🧠 **"Normal Potassium Balance"**
This refers to how the body **keeps potassium levels stable** in both the blood and inside cells.

🧪 **"100 mEq K^+"**
This means we **take in about 100 milliequivalents** of potassium every day through food.

🩸 **"Extracellular fluid: 65 mEq"**
Only **about 65 mEq of total body potassium is in the blood and other fluid outside cells.** That's only around 2% of all potassium!

💪 **"RBC ~250 | Muscle ~2500 | Liver ~250 | Bone ~500"**
Most potassium is **inside cells**:

- Red blood cells: ~250
- Muscles: **a huge amount** (~2500)
- Liver and bones store some too.

🧍 **"Mainly intracellular"**
Almost **all of the body's potassium is inside the cells** (intracellular). Only a tiny part is in the blood.

💊 **"Hypokalemia treated by urine diuretics. Gut we give potassium."**

- **If low K^+ (hypokalemia)**: You can treat by **giving potassium orally (gut)** or **stop diuretics that cause loss through urine**.
- Diuretics like furosemide can **make you lose K^+ in urine**.

🔁 **"Exchange hormones trigger it. Target = 3.5 – 5.0 mmol/L"**

- The **goal** of the body is to keep **blood potassium between 3.5–5.0**.
- **Hormones like insulin and aldosterone** help adjust potassium by moving it into cells or making you pee it out.

🚽 **"Excretion ~100 mmol"**
The body **excretes about 100 mmol/day**, mostly in **urine**. That balances what you eat. . kidney (90-95 mmol or mEq) / gut (5-10 mmol or mEq)

🔄 **"Extra-renal K^+ homeostasis: Shift/Redistribution"**
This means **potassium moves between cells and blood** (not through the kidneys) — it's called **redistribution**.

🔑 **"4 major factors: for shift/ redistribution**
Now we'll list the **four key things** that control where potassium is (inside vs. outside the cell):

- Note : anything that pushes inside the cell-> hypokalemia since we have less k in blood and the opposite of pushing out)

✅ **"– Hormones" → (like insulin or epinephrine)**
These hormones **push potassium into cells**.

✅ **"– Acid-base status"**
Acidosis = pushes K^+ **out of cells** **Alkalosis** = pushes K^+ **into cells**

✅ **"– Plasma tonicity"**
If the blood becomes more **concentrated (hypertonic)**, it pulls water **and potassium out of cells**.

✅ **"– Plasma [K^+]"**

If potassium in the blood gets high, the body tries to **shift it into cells or pee it out**.

Acute

Factor	Effect on potassium
Insulin	Enhanced cell uptake
β-Catecholamines	Enhanced cell uptake
α-Catecholamines	Impaired cell uptake
Acidosis	Impaired cell uptake
Alkalosis	Enhanced cell uptake
External potassium balance	Loose correlation
Cell damage	Impaired cell uptake
Hyperosmolality	Enhanced cell efflux

Chronic

Factor	Effect on ATP pump density
Thyroid	Enhanced
Adrenal steroids	Enhanced
Exercise (training)	Enhanced
Growth	Enhanced
Diabetes	Impaired
Potassium deficiency	Impaired
Chronic renal failure	Impaired

🧬 **"Zona Glomerulosa of the Adrenal cortex"**
This is the part of the adrenal gland that **makes aldosterone**, a hormone that controls potassium and sodium.

1+ 2 = what controls the aldosterone
1- 🔄 **"Release stimulated by Renin/Angiotensin system"**
If your blood pressure or sodium is low, this system tells the adrenal gland to **release aldosterone**.

2- 🧪 **"Direct effect of K^+ on adrenal"**
If potassium in blood gets too high, that also **directly triggers** aldosterone release to remove the extra.

⚙️ **"Effects of Aldosterone: Exchange Na^+ for K^+ or H^+"**
Aldosterone **pulls sodium into the blood** and **pushes K^+ and H^+ into urine**.

