

Analyzing & Interpreting Arterial Blood Gases

AARC Approved for 1.5 CRCE Credit Hours

Keith Varnes, RRT, RRT-ACCS,
RRT-NPS, AE-C

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Learner Objectives

Describe	Describe collection methods for arterial blood gases
Discuss	Discuss avoidance strategies for pre-analytical errors
List	List the process steps for ABG analysis
Discuss	Discuss the causes of metabolic acidosis & alkalosis
Discuss	Discuss the causes of respiratory acidosis & alkalosis
Identify	Identify the role of ABG analysis with mechanical ventilation

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Alternatives to Traditional Arterial Sampling

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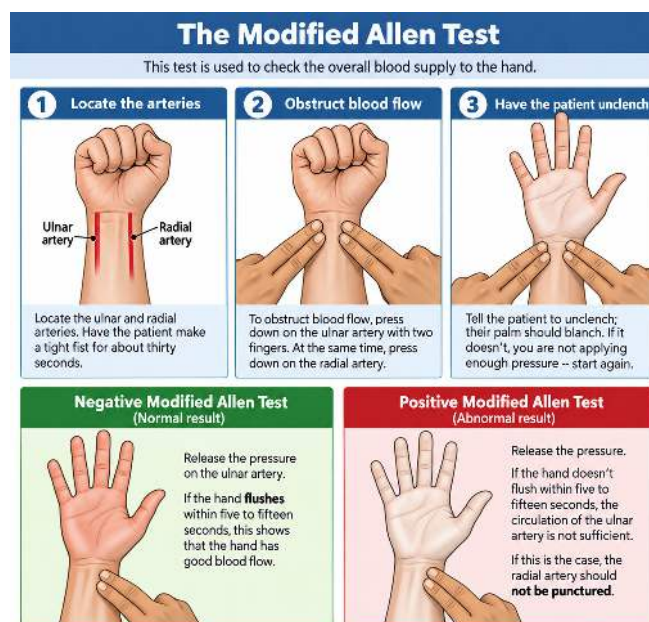


Image generated using AI.

References: 1, 2, 9

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Image courtesy of Radiometer. Used with permission.

References: 1, 2, 7, 8, 9

5



References: 2, 7, 8, 9

6

Influencing Factors

Room Air

Leukocytes

Hypo/hyperthermic

References: 1, 7, 8, 9

7



Image courtesy of Radiometer. Used with permission.

References: 1, 9

8



Image courtesy of Radiometer. Used with permission.

9



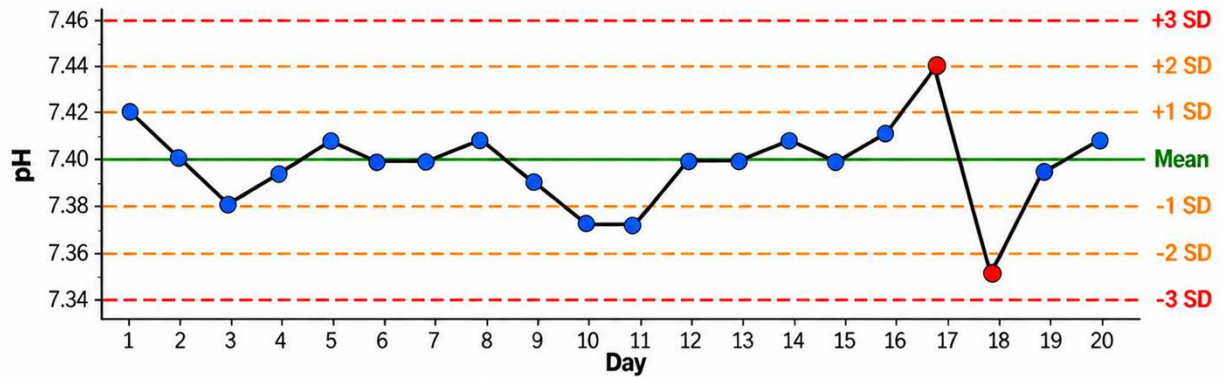
Image courtesy of Radiometer. Used with permission.

