Unit 11 · Bioinorganic Chemistry

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Inorganic Chemistry (Units 9–11 together): 20 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ: the sodium–glucose pump is a **secondary active** transport protein
- **MCQ (1 mark)**: match nutrient and job (rice energy, Fe oxygen, Cu fetus, Na^+ osmotic pressure); Na^+/K^+ pump: **primary** active, from its picture; most abundant of Zn, Ti, Fe, Cu: Fe; zinc catalytic; a macronutrient: glucose; methylmercury: brain; body-building: protein; essential set Fe, Mo, Cu, Zn; Mg in chlorophyll
- **Short (5 marks, in parts)**
  - Na^+/K^+ pump vs Na^+–glucose pump (five points); the pump's picture explained
  - draw and label the sodium–glucose pump, explain it
  - macronutrients, two jobs each; enzymes and how to get enough
  - name the mineral from symptoms or a job (zinc, iron, calcium, chromium, potassium)
  - weak bones and memory loss: which nutrients short; five jobs each of Ca and Mg; Na and K
  - metal poisoning; mercury in detail; cadmium vs mercury; harm from Cd, Hg, As, Pb, Fe
  - a pump that fails: its effects

Key terms

Bioinorganic chemistry: role of metals and metal compounds in living things; between inorganic chemistry and biology.

Bioinorganic molecule (metallobiomolecule): biomolecule with a metal ion as an essential part: hemoglobin (Fe), chlorophyll (Mg), vitamin B12 (Co).

Metalloenzyme: enzyme with a metal bound tightly at its **active site**; about a third of enzymes need a metal.

Enzyme: biological catalyst (biocatalyst), a protein; **cofactor**: the metal ion or small helper it needs.

Micronutrients: needed in mg or μg a day: vitamins, minerals, trace elements; no energy.

Macronutrients: needed in grams a day: carbohydrates, proteins, fats (and water, fiber); energy and building.

Antioxidant: stops harmful oxidation by free radicals: vitamins C, E; Se, Zn, Cu in enzymes.

Concentration gradient: difference in concentration across a membrane.

Passive transport: **down** the gradient (high → low), no energy (diffusion, channels, carriers).

Active transport: **against** the gradient (low → high), uses energy, usually ATP.

Primary active transport: energy straight from ATP (Na^+/K^+ pump).

Secondary active transport: energy from another ion's gradient made by a primary pump (SGLT).

Antiport: two substances in opposite directions; **symport**: in the same direction.

Metal toxicity: harm from metals building up in soft tissues (kidneys, liver, brain, nerves, blood, lungs).

Biomagnification: a poison more concentrated at each step of a food chain (methylmercury in fish).

Nutrients

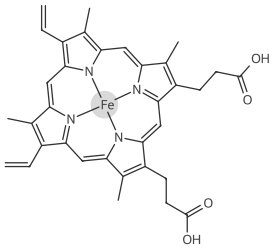
- macronutrients
  - carbohydrates: main fuel (brain), starch → glucose; rice, wheat, maize, millet, potatoes, sugar
  - proteins: amino acid chains (9 of 20 essential); build and repair; enzymes, antibodies, insulin, hemoglobin; dal, soya, milk, eggs, meat
  - fats: store energy (37 kJ/g vs 17), membranes, hormones, warmth, carry vitamins A, D, E, K; ghee, oils, nuts
- energy shares: carbohydrate **45–65%**, protein **10–35%**, fat **20–35%**
- shortage: malnutrition: **marasmus** (all food), **kwashiorkor** (protein)
- micronutrients: run enzymes; vitamins release energy, immunity, blood (folate, B12, vitamin K); antioxidants
- deficiency: anemia (Fe), scurvy (vitamin C), goiter (iodine), rickets (vitamin D)
- macrominerals (by the gram): Ca, P, K, Na, Cl, Mg, S; trace elements (mg or less): Fe, Zn, Cu, Mn, I, Se, Mo, Co

Jobs of metal ions

- regulate cells (Ca^{2+} signals); cofactors of enzymes; carriers (Fe: O_2; Fe, Cu: electrons); osmotic pressure (Na^+ out, K^+ in); balance charges and hold structures (Mg^{2+} on DNA, ATP; Zn^{2+} proteins; Ca^{2+} bones); vitamins (Co in B12)
- in enzymes: hold the molecule (Mg–ATP), pull electrons (Zn^{2+} in carbonic anhydrase), pass electrons by changing oxidation state ($Fe^{2+} \rightleftharpoons Fe^{3+}$, $Cu^+ \rightleftharpoons Cu^{2+}$)

- enzymes in industry: washing powders, glucose syrups, test strips (glucose oxidase)
- enough enzymes: the body **makes its own** (eaten ones are digested); supply protein (amino acids), mineral cofactors (Zn, Fe, Mg, Cu, Mn, Se), B vitamins (coenzymes); normal temperature and pH
- raw potato's catalase splits H_2O_2 into bubbles of O_2; boiled potato: none (enzyme destroyed)
- symptoms → mineral: slow growth, skin, late maturation: **Zn**; anemia, weak immunity: **Fe** (Cu too); weak bones: **Ca** (with vitamin D, Mg); diabetes-like: **Cr**; ribosomes: **K** (and Mg)
- weak bones + memory loss: Ca and vitamin D; vitamin B12 (Co) for the nerves; antioxidants

