

Acid-base

Acid-base means: pH direction, main troublemaker (CO_2 or bicarbonate), how hard the body is working to fix it, anion gap clues, then find what broke upstream.

THE ONE-LINE TRUTH

For every blood gas, ask: which way is pH moving, is the main problem CO_2 or bicarbonate, is the body fixing it the right amount, does anion gap show hidden acids, then fix what broke—not the number itself.

The chain — how it unfolds

1. Acidemia confuses the brain, weakens heart squeeze, and raises blood potassium. — why: Acidemia (pH below 7.35) means extra H^+ ions compete with calcium for spots on troponin (the protein that makes heart muscle squeeze), so the heart pumps weaker and blood pressure can drop. H^+ also disrupts nerve cell electrical signals (changes sodium and potassium channel function), causing confusion, sleepiness, or coma. H^+ shifts into cells in exchange for K^+ (the cell membrane pump trades one for the other to buffer the acid), pushing potassium out into the blood—serum potassium rises about 0.6 mEq/L for every 0.1 pH drop—and risking deadly heart rhythms (peaked T waves, wide QRS, ventricular fibrillation).
2. Alkalemia drops active calcium and causes muscle spasms, seizures, and abnormal heart rhythms. — why: Alkalemia (pH above 7.45) makes blood proteins (albumin) grab more calcium ions, so free ionized calcium (the active form that nerves and muscles use) drops even though total calcium looks normal. Nerve and muscle cells become hyperexcitable (fire too easily) because calcium normally stabilizes the cell membrane. Result: tetany (muscle spasms, especially hands and feet—Trousseau sign, Chvostek sign), seizures, and heart rhythm problems (prolonged QT interval, torsades de pointes). Alkalemia also shifts the oxygen-hemoglobin curve left, making hemoglobin hold oxygen tighter and deliver less to tissues.

3. Compensation follows predictable formulas: for metabolic acidosis (acid building up in the blood), expected CO_2 equals 1.5 times bicarbonate plus 8 (Winter formula); for respiratory acidosis (acid building up from trapped carbon dioxide), bicarbonate rises 1 mEq/L per 10 mmHg CO_2 rise (acute) or 3.5 mEq/L per 10 mmHg (chronic). If the measured value does not match the expected, a second hidden disorder is present. — why: The body's three rescue teams—buffers (instant), lungs (minutes to hours), kidneys (days)—work together to hold pH in the narrow zone 7.35 to 7.45 so enzymes work at the right speed, oxygen delivery stays optimal (hemoglobin releases oxygen to tissues), and electrolyte balance holds (potassium, calcium stay in safe ranges). When one system breaks, the other two compensate, creating predictable blood gas patterns. Deviation from formulas signals a mixed disorder—for example, metabolic acidosis (acid building up in the blood) plus hidden metabolic alkalosis (the blood turning too alkaline) (vomiting and septic shock together), or respiratory acidosis (acid building up from trapped carbon dioxide) plus metabolic alkalosis (COPD patient on diuretics).
4. Calculate anion gap (sodium minus the sum of chloride and bicarbonate, normal 8 to 12) for every metabolic acidosis (acid building up in the blood) to see if unmeasured acids are present. — why: Elevated anion gap (above 12) means unmeasured anions—lactate (from shock, seizures, blood-starved (ischemic) bowel), ketones (diabetic ketoacidosis, alcoholic ketoacidosis, starvation), toxins (methanol, ethylene glycol, aspirin as salicylate), or uremic acids (kidney failure)—are filling the blood. Normal anion gap (8 to 12) metabolic acidosis (acid building up in the blood) means bicarbonate was lost directly (diarrhea loses bicarbonate in stool, renal tubular too much acid in the blood (acidosis) loses it in urine) or chloride was added (normal saline resuscitation, acetazolamide). The gap directs you to the cause: high gap → think GOLD MARK mnemonic (Glycols—ethylene/propylene, Oxoproline, L-lactate, D-lactate, Methanol, Aspirin, Renal failure, Ketoacidosis); normal gap → think diarrhea, RTA, saline.
5. Use delta-delta (change in anion gap divided by change in bicarbonate from normal) to unmask hidden mixed disorders. — why: Delta-delta compares how much the anion gap rose versus how much bicarbonate dropped. Normally they move together 1:1 (one unmeasured anion replaces one bicarbonate). If delta-delta is above 2, hidden metabolic alkalosis (the blood turning too alkaline) is present (vomiting, diuretics on top of lactic acidosis (acid from oxygen-starved tissues)). If delta-delta is below 1, hidden normal-gap too much acid in the blood (acidosis) is present (diarrhea plus ketoacidosis). If delta-delta is 1 to 2, pure high anion gap too much acid in the blood. This catches coexisting problems that one blood gas snapshot hides—common in ICU patients with multiple organ failures.

