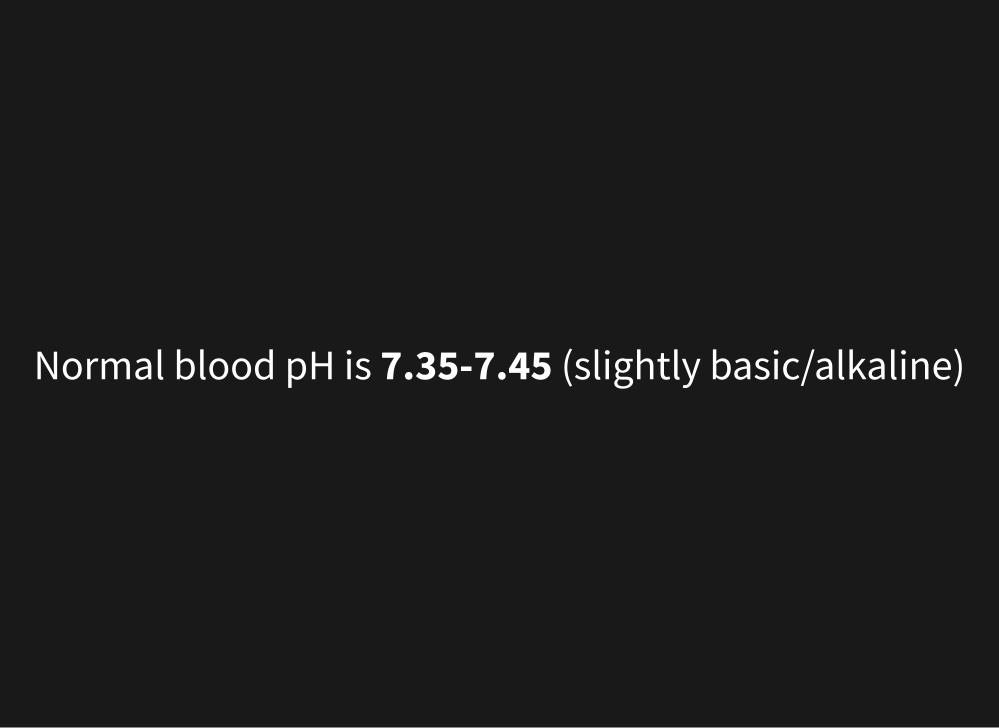
ACID-BASE BALANCE (CHAPTER 9)

What is the normal pH of adult blood?



Death can occur when blood pH falls above ____ or below ____.

Above **7.8** (more alkaline) or below **6.9** (more acidic)

This is a very narrow range–roughly equivalent to seawater vs. distilled water!

Describe the normal values for P_aCO₂ and HCO₃⁻.

P_aCO₂ (partial arterial pressure of CO₂): **36-44** mmHg

HCO₃⁻ (bicarbonate): **22-26** mEq/l

P_aCO₂, HCO₃, and serum pH are all part of a set of five tests known as ABGs—**arterial blood gases**.

The other tests are P_aO₂ and S_pO₂, but these have to do with oxygenation rather than acid-base balance.

Explain the three major mechanisms that regulate acid-base.

Three main categories:

- Buffer systems
- Respiration
- Renal system

Buffer systems are the **fastest-acting** of the three categories, and make small adjustments to pH by "soaking up" and "spitting out" H⁺ ions as necessary.

One of the major pH buffers in the body is the carbonic acid-bicarbonate buffer.

We'll talk more about this in a second, but the important thing for now is **carbonic acid**—H₂CO₃

What's special about H₂CO₃?

$$H_2CO_3 \rightleftharpoons H_2O + CO_2$$

Carbonic acid is just carbon dioxide plus water.

That brings us to our second system: **respiration**.

Carbonic acid is very easy to get rid of. Break it down, breathe out the CO₂, and we're left with just water.

Water is **neutral**—boom, acid gone.

pH balance through respiration is **slower** than buffer systems, but actually **removes** the acid from the body.

It also helps correct the ratio between carbonic acid and bicarbonate.

What's special about HCO₃⁻?