References: 9

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Levey-Jennings Chart Example

pH Control (Mean = 7.40, SD = 0.02)



Review unexpected QC patterns using the laboratory's established QC rules.

References: 9

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What Can a Blood Gas Analyzer Tell Us?

Blood gases	Acid-base status, ventilation, and oxygenation
Co-oximetry	Hemoglobin, oxygen saturation, and dyshemoglobins
Electrolytes	Clinically important ions
Metabolites	Markers of metabolism and tissue perfusion

Available measurements depend on the analyzer and its configuration.

References: 1, 9

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Interpretation

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Acid-base processes

Acidosis	↑ H ⁺ , tends to lower pH
Alkalosis	↓ H ⁺ , tends to raise pH

Regulatory systems

Lungs	regulate CO ₂
Kidneys	regulate HCO ₃ ⁻ and H ⁺ excretion

Acidosis/alkalosis describe the processes.
Acidemia/alkalemia describe the actual blood pH.

References: 3, 4, 5

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Henderson-Hasselbalch Concept

$$\text{pH} = \text{pK}_a + \log \frac{\text{[conjugate base]}}{\text{[weak acid]}} \quad (\text{for weak acid})$$

In the bicarbonate buffer system:
 HCO_3^- reflects the metabolic component
 CO_2 reflects the respiratory component

pH rises when HCO_3^- increases relative to CO_2
pH falls when CO_2 increases relative to HCO_3^-

References: 3, 4, 5

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ABG Shortcut

pH Reflects the $\text{HCO}_3^-/\text{PaCO}_2$ Balance

$$\text{pH} \propto \frac{\text{HCO}_3^-}{\text{PaCO}_2}$$

Bicarbonate HCO_3^-
Metabolic component

Carbon Dioxide PaCO_2
Respiratory component

Ask: which side of the ratio changed?

References: 3, 4, 5

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Normal ABG Values and Reporting Order

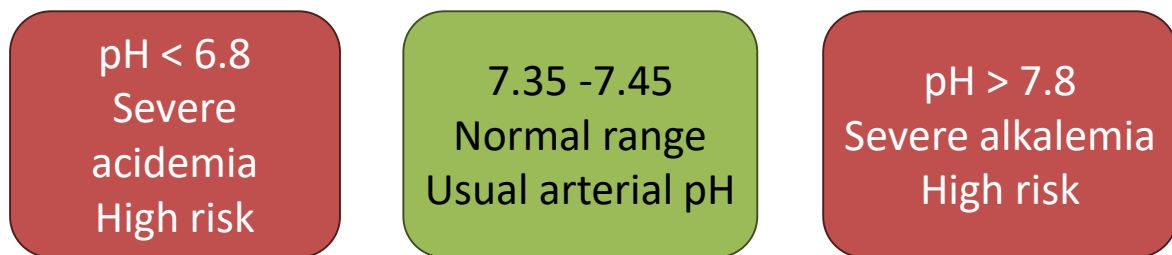
Parameter	Normal range	What it tells you
pH	7.35–7.45	Overall acid-base status
PaCO ₂	35–45 mm Hg	Respiratory component
PaO ₂	80–100 mm Hg	Oxygenation
HCO ₃ ⁻	22–26 mmol/L	Metabolic component
Base excess	-2 to +2 mmol/L	Metabolic component

Report in order: pH → PaCO₂ → PaO₂ → HCO₃⁻ → base excess

References: 1, 3, 4

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Extreme pH Values Signal High Risk



Risk increases as pH moves farther from normal.
These are warning thresholds, not absolute survival limits.

