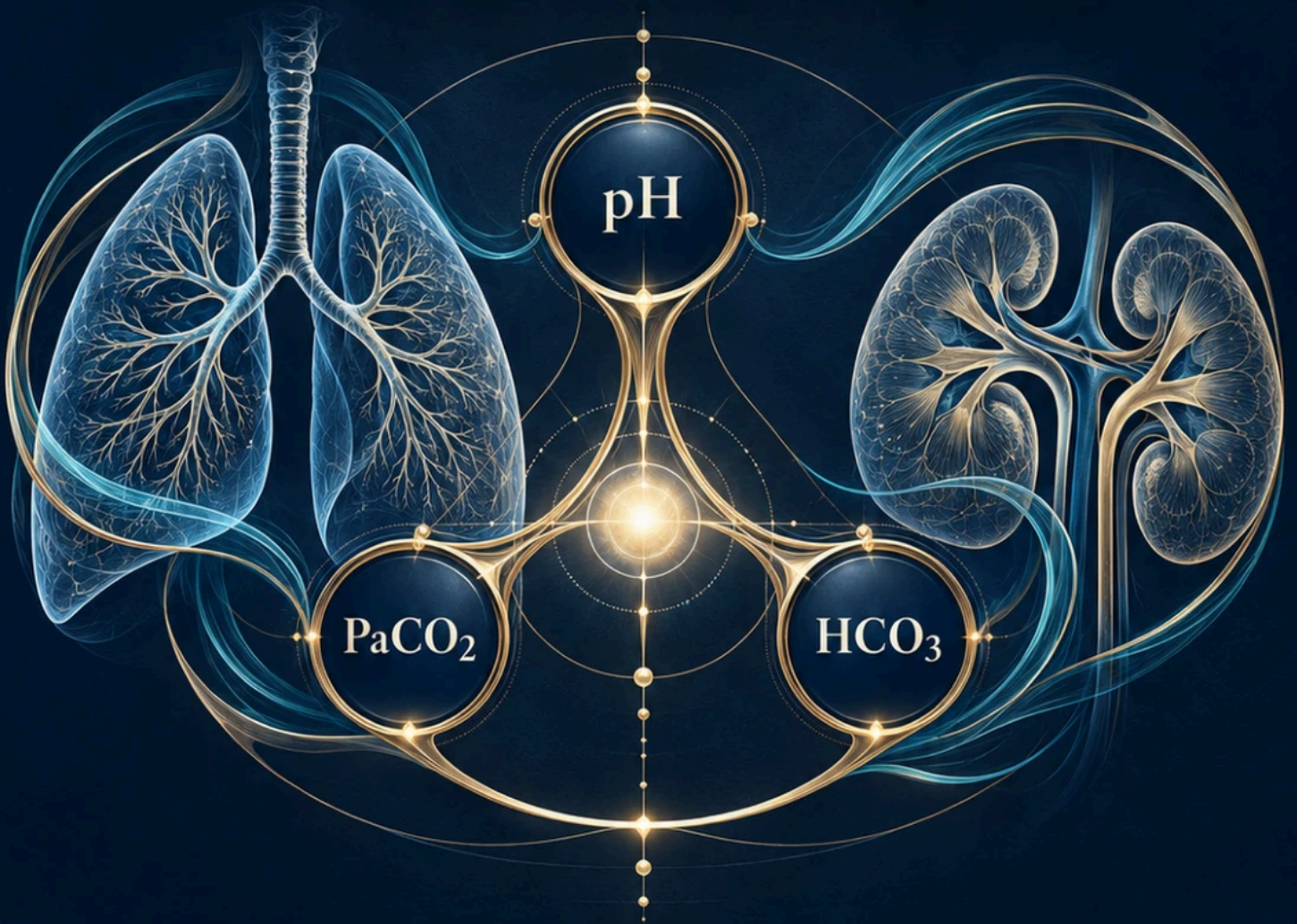


DECODED MEDICAL LIBRARY

# ABG Decoded



Acid-base clarity. Clinical confidence.

Dr Fuad Mustafa

FIRST EDITION

## CONTENTS

# ABG Decoded

Fifteen chapters in five parts, four appendices and an index.