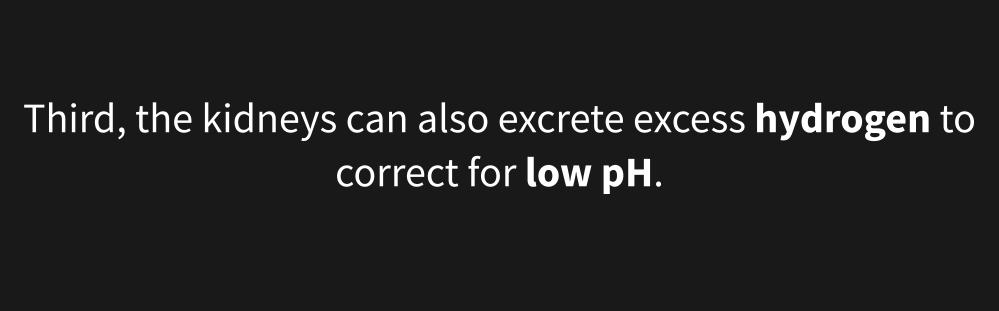
$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3$$

Bicarbonate is carbonic acid minus hydrogen.

On to the third system of pH balance: the kidneys.

First and foremost, the kidneys are actually where (some) bicarbonate is **produced**.

Second, the kidneys can also **excrete** excess bicarbonate from the blood, or reabsorb it if needed.



Kidneys produce **ammonia** (NH₃). Excess hydrogen bonds to it to form **ammonium** (NH₄⁺).

Ammonium is excreted in the urine, taking the hydrogen ions with it.

(can handle any acid **except** H₂CO₃, which must be expelled as CO₂)

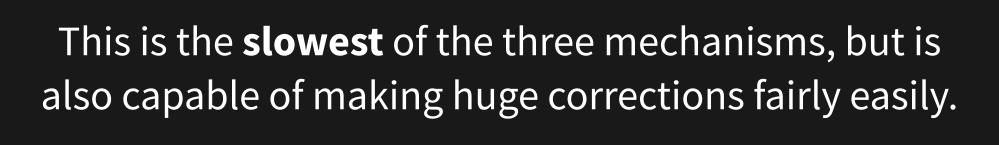
Too much acid?

reabsorb filtered bicarbonate

increase bicarbonate production

excrete hydrogen ions as NH₄⁺

Too much base? excrete bicarbonate in the urine reduce bicarbonate production reabsorb filtered metabolic acids



Buffers: nearly **instant**, but **limited** by HCO₃⁻ levels

Respiration: **slower**, but actually **removes** acid from the body in the form of CO₂

Renal system: the "big guns"—slowest of all, but capable of making the most drastic adjustments

What do these mechanisms reflect?

P_aCO₂ – respiratory function

HCO₃ – renal function

Serum pH – overall acid-base balance

Describe the bicarbonate buffer system.

A quick word on **carbonic acid**: H₂CO₃ is a **weak acid**, meaning that it's usually perfectly content to stay in solution without shedding an H⁺ ion.

The **stronger** an acid, the more its H⁺ ion wants to "pop off" when given the opportunity.

We can quickly **reduce** the number of free H⁺ by bonding them to **bicarbonate**, creating **carbonic acid**.

$$HCO_3^- + H^+ \rightarrow H_2CO_3$$

We can also **increase** the number of free H⁺ by taking them from **carbonic acid**, creating **bicarbonate**.

$$H_2CO_3 \rightarrow HCO_3^- + H^+$$

This is the carbonic acid-bicarbonate buffer system.

The body can respond to changes in pH **almost instantly** with just one chemical reaction.

Carbonic acid will stay in solution until...

If pH increases – turned back into bicarbonate

If pH remains low – broken down and exhaled as CO₂

Bicarbonate will stay in solution until...

If pH decreases – turned back into carbonic acid

If pH remains high – excreted by the kidneys

What is the ratio of bicarbonate ions to carbonic acid?

20 bicarbonate (HCO₃⁻) to **1 carbonic acid** (H₂CO₃)

Kidneys and lungs will **try** to preserve this ratio if working properly.

What happens in the bicarbonate buffer system when there is too much acid? Too little acid?

Too much acid – bicarbonate bonds to free H⁺, creating carbonic acid

Too little acid – carbonic acid sheds H⁺, creating bicarbonate

What can the respiratory system contribute to pH regulation?

Respiratory rate and depth control how much carbon dioxide is blown off, affecting carbonic acid levels.

