ENVIRONMENT

THE SCIENCE BEHIND THE STORIES

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Ch 4

From Chemistry to Energy to Life

Part 1: Foundations of Environmental Science

PowerPoint® Slides prepared by
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This lecture will help you understand:

- The fundamentals of environmental chemistry
- The molecular building blocks of organisms
- Energy and energy flow
- Photosynthesis, respiration, and chemosynthesis
- Major hypotheses for life's origins
- Our knowledge of early life

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Central Case: Bioremediation of the *Exxon Valdez* Oil Spill

- In 1989, 11 million gallons coated the Alaskan coastline
  - The largest spill in U.S. history (not any more)
- Defiled the pristine environment
- Tourism plummeted and jobs were lost
- **Bioremediation**= pollution cleanup through enhanced natural biodegradation

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Chemistry is crucial for understanding:

- How gases contribute to global climate change
- How pollutants cause acid rain
- The effects on health of wildlife and people
- Water pollution
- Wastewater treatment
- Atmospheric ozone depletion
- Energy issues

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Chemical building blocks

- **Matter** = all material in the universe that has mass and occupies space
  - Can be transformed from one type of substance into others
  - But it cannot be destroyed or created which is…
  - The **law of conservation of matter**
    - Helps us understand that the amount of matter stays constant
    - It is recycled in nutrient cycles and ecosystems

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Chemical building blocks

- **Element** = a fundamental type of matter, with a given set of properties
  - **Atoms** = the smallest components that maintain an element's chemical properties
  - The atom's nucleus has **protons** (positively charged particles) and **neutrons** (particles lacking electric charge)
  - **Atomic number** = the defined number of protons
  - **Electrons =** negatively charged particles surrounding the nucleus
    - Balances the positively charged protons

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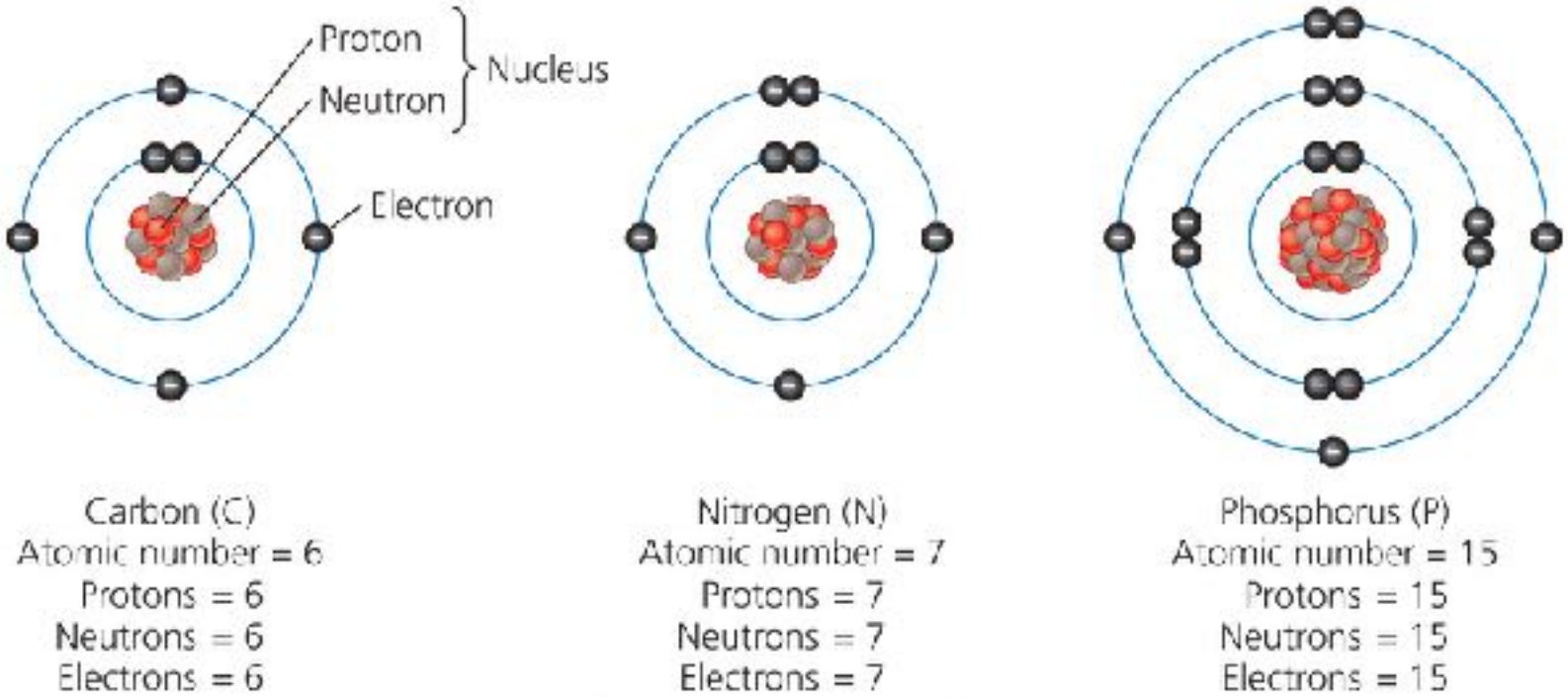
The structure of an atom



