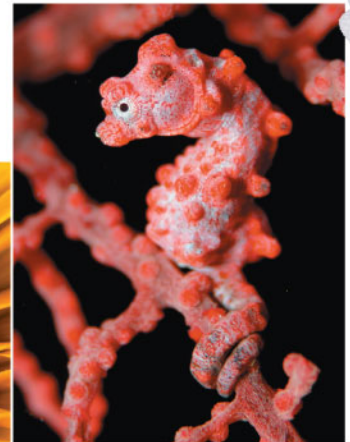
Overview: Inquiring About Life

- An organism's adaptations to its environment are the result of evolution
  - For example, the ghost plant is adapted to conserving water; this helps it to survive in the crevices of rock walls

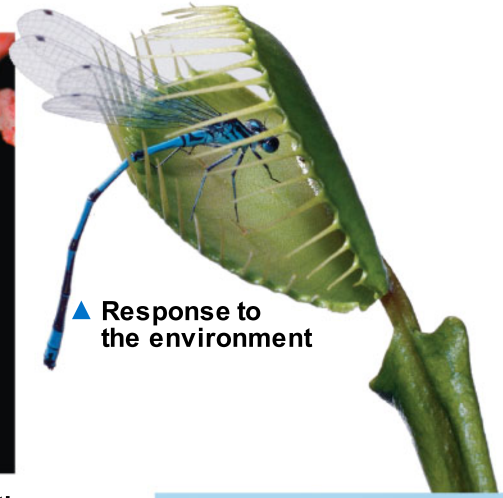
- **Evolution** is the process of change that has transformed life on Earth.

Some
properties of life.