- This keeps Na^+ and BP up, and K^+ + H^+ under control.

🧱 **"Sites of action: Distal renal tubule, colon, sweat glands"**
Aldosterone works mainly in the **last part of the nephron (distal tubule)**, but also in the **colon and sweat glands**, especially if kidneys aren't working well.

🧠 **"In renal failure, the colon is an important site for K^+ regulation"**
If the kidneys **can't get rid of K^+**, the **colon becomes more important** in helping excrete it. (note that normally we have execration by kidneys in 90% and gut 10%. But if we have renal failure: kidney is 70% and gut is 30%)

📌 **"Cortisol has mineralocorticoid activity"**
At very high levels (like in **Cushing's syndrome**), **cortisol** can act like aldosterone and affect K^+ and Na^+.

🧪 **Acid/Base**

- Note : principle cells control k+/ intercalated cells control h+

🧪 **"Metabolic Acidosis ↑ [K^+]"**
When you have **metabolic acidosis**, the blood has **too much H^+ (acid)**. To fix this:

- H^+ **enters cells**.
- To keep balance, **K^+ exits the cells** → leading to **high K^+ in blood** (hyperkalemia).

🚽 **"Inhibition of renal tubular K^+ secretion"**
In acidosis, the kidney **stops secreting K^+ properly**, which means more K^+ stays in the blood → again, **hyperkalemia**.

🔽 **"Shift of K^+ from ICF to ECF"**

ICF = inside cells; ECF = outside (blood). **Acidosis pushes K^+ out of cells** into blood → again causes **hyperkalemia**.

📉 **"Metabolic Alkalosis ↓ $[K^+]$"**

Opposite of acidosis:

- Less H^+ in the blood → H^+ comes **out of cells**
- To balance, **K^+ goes into cells** → Result: **hypokalemia** (low blood K^+)

🧪 **"Patient has acidosis and hypokalemia. What are 2 DDx?"**

❓ **"DDx" = differential diagnoses (possible causes)**

1. **Proximal renal tubular acidosis (RTA Type 2)**:
   - Kidney can't reabsorb bicarbonate → causes acidosis
   - Also leads to K^+ loss = hypokalemia
2. **Diarrhea**:
   - You lose both **bicarbonate (→ acidosis)** and **K^+ (→ hypokalemia)** in the stool

⚖️ **Intake vs. Output**

🍌 **Intake: from food (about 100 mEq/day)**

You eat potassium every day in fruits, vegetables, etc.

🚽 **Output:**

1. **Kidney**: Most important way to remove potassium
2. **Sweat glands**
3. **Gut (colon)** — especially important in kidney failure

⚖️ **ECF $[K^+]$ depends on:**

- How much K^+ moves **between cells and blood**
- Controlled by:
- Hormones (insulin, aldosterone)
- Acid/base
- Tonicity (concentration of solutes in blood)
- Blood potassium level itself

TABLE 4. FOODS WITH HIGH POTASSIUM CONTENT.

Highest content (>1000 mg [25 mmol]/100 g)
Dried figs
Molasses
Seaweed
Very high content (>500 mg [12.5 mmol]/100 g)
Dried fruits (dates, prunes)
Nuts
Avocados
Bran cereals
Wheat germ
Lima beans
High content (>250 mg [6.2 mmol]/100 g)
Vegetables
Spinach
Tomatoes
Broccoli
Winter squash
Beets
Carrots
Cauliflower
Potatoes
Fruits
Bananas
Cantaloupe
Kiwis
Oranges
Mangos
Meats
Ground beef
Steak
Pork
Veal
Lamb

🧠 **"Renal artery → Glomerulus → Distal Tubule = Fine tuning"**

Potassium handling in the kidney:

- **Proximal tubule**: absorbs most of the K^+
- **Distal tubule**: adjusts how much is lost → "fine tuning"
- Controlled by **aldosterone**

⚖️ **Aldosterone causes K^+/H^+ secretion and Na^+ reabsorption**

This is **the key job** of aldosterone:

- K^+ and H^+ go **into urine**
- Na^+ goes **into blood** → water follows → raises BP

💧 **600 mmol/day K^+ filtered**

Your kidneys **filter 600 mmol of potassium** every day.