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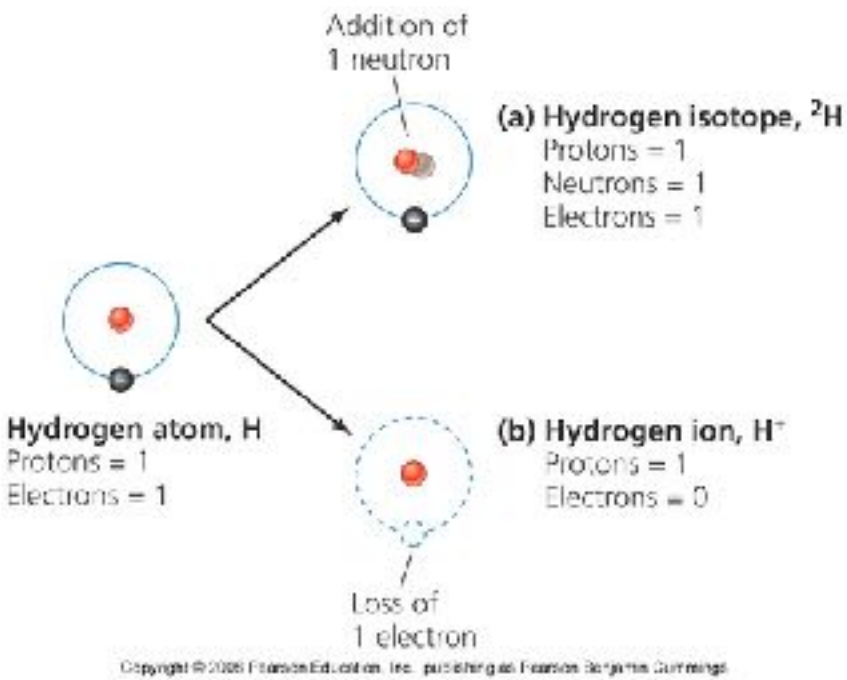
Chemical building blocks



Isotopes = atoms with differing numbers of neutrons

- **Mass number** = the combined number of protons and neutrons
- Isotopes of an element behave differently
- Some isotopes are **radioactive** and decay until they become non-radioactive **stable isotopes**
  - Emit high-energy radiation

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Radioactive decay

- **Half-life** = the amount of time it takes for one-half of the atoms to give off radiation and decay
  - Different radioscopes have different half-lives ranging from fractions of a second to billions of years
  - *Uranium-235, used in commercial nuclear power, has a half-life of 700 million years*
- Atoms may also gain or lose electrons to become **ions**, electrically charged atoms

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Molecules & Compounds

- **Molecules** = Combinations of two or more atoms
  - Oxygen gas = O_2
- **Compounds** = A molecule composed of atoms of two or more different elements
  - Water = two hydrogen atoms bonded to one oxygen atom: H_20
  - Carbon dioxide = one carbon atom with two oxygen atoms: CO2

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Atoms are held together with bonds

- **Covalent bond =** atoms in a molecule share electrons
  - For example, the atoms that bond to form H_20
- **Polar covalent bonds =** Atoms share electrons unequally, with one atom exerting a greater pull
  - The oxygen in a water molecule attracts electrons
- **Ionic bonds** = an electron is transferred from one atom to another
  - Are not molecules, but are salts, such as table salt, NaCl
- **Solutions** = no chemical bonding, but is a mixture of substances (i.e., blood, oil)

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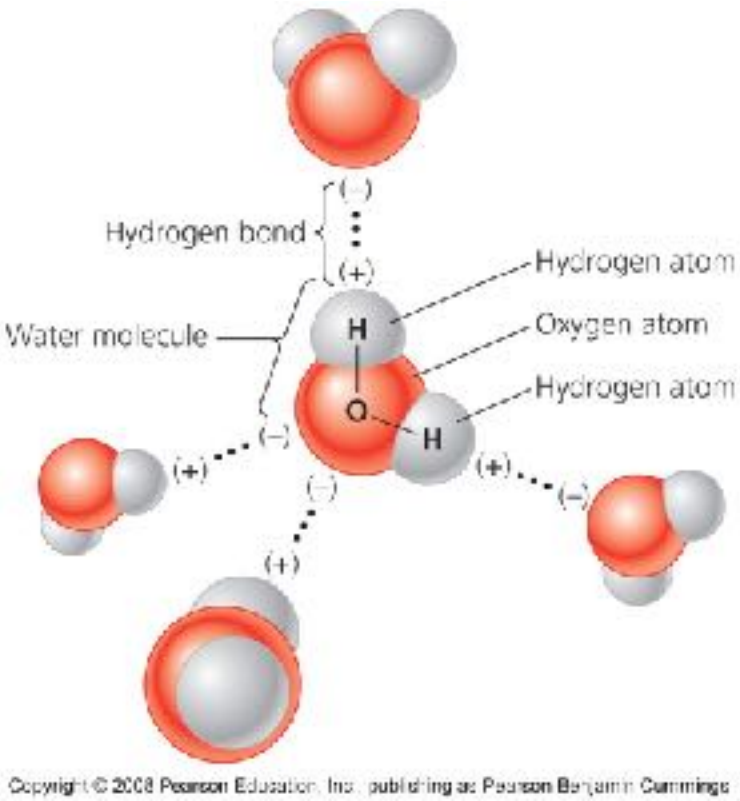
Water: the main reason life can exist



