

Introduction to Chemistry:

Matter and Reactions



- Explore the nature of matter and chemical reactions that transform it



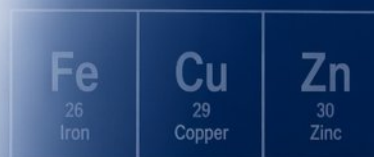
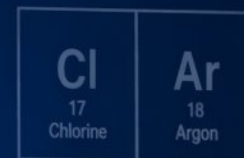
- See chemistry in cooking, cleaning, climate, and advanced materials



- Build from atoms and bonding to reaction energy and real-world applications



- Replace common beginner misconceptions with clear, evidence-based understanding



What Is Matter?

The Particle Model and Physical States



- Matter is anything with mass and volume — like water, air, and your phone



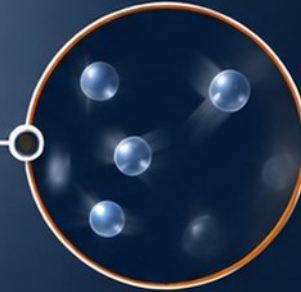
- All matter is made of tiny, constantly moving particles



- Solids: particles packed tight; liquids: close but mobile; gases: far apart and fast

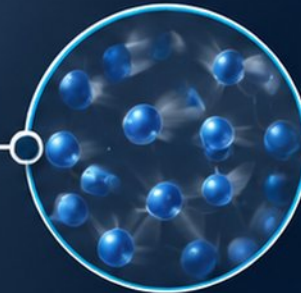


- Gaining or losing heat drives melting, freezing, boiling, and sublimation



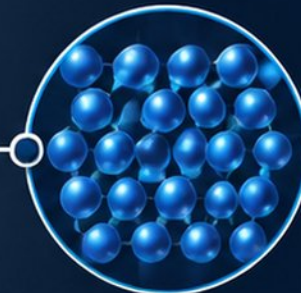
GAS (STEAM)

Particles are far apart and move very fast.



LIQUID (WATER)

Particles are close together but can move around each other.



SOLID (ICE)

Particles are packed tightly in fixed positions.



Pure Substances and Mixtures: The Stuff Around Us



- **Elements:** one type of atom; compounds: two or more bonded



- **Homogeneous mixtures:** uniform composition (air, salt water)



- **Heterogeneous mixtures:** visibly distinct parts (sand, salad)

