Major minerals

Electrolyte balance, cell signaling, bone modification
Major minerals

- Electrolyte balance & cell signalling
  - Na$^+$
  - K$^+$
  - Cl$^-$
  - Ca$^{2+}$

- Bone Growth
  - Ca$^{2+}$
  - Mg$^{2+}$
  - P

- General Growth
  - S (protein structure)
Skeleton as Mineral Reserve

- Bones store calcium and other minerals
- **Calcium** is the most abundant mineral in the body
The Minerals

**MAJOR MINERALS**
The major minerals are those present in amounts larger than 5 g (a teaspoon). A pound is about 454 g; thus only calcium and phosphorus appear in amounts larger than a pound.

**TRACE MINERALS**
There are more than a dozen trace minerals, although only six are shown here.
We're mostly fluid

- About 2/3 of our fluid is **intracellular**
- Remaining 1/3 is **extracellular**
  - **Tissue fluid**: occurs between cells of all tissues
  - **Plasma**: liquid portion of blood
Percentage by body weight

- Blood: 8%
- Other fluids and tissues: 92%

Percentage by volume

- Plasma: 55%
- Other solutes: 2%

Plasma (percentage by weight)

- Water: 91%
- Proteins: 7%

Formed elements (number per cubic mm)

- Platelets: 250–400 thousand
- White blood cells: 5–9 thousand
- Red blood cells: 4.2–6.2 million

Formed elements

- White blood cells: Neutrophils 60%–70%, Lymphocytes 20%–25%, Monocytes 3%–8%, Eosinophils 2%–4%, Basophils 0.5%–1%
- Platelets: 250–400 thousand
- Red blood cells: 4.2–6.2 million
Body Composition

- Varies between:
  - **Sexes**: males have more lean tissue. Muscle stores more \( \text{H}_2\text{O} \) than fat
  - **Age**: lose lean tissue as we age; lose \( \text{H}_2\text{O} \)
Composition of fluids

- $\text{H}_2\text{O} +$ dissolved proteins and minerals (solute)
- 4 most important electrolytes for fluid balance:
  - Sodium ($\text{Na}^+$)
  - Potassium ($\text{K}^+$)
  - Chloride ($\text{Cl}^-$)
  - Phosphorous ($\text{HPO}_4^{2-}$)
Function of body fluids

- Dissolve & transport substances
- Maintain blood volume
- Help maintain body temp
- Protect & lubricate tissues
As solvents

- Dissolve & transport solutes
  - $\text{H}_2\text{O}$ is polar = excellent solvent of polar molecules
  - Blood = 40% $\text{H}_2\text{O}$ by volume
    - responsible for transporting polar molecules (and non-polar, via polar chaperone molecules)
Blood volume

• blood volume largely determines blood pressure
  - High BP is associated with increased risk of HA & stroke
  - Low BP is generally healthy (but exceptionally low is not)
    • dizziness, lethargy, confusion
Maintains body temp

- H$_2$O has high **heat capacity**
  - Takes LOTS of energy to change its temperature and LOTS to change its state (liquid to gas), so:
    - It’s a good buffer against environmental heat
    - Coupled with sweat, provides a good **mechanism for cooling** the core temp.
Maintains body temp

• Primary coolant
  - By *shunting* hot blood to capillary beds below skin we *radiate* heat to environment
  - By *sweating*, we allow water to evaporate from skin (via convection or radiant heat); this change of state *removes* heat
As protection & lube

• **CSF** protects brain from exploding inside skull when we smack it against a rock
• **Amniotic fluid** protects baby when it’s jostled
• **Synovial fluid** lubricates joint cavities
• **Tears** protect and lubricate eye
• **Saliva** moistens food
• **Mucus** in digestive tract & nose protect against foreign particles
Electrolytes regulate fluid balance

- $H_2O$ moves “freely” through semi-permeable cell membranes; many solutes do not require pumps
- $H_2O$ is “attracted” to areas of high solute concentration. “Wants” to keep solute concentration the same on both sides of semi-permeable membrane
A nephron (a working unit of the kidney). Each kidney contains over one million nephrons.