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- **Hydrogen bond** = oxygen from one water molecule attracts hydrogen atoms of another
- Water's strong cohesion allows nutrients and waste to be transported
- Water absorbs heat with only small changes in its temperature, which stabilizes systems

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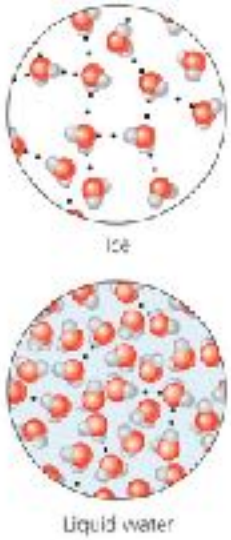
Additional properties of water

- Less dense ice floats on liquid water
- Water dissolves other molecules



(a) Why ice floats on water

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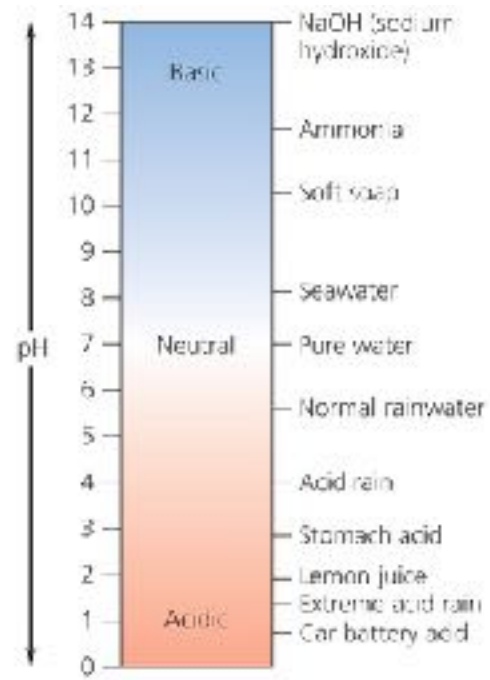
Hydrogen ions determine acidity

- The pH scale ranges from 0 to 14 and quantifies the acidity of solutions
  - **Acidic** solutions have a pH less than 7
  - **Basic** solutions have a pH greater than 7
  - **Neutral** solutions have a pH of 7
- A substance with pH of 6 contains 10 times as many hydrogen ions as a substance with pH of 7



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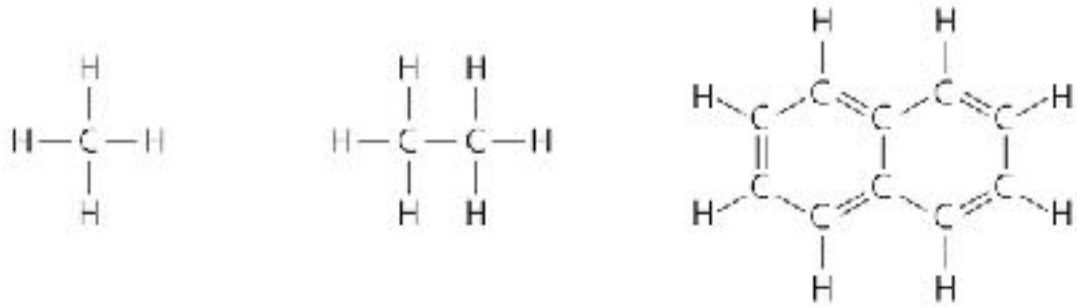
Organic Compounds

- **Organic Compounds** = carbon atoms joined by covalent bonds and may include other elements
  - Such as nitrogen, oxygen, sulfur, and phosphorus
- **Hydrocarbons** = contain only carbon and hydrogen
  - The simplest hydrocarbon is methane
  - Hydrocarbons can be a gas, liquid or solid



(a) Methane, CH_4 (b) Ethane, C_2H_6 (c) Naphthalene, $C_{10}H_8$ (a polycyclic aromatic hydrocarbon)

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Macromolecules

- **Polymers =** long chains of repeated molecules
  - The building blocks of life
- **Macromolecules** = large-size molecules
  - Three types of polymers are essential to life
    - Proteins
    - Nucleic acids
    - Carbohydrates
  - Lipids (are not polymers, but are also essential)