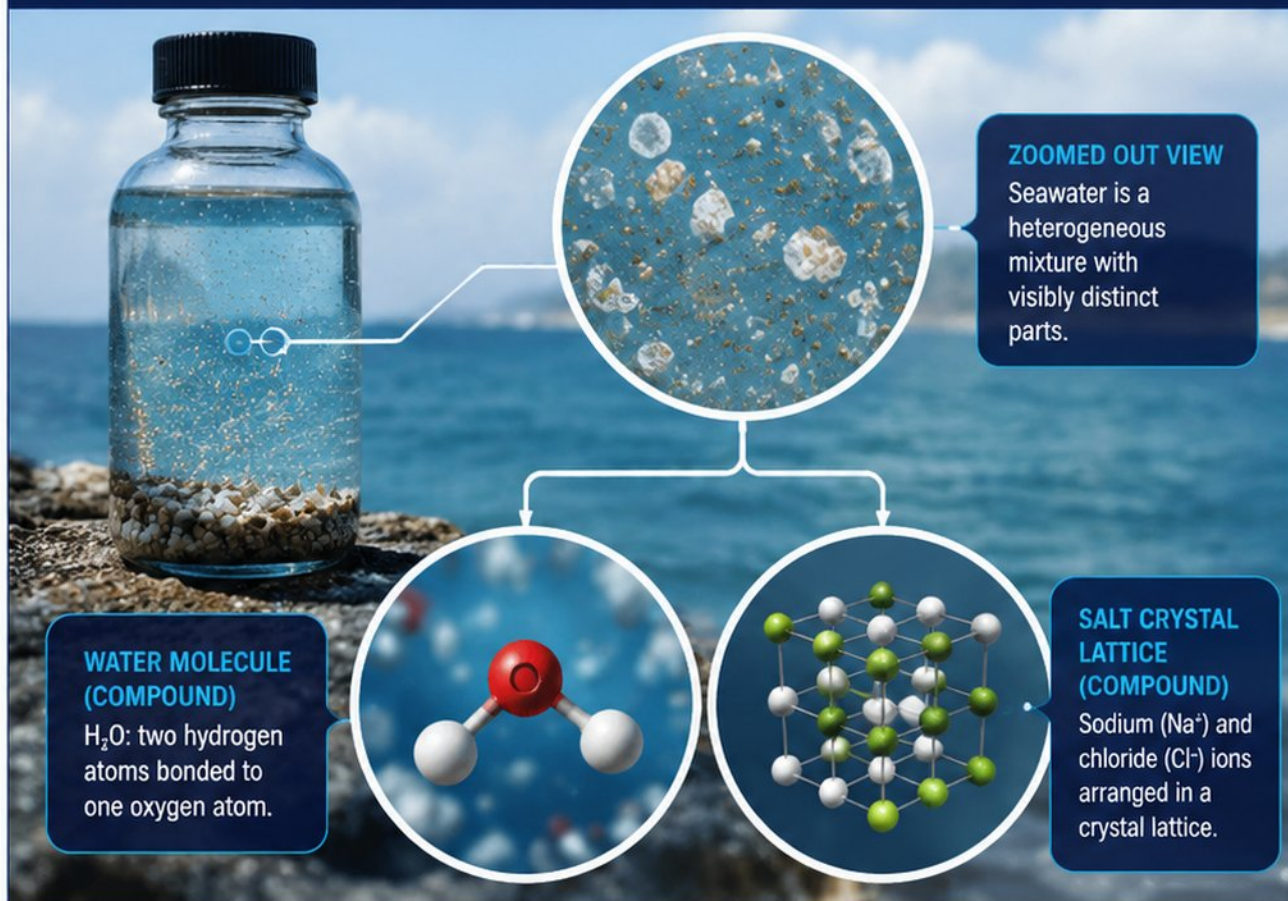


- **Separation:** filtration, distillation, and chromatography



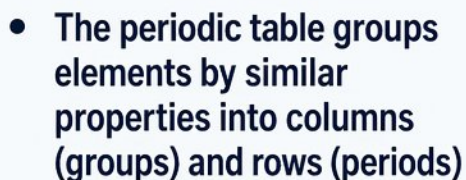
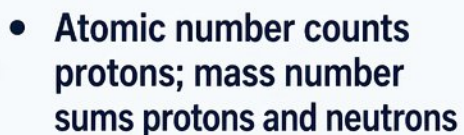
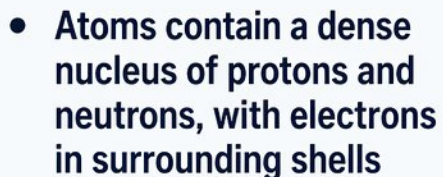
FIELD GUIDE: SEAWATER SAMPLE

A naturally occurring heterogeneous mixture



MAGNIFIED PARTICLE VIEW

Looking closer reveals the tiny particles that make up this mixture.



Metals: shiny, conductive, and malleable

Nonmetals: brittle
insulators

Metalloids: properties between metals and nonmetals

The diagram illustrates the structure of an atom. At the center is the nucleus, composed of red spheres with a '+' sign (protons) and grey spheres with a '0' sign (neutrons). Surrounding the nucleus are two concentric blue rings representing electron shells. The inner ring is labeled 'First Shell (holds up to 2 electrons)' and contains two blue spheres with a '-' sign (electrons). The outer ring is labeled 'Second Shell (holds up to 8 electrons)' and contains six blue spheres with a '-' sign (electrons). Labels with dashed arrows point to specific components: 'Electron (-)' points to an electron in the second shell, 'Proton (+)' points to a proton in the nucleus, 'Neutron (0)' points to a neutron in the nucleus, and 'Electron (-)' points to an electron in the first shell.