References: 3, 4, 5

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Respiratory Acidosis

pH < 7.35

PaCO₂ > 45

Acute or Chronic

References: 3, 4, 5

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Acute Respiratory Acidosis

Headache

Confusion

Drowsiness

**Heart
Contraction**

Catecholamines

Medications

References: 3, 4, 5

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Acute Respiratory Acidosis

- Ventilation chain defect
- Increased CO₂ production

Arterial Blood Gas (ABG)	
pH	7.27
HCO₃⁻ (mEq/L)	24
PaCO₂ (mm Hg)	55
Calculation (Henderson-Hasselbalch) $\text{pH} = 6.1 + \log \frac{24}{0.03 \times 55}$ $\text{pH} = 6.1 + \log(14.55)$ $\text{pH} \approx \mathbf{7.27}$	

References: 3, 4, 5

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Chronic Respiratory Acidosis

- Increased PaCO₂
- Increased HCO₃⁻
- Normal pH

Arterial Blood Gas (ABG)	
pH	7.39
HCO₃⁻ (mEq/L)	33
PaCO₂ (mm Hg)	55
Calculation (Henderson-Hasselbalch) $\text{pH} = 6.1 + \log \frac{33}{0.03 \times 55}$ $\text{pH} = 6.1 + \log(20.00)$ $\text{pH} \approx \mathbf{7.39}$	

References: 3, 4, 5

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Respiratory Alkalosis

$\text{PaCO}_2 < 35$

$\text{pH} > 7.45$

References: 3, 4, 5

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Respiratory Alkalosis

- Pain
- Fear
- Hypoxia
- Increased metabolic demand

Arterial Blood Gas (ABG)

pH

7.52

HCO_3^-
(mEq/L)

24

PaCO_2
(mm Hg)

25

Calculation (Henderson-Hasselbalch)

$$\text{pH} = 6.1 + \log \frac{24}{0.03 \times 25}$$

$$\text{pH} = 6.1 + \log(32.00)$$

$$\text{pH} \approx \mathbf{7.52}$$

References: 3, 4, 5

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Respiratory Alkalosis

Numbness

Tingling

Confusion

Blurred
vision

Muscle
spasms

Dysrhythmias

References: 3, 4, 5

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Metabolic Acidosis

- $\text{HCO}_3^- < 22$
- $\text{pH} < 7.35$

Arterial Blood Gas (ABG)

pH

7.26

HCO_3^-
(mEq/L)

16

PaCO_2
(mm Hg)

40

Calculation (Henderson-Hasselbalch)

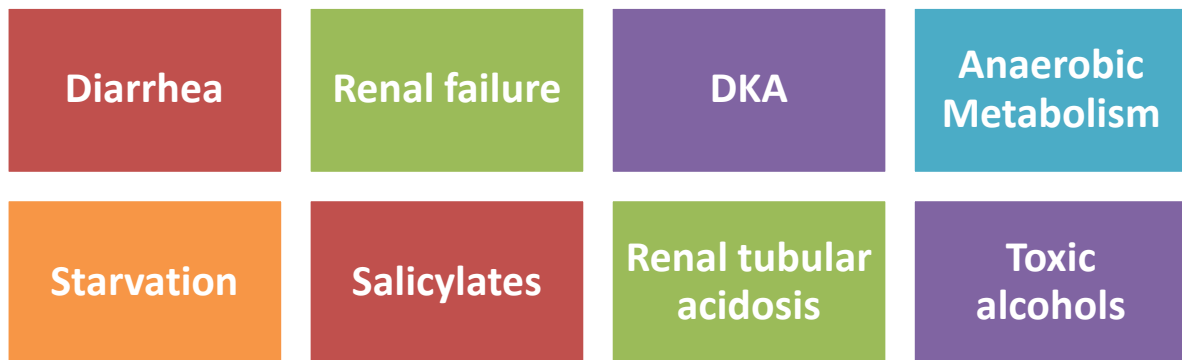
$$\text{pH} = 6.1 + \log \frac{16}{0.03 \times 40}$$

$$\text{pH} = 6.1 + \log(13.33)$$

$$\text{pH} \approx \mathbf{7.26}$$

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Metabolic Acidosis



References: 3, 4, 5, 6

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Metabolic Acidosis

Headache

Confusion

Coma

Dysrhythmias

Kussmaul Breathing (DKA)