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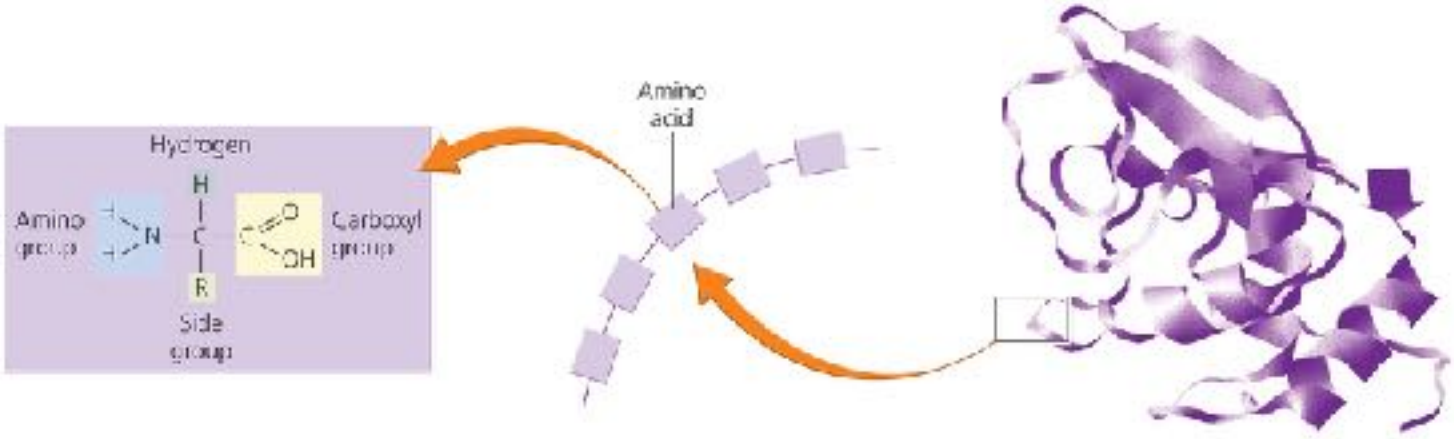
Proteins

- Produce tissues, provide structural support, store and others transport energy
  - Animals use proteins to generate skin, hair, muscles, and tendons
  - Some function as components of the immune system
  - They can serve as **enzymes**, molecules that promote certain chemical reactions



(a) General structure of an amino acid (b) Chain of amino acids (c) Protein

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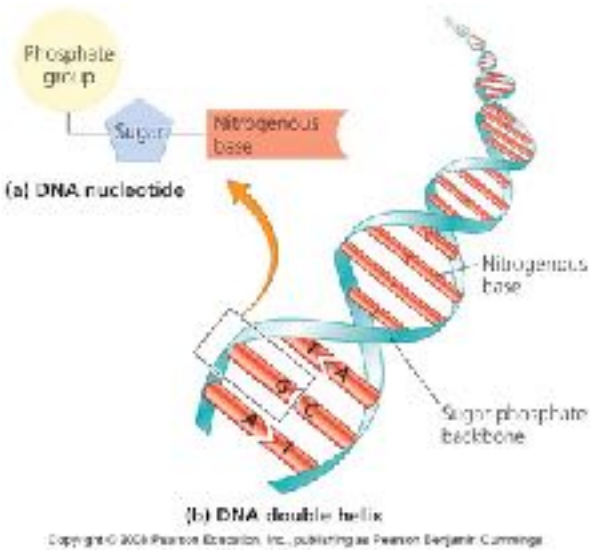
A special process involving proteins

- **Deoxyribonucleic acid (DNA)** and **Ribonucleic Acid (RNA)** carry the hereditary information of organisms
  - Long chains of nucleotides that contain
    - Sugar, phosphate, and a nitrogen base
- Information in DNA is rewritten to RNA
- RNA directs amino acid assembly into proteins
- **Genes** = regions of DNA that code for proteins that perform certain functions
- **Genome** = an organism's genes
  - Divided into chromosomes



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Carbohydrates and lipids

- **Carbohydrates =** consist of atoms of carbon, hydrogen, and oxygen
  - Sugars = simple carbohydrates
    - Glucose = provides energy for cells
  - Complex carbohydrates build structures and store energy
    - Starch = a complex carbohydrate
- **Lipids =** a chemically diverse group of compounds grouped together because they don't dissolve in water
  - For energy, cell membranes, structural support, and steroids

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We create synthetic polymers

- **Plastics** = synthetic (human-made) polymers
  - Best known by their brand names (Nylon, Teflon, Kevlar)
  - Many are derived from petroleum hydrocarbons
  - Valuable because they resist chemical breakdown
  - Problematic because they cause long-lasting waste and pollution
    - Wildlife and health problems, water quality issues, harmful to marine animals
  - We must design less-polluting alternatives and increase recycling

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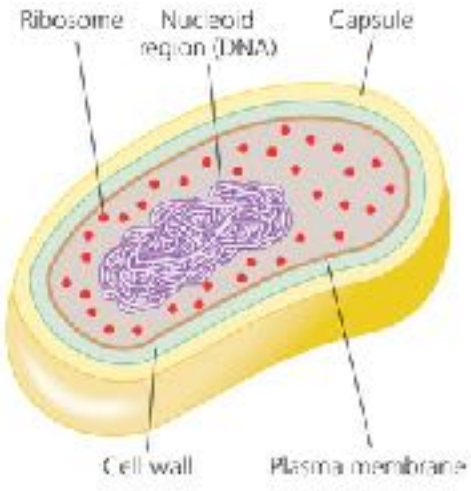
Organization of matter in living things

- **Cell** = the basic unit of life's organization
- **Eukaryotes** = multi-celled organisms containing internal structures (*organelles*)
  - Plants, animals, fungi, protists
  - Ribosomes synthesize proteins
  - Mitrochondria extract energy from sugars and fats
  - Nucleus houses DNA
- **Prokaryotes** = single-celled organisms lacking organelles and a nucleus



(b) Prokaryotic cell

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Hierarchy of matter in organisms