6

Number of protons

Mass Number

12

Protons +
neutrons

Carbon-12 has **6 protons**, 6 neutrons, and **6 electrons**

		GROUPS (COLUMNS)																		
		1	2											13	14	15	16	17	18	
PERIODS (ROWS)	1	H		3	4	5	6	7	8	9	10	11	12							He
	2	Li	Be											B	C	N	O	F	Ne	
	3	Na	Mg											Al	Si	P	S	Cl	Ar	
	4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
	5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
	6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
	7	Fr	Ra																	
				La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
				Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

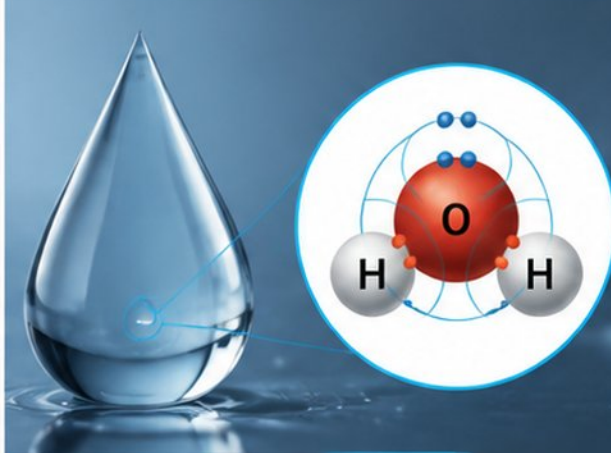
Why Atoms Stick Together: Ionic, Covalent, and Metallic Bonds

IONIC BONDS



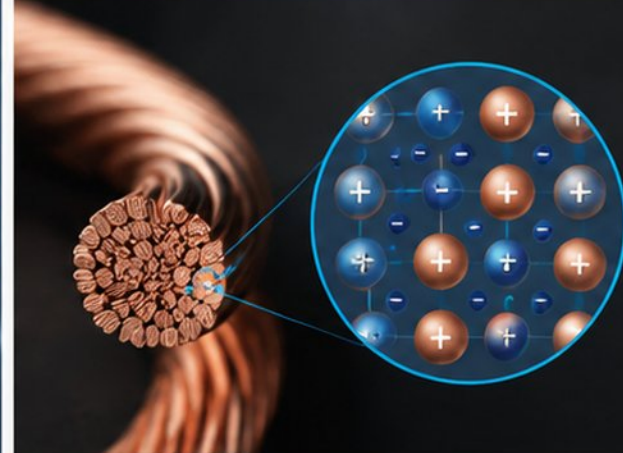
Electron transfer between metals and nonmetals, forming charged ions

COVALENT BONDS



Electron sharing between nonmetals, forming distinct molecules

METALLIC BONDS



A sea of delocalized electrons enabling conductivity and malleability



- Bond type determines melting point, solubility, and electrical conductivity



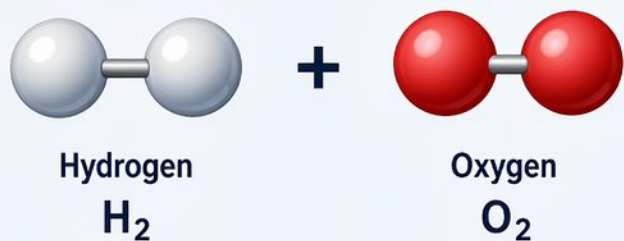
- Everyday examples: salt dissolves in water, copper conducts electricity



Chemical Reactions: Equations and the Conservation of Mass

VISUAL RECIPE: FORMATION OF WATER

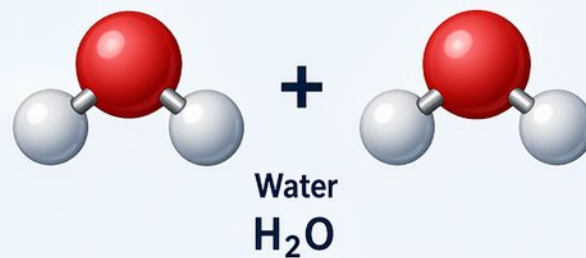
1. INGREDIENTS (REACTANTS)