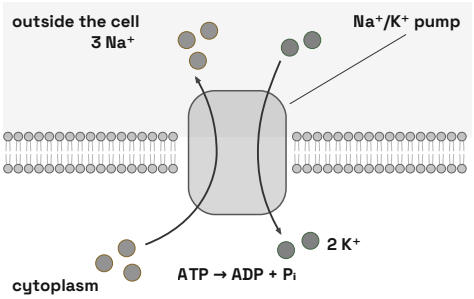
Ion	Main jobs
Na^+	main ion **outside** cells (145 mmol/L): osmotic pressure, water; nerve impulse; drives glucose and amino acid uptake; $NaHCO_3$ blood buffer (pH 7.4); too much → high blood pressure (< 5 g salt a day)
K^+	main ion **inside** cells (140 mmol/L): nerves, muscles, heartbeat; opens stomata (guard cells); turgor in plants; ribosomes, enzymes; lowers blood pressure, Ca in urine (kidney stones)
Mg^{2+}	center of **chlorophyll**; **Mg–ATP** (binds the P–O–P pyrophosphate links); cofactor of 300+ enzymes (DNA, RNA, proteins); holds ribosomes; 60% in bones and teeth; blood glucose and pressure
Ca^{2+}	**bones and teeth** (hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$, 99%); signal: muscle contraction, nerve chemicals, insulin release; **blood clotting**; enzymes, cell division; **middle lamella** (calcium pectate) in plants
Fe^{2+}/ Fe^{3+}	**hemoglobin** carries O_2, myoglobin stores it; cytochromes pass electrons; catalase; thyroid hormones; nitrogenase (Fe, Mo) fixes N_2; lack → **anemia**
Cu^+/ Cu^{2+}	electron carrier: cytochrome c oxidase, plastocyanin; tyrosinase → **melanin**; collagen, connective tissue; helps use iron (lack → anemia); brain, fetus
Zn^{2+}	300+ enzymes; **carbonic anhydrase**: $CO_2 + H_2O \rightleftharpoons HCO_3^- + H^+$; stores **insulin**; growth, sexual maturation, proteins, DNA, wounds, immunity; zinc fingers (gene transcription); vitamin A in blood; auxin in plants (khaira disease of rice)
Ni^{2+}	**urease** in plants (2 Ni; first enzyme crystallized, Sumner 1926); hydrogenases in bacteria; for humans not settled
Co^{3+}	**vitamin B12** (cobalamin, corrin ring): red blood cells, nerves; only bacteria make it, so only animal foods
Cr^{3+}	thought to help insulin (carbohydrate, fat metabolism); evidence weak (EFSA 2014); Cr(VI) toxic, causes cancer



Heme, the iron-holding part of hemoglobin: Fe^{2+} held by four N atoms of a flat ring of four small rings.

- chlorophyll: the same kind of ring with **Mg^{2+}** at its center, a fifth ring and a long phytol tail
- each N gives a lone pair to the metal: **coordinate bonds**; blood: Fe^{2+} catches O_2; leaves: Mg^{2+} catches light
- hemoglobin: four hemes, each Fe carries one O_2; about two-thirds of the body's 4 g of iron
- essential trace metals to name: Fe, Zn, Cu, Co, Mn, Mo (Ni, Cr not settled for people)

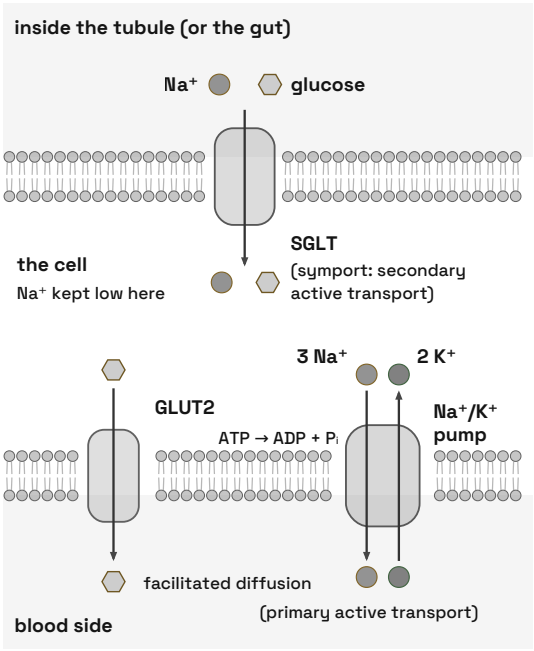
Ion pumps



The sodium–potassium pump (Na^+/K^+-ATPase): 3 Na^+ out, 2 K^+ in, both against their gradients, one ATP split on the cytoplasm side.