Matter is organized in a hierarchy of levels, from atoms through cells through organ systems

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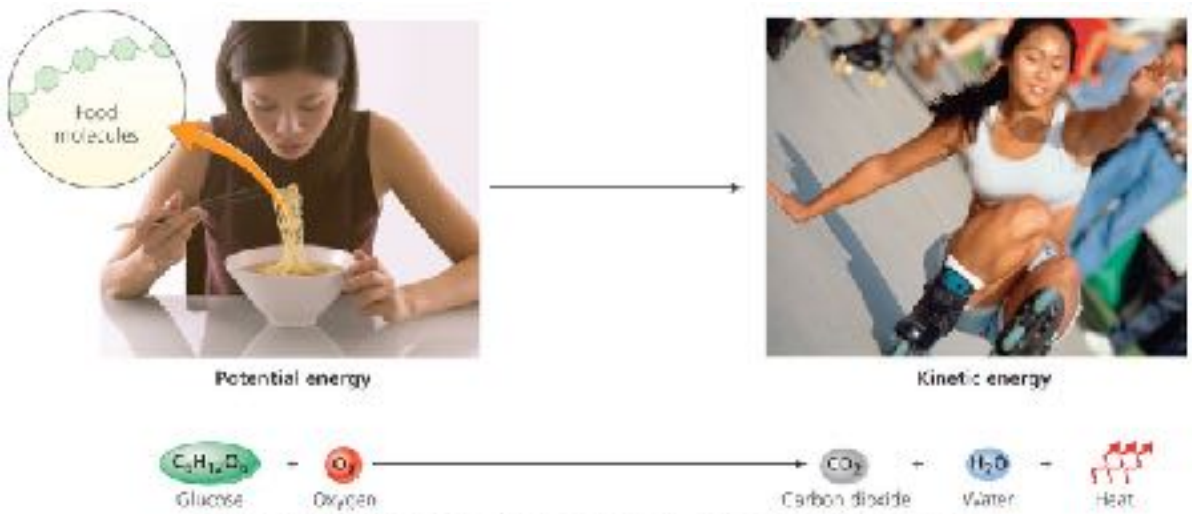
Energy fundamentals

- **Energy** = that which can change the position, physical composition or temperature of matter
  - **Potential energy** = energy of position
  - **Kinetic energy** = energy of motion
  - **Chemical energy** = potential energy held in the bonds between atoms
- Potential energy is changed into kinetic energy to produce motion, action, and heat



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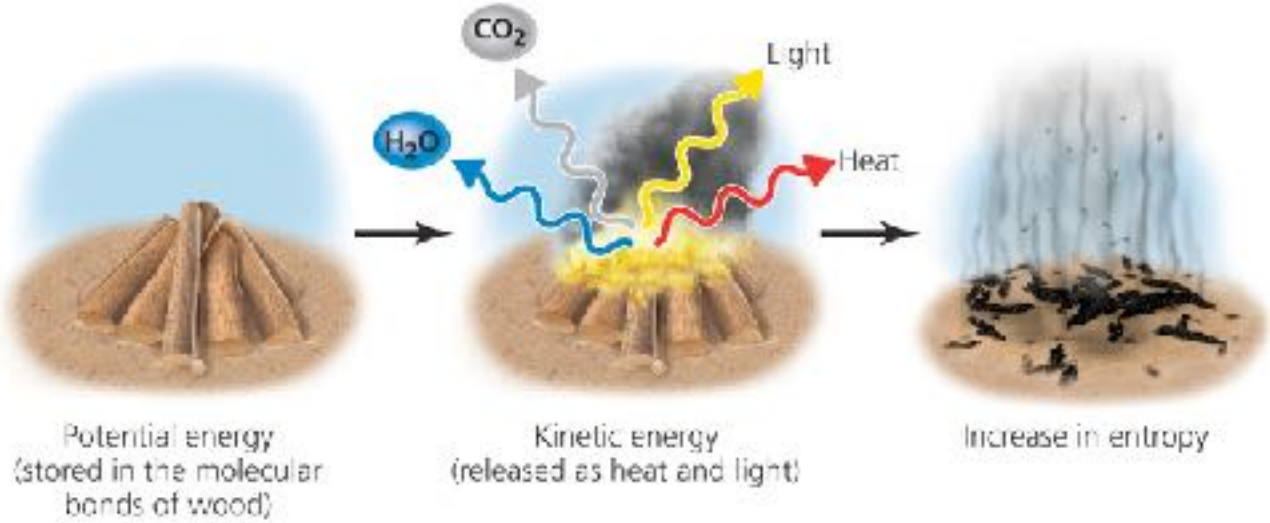
Energy is conserved...but changes in quality

- **First law of thermodynamics** = energy can change forms, but cannot be created or destroyed
- **Second law of thermodynamics** = the nature of energy changes from a more-ordered to a less-ordered state
  - Entropy = an increasing state of disorder



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People harness energy

- An energy source's nature determines how easily energy can be harnessed
  - Petroleum provide large amounts of efficient energy
  - Sunlight provides low-quality energy, because it is spread out and difficult to harness
- **Energy conversion efficiency** = the ratio of useful energy output to the amount needing to be input
  - An engine burns petroleum to power a car, but most energy is lost as heat
- Organisms maintain life by consuming energy