2. REACTION (MIX)



3. PRODUCT(S)



- Reactants transform into products, shown in a chemical equation



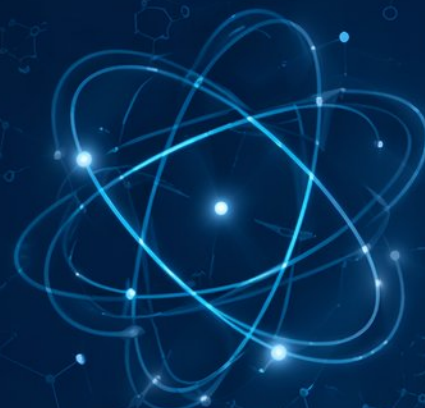
- Atoms rearrange; they are never created or destroyed



- Balancing uses coefficients to equalize atom counts on both sides



- Subscripts define molecules and never change during balancing



Common Reaction Types: Synthesis, Decomposition, and Combustion

1 SYNTHESIS



2 DECOMPOSITION



3 COMBUSTION



4 SINGLE/DOUBLE DISPLACEMENT



- **Synthesis:** two or more substances combine into one product
- **Decomposition:** a single compound breaks down into simpler parts
- **Combustion:** rapid reaction with oxygen releases heat and light
- **Single/double displacement:** elements or ions swap partners
- Spot these patterns in rusting, baking, and burning fuels

Energy in Chemical Reactions:

Exothermic and Endothermic



- **Exothermic:** energy released, surroundings heat up (combustion, hand warmers)