▼ Order

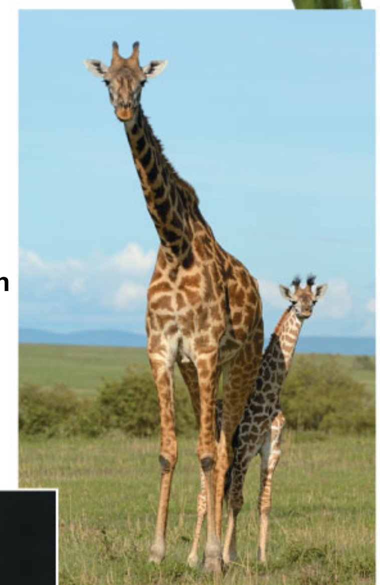


▲ Evolutionary adaptation



▲ Response to the environment

▶ Reproduction

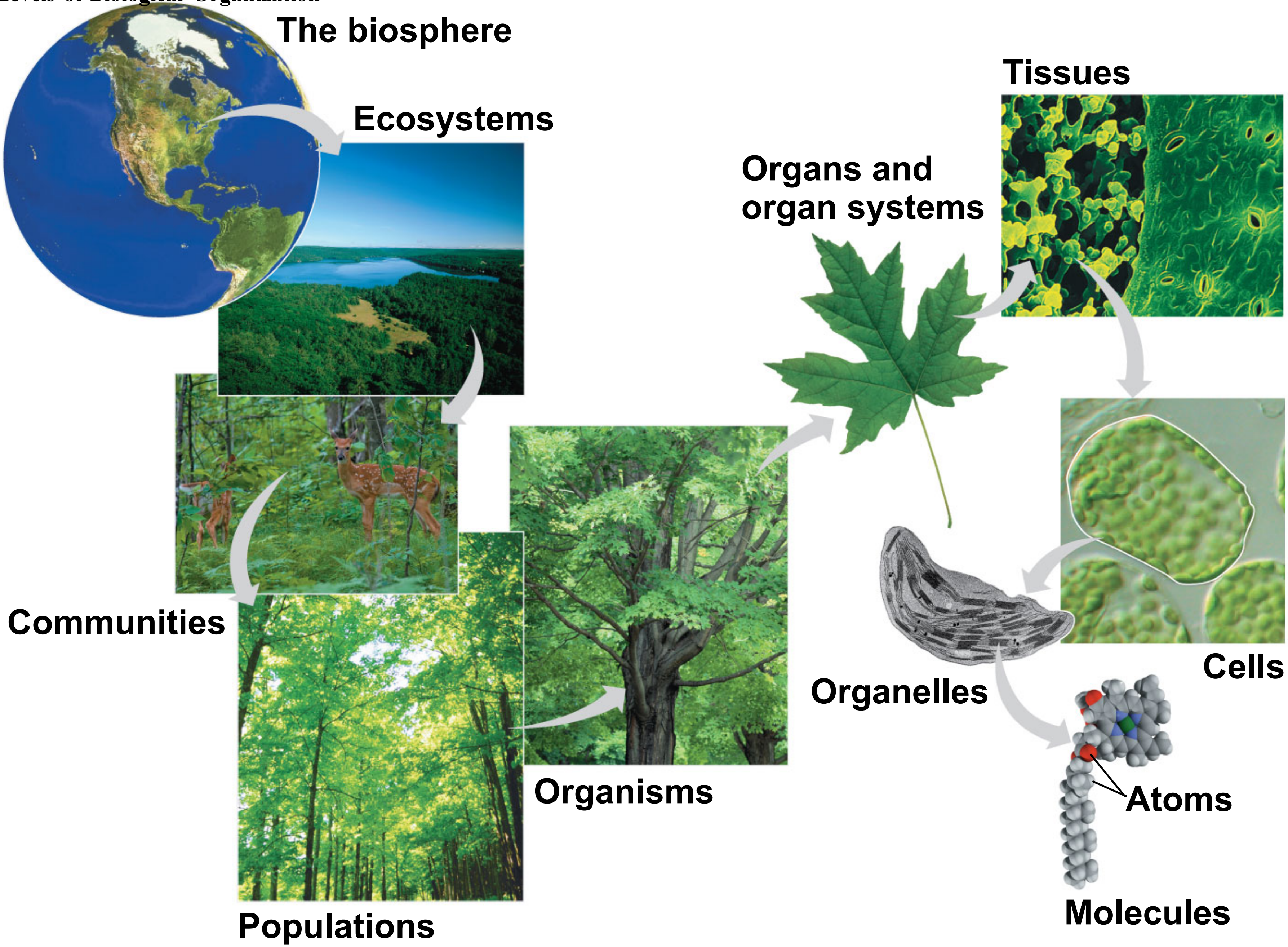


▲ Regulation

▲ Energy processing

◀ Growth and development

Levels of Biological Organization



Emergent Properties

- **Emergent properties** result from the arrangement and interaction of parts within a system
- Emergent properties characterize nonbiological entities as well
  - For example, a functioning bicycle emerges only when all of the necessary parts connect in the correct way

Systems Biology

- A system is a combination of components that function together
- **Systems biology** constructs models for the dynamic behavior of whole biological systems
- The systems approach poses questions such as
  – How does a drug for blood pressure affect other organs?
  – How does increasing CO_2 alter the biosphere?

Theme: Organisms Interact with Other Organisms and the Physical Environment

- Every organism interacts with its environment, including nonliving factors and other organisms
- Both organisms and their environments are affected by the interactions between them
  - For example, a tree takes up water and minerals from the soil and carbon dioxide from the air; the tree releases oxygen to the air and roots help form soil

- Humans have modified our environment
  - For example, half the human-generated CO_2 stays in the atmosphere and contributes to global warming
- Global warming is a major aspect of **global climate change**
- It is important to understand the effects of global climate change on the Earth and its populations

Theme: Life Requires Energy Transfer and Transformation

- A fundamental characteristic of living organisms is their use of energy to carry out life's activities
- Work, including moving, growing, and reproducing, requires a source of energy
- Living organisms transform energy from one form to another
  - For example, light energy is converted to chemical energy, then kinetic energy
- Energy flows through an ecosystem, usually entering as light and exiting as heat