💩 **100 mmol/day K^+ excreted (about 10–20%)**

Even though a lot is filtered, the kidney **reabsorbs most** and only **excretes what you don't need**.

🧪 **Renal Handling of K^+**

Segment	% of K^+ Reabsorbed
Proximal tubule	60–70%
Loop of Henle	20–30%
Distal tubule & collecting duct	Fine tuning of last 10%

💡 **100% of filtered K^+ is reabsorbed before the distal tubule**
So the **distal tubule's job is to add back what needs to be excreted.**

🔁 **"Substance | Effect of Aldosterone | Mechanism"**
Let's explain the effects of aldosterone on each substance clearly:

💊 **Potassium (K^+):**
- **Effect:** 🔻 Decreases in blood (because more K^+ goes into urine).
- **How:** Aldosterone **opens K^+ channels** in principal cells → K^+ goes into urine.

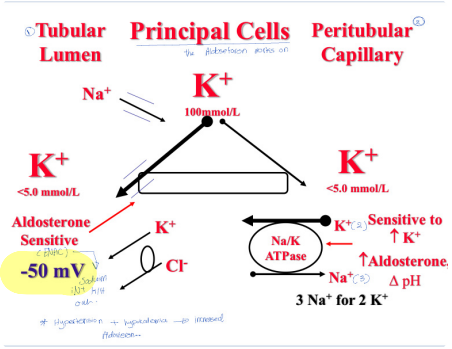
🔶 **Hydrogen ions (H^+):**
- **Effect:** 🔻 Decreases in blood (more acid secreted).
- **How:** Aldosterone **activates intercalated cells**, which push H^+ into urine.

🧂 **Sodium (Na^+):**
- **Effect:** 🔺 Increases in blood (reabsorbed).
- **How:** Aldosterone **activates ENaC channels**, which pull Na^+ from urine into the body.

🩸 **Blood Pressure (BP):**
- **Effect:** 🔺 Increases
- **How:** More Na^+ → More water follows → More volume → ↑ BP

📌 **Mnemonic:** 👉 **"Aldosterone saves salt (Na^+), pumps out K^+ and H^+."** (Save salt, pee potassium and protons)

⚙️ **Na^+/K^+ ATPase Pump Diagram (in words)**



Imagine:
- **Aldosterone works on tubular lumen and pre tubular capillary**

📦 Inside the kidney **principal cell**, you have a pump:
- 🔁 It moves:
- **3 Na^+ OUT → into blood**
- **2 K^+ IN ← from blood**
- It needs **ATP** (energy) to work
- Creates a **negative charge inside** the cell → helps pull more Na^+ from urine

This gradient helps **exchange Na^+ for K^+** and is the **engine** behind aldosterone's effects.

⚠️ **Electrochemical Gradient – Why K^+ is Secreted**
- When Na^+ is reabsorbed, it makes the inside of the tubule more negative.
- This **pulls K^+ out of cells** and into the urine.
- That's why anything that increases Na^+ reabsorption → **also increases K^+ loss**.

📊 **Factors Favoring K^+ Secretion**

Factor	Why it Increases K^+ Loss
✅ **High Na^+ reabsorption**	Makes tubule more negative
✅ **High intracellular K^+**	More K^+ leaks into urine
✅ **Increased fluid to distal nephron**	"Washes out" K^+

✅ **Aldosterone**	Opens K^+ channels
❌ **Low H^+ (alkalosis)**	More K^+ secreted in exchange

💡 **Examples of wash-out:**

- **Diuretics** increase flow
- **Osmotic diuresis** (like in diabetes)
- **Poorly absorbed anions** (e.g., bicarbonate)

🔄 **Electrochemical Competition Between K^+ and H^+**

- K^+ and H^+ both want to leave the cell.
- They use **the same exit path** (the negative gradient).
- So:
- If more **H^+ exits**, less **K^+ can exit**, and vice versa.
- That's why in **acidosis**, H^+ exits and **K^+ builds up** → hyperkalemia.