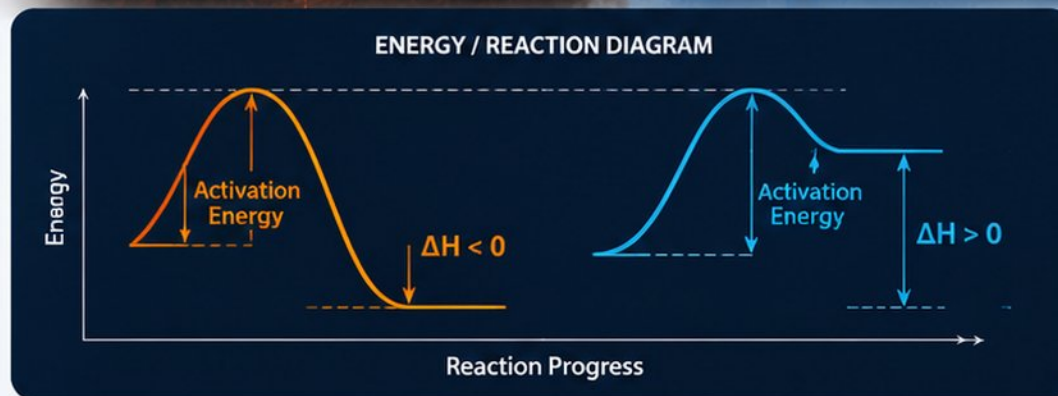
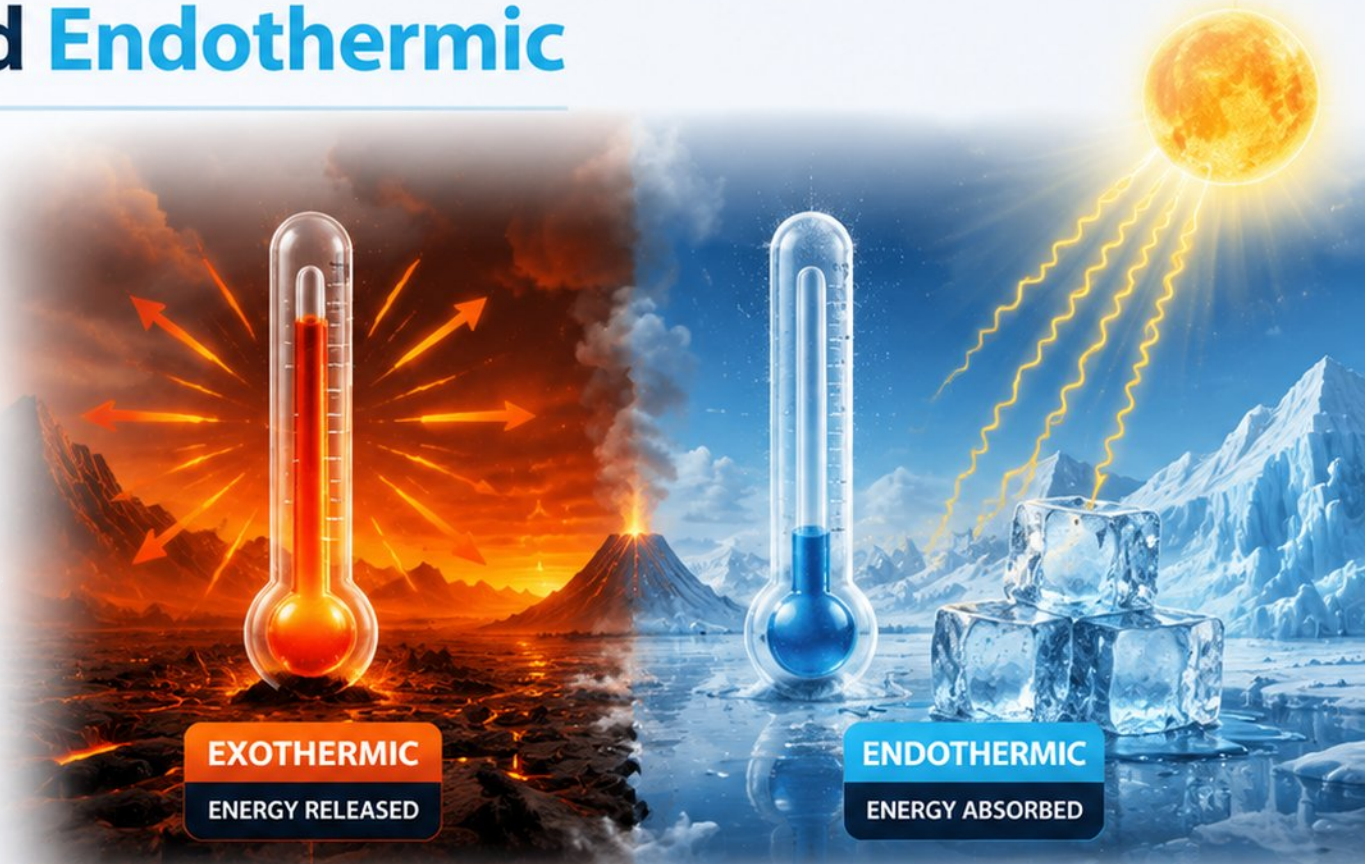
- **Endothermic:** energy absorbed, surroundings cool down (photosynthesis, cold packs)



- **Enthalpy (ΔH):** negative for exothermic, positive for endothermic



- **Activation energy:** the initial energy spark needed to start any reaction



Reaction Rates:

How Fast or Slow Do Reactions Happen?