Nausea

Vomiting

References: 3, 4, 5, 6

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Metabolic Alkalosis

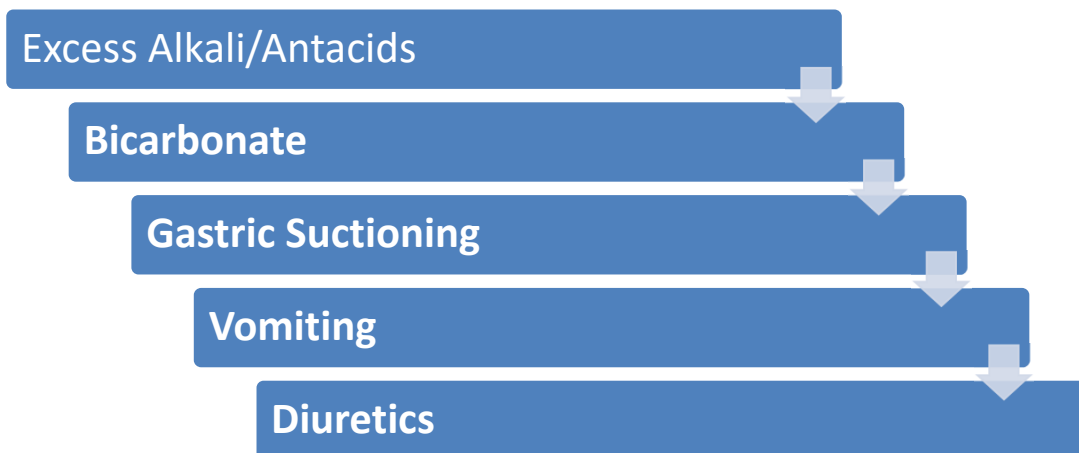
- $\text{HCO}_3^- > 26$
- $\text{pH} > 7.45$

Arterial Blood Gas (ABG)	
pH	7.60
HCO_3^- (mEq/L)	38
PaCO_2 (mm Hg)	40
Henderson-Hasselbalch Calculation	
$\text{pH} = 6.1 + \log \frac{\text{HCO}_3^-}{0.03 \times \text{PaCO}_2}$	
$\text{pH} = 6.1 + \log \frac{38}{0.03 \times 40}$	
$\text{pH} = 6.1 + \log(38 \div 1.2)$	
$\text{pH} = 6.1 + \log(31.67)$	
$\text{pH} = 6.1 + 1.50$	
$\text{pH} \approx \mathbf{7.60}$	

References: 3, 4, 5, 6

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Metabolic Alkalosis



References: 3, 4, 5, 6

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Metabolic Alkalosis

Hypoventilation (compensation)

Dizziness

Seizures

Coma

Muscle twitching

Cramps

Nausea

Vomiting

References: 3, 4, 5, 6

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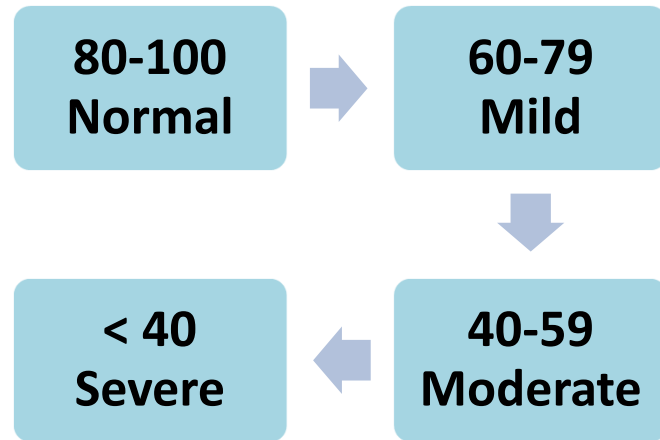


Mixed Respiratory Metabolic

References: 3, 5, 6

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Classification of Hypoxemia by PaO₂