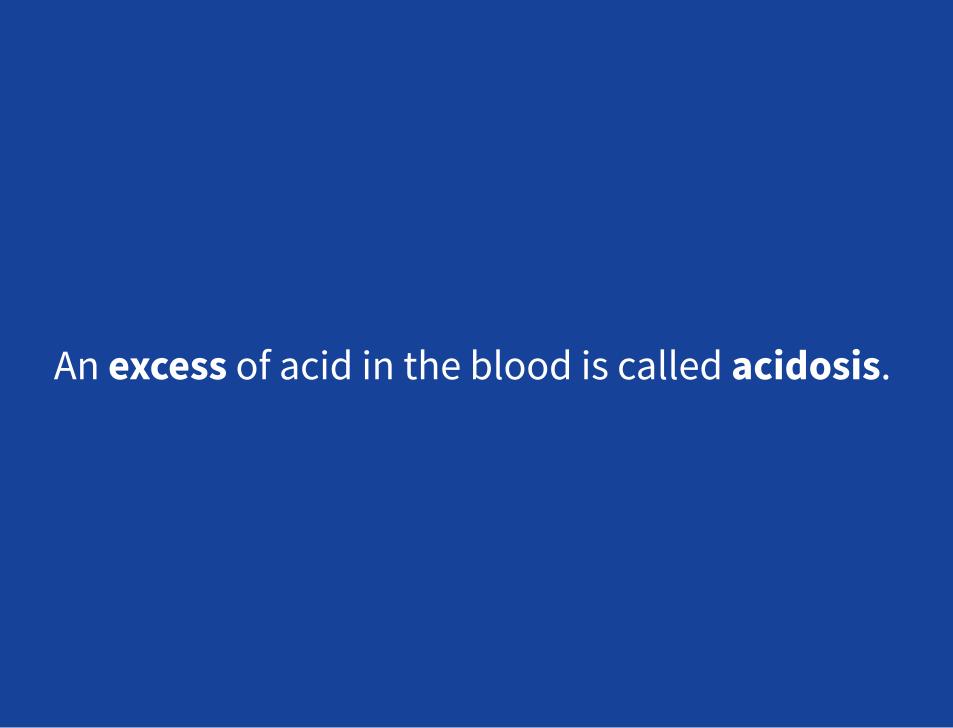
Breathe **faster** or **deeper**span class="fragment fadeup"> → **decreases** H₂CO₃

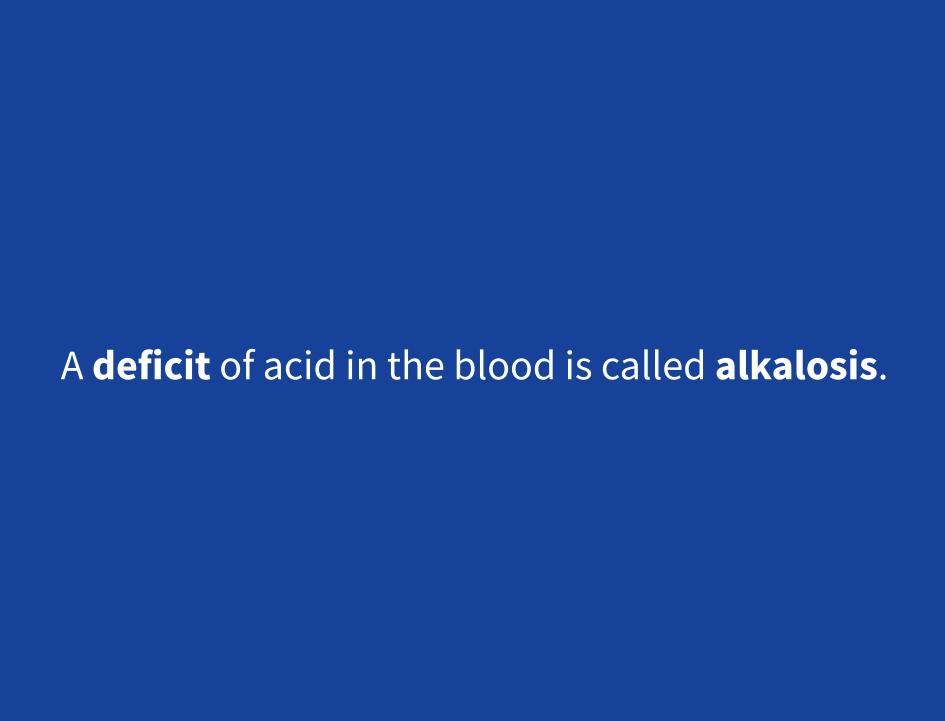
Breathe **slower** or **shallower**span class="fragment fade-up"> → **increases** H₂CO₃

What is the body's volatile acid? Give examples of metabolic acids?

volatile acid – carbonic acidmetabolic acids – lactic, pyruvic, acetic, etc.