- Reaction rate measures how quickly reactants turn into products



- Collision theory: particles need correct orientation and sufficient energy



- Rate increases with higher concentration, temperature, and surface area



- Catalysts lower activation energy without being consumed in the reaction



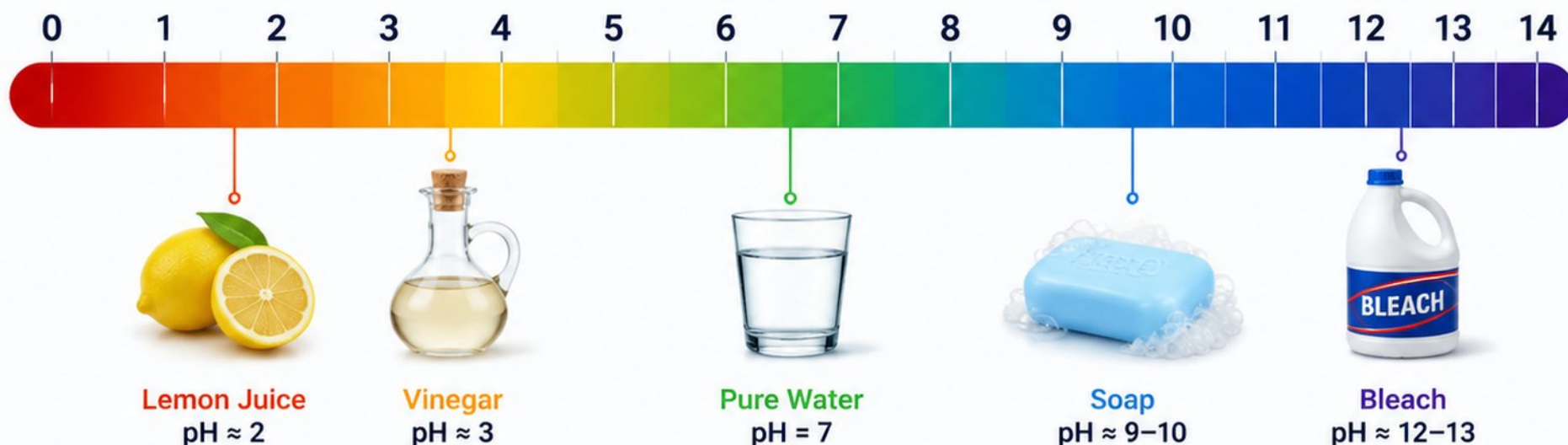
- Enzymes are biological catalysts that speed up life-sustaining reactions



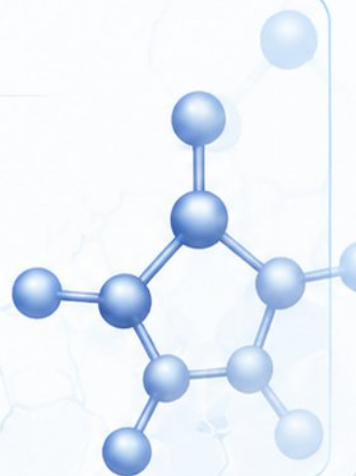
Acids and Bases:

Everyday Chemistry from the Kitchen to the Ocean

• The pH Scale •



- Acids donate H^+ ions; bases accept H^+ or produce OH^-
- pH scale ranges 0 (acidic) to 7 (neutral) to 14 (alkaline)
- Home acids: vinegar, lemon juice, stomach acid (HCl)
- Home bases: baking soda, soap, ammonia cleaners
- Neutralization: acid + base $\rightarrow$ salt + water



Acid-Base Indicators and Measuring pH



- Natural indicators: litmus, red cabbage, and turmeric



- Synthetic indicators: universal indicator and pH meters



- Colors shift predictably across the 0–14 pH scale



- Test vinegar, baking soda, and soap at home safely



- pH is vital for blood, soil, crops, and clean water



Ocean Acidification: A Real-World Acid-Base Story



- Excess CO_2 dissolves in seawater, forming carbonic acid and lowering pH



- Surface pH dropped >0.1 units since the Industrial Revolution



- 26% increase in acidity over 250 years



- Reduced carbonate ions harm shell-building organisms (corals, pteropods, bivalves)



- Satellites, machine learning, and in-situ sensors now monitor acidification globally

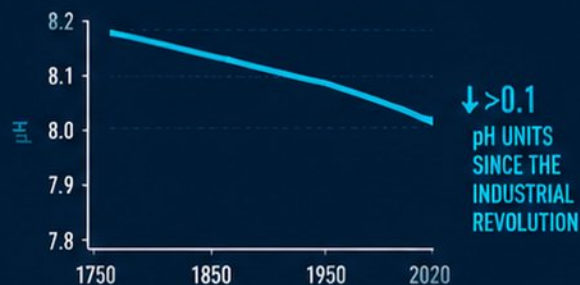
HEALTHY REEF



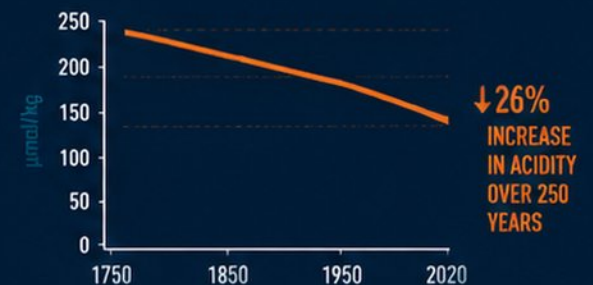
BLEACHED REEF



SURFACE OCEAN pH (GLOBAL AVERAGE)



