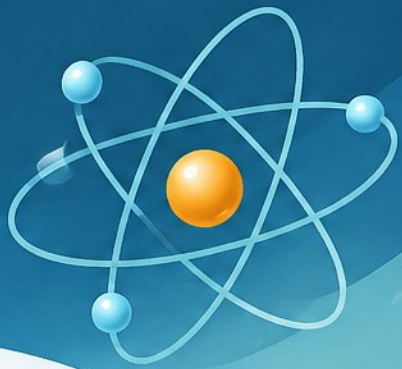
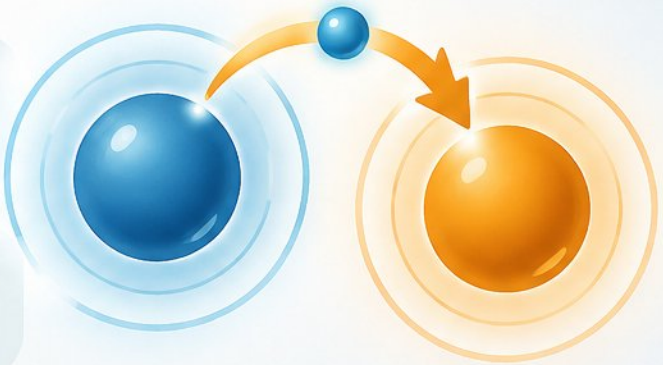
Oxidation and Reduction:
Following the Electrons



- **Course promise:** track electrons in any reaction and identify what is oxidized and reduced

- **Everyday anchors:** rusting iron, burning fuel, batteries, bleaching, respiration



- **Three lenses:** oxygen/hydrogen, electron transfer, oxidation number — one idea, three views

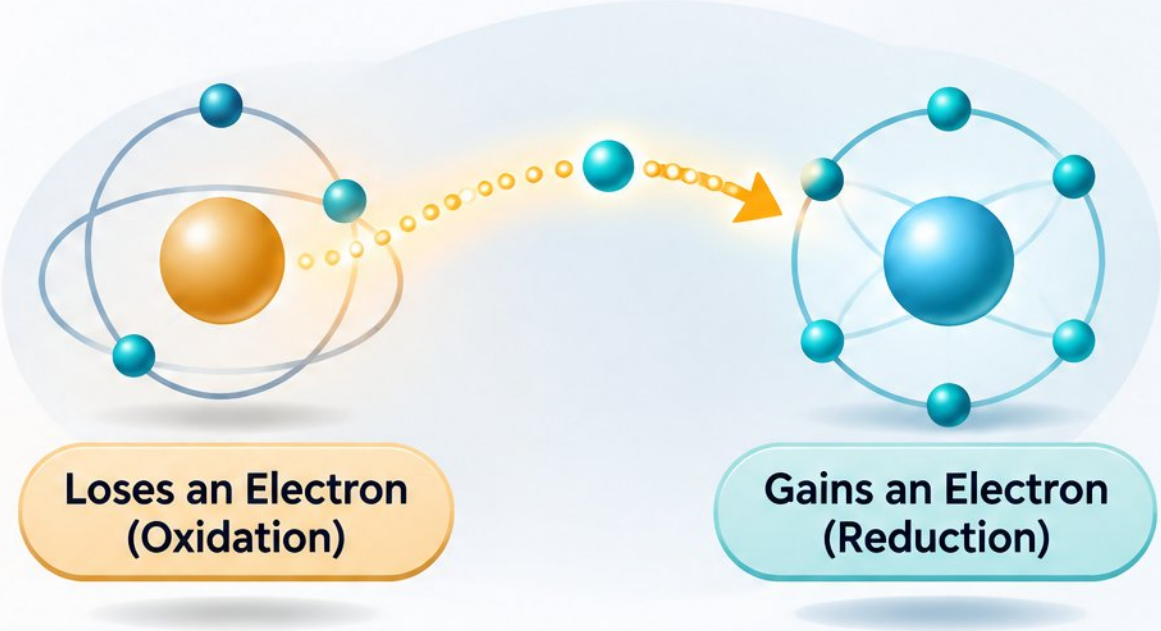
- **Roadmap:** background → oxidation numbers → balancing → industry → electrochemistry → biology and environment → misconceptions → demonstrations → wrap-up



- **For beginners, students, and teachers;** prerequisite: atoms, ions, and formula equations