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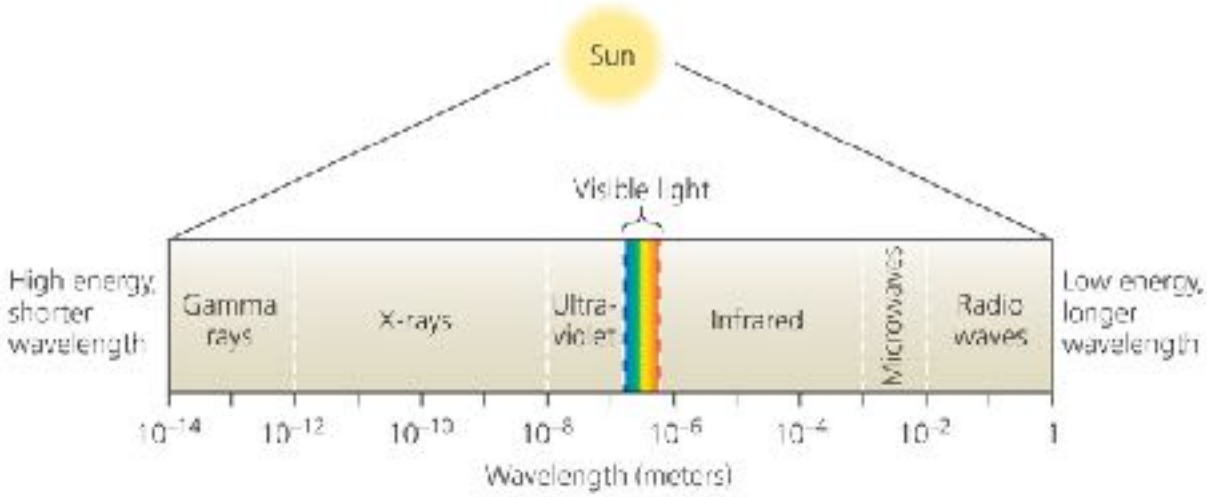
The sun's energy powers life

- The sun releases radiation from the electromagnetic spectrum
  - Some is visible light
- Solar energy drives weather and climate, and powers plant growth



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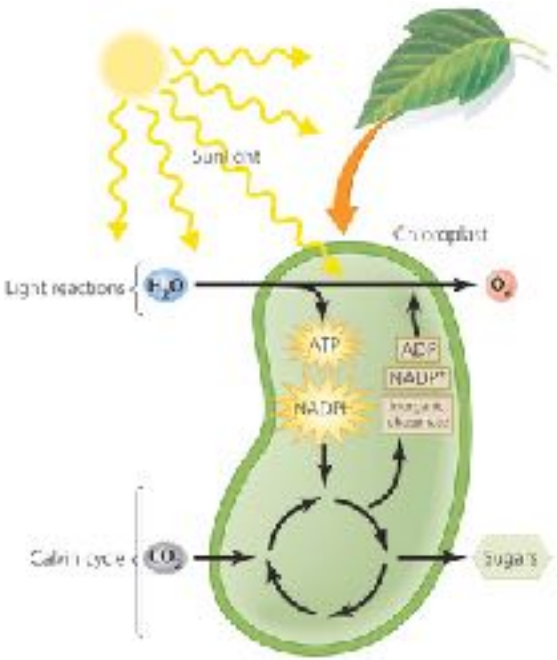
Photosynthesis

- **Autotrophs (primary producers)** = organisms such as green plants, algae and cyanobacteria produce their owr food from the sun's energy
- **Photosynthesis** = the process of turning light energy from the sun int chemical energy
  - Carbon dioxide + water + sun's energy is converted into sugars and high-quality energy



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Photosynthesis produces food

- **Chloroplasts** = organelles where photosynthesis occurs
  - Contain **chlorophyll** = a light-absorbing pigment
  - **Light reaction** = splits water by using solar energy
  - **Calvin cycle** = links carbon atoms from carbon dioxide into sugar (glucose)

$$6CO_2 + 6H_20 + \text{the sun's energy} \longrightarrow C_6H_{12}O_6 + 6O_2$$

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Cellular respiration releases chemical energy

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- Organisms use chemical energy from photosynthesis
- Oxygen is used to convert glucose into water + carbon dioxide + energy
- Heterotrophs = organisms that gain energy by feeding on others
  - Animals, fungi, microbes

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_20 + \text{energy}$$

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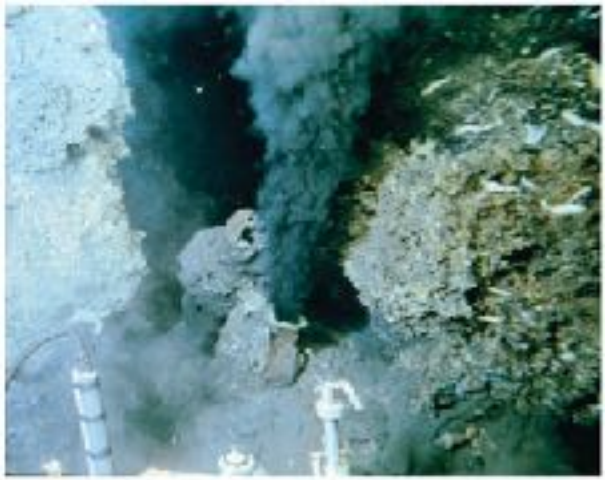
Geothermal energy powers Earth's systems