1. Blood flows into the glomerulus, and some of its fluid, with dissolved substances, is absorbed into the tubule.

2. Then the fluid and substances needed by the body are returned to the blood in vessels alongside the tubule.

3. The tubule passes waste materials on to the bladder.

The cleansing of blood in the nephron is roughly analogous to the way you might clean your car. First you remove all your possessions and trash so that the car can be vacuumed. 1 Then you put back in the car what you want to keep 2 and throw away the trash 3.
Imbalances trigger responses

- Too little water leads to cell *crenation*
- Too little salt lead to cell *lysis*
Electrolytes & Nerves

- Critical to signalling along neurons
- Na\(^+\) & K\(^+\) move
- Signals carry information along nerves to muscles, glands, other neurons
Electrolytes & Muscles

- **ALL** motor nerves contact muscle. Their message (to contract) is transmitted via Na\(^+\) and K\(^+\) ions.
- Additionally, virtually **ALL** sensory modalities rely on movements of Na\(^+\) and K\(^+\) ions!
Maintaining fluid balance

- Regulated by thirst mechanism of hypothalamus; causes us to feel thirsty in response to:
  - Increased salt (solute) concentration of blood
  - Reduced blood volume or blood pressure
  - Dry mouth; low fluid concentration of blood
Thirst mechanism

- **Hormonal control**
  - ADH (antidiuretic hormone) increases $\text{H}_2\text{O}$ reabsorption at the kidneys
  - Kidneys secrete enzymes that cause vasoconstriction

- **Behavioral control**
  - Causes us to seek water
How do we gain fluids?

- We drink!
- **Metabolic water**
  - macromolecule breakdown produces $\text{H}_2\text{O}$
  - Can be used locally, or regained from blood as it is filtered by kidney
How do we lose fluids?

• **Urine**: some water reclamation in kidneys
  - Response to increased salt concentrations of extracellular (interstitial fluid)

• **Sweat**: Radiant heat & convective currents evaporate H₂O from skin

• **Exhalation**: Lose some moisture, but we do dehumidify air as is passes over mucous membranes of nasal epithelium

• **Feces**: Little lost here
The magnificent K-rat

- Uses metabolic water ONLY
  - Tolerates extremely high blood solute levels
  - Efficient water reclamation at:
    - Kidneys
    - Nasal epithelium (nose)
- Nocturnal
- Humidify burrows
Odd sources of water loss

• Vomiting, diarrhea, sneezing
• Blood donation, hemorrhaging (any blood loss)
• Exercise (sweat, respiration)
• High altitude, extreme temps.
• Pregnancy, breastfeeding, consumption of diuretics
Water Balance

- **Metabolic water**: 300-400 ml
- **Food**: 1,000 ml
- **Beverages**: 1,300-1,400 ml

**Total water intake**: 2,700 ml

- **Urine**: 1,400 ml
- **Skin and lungs**: 1,100 ml
- **Feces**: 200 ml

**Total water excretion**: 2,700 ml
Na⁺

- **Chief functions**
  - Maintains fluid & electrolyte balance
  - Cell communication (nerve impulse transmission & muscle contraction)

- **Deficiency symptoms**
  - Muscle cramps, mental apathy, loss of appetite

- **Toxicity symptoms**
  - Edema (bloating), acute hypertension (high BP)
Na$^+$

- Toxicity symptoms
  - Edema (bloating) Why?
  - Acute hypertension (high BP) why?
  - May lead to increased $Ca^{2+}$ excretion in some = bone loss
Potassium ($K^+$)

- Principal intracellular cation
- Chief **functions** in the body
  - Maintains fluid and electrolyte balance
  - Cell communication (nerve impulse transmission & muscle contraction)
• **Deficiency symptoms**
  - Muscular weakness
  - Paralysis
  - Confusion

