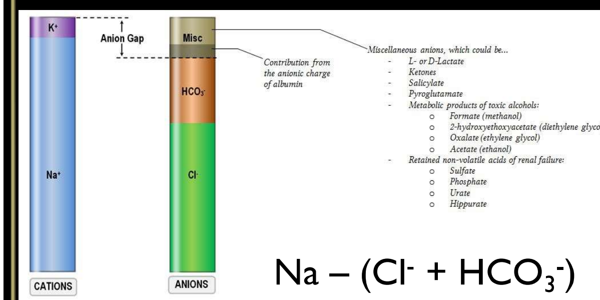
Metabolic Acidosis

$$\downarrow pH \propto \frac{\downarrow [HCO_3^-]}{[CO_2]}$$



$$Na - (Cl^- + HCO_3^-)$$

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High Anion-Gap Metabolic Acidosis

- **C** *arbon monoxide, cyanide*
- **A** *minoglycosides*
- **T** *heophyline, toluene*
- **M** *ethanol*
- **U** *remia*
- **D** *iabetic ketoacidosis*
- **P** *ropylene glycol*
- **I** *nborn errors of metabolism*
- **L** *actic acidosis*
- **E** *thylene glycol, ethanol*
- **S** *alicylates*

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STEP #5

If HAGMA,
calculate delta gap

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High Anion-Gap Metabolic Acidosis

$$\text{Delta Gap} = \frac{AG - 12}{24 - HCO_3^-}$$

Δ Gap	Interpretation
< 0.4	Hyperchloremic NAGMA
0.4-1.0	HAGMA + NAGMA
1.0-2.0	Uncomplicated/Pure HAGMA
> 2.0	HAGMA + metabolic alkalosis/compensation

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Non-Anion-Gap Metabolic Acidosis

- **U** *reteric diversion*
- **S** *mall bowel fistulae*
- **E** *xcessive saline*
- **D** *iarrhea*
- **C** *arbonic anhydrase inhibitors*
- **R** *enal tubular acidosis*
- **A** *drenal insufficiency*
- **P** *ancreatic fistulae*

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Non-Anion-Gap Metabolic Acidosis

Cause	Renal Defect	Urine pH	Urinary Anion Gap	Serum K^+
Dilutional	None	< 5.5	Negative	Normal
GI Loss	None	< 5.5	Ne-GUT-ive	↓
Renal Tubular Acidosis				
Type I (Distal)	Distal H^+ secretion	> 5.5	Positive	↓
Type II (Proximal)	Proximal HCO_3^- reabsorption	< 5.5	Positive	↓
Type IV (adrenal insufficiency)	Distal Na^+ reabsorption, K^+ and H^+ secretion	< 5.5	Positive	↑

UAG = (Na + K) - Cl

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Metabolic Acidosis

RESPIRATORY COMPENSATION

Expected $PaCO_2$

$$8 + (1.5 \times HCO_3^-) \pm 2$$

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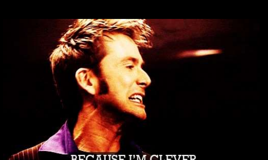
Metabolic Alkalosis

$$\uparrow pH \propto \frac{\uparrow [HCO_3^-]}{[CO_2]}$$



C ontraction
L icorice
E ndocrine
V omiting
E xcessive NG suction
R inger's solution
P ost-hypercapnia
D iuretics

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Metabolic Alkalosis

RESPIRATORY COMPENSATION

Expected $PaCO_2$

$$20 + (0.7 \times HCO_3^-) \pm 5$$

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