⚠️ **Causes of Hyperkalemia**

💥 **1. Increased intake**

- Rare unless you have **kidney problems**
- Ex: Too many K^+ supplements or bananas + renal failure

💥 **2. Shift from cells to blood**

(Redistribution) — potassium moves from inside the cell to outside:

Cause	Why
Acidosis	H^+ enters cells, K^+ leaves
Insulin deficiency	No insulin → K^+ stays outside
Beta blockers	Block the "push K^+ into cells" action of adrenaline
Exercise or trauma	Muscle breaks → K^+ leaks out
Digitalis overdose	Messes with Na^+/K^+ ATPase
Tumor lysis	Cells break open from chemo → K^+ released
Succinylcholine	Muscle relaxant → K^+ outflow
Hyperkalemic periodic paralysis	Genetic disorder — sudden K^+ rise in blood
Post cardiac surgery	
Tissue catabolism	Trauma/ cytotoxic agents (TLS)/ severe hypothermia
Pseudohyperkalemia	Movement of k+ out of cells during or after blood drawing : hemolysis/ fist clenching(local exercise effect)/ marked leukocytosis

💥 **3. Decreased Excretion**

Condition	Mechanism
Renal failure	Kidney can't pee out K^+
Low aldosterone	**1-Decreased activity of renin-angiotensin system** – Hyporeninemic hypoaldosteronism (T4 RTA)/ NSAIDS, ACE-I, CSA 2• **Primary decrease in adrenal synthesis** – Adrenal insufficiency, CAH, heparin •**3- Aldosterone resistance** – K+sparing diuretics, trimethoprim, CSA – pseudohypoaldosteronism
Tubular problems	Type 4 RTA, drugs like spironolactone

📌 **Most common causes** = renal failure + redistribution due to acidosis + medications.

🛑 **Symptoms of Hyperkalemia**

System	Symptoms
Muscles	Weakness, paralysis
Heart	ECG changes, arrhythmias, cardiac arrest
Gut	Nausea, vomiting, ileus (no movement)

❤️‍🩹 **ECG in Hyperkalemia = PQRST Gets Lost!**

- P wave disappears
- Prolonged PR
- QRS widens
- T wave tall & peaked
- Depressed ST
- Ends in **Sine wave** → then cardiac arrest (v.fib/ v. Tach)

Muscle weakness –
decr magnitude of
resting MP
• Cardiac toxicity
Enhanced by :
– Hypocalcemia
– Acidemia
– Hypomagnesemia
– Rapid onset

🩹 **Treatment of Acute Hyperkalemia (Life-threatening)**

1. **Stabilize the heart** ✅ Give IV **Calcium Gluconate**
2. **Push K^+ into cells (buying time but this is not the final tx)** ✅ **Insulin + Glucose, Albuterol, Bicarbonate**
3. **Remove K^+ from body** ✅ **Kayexalate (GUT) , Diuretics(kidney) , Dialysis (if nothing works)**

📦 **Treatment of Chronic Hyperkalemia (Less urgent)**

- ✅ Reduce potassium intake (diet) - 2g/day // OTC that contains k+
- 🚫 Avoid NSAIDs, ACEi, ARBs
- ✅ Use diuretics to increase loss
- ✅ Treat constipation (K^+ can be excreted in stool too)
- 💊 Kayexalate as needed

🧂 **Hypokalemia = Low Potassium (K^+ < 3.5 mmol/L)**

❗ **Etiology of Hypokalemia (Causes)**

🥣 **1. Decreased net intake**

- Rare by itself.
- But low intake **combined with loss** makes hypokalemia worse.
- Ex: **Starvation**, **eating clay (pica)** — binds K^+ and stops absorption.