Theme: Structure and Function Are Correlated at All Levels of Biological Organization

- Structure and function of living organisms are closely related
  - For example, a leaf is thin and flat, maximizing the capture of light by chloroplasts
  - For example, the structure of a bird's wing is adapted to flight

Theme: The Cell Is an Organism's Basic Unit of Structure and Function

- The cell is the lowest level of organization that can perform all activities required for life
- All cells
  - Are enclosed by a membrane
  - Use DNA as their genetic information

- A **eukaryotic cell** has membrane-enclosed organelles, the largest of which is usually the nucleus
- By comparison, a **prokaryotic cell** is simpler and usually smaller, and does not contain a nucleus or other membrane-enclosed organelles

Theme: The Continuity of Life Is Based on Heritable Information in the Form of DNA

- Chromosomes contain most of a cell's genetic material in the form of **DNA** (deoxyribonucleic acid)
- DNA is the substance of genes
- **Genes** are the units of inheritance that transmit information from parents to offspring
- The ability of cells to divide is the basis of all reproduction, growth, and repair of multicellular organisms.

DNA Structure and Function

- Each chromosome has one long DNA molecule with hundreds or thousands of genes
- Genes encode information for building proteins
- DNA is inherited by offspring from their parents
- DNA controls the development and maintenance of organisms

- Each DNA molecule is made up of two long chains arranged in a double helix
- Each link of a chain is one of four kinds of chemical building blocks called nucleotides and nicknamed A, G, C, and T

- Genes control protein production indirectly
- DNA is transcribed into RNA then translated into a protein
- **Gene expression** is the process of converting information from gene to cellular product

Genomics: Large-Scale Analysis of DNA Sequences

- An organism's **genome** is its entire set of genetic instructions
- The human genome and those of many other organisms have been sequenced using DNA-sequencing machines
- **Genomics** is the study of sets of genes within and between species

- The genomics approach depends on
  - "High-throughput" technology, which yields enormous amounts of data
  - **Bioinformatics,** which is the use of computational tools to process a large volume of data
  - Interdisciplinary research teams

Theme: Feedback Mechanisms Regulate Biological Systems

- Feedback mechanisms allow biological processes to self-regulate
- **Negative feedback** means that as more of a product accumulates, the process that creates it slows and less of the product is produced
- **Positive feedback** means that as more of a product accumulates, the process that creates it speeds up and more of the product is produced

Evolution, the Overarching Theme of Biology

- Evolution makes sense of everything we know about biology
- Organisms are modified descendants of common ancestors

- Evolution explains patterns of unity and diversity in living organisms
- Similar traits among organisms are explained by descent from common ancestors
- Differences among organisms are explained by the accumulation of heritable changes

