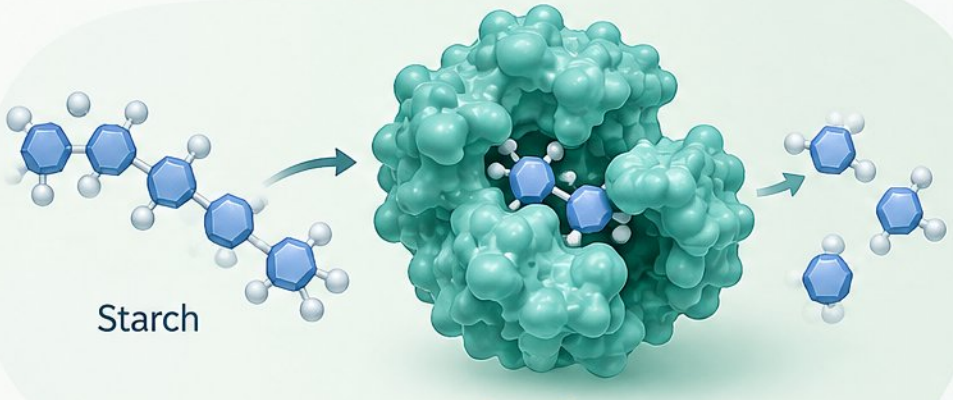
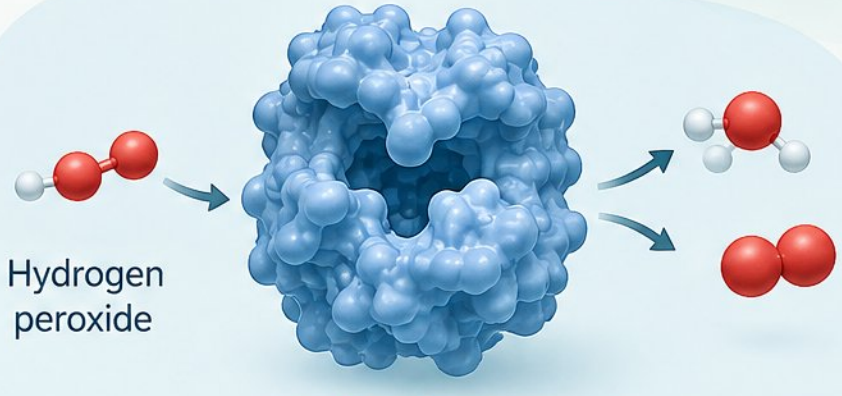
How Biological Catalysts Work

- Enzymes are biological catalysts that speed up reactions without being consumed
- They lower activation energy but never change overall free energy
- Enzymes enable life at mild temperature and near-neutral pH
- Roadmap: enzyme structure, catalytic strategies, regulation, and real-world uses
- Everyday examples: amylase digests starch; catalase breaks down hydrogen peroxide