- **Hydrothermal vents** = host entire communities that thrive in high temperature and pressure
  - Lack of sun prevents photosynthesis
  - **Chemosynthesis** = uses energy in hydrogen sulfide to produce sugar



(a) Hydrothermal vent

(b) Giant tubeworms

$$6CO_2 + 6H_20 + 3H_2S \longrightarrow C_6H_{12}O_6 + 3H_2SO_4$$

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Early Earth was a very different place

- 4.5 billion years ago, Earth was a hostile place
  - Severe volcanic and tectonic activity
  - Intense ultraviolet energy from the sun
  - No oxygen existed in the atmosphere, until photosynthesis developed in microbes
  - No life existed

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Several hypotheses explain life's origin

- **Primordial soup (the heterotrophic hypothesis)** = life originated from a "primordial soup" of simple inorganic chemicals in the oceans
  - First life forms used organic compounds for energy
- **"Seeds" from space (the panspermia hypothesis)** = microbes from space traveled on meteorites to Earth
- **Life from the depths (the chemoautotrophic hypothesis)** = life originated in deep-sea hydrothermal vents, with abundant sulfur
  - First organisms were chemoautrotrophs

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The fossil record teaches about life's history

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- Single-celled bacteria occurred on Earth 3 billion years ago
- **Fossil** = an imprint in stone of a dead organism
- **Fossil record** = gives information about the history of past life

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The fossil record shows that…

- Earlier organisms evolved into later ones
- The vast majority of species are extinct
- Numbers of species increase over time
- Earlier organisms were smaller and simpler
- Several mass extinctions have occurred
- Large, complex organisms occurred 600 million years ago
  - Plants, animals, fungi

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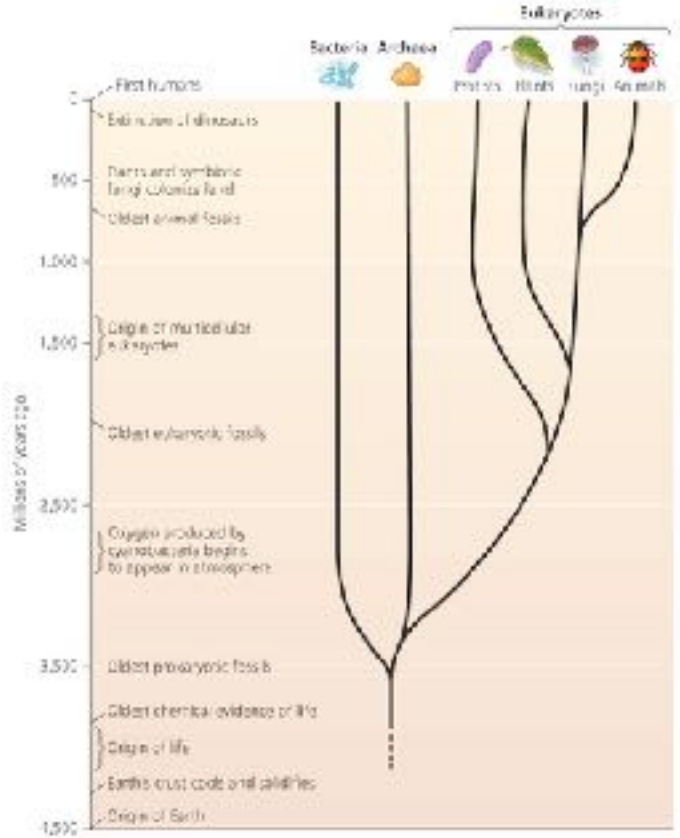
Present-day organisms help decipher history

- Biologists use present-day organisms to get information about evolution
- **Archea** = single-celled prokaryotes very different from bacteria
- The tree of life now consists of 3 prongs: bacteria, archaea, eukaryotes



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Conclusion

- Life on Earth has flourished for over 3 billion years
- Deciphering life's origins depends on understanding
  - Energy
  - Energy flow
  - Chemistry
- Chemistry can also help find solutions to environmental problems

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QUESTION: Review

Which of the following part of an atom has a negative charge?

a) Proton
b) Neutron
c) Electron
d) Hydrogen

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QUESTION: Review

Ionic bonds are bonds that ……

a) Share electrons

b) Occur when an electron is transferred from one atom to another

c) Share electrons unequally

d) Lose an electron

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QUESTION: Review

Which of the following is NOT a reason water is essential for life?

a) Water can absorb large amounts of heat without changing temperature

b) Waste and nutrients can be transported in water

c) Ice floats on liquid water, so fish survive cold winters

d) Water usually cannot dissolve other molecules

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QUESTION: Review

Of the following macromolecules, which one is NOT a polymer?

a) Lipids

b) Proteins

c) Carbohydrates

d) Nucleic acids

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QUESTION: Review

Sugars, starches, and glucose are all:

a) Lipids

b) Proteins

c) Carbohydrates

d) Nucleic acids

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QUESTION: Review

According to the second law of thermodynamics …?