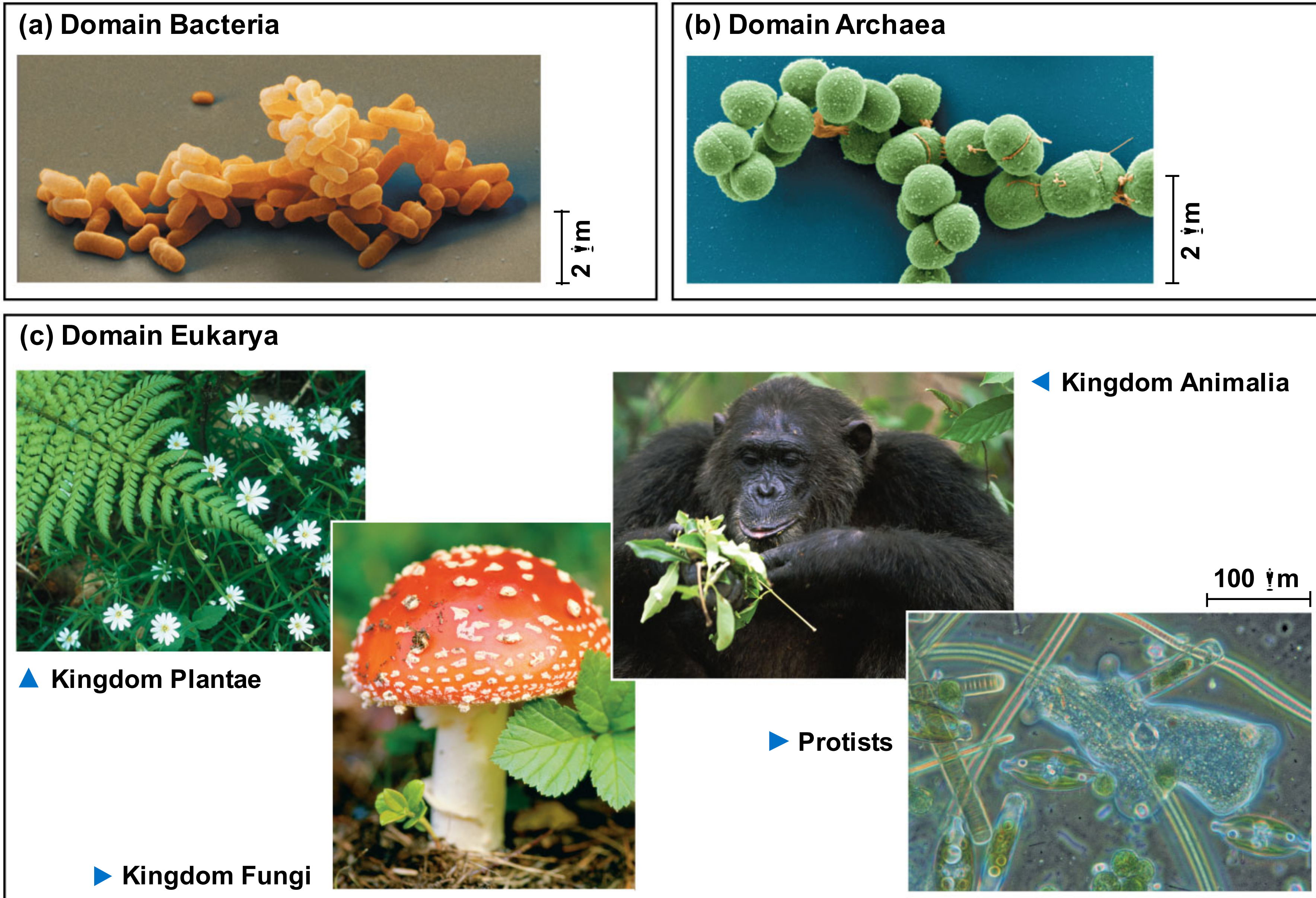
Classifying the Diversity of Life

- Approximately 1.8 million species have been identified and named to date, and thousands more are identified each year
- Estimates of the total number of species that actually exist range from 10 million to over 100 million

Grouping Species: The Basic Idea

- Taxonomy is the branch of biology that names and classifies species into groups of increasing breadth
- Domains, followed by kingdoms, are the broadest units of classification

Figure 1.15


(a) Domain Bacteria
2 µm
(b) Domain Archaea
2 µm
(c) Domain Eukarya
Kingdom Plantae
Kingdom Fungi
Kingdom Animalia
100 µm
Protists

The Three Domains of Life

- Organisms are divided into three domains
- Domain **Bacteria** and domain **Archaea** compose the prokaryotes
- Most prokaryotes are single-celled and microscopic

- Domain **Eukarya** includes all eukaryotic organisms
- Domain Eukarya includes three multicellular kingdoms
  - Plants, which produce their own food by photosynthesis
  - Fungi, which absorb nutrients
  - Animals, which ingest their food