References: 1, 3

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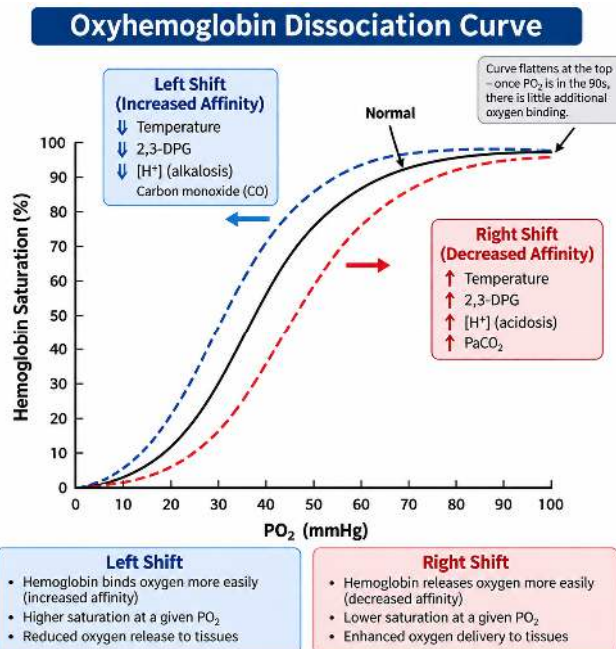


Image generated using AI.

References: 3, 4

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HOT ACID goes RIGHT.

References: 3, 4

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Arterial Oxygen Content (CaO_2)

$$\text{CaO}_2 = (1.34 \times \text{Hb} \times \text{SaO}_2) + (\text{PaO}_2 \times 0.003)$$

Most oxygen content comes from hemoglobin-bound oxygen.

Example:

Hb = 15 SaO₂ = 0.98 PaO₂ = 100 mmHg

CaO₂ = (1.34 × 15 × 0.98) + (100 × 0.003)

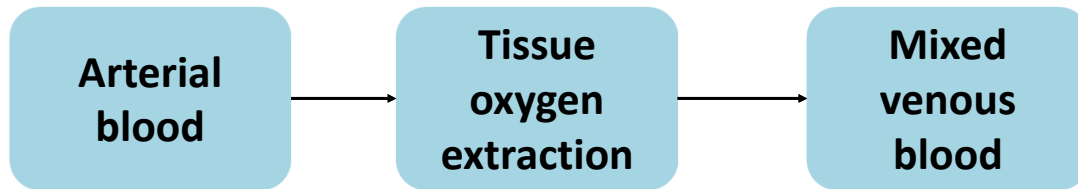
CaO₂ = 19.7 + 0.3 = **20.0 mL O₂/dL**

Severe anemia can reduce oxygen content even when PaO₂ and SaO₂ look normal.

References: 1, 3

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Mixed Venous Oxygen Saturation (SvO₂)



SaO₂ near 100% → tissues extract oxygen → SvO₂ ~65–75%

Low SvO₂ may suggest:

Increased demand · reduced delivery · impaired delivery/consumption balance

High SvO₂ does not always mean adequate tissue oxygen use.

References: 3

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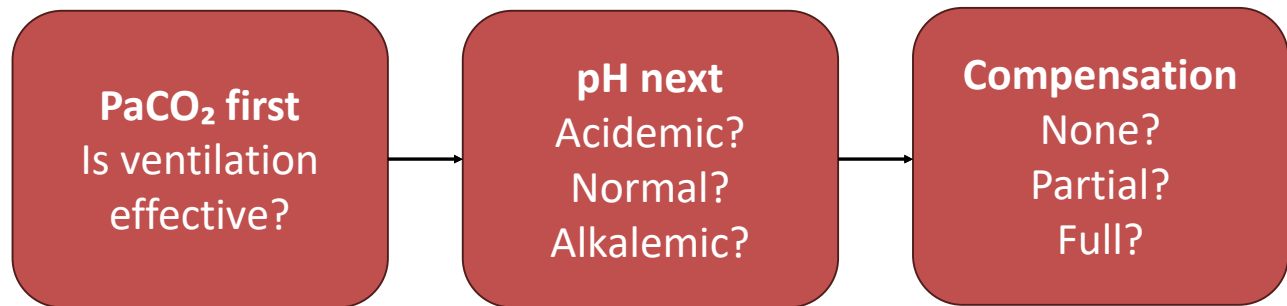
Base
Excess