Why Electrons Move:
Atoms, Ions, and the OIL RIG Rule

- Refresher: valence electrons and where they sit in atoms and ions
- Oxidation is loss of electrons; reduction is gain — OIL RIG / LEO GER
- Electronegativity and electron affinity decide which partner pulls electrons
- Oxidation = net removal of electrons; reduction = electrons transferred to a species
- Oxidizing agent takes electrons and is reduced; reducing agent gives electrons and is oxidized
- The agent is the reactant, not the product



OIL RIG	Oxidation Is Loss, Reduction Is Gain
LEO GER	Loss of Electrons = Oxidation, Gain of Electrons = Reduction

Oxidation Numbers: Reliable Electron Bookkeeping

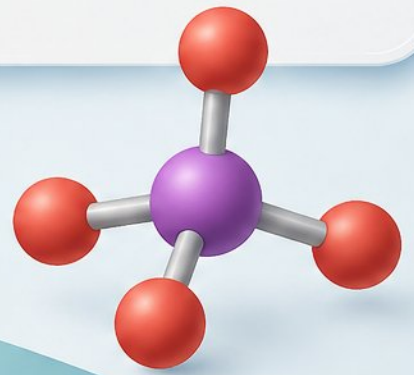
- Rules in priority order; increase means oxidation, decrease means reduction
- Bookkeeping device, not real charge: write Ca^{2+} for charge, +2 for oxidation number
- Worked examples: H_2O, CO_2, Fe_2O_3, MnO_4^-, $Cr_2O_7^{2-}$, H_2O_2
- Special cases: standard-state elements, peroxides, hydrides, oxygen fluorides, Fe_3O_4 (+2/+3)
- ~30% of general chemistry students confuse oxidation number with charge — often confidently

Oxidation-State Ledger

Oxidation number → +7 −2 −2 −2 −2

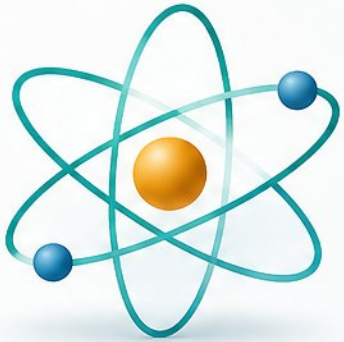
MnO_4^-

True ionic charge → Mn^{7+} O^{2-}

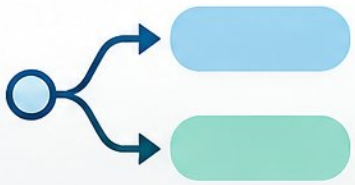


Separating and Balancing Half-Reactions

- Balance atoms first, then charge by adding electrons — strictly in that order
- Split into half-reactions: electrons are products in oxidation, reactants in reduction
- Balance electrons lost and gained, then recombine the halves
- Cross-check with the oxidation-number-change method
- Acidic: add H^+ and H_2O. Basic: add OH^- and H_2O
- Triple check: atoms, total charge, and electron count all balance