- Other eukaryotic organisms were formerly grouped into the Protist kingdom, though these are now often grouped into many separate groups

Unity in the Diversity of Life

- A striking unity underlies the diversity of life; for example
  - DNA is the universal genetic language common to all organisms
  - Unity is evident in many features of cell structure

Charles Darwin and the Theory of Natural Selection

- Fossils and other evidence document the evolution of life on Earth over billions of years

- Charles Darwin published *On the Origin of Species by Means of Natural Selection* in 1859
- Darwin made two main points
  - Species showed evidence of “descent with modification” from common ancestors
  - Natural selection is the mechanism behind “descent with modification”
- Darwin’s theory explained the duality of unity and diversity

- Darwin observed that
  - Individuals in a population vary in their traits, many of which are heritable
  - More offspring are produced than survive, and competition is inevitable
  - Species generally suit their environment

- Darwin inferred that
  - Individuals that are best suited to their environment are more likely to survive and reproduce
  - Over time, more individuals in a population will have the advantageous traits
- Evolution occurs as the unequal reproductive success of individuals

- In other words, the environment “selects” for the propagation of beneficial traits
- Darwin called this process **natural selection**

Natural selection results in the adaptation of organisms to their environment

The Tree of Life

- “Unity in diversity” arises from “descent with modification”
  - For example, the forelimb of the bat, human, and horse and the whale flipper all share a common skeletal architecture
- Fossils provide additional evidence of anatomical unity from descent with modification

- Darwin proposed that natural selection could cause an ancestral species to give rise to two or more descendent species
  - For example, the finch species of the Galápagos Islands are descended from a common ancestor
- Evolutionary relationships are often illustrated with treelike diagrams that show ancestors and their descendants

SCIENTIFIC INQUIRY:

"the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world." NSTA

Scientific inquiry is a powerful way of understanding science content. Students learn how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from a variety of sources, develop an explanation from the data, and communicate and defend their conclusions.

In studying nature, scientists make observations and then form and test hypotheses

- The word **science** is derived from Latin and means “to know”
- **Inquiry** is the search for information and explanation
- The scientific process includes making observations, forming logical hypotheses, and testing them

Making Observations

- Biologists describe natural structures and processes
- This approach is based on observation and the analysis of data

Types of Data

- **Data** are recorded observations or items of information; these fall into two categories
  - Qualitative data, or descriptions rather than measurements
    - For example, Jane Goodall's observations of chimpanzee behavior
  - Quantitative data, or recorded measurements, which are sometimes organized into tables and graphs

Inductive Reasoning

- **Inductive reasoning** draws conclusions through the logical process of induction
- Repeating specific observations can lead to important generalizations
  - – For example, “the sun always rises in the east”

Forming and Testing Hypotheses

- Observations and inductive reasoning can lead us to ask questions and propose hypothetical explanations called hypotheses

The Role of Hypotheses in Inquiry

- A **hypothesis** is a tentative answer to a well-framed question
- A scientific hypothesis leads to predictions that can be tested by observation or experimentation

Deductive Reasoning and Hypothesis Testing

- **Deductive reasoning** uses general premises to make specific predictions
- For example, if organisms are made of cells (premise 1), and humans are organisms (premise 2), then humans are composed of cells (deductive prediction)

Questions That Can and Cannot Be Addressed by Science

- A hypothesis must be testable and falsifiable
- Supernatural and religious explanations are outside the bounds of science

The Flexibility of the Scientific Method

- The scientific method is an idealized process of inquiry
- Hypothesis-based science is based on the "textbook" scientific method but rarely follows all the ordered steps

- In science, observations and experimental results must be repeatable

Theories in Science

- In the context of science, a **theory** is
  - Broader in scope than a hypothesis
  - General, and can lead to new testable hypotheses
  - Supported by a large body of evidence in comparison to a hypothesis