Normal +/- 2 mEq/L

References: 3, 4, 5

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ABG Interpretation Framework



High PaCO₂ with near-normal pH may suggest chronic compensation.

References: 3, 5, 6

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Quick Practice: Interpret the ABG.



pH	PaCO ₂	PaO ₂	HCO ₃ ⁻
7.30	50	65	24
7.36	54	65	30
7.49	30	65	22
7.30	32	80	15

30 Seconds

References: 3, 5, 6

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Quick Practice: Interpret the ABG.

pH **7.30** / PaCO₂ **50** / PaO₂ **65** / HCO₃⁻ **24** →

Acute respiratory acidosis

pH **7.36** / PaCO₂ **54** / PaO₂ **65** / HCO₃⁻ **30** →

Chronic compensated respiratory acidosis

pH **7.49** / PaCO₂ **30** / PaO₂ **65** / HCO₃⁻ **22** →

Acute respiratory alkalosis

pH **7.30** / PaCO₂ **32** / PaO₂ **80** / HCO₃⁻ **15** →

Metabolic acidosis with appropriate respiratory compensation



References: 3, 5, 6

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Example #1

58-year-old male, 5'9", 295 lb, stroke-like symptoms

History: CVA, diabetes, obesity

Vent: A/C 16 / VT 450 / PEEP 5 / FiO₂ 50%

ABG: pH **7.37** / PaCO₂ **47.1** / PaO₂ **72.4** / HCO₃⁻ **26.4** / BE **+1.3**

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Example #2

22-year-old male, 6' 1", 146 lbs., AMS & acute encephalopathy

Hx: Asthma

Vent: A/C 16/400/5 FiO₂ 50%

ABG: pH **7.20** / PaCO₂ **60** / PaO₂ **254** / HCO₃⁻ **23** / BE **-5**

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Example #3

64-year-old male, 5' 7", 160 lbs., admitted w/ sepsis and respiratory failure

Failed NIV

Vent: A/C 14/450/5 FiO₂ 40%

ABG: pH **7.42** / PaCO₂ **44.5** / PaO₂ **79.4** / HCO₃⁻ **28.4** / BE **+4**

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Example #4

46-year-old female, 5' 0", 130 lbs., 8 days SOB & COVID+

Vent: AC-PC f 26, Pi 23, Ti 1.0, PEEP 5, FiO₂ 100%

ABG: pH **7.29** / PaCO₂ **62.8** / PaO₂ **53.1** / HCO₃⁻ **29** / BE **+1.6**

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Example #5

44-year-old male, 5' 6", 223 lbs., urinary retention and lower-extremity edema.