## PART I · THE METHOD

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## BEFORE YOU BEGIN

# How to use this book

ABG Decoded teaches one method and applies it to every blood gas. Each chapter is written in three layers, so a student, a resident and a fellow can read the same page and each take what they need.

## Three layers, one page

| Layer                 | Written for                                              | What it gives you                                                                                                 |
|-----------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| <b>L1 Foundations</b> | Medical students, interns                                | The method, normal values and the common patterns you must never miss.                                            |
| <b>L2 Practice</b>    | Residents, junior registrars                             | Mixed disorders, the management decision attached to each result, and the pitfalls that catch working clinicians. |
| <b>L3 Mastery</b>     | Critical care, emergency and trauma fellows; consultants | Mechanism in depth, the physicochemical (Stewart) view, key trials, controversies and where the field is heading. |

Text without a tag is core reading for everyone. Shaded L2 and L3 panels can be skipped on a first pass and returned to later.

## The features in every chapter



### PEARL

A short, practical insight that makes the next gas easier to read.



### TRAP

A common error, the reason it happens, and how to avoid it.



### EVIDENCE

The study or guideline behind a rule, with numbers.



### DECODE REFLEX

A fixed "if you see this, look for that" link that experienced readers apply automatically.



### RED FLAG

A result that needs action within minutes, not a routine report.



### BEDSIDE CARD

A one-page summary at the end of each chapter, built to be printed or kept on a phone.

## Reading the reports

Every case comes with an analyser report laid out as blood gas machines print it: blood gas values, oximetry, electrolytes, metabolites and calculated values, each with its reference range and an arrow when outside it. Gas tensions are in mmHg with kPa alongside. Chapter 1 is the backbone of the book; Part V, the ABG Atlas, gives sixty unseen reports for practice.