• **Toxicity symptoms**
  - Muscular weakness
  - Vomiting
K Sources

- All whole foods
- Meats, milks, fruits, vegetables, grains, legumes
Chloride (Cl)

- Roles in body
  - Principal extracellular anion
- Chief functions
  - Maintains fluid & electrolyte balance
  - Part of hydrochloric acid (HCl) in the stomach;
  
  For what purpose do we use it?
Cl⁻

- Significant sources
  - Table salt, soy sauce
  - Moderate amounts in meats, milks, eggs
  - Large amounts in processed foods
- Why?
Calcium (Ca$^{2+}$)

- 1997 adequate intake (AI)
  - Adults 19-50 years: 1000 mg/day
  - Adults 51 and older:
    1200 mg/day

- Upper level for adults:
  2500 mg/day
Functions of Ca$^{2+}$

- **Membrane function**
  - Changes permeability of cell membranes to Na$^+$
- **Neurons**
  - Neurotransmitter; influences neural sensitivity
- **Muscle cells, especially heart cells**
  - Directly transmits stimuli; influences heart rate and blood pressure.
- **Cell messages**
  - Induce blood clotting
  - Stimulate immune defenses
Ca$^{2+}$

- Deficiency symptoms?
Calcium: In Summary

- Significant sources
  - Milk and milk products
  - Small fish (with bones)
  - Tofu (bean curd), greens (broccoli, chard), legumes
Skeleton as Mineral Reserve

- Bones store calcium and other minerals
- **Calcium** is the most abundant mineral in the body

![Composition of Bone](image_url)

**Composition of Bone**

- Calcium: 39%
- Potassium: 0.2%
- Sodium: 0.7%
- Magnesium: 0.5%
- Carbonate: 9.8%
- Phosphate: 17%
- Total inorganic components: 67%

<table>
<thead>
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<th>Amount in bone as percentage of the total amount in the body</th>
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<td>Carbonate</td>
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<td>Phosphate</td>
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Ca\textsuperscript{2+} Regulation

- Homeostasis is maintained by hormones having OPPOSING effects:
  - Calcitonin and parathyroid hormone control storage (bones), absorption (small intestine), and excretion (kidneys) of Calcium
Ca$^{2+}$ Regulation

- You drink some milk
  - Vitamin D (in your fortified milk?) aids Ca$^{2+}$ absorption in small intestine
  - Absorptive cells deliver Ca$^{2+}$ to blood
  - Blood delivers Ca$^{2+}$ to osteoblasts
**Ca\textsuperscript{2+} Regulation**

- Blood Ca\textsuperscript{2+} level drops *below set point*
  - Parathyroid hormone (PTH) is released
    - **Stimulates** osteoclasts
    - **Increases** Ca\textsuperscript{2+} retention in kidneys
    - **Stimulates** active vitamin D production
Ca\textsuperscript{2+} Regulation

- Blood Ca\textsuperscript{2+} level rises **above** set point
  - **Calcitonin** (hormone) is secreted from thyroid gland
    - **Inhibits** osteoclasts
    - **Increases** Ca\textsuperscript{2+} excretion at the kidneys
Phosphorous (P)