↩️ **2. Increased entry of K^+ into cells**
This means K^+ moves from **blood into cells**, lowering blood potassium.

Cause	Why it happens
Alkalosis	H^+ leaves cells, so K^+ goes in to balance charge
Insulin	Insulin activates Na^+/K^+ pump → pushes K^+ into cells
Beta-adrenergic stimulation	Epinephrine pushes K^+ into cells

🧬 **Periodic Paralysis**

- K^+ shifts into cells **suddenly**, causing severe hypokalemia.
- Two types:
- **Familial** (genetic, in young males)
- **Acquired** (from **thyrotoxicosis**, especially in Asian men)
- Triggered by:
- High-carb meals
- Rest after exercise
- Cold, stress
- Insulin or adrenaline
- NOTE : K+ would be normal between attacks

💩 **3. Increased GI Losses**

Cause	Explanation
Vomiting	Loss of stomach acid → kidneys excrete K^+ to compensate
Diarrhea	Direct loss of K^+ from stool
Fistulas / tube drainage	Loss of intestinal fluid with high K^+
Laxative abuse	Like diarrhea – causes K^+ loss
Diuretic abuse	
Villous adenoma	

All the causes end with hypokalemia but its different when it comes to metabolic alkalosis or acidosis

Cause	What is lost?	Acid-base status	Why?
Vomiting / NG tube	H^+ (stomach acid)	Alkalosis	Losing acid directly
Diarrhea / Laxatives	HCO_3^- (bicarbonate) + K^+	Acidosis	Losing base
Diuretics	K^+ and H^+ (via kidney)	Alkalosis	RAAS activation → aldosterone increases H^+ loss

📌 **Clue:**

- **Vomiting → metabolic alkalosis**
- **Diarrhea → metabolic acidosis**

note: lose of upper GI (HCl) = Alkalosis → same as NG tube.
use of lower GI → Bicarbonate
mainly found in colon → Acidosis
(same as laxative)

🚽 **4. Increased Urinary Losses**

Cause	Mechanism
Diuretics (loop or thiazides)	Increased Na^+ delivery → ↑ K^+ secretion
Bartter / Gitelman syndromes	Genetic tubule disorders → kidney loses K^+
Hyperaldosteronism	Aldosterone pushes K^+ out
RTA (Renal Tubular Acidosis)	Some types waste K^+

📌 **Bartter vs. Gitelman**:

- **Bartter** = Thiazide
- **Gitelman** = loop diuritics

high urine calcium

has hypo Mg more than bartter / normal urine calcium

Both → ↑ renin, ↑ aldosterone → hypokalemia

💦 5. Increased Sweat Losses

- Seen in **athletes**, **hot climates**
- Sweat contains small but significant K^+

💉 6. Other losses: Dialysis

- Removes K^+ during treatment, especially if not adjusted correctly

⚠️ Consequences of Hypokalemia

Organ System	What Happens
🧠 **Muscles**	Weakness, cramps, paralysis
🧠 **Heart**	ECG changes, arrhythmias, ↑ Digoxin toxicity
🧠 **Kidneys**	Poor urine concentration, tubular damage
🧠 **Gut**	Constipation, **paralytic ileus** (no movement)

💉 Hypokalemia & Hypertension Workup

When you see **low K^+ + high BP**, think of **aldosterone problems**.

Lab Test	What It Tells You
Urine K^+ > 30 mEq/day	Kidney is wasting K^+
Renin level	High = Secondary cause (e.g. renal artery stenosis) Low = Primary (like Conn's) → 1° Hyperaldosterone
Aldosterone level	High = Hyperaldosteronism Low = other causes

📌 Example:

- **High BP + low K^+ + high aldosterone** = **Conn's syndrome** (aldosterone-producing tumor)

🧠 Cortisol and Potassium

- Cortisol **can act like aldosterone** if in high amounts.
- Normally, an enzyme (**11β-HSD**) converts cortisol → cortisone (inactive).
- If this enzyme is **blocked** (like in **licorice ingestion** عرق السوس), cortisol starts acting like aldosterone.