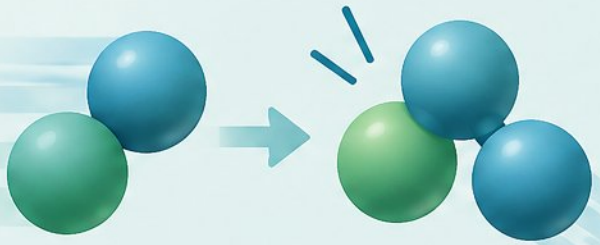
Amylase
digests starch



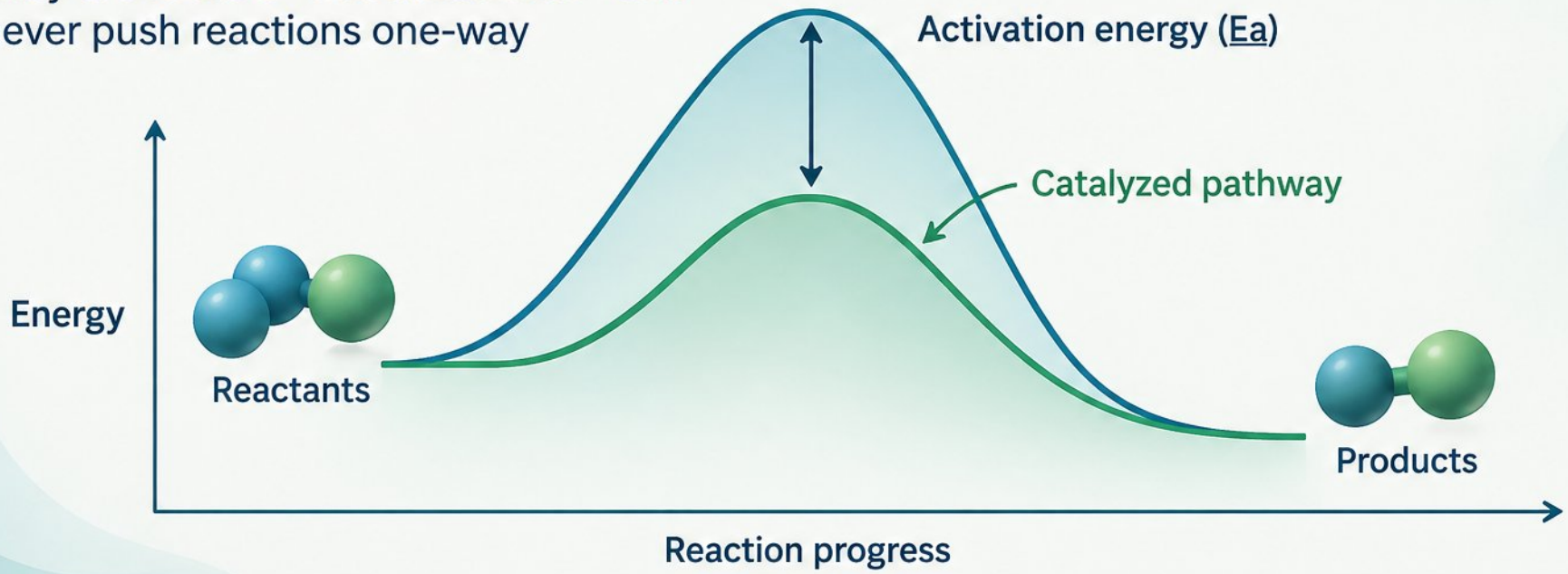
Catalase
breaks down hydrogen peroxide

Why Reactions Need a Push: Activation Energy and Reaction Rates

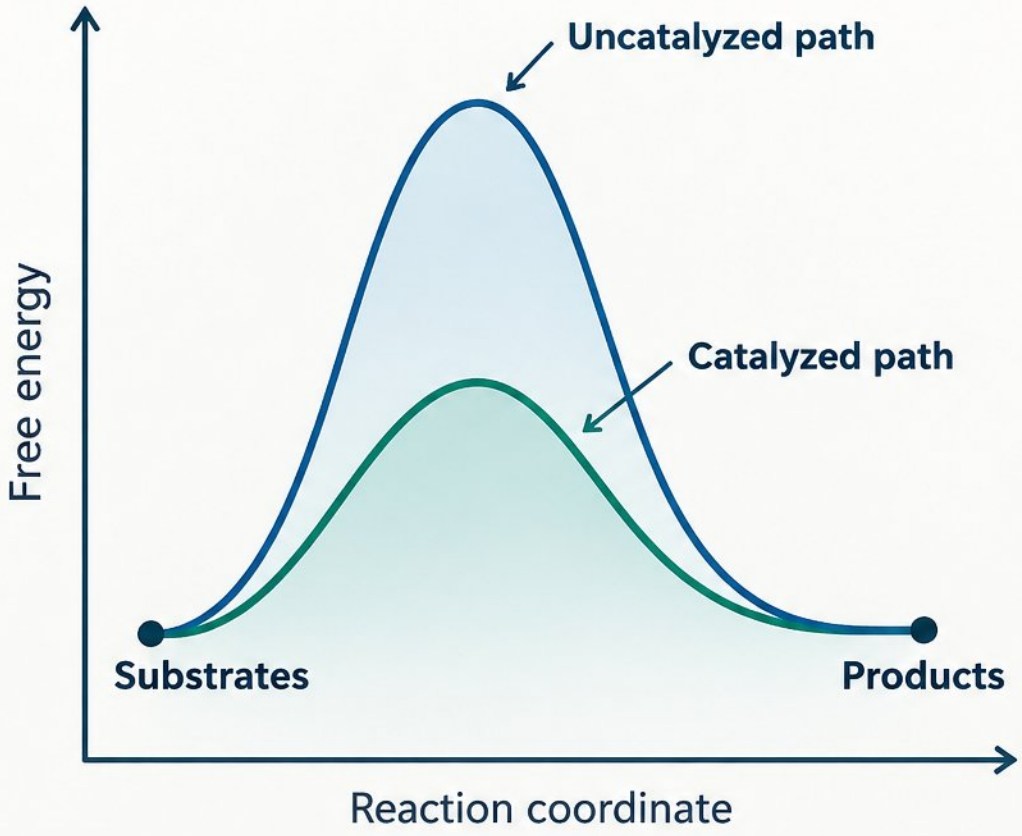
- Molecules must collide with enough energy and correct orientation
- Activation energy (Ea): the energy hill that slows reactions
- Rate rises with reactant concentration, temperature, or a catalyst
- Catalysts offer a lower-energy pathway without adding energy
- They are reused—not consumed—and never push reactions one-way



Molecules must collide with enough energy and correct orientation



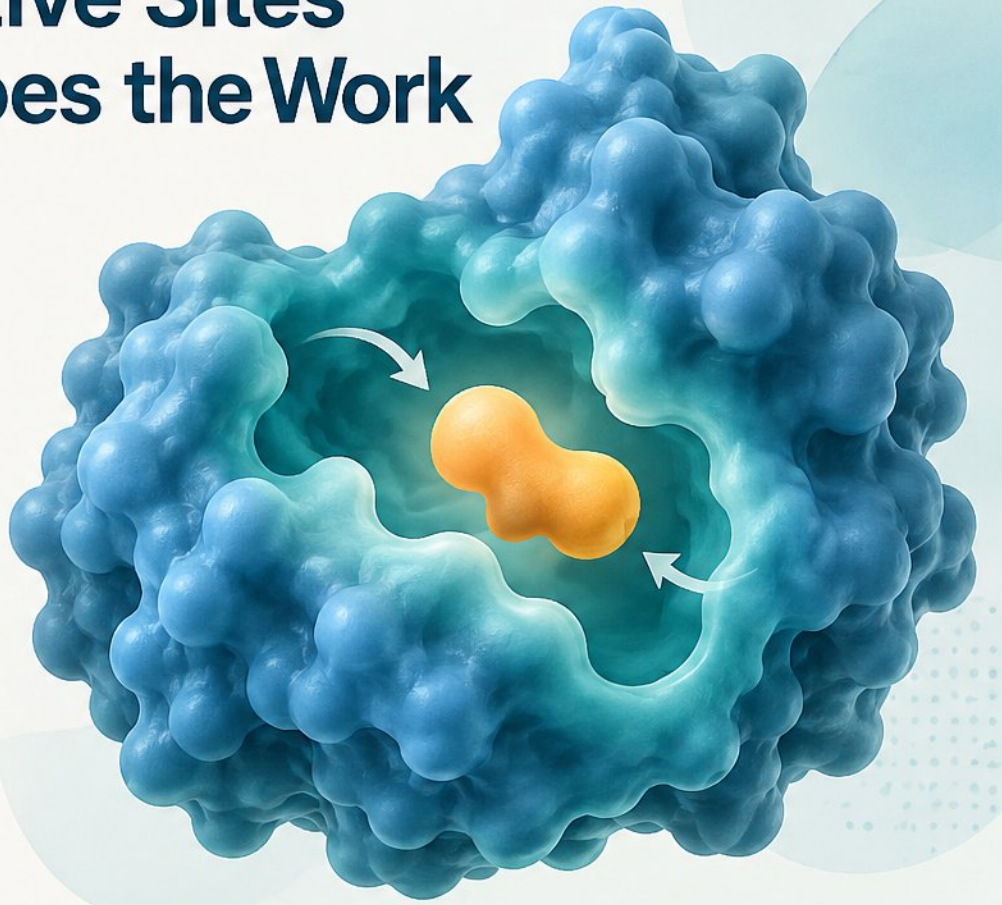
Energy Profiles: Comparing Catalyzed and Uncatalyzed Pathways