# 01

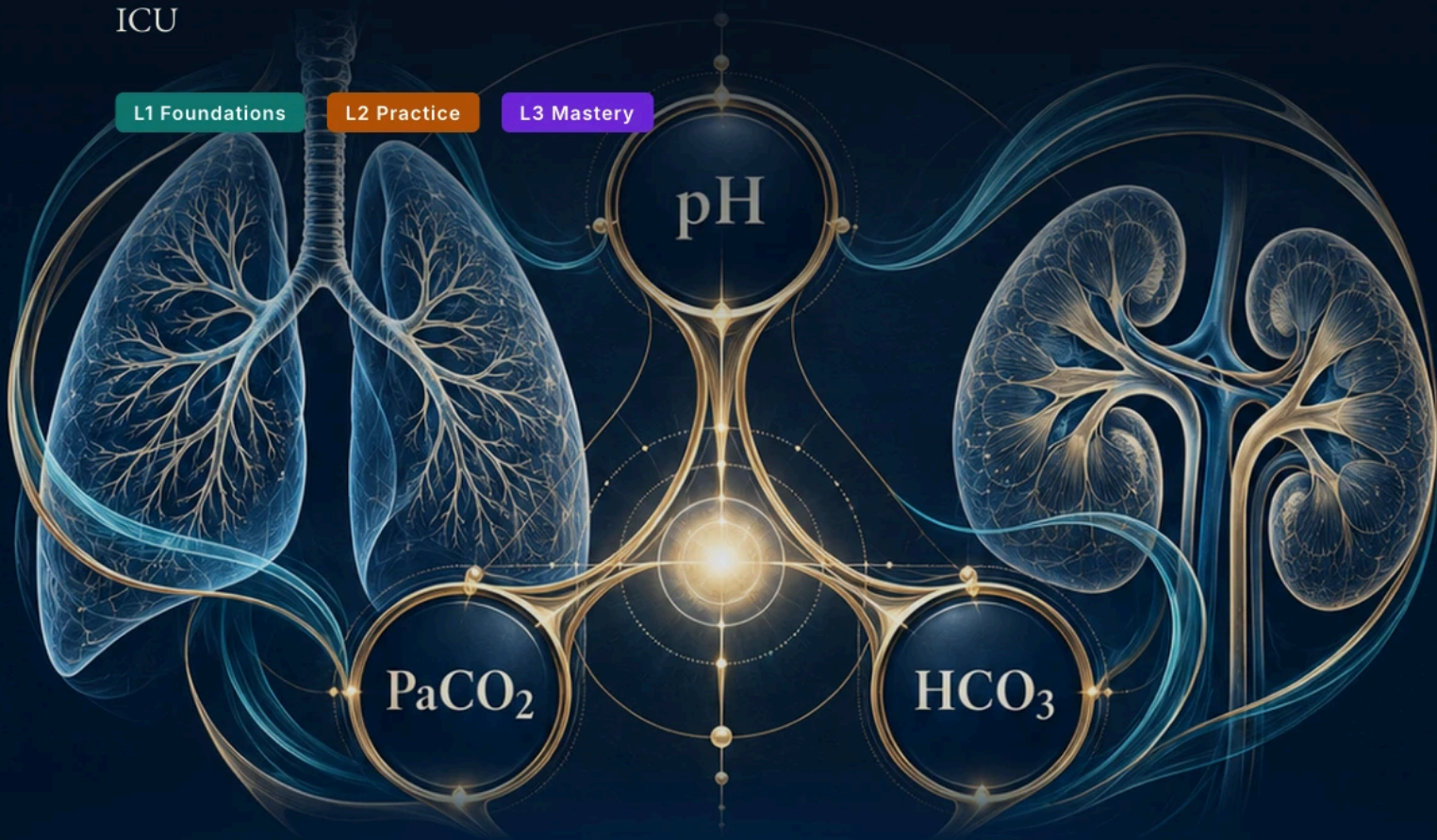
## The ABG Decode Sequence

One method for every blood gas, from the emergency department to the ICU

L1 Foundations

L2 Practice

L3 Mastery



### IN THIS CHAPTER

- 01 Why a fixed sequence beats pattern-spotting
- 02 Step 0: is this the sample you think it is?
- 03 Step 1: oxygenation, the P/F ratio and the A-a gradient
- 04 Steps 2–4: pH, the primary process and compensation
- 05 Steps 5–6: the anion gap and the delta ratio
- 06 Step 7: lactate, ketones, osmolar gap and electrolytes
- 07 Step 8: synthesis and the one-line report
- 08 A worked example, three graded cases, a bedside card and eight self-test questions

**OPENING CASE** "The gas is fine, she's compensating"

A 67-year-old woman with urosepsis is on noradrenaline 0.2 µg/kg/min and 40% oxygen by face mask. Respiratory rate 32/min. Albumin is 25 g/L. A colleague glances at the gas: "Metabolic acidosis, she is compensating well."

BLOOD GAS REPORT

Sample: ARTERIAL

Opening case · 67-year-old, urosepsis, noradrenaline

FiO<sub>2</sub> 0.40 · Temperature 37.0 °C · Drawn 02:40

BLOOD GAS

|                  |                     |           |
|------------------|---------------------|-----------|
| pH               | 7.24 ↓              | 7.35–7.45 |
| pCO <sub>2</sub> | 30 ↓ mmHg (4.0 kPa) | 35–45     |
| pO <sub>2</sub>  | 68 ↓ mmHg (9.1 kPa) | 80–100    |

OXIMETRY

|                 |           |         |
|-----------------|-----------|---------|
| ctHb            | 104 ↓ g/L | 130–170 |
| sO <sub>2</sub> | 90.0 ↓ %  | 95–99   |
| FCOHb           | 1.1 %     | 0.5–1.5 |
| FMetHb          | 0.6 %     | 0.0–1.5 |

ELECTROLYTES

|                   |        |        |           |
|-------------------|--------|--------|-----------|
| cNa <sup>+</sup>  | 138    | mmol/L | 135–145   |
| cK <sup>+</sup>   | 4.6    | mmol/L | 3.5–5.0   |
| cCl <sup>−</sup>  | 104    | mmol/L | 98–107    |
| cCa <sup>2+</sup> | 1.08 ↓ | mmol/L | 1.15–1.30 |

METABOLITES

|      |       |        |         |
|------|-------|--------|---------|
| cGlu | 9.6 ↑ | mmol/L | 4.0–7.8 |
| cLac | 6.8 ↑ | mmol/L | 0.5–2.0 |

CALCULATED

|                                   |         |        |          |
|-----------------------------------|---------|--------|----------|
| cHCO <sub>3</sub> <sup>−</sup>    | 12.7 ↓  | mmol/L | 22–26    |
| cBase(Ecf)                        | −13.1 ↓ | mmol/L | −2 to +2 |
| Anion gap                         | 21 ↑    | mmol/L | 8–16     |
| pO <sub>2</sub> /FiO <sub>2</sub> | 170 ↓   | mmHg   | >400     |

**Figure 1.1** Opening case. Keep it in mind as you read; we decode it at the end of the chapter.

Is she compensating? What else is this gas telling you?