6. Each abnormal number you see (high potassium, confusion, weak heart, deep gasping breaths) is not the disease itself—it is the body's response to the real broken thing upstream. — why: Kussmaul breathing (deep, fast, rhythmic breathing—like a marathon runner but at rest) is the lungs trying to blow off CO_2 to raise pH in metabolic acidosis (acid building up in the blood) (seen in diabetic ketoacidosis (the acid crisis of missing insulin), severe waste buildup in the blood (uremia), severe lactic acidosis (acid from oxygen-starved tissues)). High potassium is the H^+ - K^+ swap trying to buffer extra acid inside cells. Confusion or coma is the brain failing as pH drops below 7.2 (H^+ disrupts neurotransmitter release and receptor function). Weak heart contraction is acidemia blocking troponin-calcium binding. Trace every finding backward to the upstream break—shock (lactate), infection (lactate), uncontrolled diabetes (ketones), toxin ingestion, kidney failure, lung failure—and fix that root cause.
7. Trace it back: identify the main disorder (metabolic vs. respiratory, too much acid in the blood (acidosis) vs. too little acid in the blood (alkalosis) from pH and CO_2 /bicarbonate direction), check if compensation matches formulas, calculate anion gap, use delta-delta, then fix the cause—resuscitate shock with fluids and pressors, give insulin and fluids for diabetic ketoacidosis (the acid crisis of missing insulin), dialyze toxins and severe waste buildup in the blood (uremia), treat infection, support or take over breathing, stop diarrhea, correct vomiting and volume loss. — why: Fixing the upstream cause reverses the whole cascade. Fluids and pressors restore blood flow, stopping lactate production. Insulin opens the glucose gate, stopping ketone production. Dialysis pulls out methanol, ethylene glycol, and uremic toxins. Antibiotics clear infection. Ventilator or BiPAP takes over breathing work. Stopping diarrhea or vomiting stops bicarbonate or acid loss. Giving bicarbonate IV (sodium bicarbonate) is reserved only for severe acidemia (pH below 7.1 to 7.2) because it can overshoot into too little acid in the blood (alkalosis), drop ionized calcium, and shift potassium dangerously—treat the cause first, support pH only as a bridge. As the root problem resolves, pH, CO_2 , bicarbonate, potassium, and mental status all normalize together.
8. Monitor response with serial blood gases (arterial or venous), lactate, and electrolytes every 1 to 4 hours in severe cases, watching for pH moving toward 7.35 to 7.45, lactate dropping toward normal (below 2 mmol/L), anion gap closing, potassium normalizing, and mental status clearing. — why: Trends tell you if your treatment is working or if the patient is decompensating despite therapy. A rising pH and falling lactate mean resuscitation is working. A stable or worsening pH, climbing lactate, or rising CO_2 despite treatment means escalate care—more fluids, pressors, higher ventilator support, or emergent dialysis. Serial monitoring catches the turn early, while you still have time to intervene, before the patient crashes into cardiac arrest or refractory shock.