Science benefits from a cooperative approach and diverse viewpoints

- Most scientists work in teams, which often include graduate and undergraduate students
- Good communication is important in order to share results through seminars, publications, and websites

Building on the Work of Others

- Scientists check each others' claims by performing similar experiments
- It is not unusual for different scientists to work on the same research question
- Scientists cooperate by sharing data about **model organisms** (e.g., the fruit fly *Drosophila melanogaster*)

Science, Technology, and Society

- The goal of science is to understand natural phenomena
- The goal of **technology** is to apply scientific knowledge for some specific purpose
- Science and technology are interdependent
- Biology is marked by "discoveries," while technology is marked by "inventions"

- The combination of science and technology has dramatic effects on society
  - For example, the discovery of DNA by James Watson and Francis Crick allowed for advances in DNA technology such as testing for hereditary diseases
- Ethical issues can arise from new technology, but have as much to do with politics, economics, and cultural values as with science and technology

The Value of Diverse Viewpoints in Science

- Many important inventions have occurred where different cultures and ideas mix
  - For example, the printing press relied on innovations from China (paper and ink) and Europe (mass production in mills)
- Science benefits from diverse views from different racial and ethnic groups, and from both women and men

Please indicate your answers to the following Questions and save this document- Review of content and submission of answers will be discussed the first week of class.

Which of the following is not a theme that unifies biology?

A. systems biology
B. emergent properties
C. inductive reasoning
D. reductionism
E. genomics

What is the correct order (from small to large)?

A. cells, organelles, organ system, community, ecosystems
B. molecules, organism, population, communities, biosphere
C. molecules, cells, tissues, ecosystems, communities
D. organelles, cells, population, biosphere, ecosystems
E. cells, organs, population, ecosystems, communities

Which of the following scientific studies would represent an example of a "systems biology" approach?

A. measuring the effect of an invading insect that eats oak leaves on the numbers of oak trees and on any subsequent changes in the number and types of decomposer fungi in the soil
B. discovering the structure of an enzyme that is important in digestion of protein
C. comparing the microscopic structure of leaves of two different species of magnolias
D. measuring the reproductive rate of emperor penguins during exceptionally warm and exceptionally cold years
E. comparing the DNA sequence of two closely related plants and inferring their evolutionary histories

Like jackrabbits, elephants have many blood vessels in their ears that help them cool their bodies by radiating heat. Which of the following statements about this radiated energy would be accurate?

A. The original source of the energy was the sun.
B. The energy will be recycled through the ecosystem.
C. The radiated energy will be trapped by predators of the elephants.
D. More energy is radiated in cold conditions than in hot conditions.
E. More energy is radiated at night than during the day.

The idea that form and function are related would *not* be exemplified by which of the following examples?