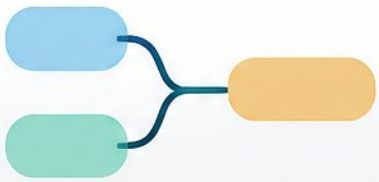
Split into half-reactions



Balance atoms then charge with electrons

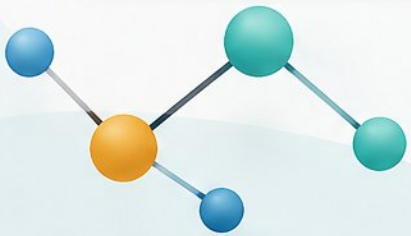


Recombine the halves



Verification

- Atoms
- Total charge
- Electron count



Redox in Industry: From Metal Ores to Cleaner Oxidants

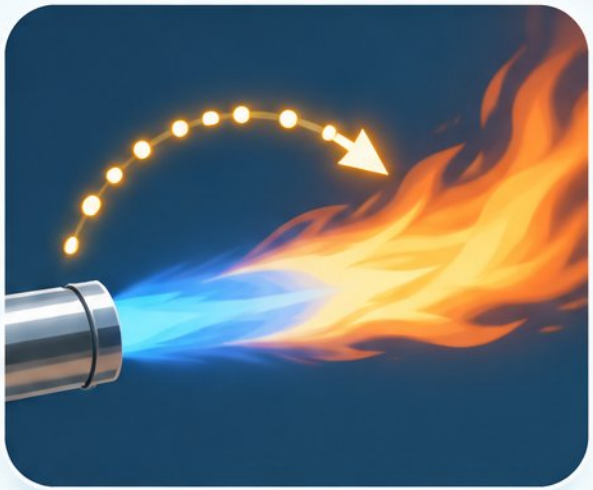
- Metallurgy as reduction: carbon smelting versus direct electrochemical iron ore reduction
- Electrons act as clean, selective redox agents for ores, e-waste, and spent batteries
- Hydrogen peroxide shifts from anthraquinone autoxidation to electrified interfacial proton-coupled electron transfer
- Sulfide waste plus oxygen reduction yields thiosulfate with net positive energy output
- Desirable redox (production) versus undesirable redox (corrosion, emissions)



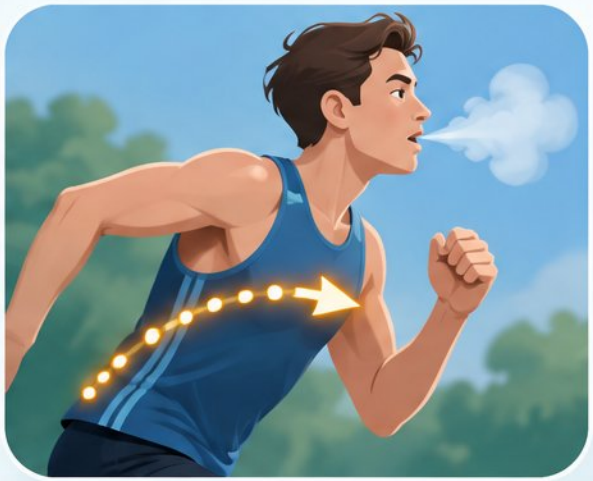
Corrosion, Combustion, Bleaching, and Respiration in Daily Life

- **Combustion:** fast, uncontrolled electron flow; respiration: same chemistry, enzyme-controlled
- **Rusting:** iron oxidized by oxygen and water; block it with barrier coatings
- **Sacrificial anodes and cathodic protection:** give electrons to save the metal
- **Bleaches and disinfectants:** hydrogen peroxide, chlorine-based oxidants at work
- **Batteries:** packaged redox couples releasing electrons on demand