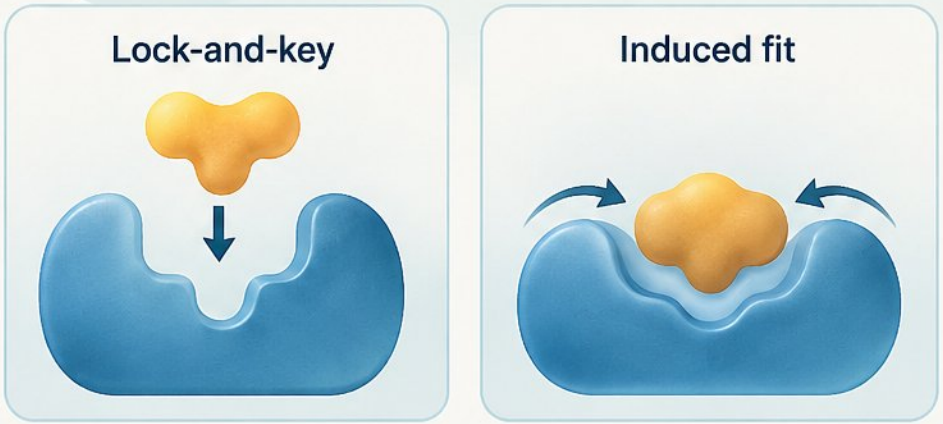


1. Energy profile plots free energy from substrates through transition state to products
2. Uncatalyzed path: high activation-energy peak; catalyzed path: much lower peak
3. Same start and end energy levels—ΔG is identical with or without enzyme
4. Peak height sets speed; start-to-end difference sets spontaneity and equilibrium
5. Lower barrier is crossed far more often, so reactions run millions of times faster

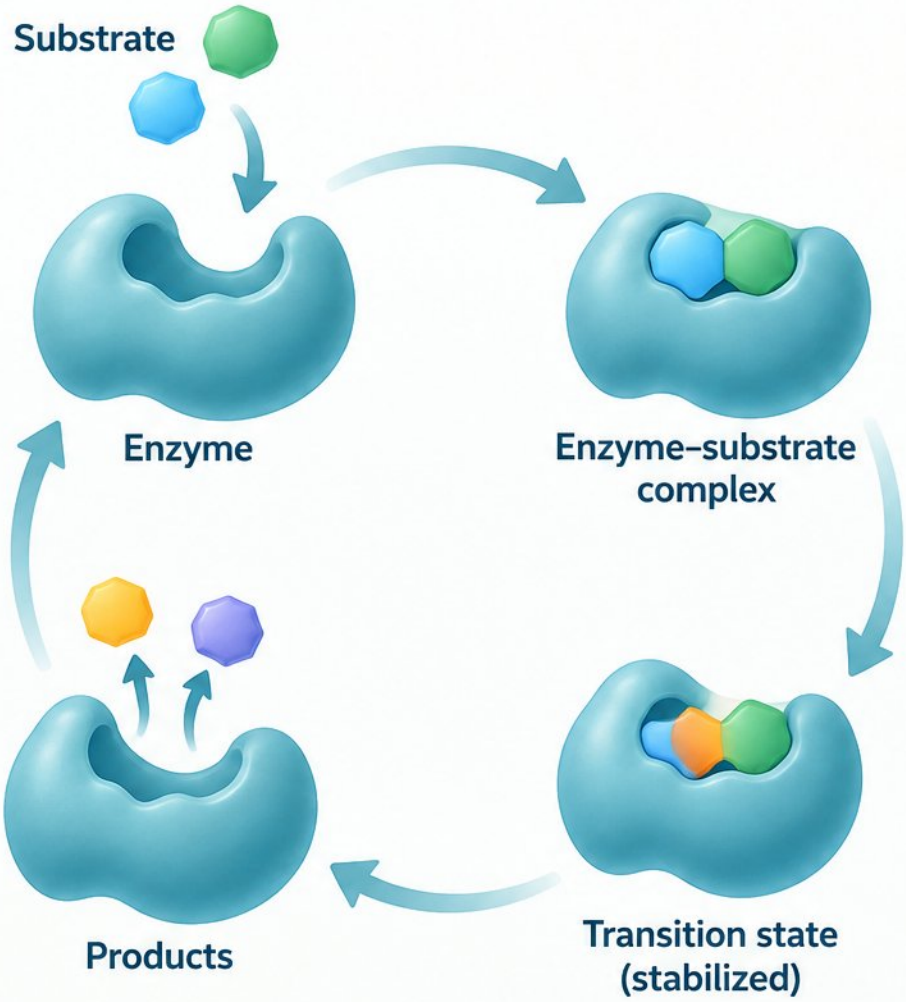
Enzyme Structure: Active Sites and the Shape That Does the Work

- Enzymes are large proteins folded into precise 3D shapes from amino acid chains
- The active site is a small pocket where substrates bind and chemistry happens
- Lock-and-key: exact shape match; induced fit: enzyme molds slightly around substrate
- Shape relies on weak interactions—hydrogen bonds, ionic bonds, hydrophobic effects
- Specificity: only the correct substrate fits, so cells contain thousands of enzymes