Hx: Significant CHF, EF 20-25%, hypertension, OSA, obesity, and prediabetes

BiPAP 24/5 FiO₂ 40%

ABG: pH **7.54** / PaCO₂ **43.1** / PaO₂ **96.8** / HCO₃⁻ **37.1** / BE **+12.8**

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Anion Gap

$$140 - (104 + 24) = 12 \text{ mEq/L}$$

References: 3, 5, 6

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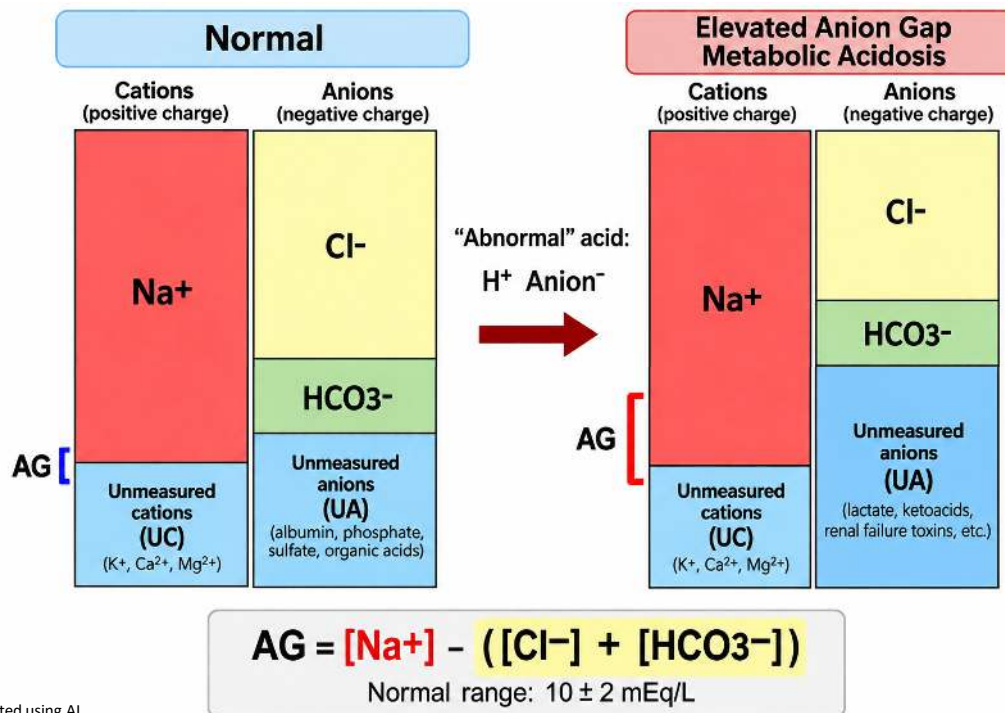


Image generated using AI.

References: 3, 5, 6

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Elevated Anion Gap

DKA/Ketoacidosis

Kidney Disease

Lactate

References: 3, 5, 6

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Normal Anion Gap

Diarrhea

**Renal Tubular
Acidosis**

References: 3, 5, 6

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Low Anion Gap

Low Albumin

References: 3, 5, 6

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Example #1

58-year-old male, 5'9", 295 lb, stroke-like symptoms

History: CVA, diabetes, obesity

Vent: A/C 16 / VT 450 / PEEP 5 / FiO₂ 50%

ABG: pH **7.37** / PaCO₂ **47.1** / PaO₂ **72.4** / HCO₃⁻ **26.4** / BE **+1.3**

Sodium (Na⁺) 141

Potassium (K⁺) 3.4

Chloride (Cl⁻) 104

$$\begin{aligned}
 141 - (104 + 26.4) &= \\
 141 - 130.4 &= \\
 \text{AG} &= 10.6 \text{ mEq/L}
 \end{aligned}$$

References: 3, 5, 6

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Example #2

22-year-old male, 6' 1", 146 lbs., AMS & acute encephalopathy

Hx: Asthma

Vent: A/C 16/400/5 FiO₂ 50%

ABG: pH 7.20 / PaCO₂ 60 / PaO₂ 254 / HCO₃⁻ 23 / BE -5

Na⁺ 140

Cl⁻ 109

$$\begin{aligned} 140 - (109 + 23) &= \\ 140 - 132 &= \\ \text{AG} &= 8 \text{ mEq/L} \end{aligned}$$

References: 3, 5, 6

53

Example #3

64-year-old male, 5' 7", 160 lbs., admitted with sepsis and respiratory failure

Earlier laboratory results:

ABG: pH 7.28 / PaCO₂ 30 / PaO₂ 70 / HCO₃⁻ 14

Na⁺ 138

Cl⁻ 102

$$\begin{aligned} 138 - (102 + 14) &= \\ 138 - 116 &= \\ \text{AG} &= 22 \text{ mEq/L} \end{aligned}$$

References: 3, 5, 6

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Delta-Delta Gap

References: 3, 5, 6

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Delta Ratio

Does the anion gap rise match the bicarbonate fall?

$$\text{Delta-delta} = \frac{(\text{Calculated AG} - \text{Expected AG})}{(24 - \text{HCO}_3^-)}$$

Use only after identifying high-anion-gap metabolic acidosis.