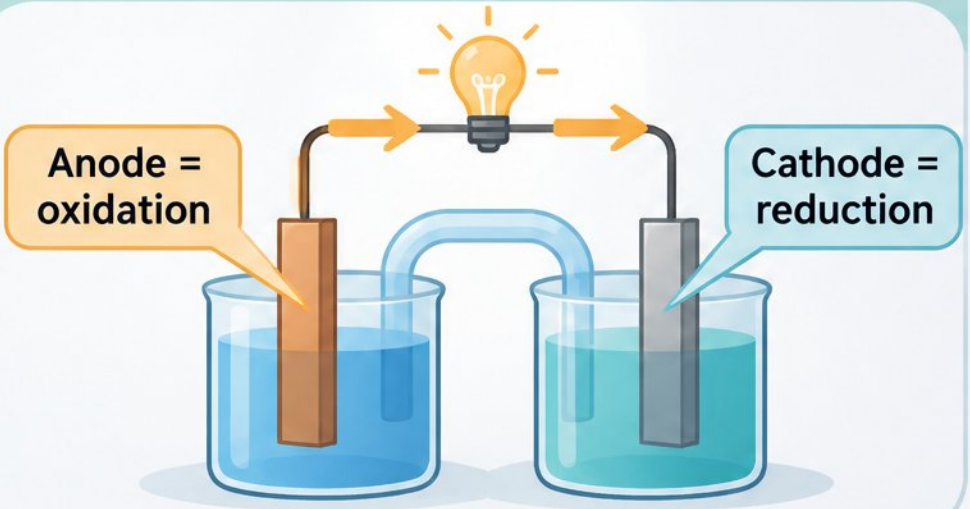




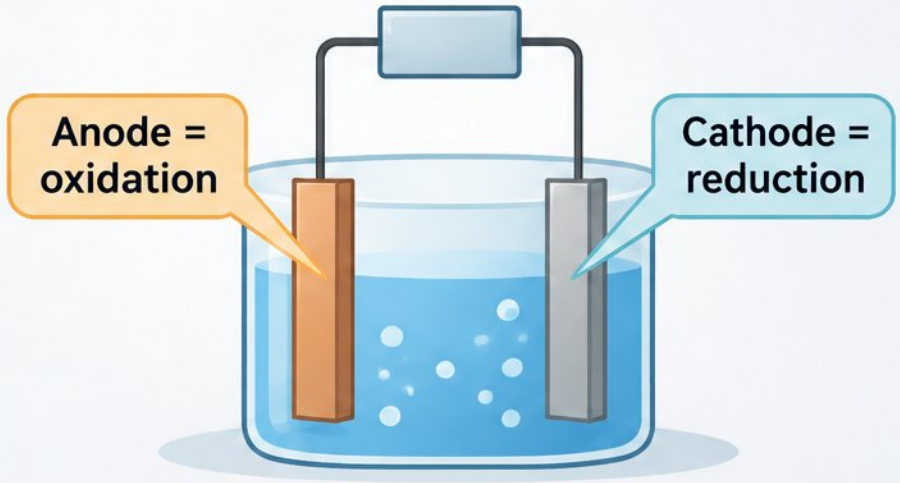


Electrochemistry: Redox Reactions That Do Useful Work

Galvanic Cell



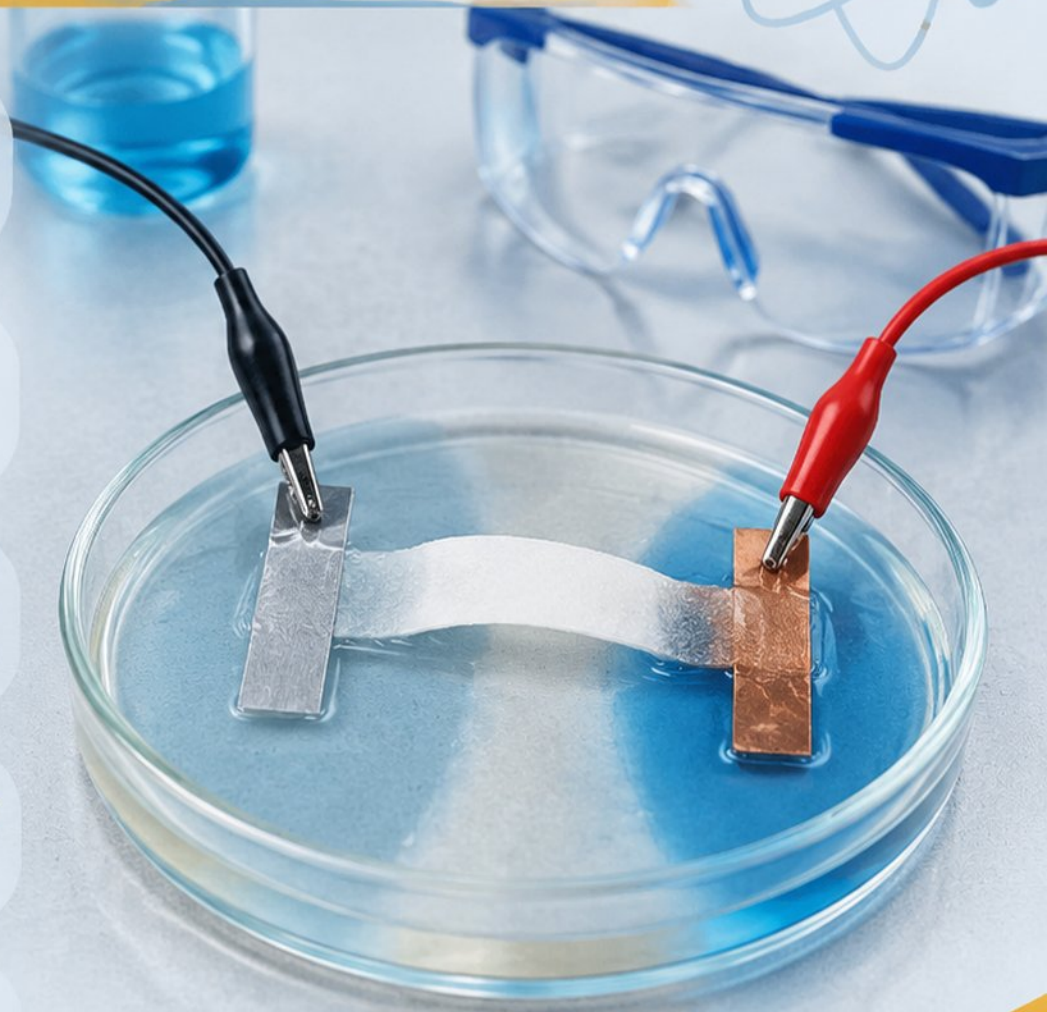
Electrolytic Cell



- Anode = oxidation, cathode = reduction; polarity flips between cell types
- Galvanic: anode releases electrons; electrolytic: electrons extracted at anode
- Standard reduction potentials (Stockholm, 1953): positive E° = stronger oxidizer
- Reversing a half-reaction flips its sign; SHE on left at E° = 0 V
- Uses: batteries, electroplating, hydrogen fuel cells, classroom-scale cells

Electrochemistry in Practice: Demonstrations and Microscale Cells

- Low-risk demos: iron rusting, magnesium burning, copper displacement, gravity cell
- Petri-dish cell: KNO_3-soaked filter paper bridges Zn and Cu half-cells; read with voltmeter
- Microscale electrolysis: thin-layer chemistry keeps chlorine visible and controllable
- Safety: eye protection, ventilation, Hazcards, proper zinc–copper waste disposal
- Adjust depth: beginners describe observations; advanced learners use electrode potentials

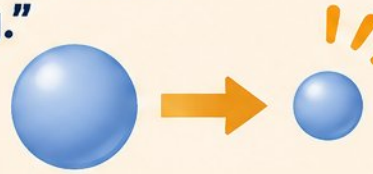


Common Misconceptions and Diagnostic Questions

- Reduction feels like shrinking, so students think it loses electrons
- Many still believe oxidation always requires oxygen (grades 10–12)
- ~70% say electrons travel through the cation–spectator ion bond
- Ion-pair and ion-attraction resources: ions seen as bonded or ‘reacting’
- 28–31% conflate oxidation number with charge, often with high confidence
- Diagnostics: predict–explain–verify, exit tickets, confidence-weighted questions



“Reduction means shrinking.”





“Electrons travel through the cation–spectator ion bond.”