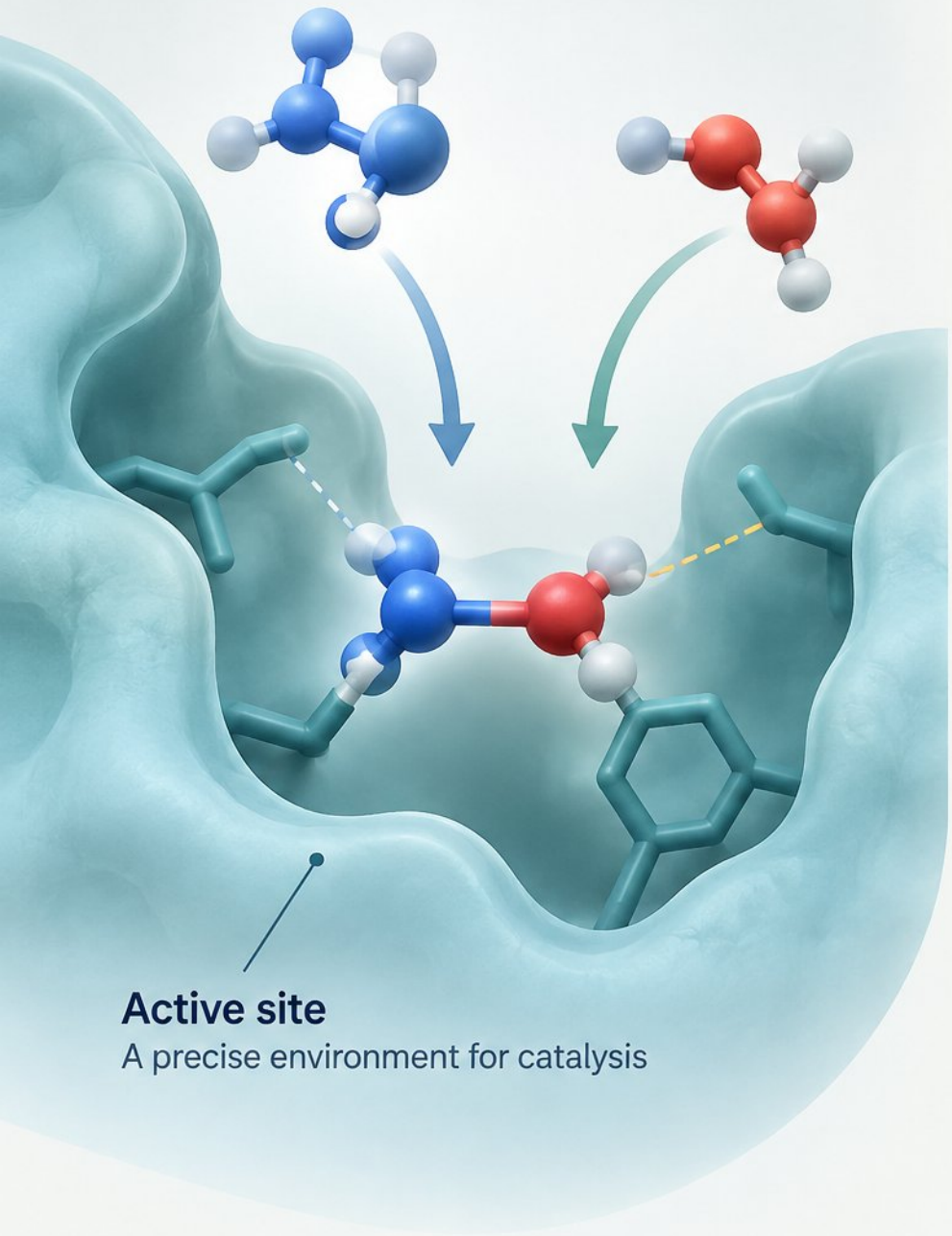


From Substrate to Product: The Catalytic Cycle



- Substrate binds the active site, forming an enzyme–substrate complex
- Weak bonds such as hydrogen bonds hold the substrate briefly in place
- Bonds rearrange; the transition state is stabilized and product forms
- Products no longer fit well, so they leave and the enzyme is reused
- k_{cat} counts substrate molecules converted per active site per second
- k_{cat}/K_M combines speed and binding, nearing the diffusion limit

How Enzymes Lower the Barrier: Key Catalytic Strategies



Active site
A precise environment for catalysis

Proximity and orientation:
active site aligns reactants precisely for reaction

Transition-state stabilization:
active site binds the high-energy intermediate more tightly

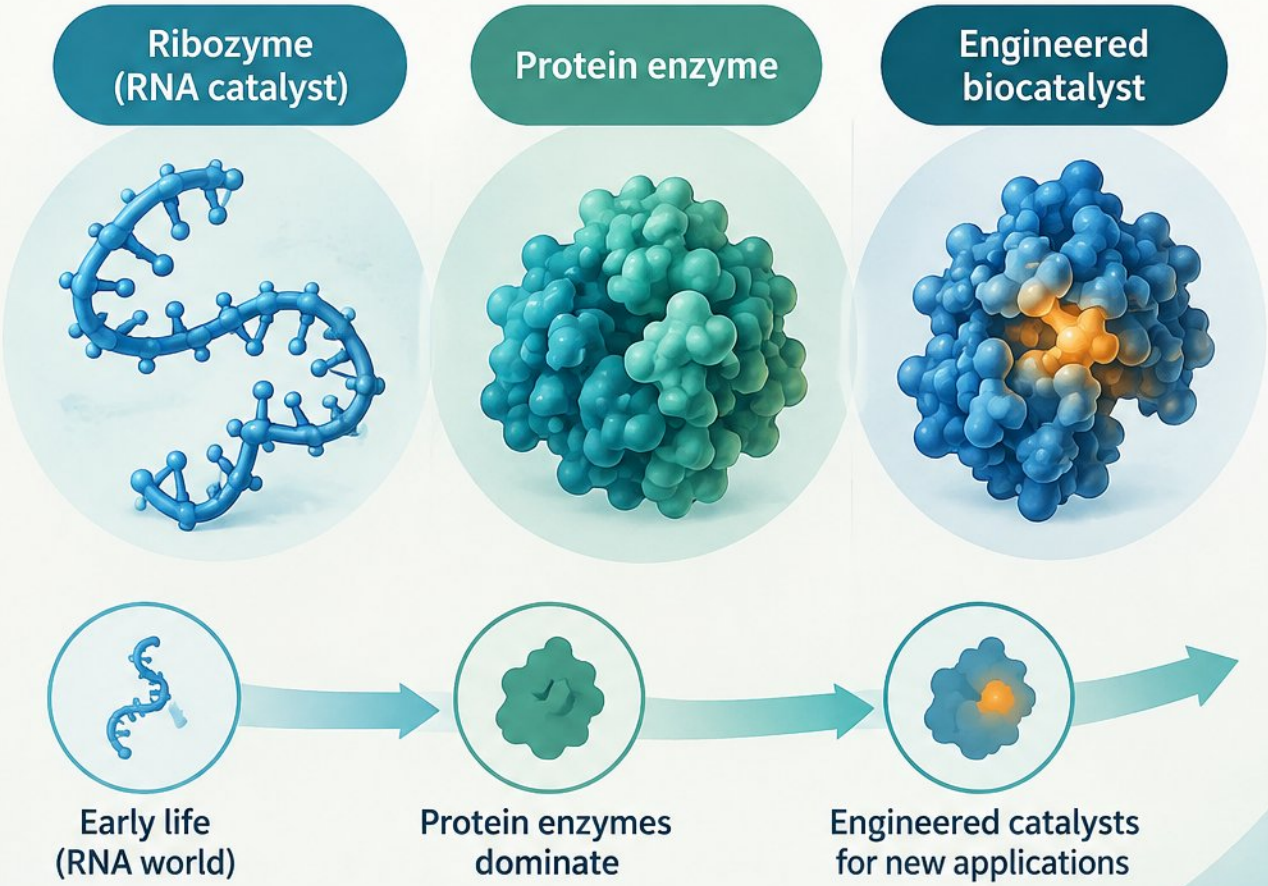
Acid–base and covalent catalysis:
side chains donate or accept protons or form temporary bonds