CARBONATE ION CONCENTRATION (CO_3^{2-})



SATELLITES

Wide-area ocean color and pH estimation



MACHINE LEARNING

Detect patterns, forecast trends



IN-SITU SENSORS

Real-time pH and carbonate measurements

Chemistry in the Kitchen: Cooking, Baking, and Cleaning



- **Maillard reaction:** browning proteins and sugars at high heat creates flavor



- **Caramelization:** sugar decomposes above 160°C into sweet, nutty compounds



- **Fermentation:** yeast and bacteria convert sugars into CO₂ and alcohol

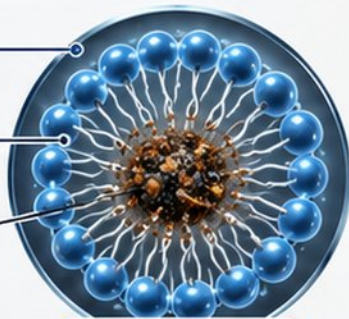


- **Cleansers:** acids dissolve scale, bases cut grease, soap traps dirt in micelles

Hydrophilic head
(loves water)

Hydrophobic tail
(loves grease)

Trapped grease
and dirt



SOAP MICELLE

MAILLARD REACTION

Amino acids + reducing sugars form complex flavor and brown pigments.



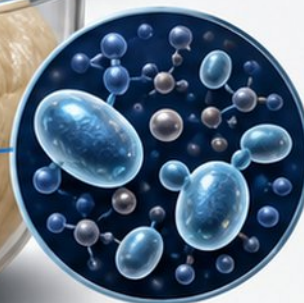
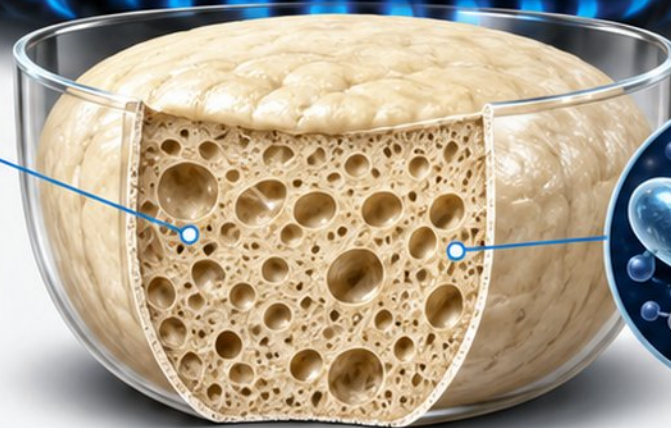
CARAMELIZATION

Sugar molecules break down above 160°C into smaller compounds.



FERMENTATION

Yeast and bacteria consume sugars and produce CO₂ and alcohol, causing dough to rise and develop flavor.



Chemistry and Energy: From Batteries to Photosynthesis



- Batteries power devices via redox reactions converting chemical energy to electricity