• **Major component of:**
  - bones & teeth
  - *Cell membranes* (phospholipid bilayer)
  - DNA & RNA (sugar-phosphate backbone)
  - ATP!!
<table>
<thead>
<tr>
<th>Food</th>
<th>Serving size (kcalories)</th>
<th>Milligrams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread, whole wheat</td>
<td>1 oz slice (70 kcal)</td>
<td></td>
</tr>
<tr>
<td>Cornflakes, fortified</td>
<td>1 oz (110 kcal)</td>
<td></td>
</tr>
<tr>
<td>Spaghetti pasta</td>
<td>1/4 c cooked (99 kcal)</td>
<td></td>
</tr>
<tr>
<td>Tortilla, flour</td>
<td>1 10”-round (234 kcal)</td>
<td></td>
</tr>
<tr>
<td>Broccoli</td>
<td>1/4 c cooked (22 kcal)</td>
<td></td>
</tr>
<tr>
<td>Carrots</td>
<td>1/2 c shredded raw (24 kcal)</td>
<td></td>
</tr>
<tr>
<td>Potato</td>
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<td>Banana</td>
<td>1 medium raw (109 kcal)</td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>1 medium raw (62 kcal)</td>
<td></td>
</tr>
<tr>
<td>Strawberries</td>
<td>1/2 c fresh (22 kcal)</td>
<td></td>
</tr>
<tr>
<td>Watermelon</td>
<td>1 slice (92 kcal)</td>
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</tr>
<tr>
<td>Milk</td>
<td>1 c reduced-fat 2% (121 kcal)</td>
<td></td>
</tr>
<tr>
<td>Yogurt, plain</td>
<td>1 c low-fat (155 kcal)</td>
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<td>Cheddar cheese</td>
<td>1/2 oz (171 kcal)</td>
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<td>Pinto beans</td>
<td>1/2 c cooked (117 kcal)</td>
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</tr>
<tr>
<td>Peanut butter</td>
<td>2 tbs (188 kcal)</td>
<td></td>
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<td>Sunflower seeds</td>
<td>1 oz dry (165 kcal)</td>
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<td>1/2 c (76 kcal)</td>
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<td>Ground beef, lean</td>
<td>3 oz broiled (244 kcal)</td>
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<td>Chicken breast</td>
<td>3 oz roasted (140 kcal)</td>
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<td>Tuna, canned in water</td>
<td>3 oz (99 kcal)</td>
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<td>Egg</td>
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**Excellent, and sometimes unusual, sources:**

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<tr>
<td>Liver</td>
<td>3 oz (184 kcal)</td>
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</tr>
<tr>
<td>Almonds</td>
<td>1 oz (165 kcal)</td>
<td></td>
</tr>
<tr>
<td>Candy bar</td>
<td>2.2 oz (278 kcal)</td>
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**Key:**
- Yellow: Breads and cereals
- Green: Vegetables
- Purple: Fruits
- Light gray: Milk and milk products
- Brown: Legumes, nuts, seeds
- Red: Meats
- Orange: Miscellaneous

**PHOSPHORUS**
Protein-rich sources, such as milk (white), meats (red), and legumes (brown), provide abundant phosphorus as well.

NOTE: See p. 327 for more information on using this figure.
Magnesium

- > 50% stored in our bones
- Remainder in other tissues (muscle)
- **Cofactor in hundreds** of enzyme systems, including immune
  - ATP formation (addition of terminal phosphate)
  - Synthesis of ALL macromolecules
  - Stimulating immune cells
- **Major source** = hard water!
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**Excellent, and sometimes unusual, sources:**

- Halibut: 3 oz baked (199 kcal)
- Cashews: 1 oz (161 kcal)
- Artichoke: 1 (60 kcal)

**Key:**
- Yellow: Breads and cereals
- Green: Vegetables
- Purple: Fruits
- White: Milk and milk products
- Red: Legumes, nuts, seeds
- Brown: Legumes, nuts, seeds

**MAGNESIUM**
Legumes (brown) are a rich source of magnesium.

RDA for men 19–30
RDA for women 19–30

**NOTE:** See p. 327 for more information on using this figure.
Healthy vs. Osteoporotic Bones
Trace minerals

- **Sources** - their presence in foods depends on:
  - Soil health
  - Water content
  - Degree of processing

- **Deficiencies** - wide-ranging, because they are widespread cofactors

- **Toxicities** - Easy to achieve in supplements; (FDA has no power to limit their quantity in supplements)

- **Interactions** - Lots; tough to control
  - Easiest solution: eat a wide variety of whole foods