Microenvironment effects:
active site provides local pH or polarity favoring chemistry

Strategies often work together;
real enzymes are impressive but not magical

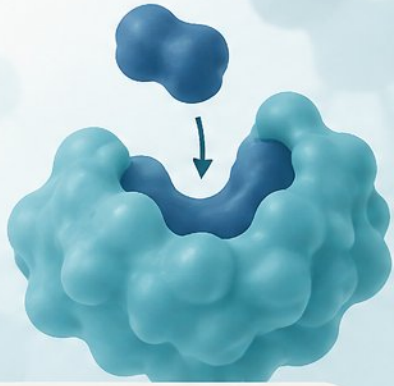
Beyond Proteins: RNA Enzymes and Engineered Catalysts

- Ribozymes are catalytic RNA molecules—proof that not all biocatalysts are proteins
- RNA world hypothesis: early life may have used RNA catalysts before protein enzymes
- Directed evolution engineers enzymes through repeated rounds of mutation and selection
- Computational design builds new biocatalysts for medicine and industry
- Protein enzymes still dominate, but ribozymes correct the “all catalysts are proteins” myth

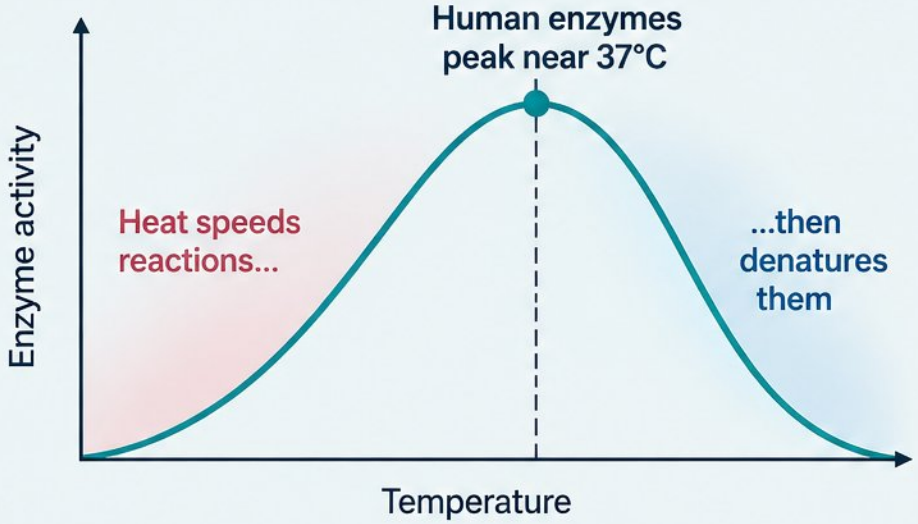


Factors That Shape Enzyme Activity: Temperature and pH

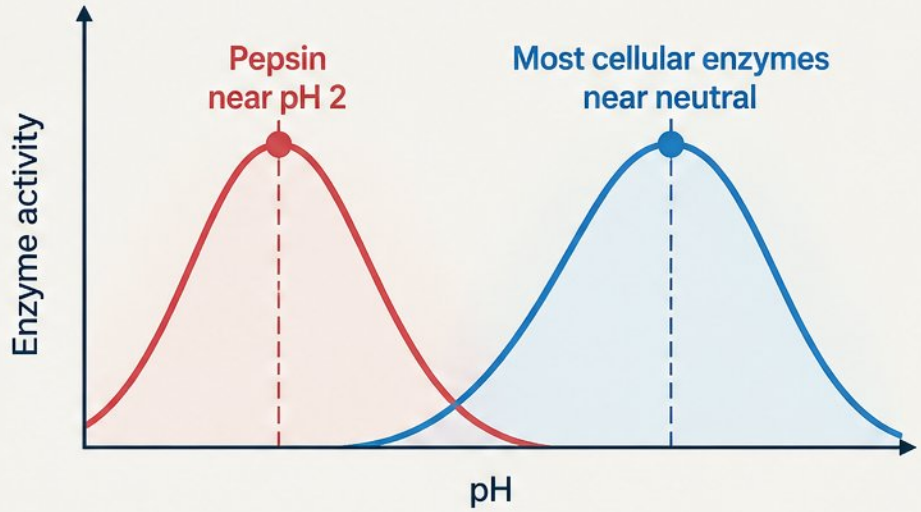
- Each enzyme has an optimal temperature; heat speeds reactions, then denatures them
- Human enzymes peak near 37°C; fever above 40°C can impair function
- Each enzyme has an optimal pH: pepsin near pH 2, most cellular enzymes near neutral
- Denaturation means the active site loses shape—substrate can no longer bind
- Practical contexts: fever, refrigeration, boiling, detergent design