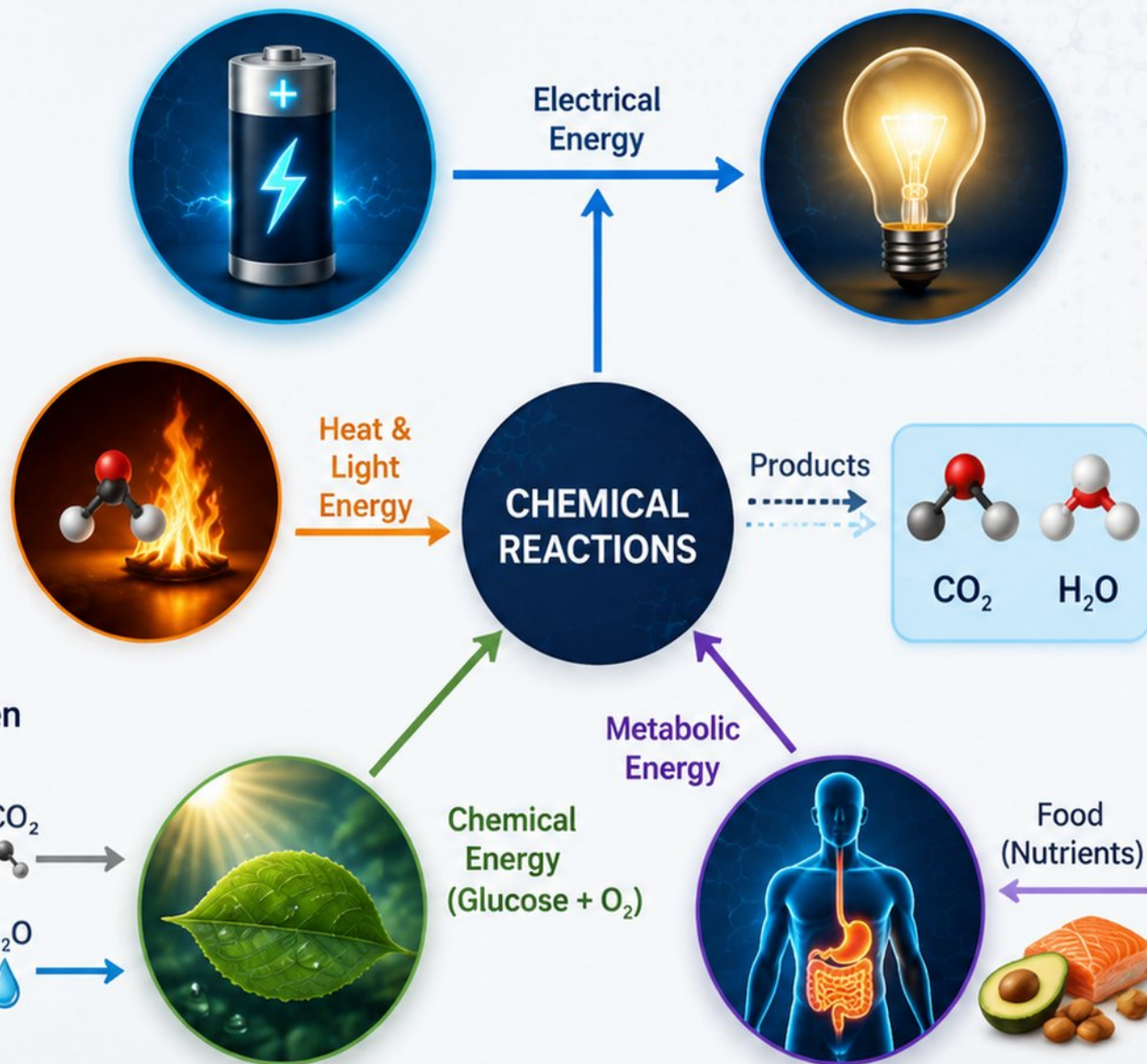
- Combustion: rapid oxidation of fuels releases heat and light, forming CO_2 and H_2O



- Photosynthesis: nature's most vital endothermic reaction, turning CO_2 and H_2O into glucose and oxygen



- Metabolism: $\sim 10^{15}$ reactions per second break down food and build tissues



Green Chemistry: Designing a Sustainable Future



PAST

- Prevent waste, use safer solvents, and design for energy efficiency



2026

- Sunlight-powered drug synthesis eliminates hazardous oxidants (2026)



FUTURE

- Soleic® biodegradable polyurethanes break down fully, leaving no microplastics
- Single-atom catalysts convert plant waste lignin into valuable chemicals



Putting It All Together: Chemistry in Your Life and Beyond



- **Recap:** From atoms and bonding to energy, reactions, and real-world systems



- **Chemical literacy:** Read labels, understand risks, and make informed choices



- **Learn more:** Citizen science, online resources, and career paths in chemistry



- **Final call:** Notice chemistry in your kitchen, body, and environment every day



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