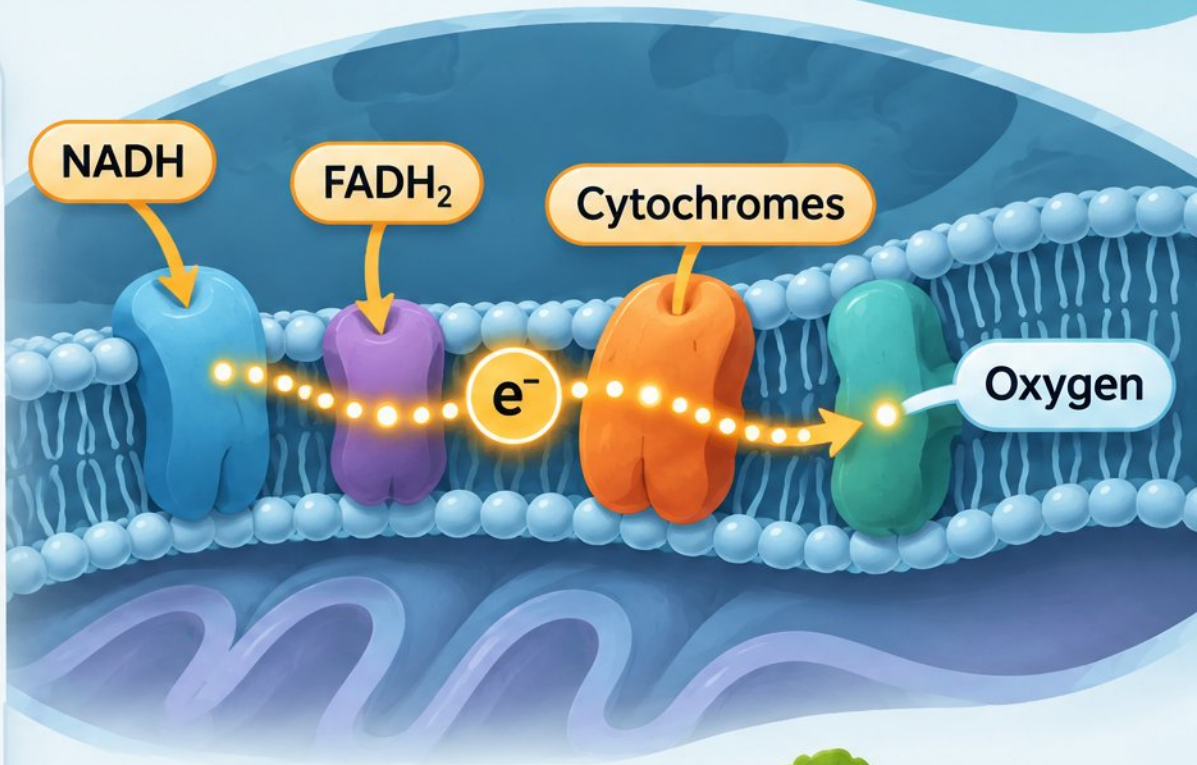


“The oxidation number is the charge.”



Redox in the Body: Respiration and Antioxidants

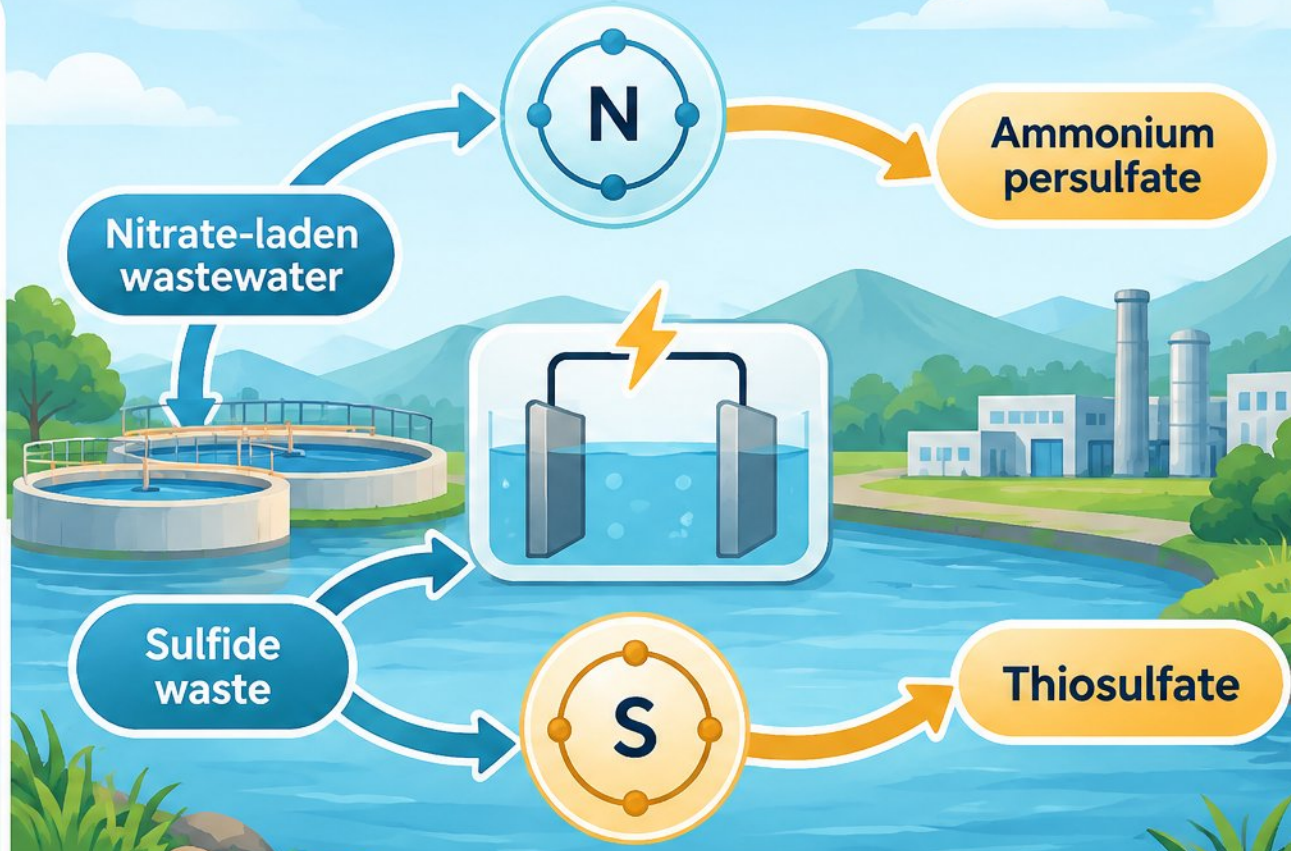
- Cellular respiration: controlled redox chain with NADH, $FADH_2$, cytochromes
- Photosynthesis reverses the flow: water oxidized, CO_2 reduced
- ROS at low levels signal; excess causes oxidative stress
- Large trials: β-carotene and vitamin E supplements show no prevention benefit
- High-dose β-carotene may raise lung cancer risk in smokers
- Fruit- and vegetable-rich diets correlate with lower chronic disease risk