Effect of Temperature on Enzyme Activity



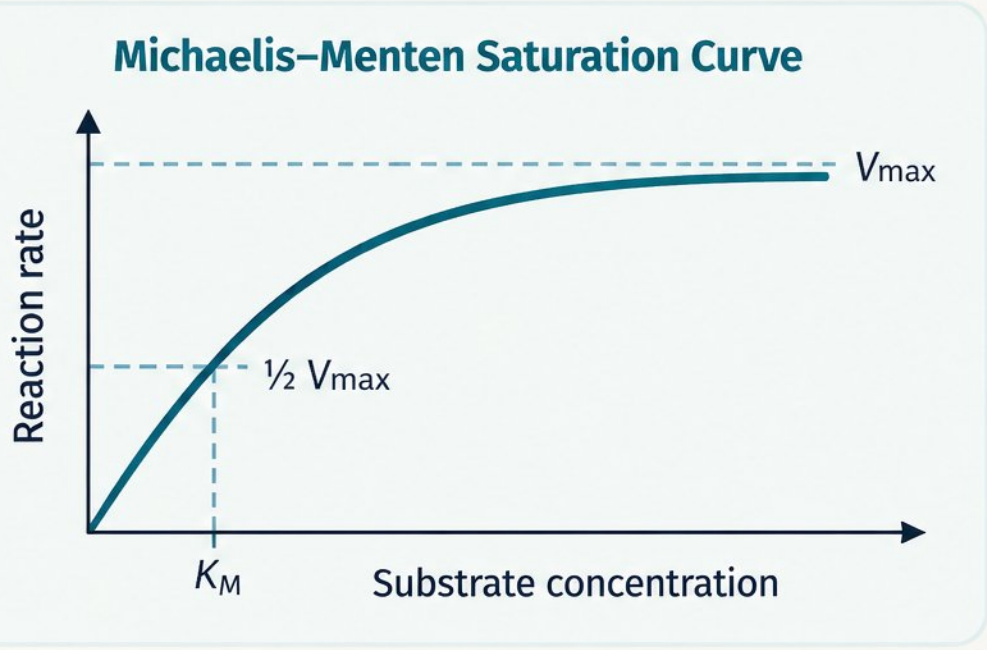
Effect of pH on Enzyme Activity



Practical contexts: fever | refrigeration | boiling | detergent design

Substrate and Enzyme Concentration: Saturation and the Michaelis–Menten Picture

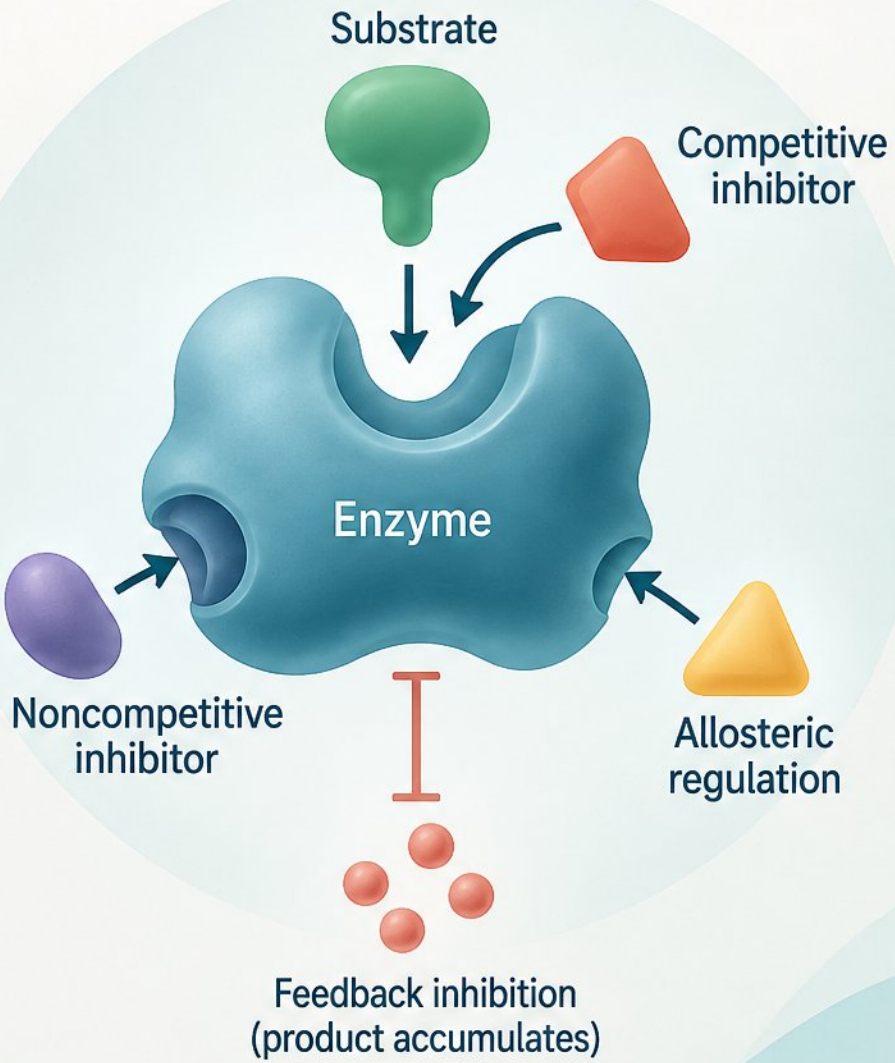
- More substrate raises rate until all active sites are occupied
- Saturation plateaus at Vmax; KM is the substrate concentration at half-Vmax
- Low KM suggests tight substrate binding; high KM suggests weaker binding
- With plentiful substrate, adding more enzyme increases the rate
- Taxi-stand analogy: full taxis can’t take more passengers
- Rate depends on both substrate supply and enzyme amount