## Learning objectives

### L1 FOUNDATIONS

- Apply the nine steps in order
- Name the primary disorder from pH, PaCO<sub>2</sub> and HCO<sub>3</sub><sup>−</sup>
- Calculate the anion gap
- Recognise type 1 and type 2 respiratory failure

### L2 PRACTICE

- Use the compensation rules to find a second disorder
- Correct the anion gap for albumin
- Calculate the A–a gradient and P/F ratio
- Write a one-line synthesis with an action

### L3 MASTERY

- Use the delta ratio for triple disorders
- Check internal consistency with [H<sup>+</sup>]
- Know the limits of each rule
- Recognise a normal pH hiding two disorders

## THE CHAPTER IN 60 SECONDS

Read every gas in the same order. **0** Check the sample. **1** Oxygenation:  $\text{PaO}_2$  for the  $\text{FiO}_2$ , P/F ratio, A–a gradient. **2** pH. **3** Which of  $\text{PaCO}_2$  or  $\text{HCO}_3^-$  explains it. **4** Is compensation what you would expect? If not, there is a **second disorder**. **5** Anion gap, corrected for albumin. **6** If the gap is high, the **delta ratio** looks for a hidden metabolic process. **7** Lactate, ketones, osmolar gap, potassium, glucose. **8** One sentence: the disorders, the cause, the next step.

Three numbers to know: Winter's formula (expected  $\text{PaCO}_2 = 1.5 \times \text{HCO}_3^- + 8 \pm 2$  mmHg), the anion gap ( $\text{Na}^+ - \text{Cl}^- - \text{HCO}_3^-$ , about 12) and the alveolar gas equation ( $\text{PAO}_2 = \text{FiO}_2 \times 713 - \text{PaCO}_2 / 0.8$  mmHg).

## Why a fixed sequence

A blood gas holds a dozen numbers, and most errors come from reading the most striking one and stopping. The commonest misses are a second acid–base disorder hidden behind "compensation", a raised anion gap disguised by low albumin, hypoxaemia that looks acceptable only because the patient is on high-flow oxygen, and a venous sample read as arterial. A fixed sequence makes every gas take a minute and miss nothing.