🧠 Disorders related 11b HSD :

Condition	Cause
Cushing's	High cortisol production
Syndromw of AME (Syndrome of Apparent Mineralocorticoid Excess)	Genetic or due to **licorice**
Liddle's syndrome	ENaC channel mutation (Na^+ kept, K^+ lost)

🩺 Work-up of Hypokalemia (Step-by-Step)

1. **History**: Vomiting, diarrhea, drugs, eating disorders, diuretics
2. **Acid-base status**: Alkalosis or acidosis?
3. **Urine K^+:**

- <15 mEq/L = loss is outside kidney , in stool for example (like diarrhea)
- 30 mEq/L = kidney is wasting it (e.g. diuretics, RTA)

💉 Treatment of Hypokalemia : not urgent UNLESS complications

Situation	Treatment
Mild	Oral K^+ — safer and preferred
Moderate to severe	IV K^+ if urgent, **max 10 mmol/hr**
Also give Mg^{++} if low	Low magnesium = hard to fix K^+!

📌 **Correction rule**:

- If K^+ is **3.0 mmol/L (from serum)**, deficit ≈ **300 mmol (from total body deficit)**
- If K^+ is **2.0 mmol/L**, deficit ≈ **600 mmol**
- So it takes time to fully replace do it slowly because it an cause arrhythmia
- **Small changes in blood K^+ = big total body losses**
- That's why **potassium replacement takes time**, even if the number doesn't look *that* low.

55 yo lady with DM >10 years associated with DM nephropathy and retinopathy, HTN >10 years, CKD III with baseline Cr around 1.8-2.0 presented for regular clinic visit. Na 138, K 5.7, HCO3 18, Cl 112, Cr 1.8. Urine pH 5.0. ABGs showed 7.32/34/18.

What is the most likely diagnosis?

- Diarrhea induced metabolic acidosis.
- Methanol overdose.
- Ethylene Glycol overdose
- RTA 4
- Distal RTA

(E)

70 yo man presented to the ER c/o fever, chills and SOB for one week. CXR showed bilateral pneumonia. BP is 100/60 (baseline around 140s-150s/80s-90s). Lab showed Cr of 5.0. K 7.0. EKG showed hyper-acute T waves.

What is the best next step?

A. IV calcium gluconate.
B. PO kayexalate.
C. IV furosemide
D. Emergent HD catheter and dialysis.
E. Call the nephrology team and tell them to come and take care of their patient since you are busy and have other patients to see in the ER.

Mnemonic: MUDPILES

Letter	Cause
M	Methanol
U	Uremia (kidney failure)
D	DKA (diabetic ketoacidosis)
P	Propylene glycol
I	Iron, INH
L	Lactic acidosis
E	Ethylene glycol
S	Salicylates (aspirin overdose)

58 year old lady presented to the ER with weakness. Na 136. K 3.1. Cl 110. CO2 15. ABGs showed pH 7.28. PaCO2 30. HCO3 16. Urine: Na 10 meq/l, K 8 meq/l, Cl- 40 meq/l.

What is the most likely diagnosis?

- DKA
- Lactic acidosis
- Severe vomiting
- Severe diarrhea
- RTA

(D)

24 year old lady presented to the ER with weakness. BP 85/45. BMI 35. Na 138. K 2.8. CO2 34. Mg 1.2. ABGs 7.49/45/34. She has been trying hardly to lose weight but denies laxatives or diuretics use.

What is the best next step to reach a most likely diagnosis?

- Given low serum Mg along with other lab values she most likely has Gitelman syndrome.
- Given low serum Mg along with other lab values she most likely has Bartter syndrome.
- She is most likely abusing laxatives. Ask more questions about laxatives abuse.
- Send a blood and urine sample for diuretics screen.
- She most likely had anorexia nervosa.