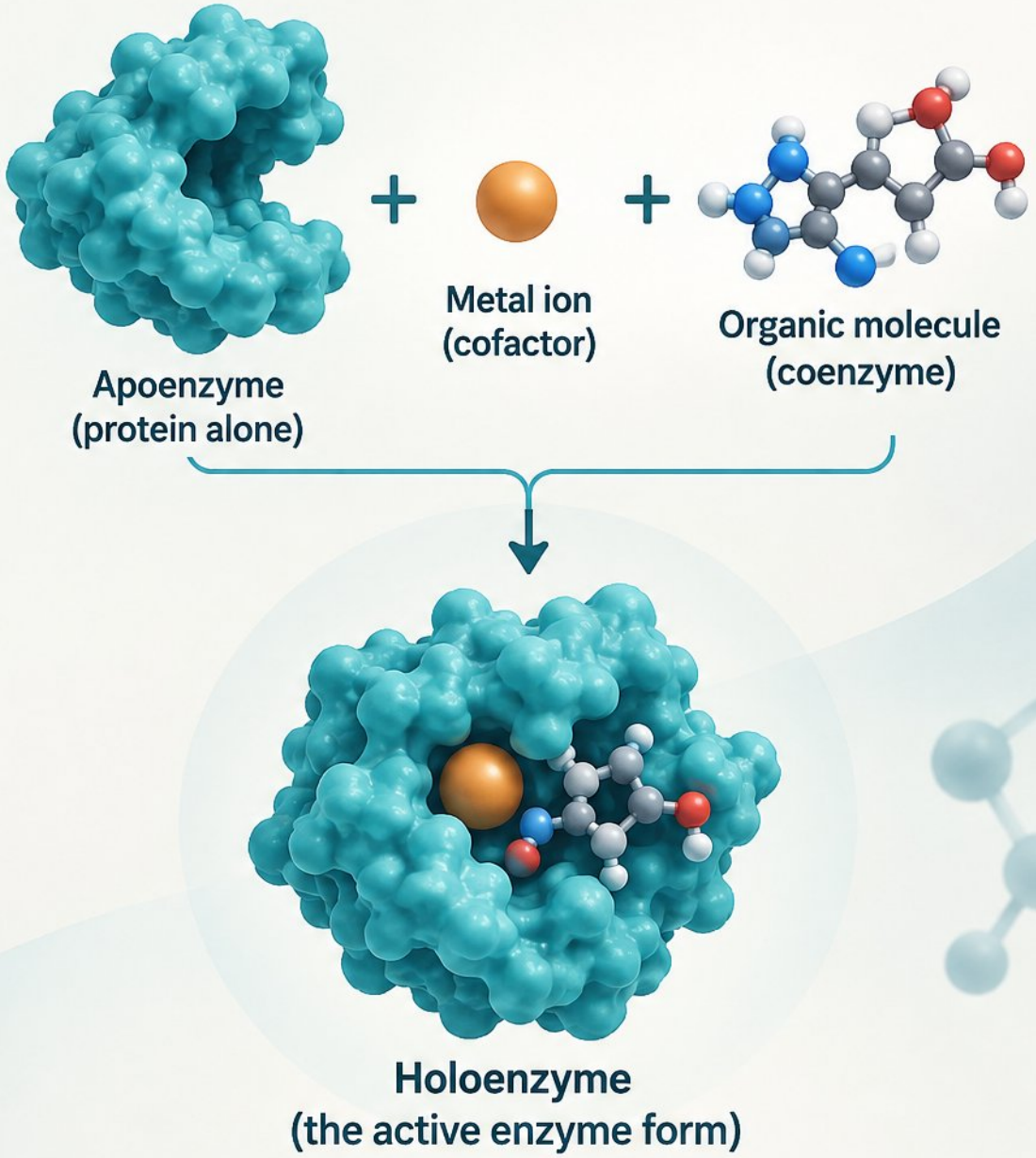
Control and Regulation:
How Cells Decide When Enzymes Work

- Cells regulate enzymes to avoid waste and maintain metabolic balance
- Competitive inhibitors compete with substrate for the active site
- Noncompetitive inhibitors bind elsewhere and change the enzyme's shape
- Allosteric regulation turns enzymes on or off at distant sites
- Feedback inhibition shuts down a pathway when product accumulates
- Phosphorylation adds rapid control; aspirin blocks cyclooxygenase, statins inhibit HMG-CoA reductase



Cofactors, Coenzymes, and the Helpers Enzymes Need

- Some enzymes need non-protein helpers: metal ions (cofactors) or organic molecules (coenzymes)
- Many vitamins are coenzyme precursors: niacin makes NAD, riboflavin makes FAD
- Apoenzyme (protein alone) + cofactor = holoenzyme, the active enzyme form
- Vitamin C deficiency blocks collagen synthesis, causing scurvy
- Not all enzymes need cofactors; it depends on the chemistry being catalyzed

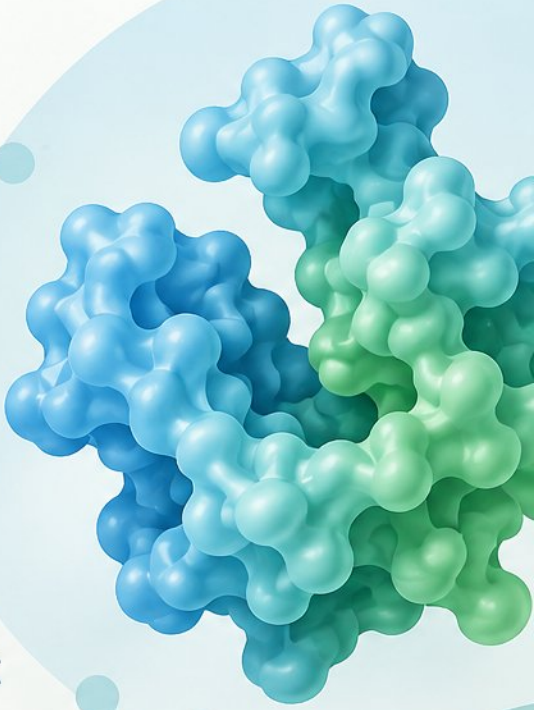


Enzymes in Medicine and Diagnostics

- Enzyme assays as diagnostic tools: liver enzymes signal tissue damage; glucose oxidase measures blood sugar
- Enzyme inhibitors as drugs: aspirin for inflammation, statins for cholesterol, protease inhibitors for viruses
- Enzyme replacement therapy restores missing enzymes in lysosomal storage disorders
- Lactase pills help lactose-intolerant people digest dairy—an everyday enzyme application
- Drug design often targets specific enzyme active or regulatory sites