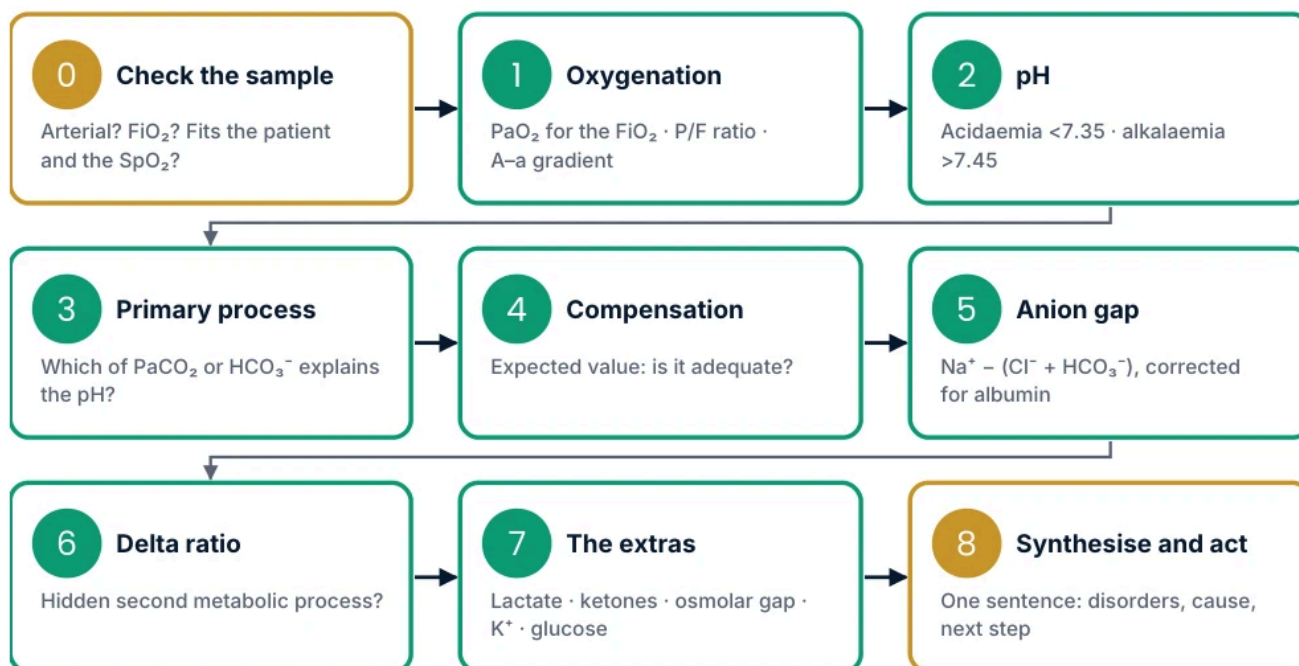


**Figure 1.2** The ABG Decode Sequence. Step 0 and Step 8 frame the read; Steps 1–7 are worked in strict order. Every later chapter expands one step or applies the sequence in one clinical setting.

**TABLE 1.1 · NORMAL ARTERIAL VALUES (ADULT, SEA LEVEL, BREATHING AIR)**

| Value                         | Normal range                | Notes                                                     |
|-------------------------------|-----------------------------|-----------------------------------------------------------|
| pH                            | 7.35–7.45                   | [H <sup>+</sup> ] 35–45 nmol/L                            |
| PaCO <sub>2</sub>             | 35–45 mmHg (4.7–6.0 kPa)    | Set entirely by alveolar ventilation                      |
| PaO <sub>2</sub>              | 80–100 mmHg (10.7–13.3 kPa) | Falls with age; interpret against FiO <sub>2</sub>        |
| HCO <sub>3</sub> <sup>−</sup> | 22–26 mmol/L                | Calculated from pH and PaCO <sub>2</sub>                  |
| Base excess                   | −2 to +2 mmol/L             | Metabolic component only                                  |
| Anion gap                     | About 8–16 mmol/L           | Analyser-specific; many modern analysers run lower (4–12) |
| Lactate                       | <2.0 mmol/L                 | ≥4 mmol/L is severe                                       |

**STEP 0**

0

**Check the sample**

- **Is it arterial?** A PaO<sub>2</sub> below 40 mmHg with a saturation of 70–75% in a patient whose pulse oximeter reads 96% is a venous sample. Compare the gas saturation with the SpO<sub>2</sub>.
- **What was the FiO<sub>2</sub>?** A PaO<sub>2</sub> of 90 mmHg is normal on air and severe impairment on 80% oxygen. Record the FiO<sub>2</sub> or device and flow on every gas.
- **When, and how handled?** Air bubbles, delay at room temperature and heparin dilution all change the numbers (Chapter 3).
- **Is it internally consistent?** [H<sup>+</sup>] (nmol/L) = 24 × PaCO<sub>2</sub> (mmHg) ÷ HCO<sub>3</sub><sup>−</sup>. Near the normal range, [H<sup>+</sup>] in nmol/L is roughly 80 minus the two digits after the decimal point of the pH (pH 7.30 ≈ 50 nmol/L).

**STEP 1**

1

**Oxygenation**

Oxygenation is assessed before acid–base, because hypoxaemia kills fastest. Three questions:

**TABLE 1.2 · ASSESSING OXYGENATION**

| Question                                 | Measure                                                                                                                        | Interpretation                                                                                                    |
|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Is the patient hypoxaemic?               | PaO <sub>2</sub> <60 mmHg (8 kPa) or SaO <sub>2</sub> <90%                                                                     | Respiratory failure: type 1 if PaCO <sub>2</sub> is normal or low, type 2 if PaCO <sub>2</sub> >45 mmHg (6 kPa)   |
| How bad is it for the FiO <sub>2</sub> ? | P/F ratio = PaO <sub>2</sub> (mmHg) ÷ FiO <sub>2</sub>                                                                         | Normal >400; <300, <200 and <100 grade ARDS severity (Chapter 11)                                                 |
| Is the lung the problem?                 | A–a gradient = PAO <sub>2</sub> – PaO <sub>2</sub> , where PAO <sub>2</sub> = FiO <sub>2</sub> × 713 – PaCO <sub>2</sub> ÷ 0.8 | On air, normal <15 mmHg in the young (roughly age/4 + 4); a normal gradient with hypoxaemia means hypoventilation |