a) Energy cannot be created or destroyed
b) Things tend to move toward a more disorderly state
c) Matter can be created, but not energy
d) Kinetic energy is the most efficient source of energy

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QUESTION: Review

Which of the following organisms is an autotroph?

a) Deep-sea tubeworm
b) Horse
c) Pine tree
d) None of these

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QUESTION: Weighing the Issues

Which hypothesis do you believe best explains the origin of life on Earth?

a) The heterotrophic hypothesis (primordial soup)
b) The panspermia hypothesis ("seeds" from space)
c) The chemoautotrophic hypothesis (life from the ocean depths)
d) None of these; life did not evolve

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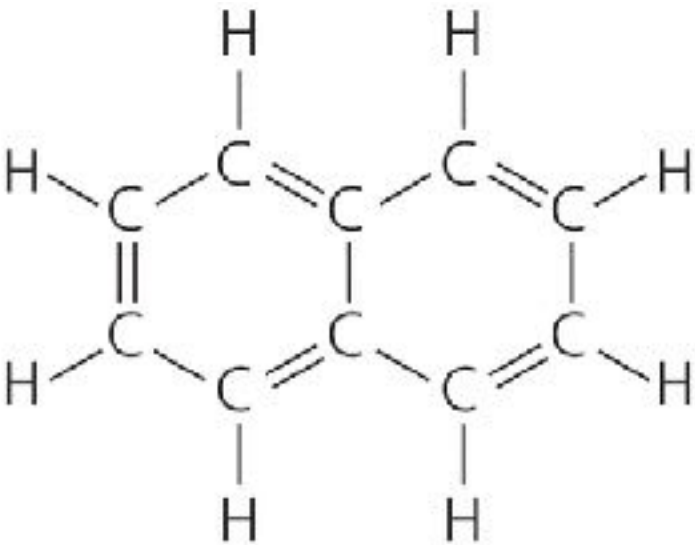
QUESTION: Interpreting Graphs and Data

A molecule of the hydrocarbon ethane contains…?



(c) Naphthalene, $C_{10}H_8$ (a polycyclic aromatic hydrocarbon)

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a) 10 carbon atoms and 8 hydrogen atoms

b) 8 carbon molecules and 10 hydrogen enzymes

c) Carbon and hydrogen DNA

d) Two different ions

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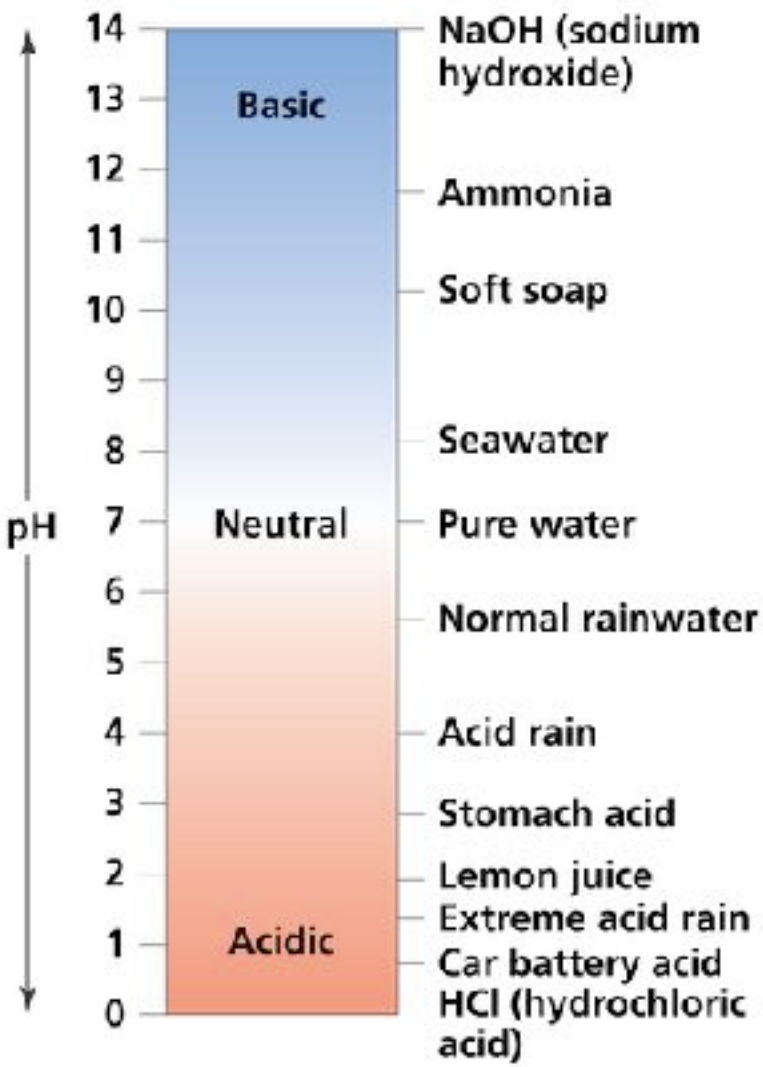
QUESTION: Interpreting Graphs and Data



Which is the most acidic material?

a) Soft soap

b) Rainwater

c) Acid rain

d) Lemon juice

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