Ratio	What it suggests
< 0.4	Predominantly normal-gap metabolic acidosis
0.4–0.8	Mixed high-gap + normal-gap metabolic acidosis
0.8–2.0	High-gap acidosis without clear additional metabolic process
> 2.0	High-gap acidosis with metabolic alkalosis or elevated baseline HCO_3^-

Ranges vary by reference. Use the ratio as a clue, not a diagnosis.

References: 3, 5, 6

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Example #1

64-year-old male, 5' 7", 160 lbs., admitted with sepsis and respiratory failure

Na⁺ 138

Cl⁻ 102

HCO₃⁻ 14

AG = 22 mEq/L

$$\begin{aligned}\text{Delta-Delta} &= (\text{AG} - 12) \div (24 - \text{HCO}_3^-) \\ &= (22 - 12) \div (24 - 14) \\ &= 10 \div 10 \\ &= 1.0\end{aligned}$$

References: 3, 5, 6

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Example #2

52-year-old female admitted with DKA and diarrhea

Na⁺ 138

Cl⁻ 109

HCO₃⁻ 10

AG = 19 mEq/L

$$\begin{aligned}\Delta/\Delta &= (19 - 12) \div (24 - 10) \\ &= 7 \div 14 \\ &= 0.5\end{aligned}$$

References: 3, 5, 6

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Example #3

27-year-old female admitted with DKA and persistent vomiting

Na⁺ 140

Cl⁻ 94

HCO₃⁻ 16

AG = 30 mEq/L

$$\begin{aligned}\Delta/\Delta &= (30 - 12) \div (24 - 16) \\ &= 18 \div 8 \\ &= 2.25\end{aligned}$$

References: 3, 5, 6

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Calculations help you notice patterns, but they don't replace clinical judgment.

Reference values vary

Cutoffs differ by source and facility.

Patient factors matter

Albumin and other conditions can affect the anion gap and delta-delta.

Use the whole clinical picture

Investigate results that don't fit the patient.

References: 3, 5, 6

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ABG Interpretation: The Big Picture

1. PaCO₂ — Ventilation
Eliminating CO₂
appropriately?

2. pH —
Acid-base status
Acidemic, normal, or
alkalemic?

3. HCO₃⁻ / BE —
Metabolic component
Metabolic disturbance
or compensation?

4. Compensation —
Does it fit?
Consider mixed
disorder if not.

5. PaO₂ + FiO₂ —
Oxygenation
Interpret PaO₂ with
delivered oxygen.

**6. Anion gap / delta-
delta —**
Dig deeper
Look for another
metabolic process.

A normal pH does not guarantee a normal ABG. Treat the patient who produced it.

References: 1, 3, 5, 6

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References

1. **Davis, M. D., Walsh, B. K., Sittig, S. E., & Restrepo, R. D. (2013).** AARC clinical practice guideline: Blood gas analysis and hemoximetry. *Respiratory Care*, 58(10), 1694–1703.
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4. **Lewis, J. L., III. (2025).** Acid-base regulation. Merck Manual Professional Edition.

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5. **Lewis, J. L., III. (2025).** Acid-base disorders. Merck Manual Professional Edition.
6. **Barletta, J. F., Muir, J., Brown, J., & Dzierba, A. (2024).** A systematic approach to understanding acid-base disorders in the critically ill. *Annals of Pharmacotherapy*, 58(1), 65–75.
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9. **Clinical and Laboratory Standards Institute. (2009). Blood gas and pH analysis and related measurements (C46-A2, 2nd ed.). CLSI.**

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The End

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