**PEARL · THE QUICK EXPECTED  $PAO_2$** 

A healthy person's  $PAO_2$  in kPa is roughly the inspired oxygen percentage minus 10 (in mmHg, about five times the percentage). On 40% oxygen, expect about 30 kPa (200 mmHg). A  $PAO_2$  of 13 kPa on 40% looks "normal" but represents a major gas-exchange defect.

**2****STEP 2****pH**

A pH below 7.35 is **acidaemia**; above 7.45 is **alkalaemia**. The words "acidosis" and "alkalosis" describe processes, and several can coexist. A normal pH does not mean a normal gas: if  $PaCO_2$  and  $HCO_3^-$  are both abnormal, two opposing processes are cancelling each other.

**3****STEP 3****Primary process****TABLE 1.3 · NAMING THE PRIMARY DISORDER**

| pH     | Change that explains it               | Primary disorder                       |
|--------|---------------------------------------|----------------------------------------|
| Low    | $PaCO_2$ high                         | Respiratory acidosis                   |
| Low    | $HCO_3^-$ low                         | Metabolic acidosis                     |
| High   | $PaCO_2$ low                          | Respiratory alkalosis                  |
| High   | $HCO_3^-$ high                        | Metabolic alkalosis                    |
| Normal | Both abnormal, in opposite directions | Mixed disorder (two primary processes) |

**4****STEP 4****Compensation**

The body defends pH by moving the other variable in the same direction: the lungs adjust  $PaCO_2$  within minutes; the kidneys adjust  $HCO_3^-$  over 3–5 days. Compensation is predictable. If the measured value lies outside the expected range, a second primary disorder is present.

TABLE 1.4 · EXPECTED COMPENSATION (PaCO<sub>2</sub> IN MMHG)

| Primary disorder              | Expected change                                                             | If outside the range                                                    |
|-------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Metabolic acidosis            | $\text{PaCO}_2 = 1.5 \times \text{HCO}_3^- + 8 (\pm 2)$ (Winter)            | Higher: added respiratory acidosis · lower: added respiratory alkalosis |
| Metabolic alkalosis           | $\text{PaCO}_2 = 0.7 \times \text{HCO}_3^- + 20 (\pm 5)$                    | Higher: added respiratory acidosis · lower: added respiratory alkalosis |
| Acute respiratory acidosis    | HCO <sub>3</sub> <sup>-</sup> rises 1 per 10 mmHg rise in PaCO <sub>2</sub> | Larger rise: chronic or added metabolic alkalosis                       |
| Chronic respiratory acidosis  | HCO <sub>3</sub> <sup>-</sup> rises 3.5 per 10 mmHg                         | Smaller rise: acute-on-chronic or added metabolic acidosis              |
| Acute respiratory alkalosis   | HCO <sub>3</sub> <sup>-</sup> falls 2 per 10 mmHg fall in PaCO <sub>2</sub> | Larger fall: chronic or added metabolic acidosis                        |
| Chronic respiratory alkalosis | HCO <sub>3</sub> <sup>-</sup> falls 4–5 per 10 mmHg                         | The only disorder in which compensation may normalise pH                |

**TRAP · "OVERCOMPENSATION"**

Compensation brings the pH towards normal but does not overshoot it. A patient with metabolic acidosis whose pH is 7.48 is not "overcompensating": there is a primary respiratory alkalosis as well (sepsis, salicylate, liver failure, pregnancy).

**DECODE REFLEX · THE PH SHORTCUT**

In metabolic acidosis, the expected PaCO<sub>2</sub> in mmHg is roughly the two digits after the decimal point of the pH (pH 7.25 → PaCO<sub>2</sub> about 25). Use it to check Winter's formula quickly at the bedside.