Spot it — what you see, and why

- **Kussmaul breathing (deep, fast, sighing breaths):** When blood pH drops (metabolic too much acid in the blood (acidosis)), the brain's breathing center sends urgent signals to blow off carbon dioxide fast. The lungs breathe harder and deeper to push out CO₂ — that raises pH back up. It's like opening a window to let heat escape when a room gets too hot.
- **Confusion, drowsiness, or coma:** When blood is too acidic (pH below 7.35) or too alkaline (pH above 7.60), nerve cells can't send electrical signals properly. Brain cells need the right pH to work — when it's off, the brain slows down. Severe pH swings (below 7.20 or above 7.60) can shut the brain down completely.
- **Nausea and vomiting:** Acidic blood irritates the vomiting trigger zone in the brainstem and slows the stomach. It's common in diabetic ketoacidosis (the acid crisis of missing insulin) (ketones spill into blood), kidney failure (waste builds up), and poisonings. The gut just stops moving when pH drops.
- **Muscle weakness or paralysis:** Acidemia pushes potassium out of cells into blood. High potassium (above 6.5 mEq/L) makes muscle cells unable to fire — like a dead battery. Alkalemia does the opposite: potassium drops too low (below 2.5), and muscles also can't contract. Either way, muscles go weak or stop working.
- **Muscle spasms, tingling in fingers and lips, or seizures (tetany):** Alkaline blood (pH above 7.45) makes calcium stick to proteins, so less free calcium floats in the blood. Nerves and muscles need free calcium to stay calm — without it they fire on their own. You see twitches, hand cramps (Trousseau sign), facial twitches (Chvostek sign), or full seizures.
- **Heart racing, fluttering, or dangerous rhythms:** Severe acidemia (pH below 7.20) weakens the heart squeeze and triggers arrhythmias. High potassium from acidemia causes peaked T waves and wide QRS on ECG — the heart can suddenly fibrillate (stop beating). Low potassium and low free calcium from alkalemia also scramble the heart's electrical rhythm.

Red flags — act now

- pH below 7.20 or above 7.60 — risk of deadly heart rhythms, seizures, or coma
- Potassium above 6.5 mEq/L with peaked T waves or wide QRS on ECG — heart can stop beating any second
- Anion gap above 30 with confusion — think poisoning (methanol, antifreeze) or septic shock with severe lactic acidosis (acid from oxygen-starved tissues)
- Bicarbonate below 10 mEq/L in diabetic ketoacidosis (the acid crisis of missing insulin) — brain can swell if you correct pH too fast; do NOT give bicarbonate unless pH is below 6.9 (ADA 2024)

- Kussmaul breathing with fruity breath and high blood sugar — diabetic ketoacidosis (the acid crisis of missing insulin) until proven otherwise; check blood or urine ketones and start insulin right away

Treat it — in this order

1. Identify the primary disorder: Look at pH first. If pH is low (below 7.35), the primary problem is too much acid in the blood (acidosis). If pH is high (above 7.45), it is too little acid in the blood (alkalosis). Then look at PaCO₂ and bicarbonate—whichever one moved in the same direction as pH (both low or both high) is the primary problem. Calculate anion gap if metabolic acidosis (acid building up in the blood) is present. → Shows whether the main problem is metabolic (bicarbonate or unmeasured acid) or respiratory (carbon dioxide). Shows whether compensation is appropriate (use Winter's formula for metabolic acidosis (acid building up in the blood): $\text{expected PaCO}_2 = 1.5 \times \text{bicarbonate} + 8 \pm 2$; if actual PaCO₂ is higher or lower, there is a second respiratory disorder). Uncovers hidden mixed disorders that need different treatments.
2. Obtain detailed history and perform targeted physical exam: Ask about vomiting, diarrhea, shortness of breath, chest pain, diabetes, medicines (diuretics, aspirin, metformin), kidney or lung disease, alcohol or drug use, possible toxic ingestion. Examine breathing pattern, mental status, skin blood flow (perfusion), heart rhythm, and abdomen. → Points directly to the root cause: sepsis with lactic acidosis (acid from oxygen-starved tissues), diabetic ketoacidosis (the acid crisis of missing insulin), bicarbonate loss from diarrhea, carbon dioxide retention from COPD, poison ingestion, vomiting with too little acid in the blood (alkalosis). Treating the cause—not just the lab number—stops progression, prevents recurrence, and prevents complications like organ failure.
3. Treat the underlying cause: IV regular insulin 0.1 units/kg/hour plus IV 0.9% saline 500–1000 mL/hour initially for diabetic ketoacidosis (the acid crisis of missing insulin) per ADA; IV fluids (crystalloid 30 mL/kg in first 3 hours) plus IV antibiotics within 1 hour plus vasopressors (norepinephrine first-line) to restore blood flow (perfusion) and clear lactate in septic shock per Surviving Sepsis Campaign; oxygen plus non-invasive ventilation (BiPAP) or intubation and mechanical ventilation for COPD with respiratory acidosis (acid building up from trapped carbon dioxide) per ATS/GOLD; stop metformin and give IV fluids for metformin-associated lactic acidosis (acid from oxygen-starved tissues); fomepizole 15 mg/kg IV load plus hemodialysis for methanol or ethylene glycol; IV sodium bicarbonate to alkalinize urine plus hemodialysis for severe aspirin toxicity; hemodialysis for kidney failure (uremic too much acid in the blood (acidosis)) per KDIGO. → Removes or stops the source of acid or carbon dioxide. Restores normal metabolism so the body's own lungs, kidneys, and buffer systems (bicarbonate, proteins, bone) can bring pH back to normal over hours to days. This is the only way to truly fix the problem.