Redox in the Environment: Nitrogen, Sulfur, and Remediation

- Nitrate-polluted wastewater becomes valuable ammonium persulfate: 55% less energy, ~99.6% less CO2
- Sulfur-mediated cell recovers copper from wastewater while generating electricity
- Sulfide waste plus oxygen reduction yields thiosulfate with net positive energy output
- Design rule: selective oxidation or reduction under mild conditions, fewer hazardous reagents
- Redox literacy helps you judge water-treatment and ‘detox’ product claims



Lab bench → Classroom demo → Industrial plants → Global cycles

Teaching Redox: Sequencing for Beginners and Advanced Learners

Teacher note: Anticipate ion-pair and ion-attraction resources; show ion distribution first

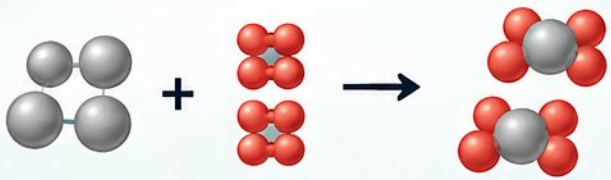
Beginners

Oxygen-based definition → Electron loss/gain → Half-equations → Oxidation numbers

Advanced

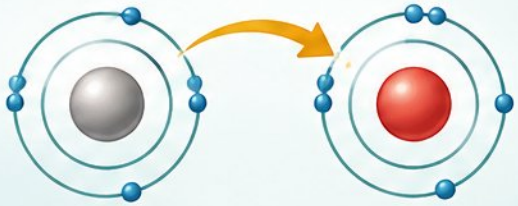
Oxygen-based definition → Electron loss/gain → Half-equations → Oxidation numbers

Oxygen/Hydrogen Lens



$4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Electron Transfer Lens



Oxidation Number Lens

$\overset{0}{4Fe} + \overset{0}{3O_2} \rightarrow \overset{+3}{2Fe_2}\overset{-2}{O_3}$

- Beginners: oxygen definition → electron loss/gain → half-equations → oxidation numbers
- No half-equations while basic symbol equations are shaky
- Show oxygen and electron definitions agree: $4Fe + 3O_2 \rightarrow 2Fe_2O_3$
- Anticipate ion-pair and ion-attraction resources; show ion distribution first
- Allow electron adding and subtracting; teach adding as standard
- Confidence matters: ~70% misdescribe electron transfer with high certainty



Integrated Problem Set: Follow the Electrons

Problem 1

assign oxidation numbers in MnO_4^-; name oxidized and reduced species.



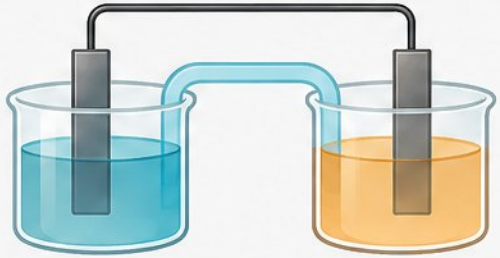
Problem 2

balance atoms, charge, and electron count in a full redox equation.



Problem 3

predict spontaneity from $E°$ values (Stockholm convention) and sketch the cell.



Oxidation-State Ledger

A^a ; B^{b-}

Problem 4

separate oxidation number from ionic charge in S, SO_4^{2-}, NO_3^-.

Problem 5

classify a biological or environmental redox process; name both agents.

Wrap-Up: Following the Electrons Beyond This Course



- Three lenses: oxygen/hydrogen, electron transfer, oxidation numbers — one idea, three views.
- Exit ticket: name the oxidized and reduced species in a new reaction.
- Paths forward: electrochemistry, biochemistry, materials science, green manufacturing.
- Curated reading list for students and for teachers.
- Electrons are the thread from rust to respiration to green steel.

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