**5****STEP 5****Anion gap**

Electrical neutrality requires that cations equal anions. The routinely measured cations (sodium) exceed the measured anions (chloride and bicarbonate); the difference, the **anion gap**, represents unmeasured anions, mainly albumin and phosphate. When an acid such as lactic acid accumulates, its hydrogen ion is buffered by bicarbonate and its anion (lactate) stays: bicarbonate falls and the gap rises. When bicarbonate is lost and replaced by chloride, the gap stays normal.

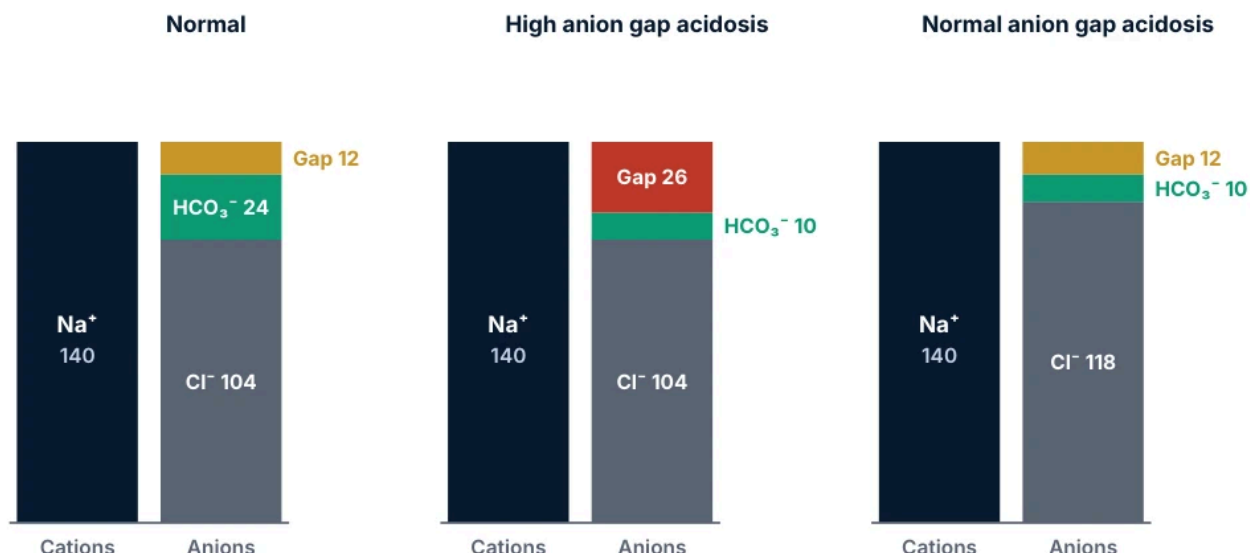


**Figure 1.3** The anion gap. In high anion gap acidosis the lost bicarbonate is replaced by an unmeasured anion; in normal anion gap (hyperchloraemic) acidosis it is replaced by chloride.

- **Anion gap** =  $\text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-)$ . Know your laboratory's normal range; this book uses 12 as the midpoint.
- **Correct for albumin**: albumin is the main unmeasured anion. Add 2.5 mmol/L to the gap for every 10 g/L that albumin is below 40 g/L. Critically ill patients often have albumin of 20–25 g/L, which hides a gap of 4–5 mmol/L.
- **High gap**: lactate, ketones, toxic alcohols, salicylate, 5-oxoproline (paracetamol), renal failure (Chapter 7). **Normal gap**: saline, diarrhoea, renal tubular acidosis (Chapter 8).

## STEP 6

6

## Delta ratio

In a pure high anion gap acidosis, each unit rise in the gap roughly matches a unit fall in bicarbonate. The **delta ratio** compares them:  $(\text{anion gap} - 12) \div (24 - \text{HCO}_3^-)$ .

**TABLE 1.5 · INTERPRETING THE DELTA RATIO**

| Delta ratio | Interpretation                                                                                                      |
|-------------|---------------------------------------------------------------------------------------------------------------------|
| <0.4        | Normal anion gap (hyperchloraemic) acidosis                                                                         |
| 0.4–0.8     | Combined high and normal anion gap acidosis (or renal failure)                                                      |
| 0.8–2.0     | Pure high anion gap acidosis (DKA often near 1; lactic acidosis often 1.6)                                          |
| >2.0        | High anion gap acidosis plus metabolic alkalosis, or a pre-existing high bicarbonate (chronic respiratory acidosis) |