In addition, pH imbalances are named after their **source**...

Where is the problem coming from?

From the lungs – respiratory
From anywhere else – metabolic

This means there are four categories of pH imbalance:

metabolic acidosis respiratory acidosis

metabolic alkalosis respiratory alkalosis

Let's go over some examples...

(These are meant to be **hard** and really get you thinking.)

A patient has a history of end-stage renal disease.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

A patient is experiencing an acute exacerbation of chronic obstructive pulmonary disease.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

A patient is experiencing intractable vomiting.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

A patient is on a high-dose IV morphine drip for pain.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

A patient is experiencing intractable diarrhea.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

A patient is experiencing an acute panic attack.

metabolic acidosis

respiratory acidosis

metabolic alkalosis

Okay, on to the next question...

Compensation for an excess of metabolic acid is ____.

Need to get rid of acid and the kidneys aren't doing it...

Convert to carbonic acid and breathe it out!

(compensation for **metabolic acidosis** – **faster**, **deeper** breathing)

Compensation for a deficit of any acid except carbonic acid is ____.

Now we need **more** acid, and the kidneys aren't correcting...

Hold on to carbonic acid and keep that H⁺!

(compensation for metabolic alkalosis – slower, shallower breathing)

The kidneys' response to changes in pH includes ____.

Too much acid?

reabsorb filtered bicarbonate

increase bicarbonate production

excrete hydrogen ions as NH₄⁺

Too much base? excrete bicarbonate in the urine reduce bicarbonate production reabsorb filtered metabolic acids

What does HCO₃⁻ in the plasma reflect?

Serum **bicarbonate** reflects both kidney function and the amount of metabolic acids in the blood.

If HCO₃⁻ is low, either not enough is being produced by the kidneys, or a lot is being converted to H₂CO₄.

What is renal compensation for an increase or decrease in carbonic acid?

respiratory acidosis – produce more bicarbonate, excrete H⁺ as ammonium

respiratory alkalosis – excrete bicarbonate, reabsorb metabolic acids

What is starvation ketoacidosis? How does it affect pH?

When they lack available glucose, cells will use triglycerides as an alternate energy source.

Acidic ketones such as **acetoacetate** are produced as a byproduct of fatty acid catabolism.



When caused by malnutrition, we call this **starvation ketoacidosis**.

When caused by a lack of insulin, we call this **diabetic ketoacidosis** (DKA.)

What are some examples of excess removal or decrease in base?

Most commonly, an excessive loss of **pancreatic** bicarbonate due to loss of intestinal contents, such as **diarrhea**.

Can also be caused by type 2 **renal tubular acidosis**, where HCO₃⁻ is not properly reabsorbed in the PCT.

Which tissues of the body are most affected by pH disturbances?

Acidosis can have a severe **negative inotropic** effect on the heart (decreases force of contraction, lowering cardiac output.)

Many tissues affected by pH due to effects of acid environment on various proteins. For example, muscle contraction is impaired by excessive acid.

How do we think about compensation versus correction when thinking about acid-base disturbances?

Correction – fixing the imbalance **at the source Compensation** – **opposite** system counteracts

Compensation for **metabolic** imbalances is **respiratory**.

Compensation for **respiratory** imbalances is **metabolic**.

Describe some conditions that could cause respiratory acidosis.

Anything that **slows** breathing or **impairs gas exchange**.

- Resiratory depression (e.g. opioids)
- Airway obstruction (COPD, asthma)
- Reduced effective lung volume (pneumonia, atelectasis)

How can base increase?

Not too many ways.

- Ingesting bicarbonate or other bases (e.g. antacids)
- Transfusion of blood preserved with citrate (conjugate base of citric acid)
- Fluid volume loss (contraction alkalosis)

How can metabolic acid decrease?

More ways.

- Emesis or gastric suction (losing stomach acid)
- Hyperaldosteronism (↑ Na⁺, ↓ H⁺)
- Hypokalemia (↑ K⁺, ↓ H⁺)
- Again, fluid volume loss (contraction alkalosis)