Enzymes in Industry and Everyday Products



- Detergent proteases and lipases lift stains at mild temperatures, saving energy
- Food enzymes: amylases for starch sugars, lactase for lactose-free milk, rennet for cheese
- Pharmaceutical biocatalysis makes chiral drug building blocks with high selectivity
- Also used in textiles, biofuels, animal feed, and waste treatment
- Meat tenderizers and laundry powders show catalysts are already in our homes



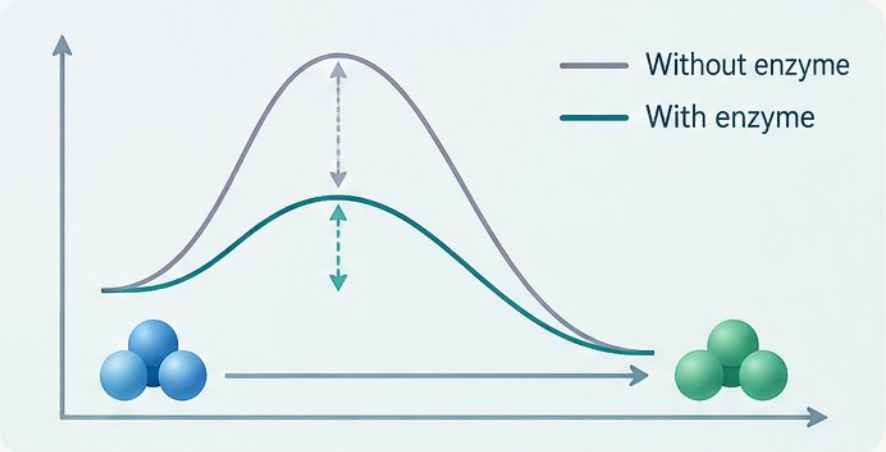


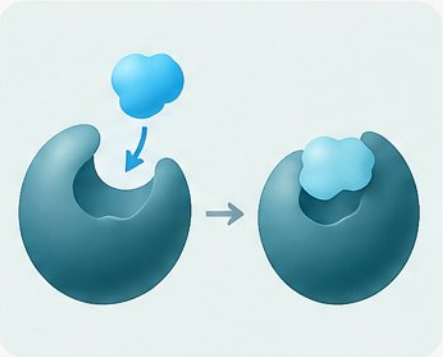


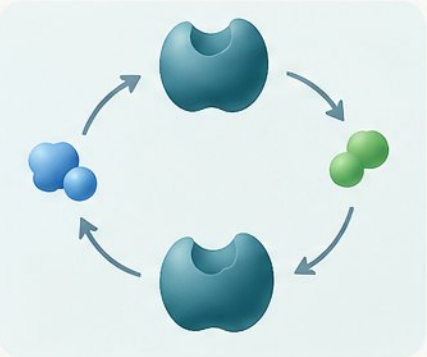


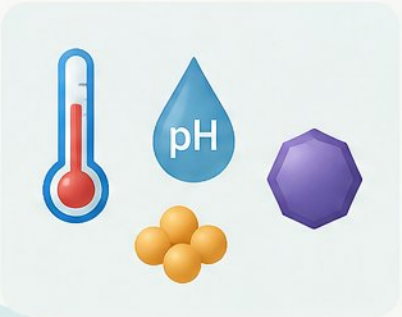
Review and Key Takeaways

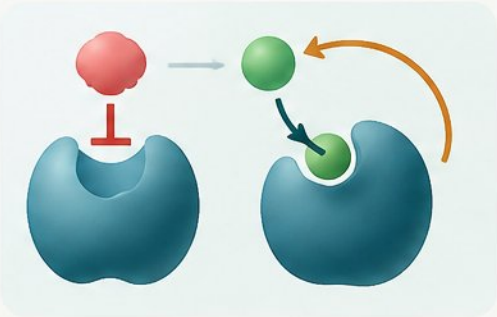
- Enzymes lower activation energy but never change ΔG or equilibrium
- Active sites, catalytic cycles, and regeneration let small amounts do much
- Activity depends on temperature, pH, substrate level, and cofactors
- Cells regulate enzymes via inhibitors, allostery, feedback, and modification
- Enzymes matter in health, medicine, industry, and daily life
- RNA catalysts show proteins are not the only biological catalysts

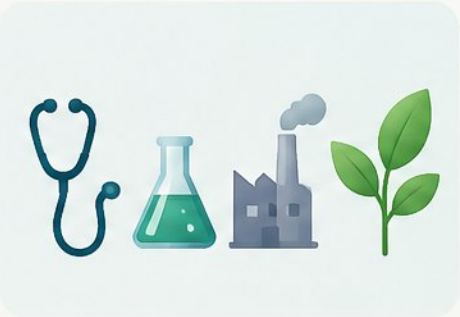


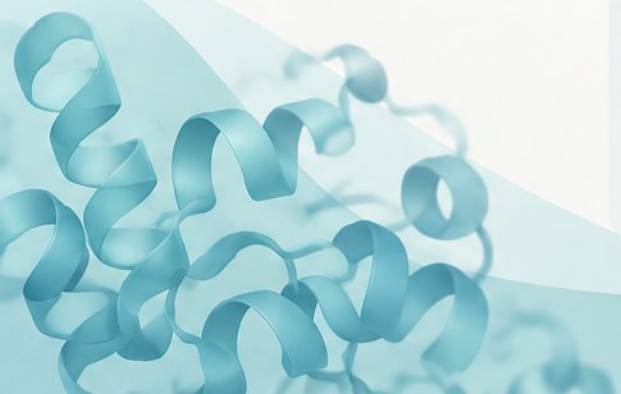












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