4. Give IV sodium bicarbonate (50–100 mEq in 1 liter of D5W over 30–60 minutes) ONLY if pH is below 7.10 AND the cause cannot be corrected quickly, OR in specific situations: tricyclic antidepressant overdose with wide QRS (above 100 ms) or arrhythmia (to overcome sodium-channel blockade), severe high potassium (hyperkalemia) (potassium above 6.5 mEq/L) with ECG changes per AHA, aspirin or methotrexate poisoning (to alkalinize urine and trap drug for faster excretion), or rhabdomyolysis with myoglobinuria (to prevent kidney damage). → Provides exogenous buffer to raise pH quickly, buying time for definitive treatment and endogenous systems to work. In tricyclic overdose, raising serum pH above 7.50 reduces drug binding to cardiac sodium channels and reverses conduction block and arrhythmias per toxicology guidelines.
5. Monitor and manage potassium closely: Measure potassium every 2–4 hours during treatment. If potassium is above 5.5 mEq/L with ECG changes (peaked T waves, wide QRS), give IV calcium gluconate 1–2 grams over 5 minutes to protect the heart, then insulin 10 units IV plus dextrose 25 grams IV to shift potassium into cells per AHA. If potassium is normal or low at presentation, start potassium replacement (20–40 mEq/L in IV fluids) before or with insulin in diabetic ketoacidosis (the acid crisis of missing insulin) per ADA. → Acidemia shifts potassium out of cells into blood by exchanging hydrogen ions into cells—raising serum potassium and increasing risk of life-threatening arrhythmias (ventricular fibrillation, asystole). As pH is corrected, potassium moves back into cells and serum potassium can drop dangerously low (hypokalemia below 3.5 mEq/L), also causing arrhythmias (torsades de pointes) and muscle weakness. Close monitoring and early replacement prevent both extremes.

Your top priorities at the bedside

1. Place patient on continuous cardiac monitor and watch for peaked T waves, wide QRS, or arrhythmias every 15 minutes if potassium is above 5.5 mEq/L. — why: Too much acid in the blood (Acidosis) pushes potassium out of cells into blood (hyperkalemia), and high potassium changes how the heart's electrical system works—peaked T waves warn that the heart may stop beating (cardiac arrest) within minutes.
2. Check blood glucose immediately with fingerstick, then obtain full metabolic panel, arterial blood gas, and anion gap calculation before any treatment. — why: You must know the pH, PaCO₂, bicarbonate, and anion gap to identify the primary problem and whether the body is compensating correctly—treating the wrong disorder (like giving bicarbonate in respiratory acidosis (acid building up from trapped carbon dioxide)) can kill the patient.

3. Start high-flow oxygen or prepare for mechanical ventilation if respiratory rate is below 8 or above 35 breaths per minute, or if patient is drowsy and cannot protect airway. — why: The lungs are the fastest way to fix acid-base problems by changing CO₂ levels—too little breathing traps CO₂ and causes respiratory acidosis (acid building up from trapped carbon dioxide), while the body uses fast deep breathing to blow off CO₂ and compensate for metabolic acidosis (acid building up in the blood), but the patient can tire out.