Na^+/K^+ pump

- Na^+ 145 out / 12 in; K^+ 4 out / 140 in (mmol/L); leaks back through channels
- discovered 1957 (Skou); in every animal cell (hundreds to millions)
- each cycle: **3 Na^+ out, 2 K^+ in, 1 ATP → ADP + P_i**
- works by changing shape: phosphate from ATP flips it outward; its loss flips it back
- net + out → inside **negative**: resting potential about −70 mV
- needed for nerve signals, muscle (heart) contraction, kidney work, cell volume



The sodium–glucose pump in a cell of the kidney tubule or gut: SGLT brings Na^+ and glucose in together; the Na^+/K^+ pump on the blood side keeps Na^+ low; GLUT2 lets glucose out into the blood.

Na^+–glucose pump (SGLT, cotransport)

1. Na^+ flows in **down** its gradient (apical side, facing gut or tubule)
2. it drags glucose in **against** its gradient, together, same way
3. the Na^+/K^+ pump (basolateral side) pumps the Na^+ back out, using ATP
4. glucose leaves into the blood through **GLUT2** by facilitated diffusion

- SGLT1: small intestine (glucose, galactose), 2 Na^+ per glucose; last few % in the kidney (S3)
- SGLT2: **over 90%** of filtered glucose, proximal tubule (S1, S2), 1 Na^+ per glucose
- kidneys filter about 180 g glucose a day; normal blood glucose 5.5 mmol/L; above **10–12 mmol/L** the carriers can't keep up → **glycosuria** (sign of diabetes); diabetes raises SGLT2, strains the kidneys

	Na^+/K^+ pump	Na^+–glucose pump
transport	primary active	secondary active
energy	ATP, directly	Na^+ gradient (made by the Na^+/K^+ pump)
carries	3 Na^+ out, 2 K^+ in	Na^+ and glucose in
direction	opposite: antiport	same: symport
where	every animal cell	gut, kidney tubule
job	gradients, membrane potential, nerves	taking up glucose

If the Na^+/K^+ pump fails: Na^+ builds up inside, K^+ leaks out; water follows → cells swell; resting potential lost → nerves and muscles (heart) fail; no Na^+ gradient → no glucose uptake by SGLT

Metal toxicity

- how: bind **–SH (thiol)** groups of enzymes (Hg, Pb, Cd, As(III)); push out the right metal (Pb for Zn and Ca, Cd for Zn); make free radicals (Fe, Cu: Fenton, $Fe^{2+} + H_2O_2 \longrightarrow Fe^{3+} + OH^- + {}^\bullet OH$) → oxidative stress, cancer, nerve damage
- harm depends on dose, route, chemical form, time, age (children, unborn most at risk)
- **Fe**: tablet overdose (children), overload (hemochromatosis, transfusions); **free** iron in either state makes radicals; gut, liver, heart, pancreas
- **As** (metalloid): groundwater (Terai, Nawalparasi), mining, pesticides; As(III) binds –SH, arsenate replaces phosphate; **arsenicosis**: dark spots, keratosis of palms and soles, skin, lung, bladder cancers; WHO 10 µg/L, Nepal 50
- **Hg**: thermometers, lamps, amalgam, chlor-alkali, gold mining, fish; **methylmercury** CH_3Hg^+ (biomagnified) attacks **brain** and nerves, kidneys: tremors, numbness, loss of vision, hearing, memory; vapor harms lungs; **Minamata disease** (Chisso factory, 1932–68)
- **Pb**: old paints, batteries, pipes, glazed pottery, cosmetics, TEL (banned 2021); **children's brains** (lower intelligence), no safe level; blood pressure, kidneys, wrist drop; **anemia** (blocks heme enzymes)
- **Cd**: zinc smelting, Ni–Cd batteries, phosphate fertilizers, **tobacco smoke**; held by metallothionein, collects in **kidneys**; half-life 10–30 years; **bones** (itai-itai), lung cancer
- Cd vs Hg: Cd mostly kidneys and bones, from smoke, food and fumes, stays for decades; Hg mostly brain and nerves, from fish (methylmercury) and vapor

COMMON MISTAKES

✗ protein 10–35%, fat 10–35% of energy
✓ fat **20–35%** (protein 10–35%).

✗ the Na^+/K^+ pump moves 2 Na^+ out, 3 K^+ in
✓ **3 Na^+ out, 2 K^+ in** per ATP.

✗ SGLT splits ATP itself
✓ it uses the **Na^+ gradient** (secondary); the Na^+/K^+ pump spends the ATP.

✗ the heme drawing is hemoglobin
✓ heme is the iron part; hemoglobin is a protein of four chains, each with a heme.

✗ copper stores oxygen in plants
✓ copper **carries electrons** (plastocyanin, cytochrome c oxidase).

✗ only Fe^{2+} is safe, other forms toxic
✓ **free** iron in either state is toxic; safe when held in proteins.

✗ Ni and Cr are proven essential for people
✓ not settled; name Fe, Zn, Cu, Co, Mn, Mo.