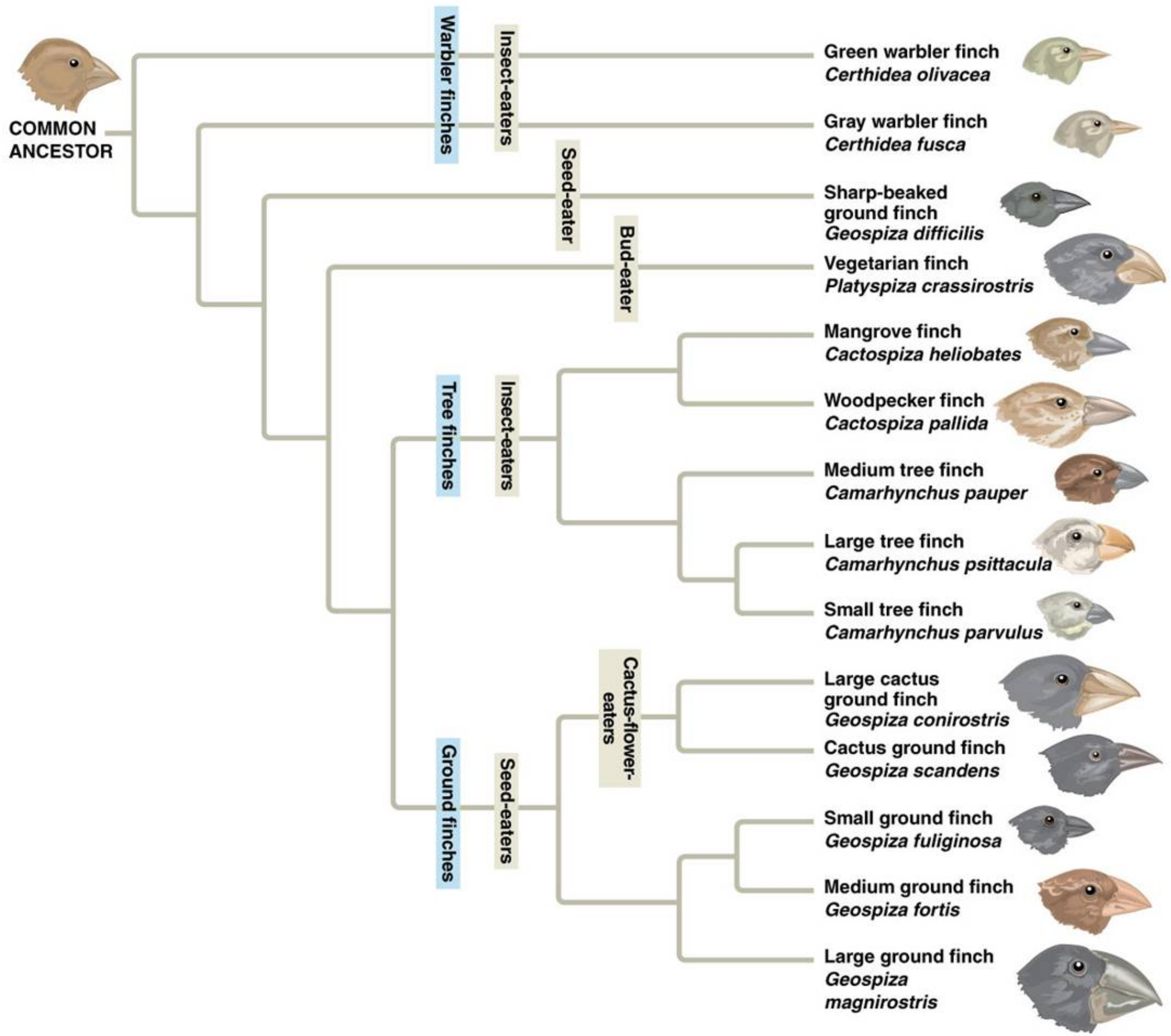
A. Cells in the intestinal lining of vertebrates have many small projections that increase the surface area for absorption of nutrients.
B. Plants that live in dry areas have large roots for absorbing water.
C. Seeds that are dispersed by wind are very light.
D. Fish that swim rapidly have bodies that are streamlined.
E. none of the above

Imagine that you have just discovered a new multicellular but microscopic organism that swims in ponds. You see that it is propelled by cilia on the outside of the organism. What can you say about the evolutionary relationships of this organism?

A. The presence of cilia shows that it is more closely related to *Paramecium* than to humans.
B. The presence of cilia shows that it shares a common ancestor with *Paramecium* and humans.
C. It is probably closely related to pond algae.
D. It is probably most closely related to prokaryotes.
E. The presence of cilia demonstrates the diversity, but not the unity, of life.

Examine the figure on the next slide and predict which species pair has the most similar DNA sequence.

A. vegetarian tree finch (*Platyspiza crassirostris*) and mangrove finch (*Cactospiza heliobates*)
B. medium tree finch (*Camarhynchus pauper*) and large tree finch (*Camarhynchus psittacula*)
C. large tree finch (*Camarhynchus psittacula*) and small tree finch (*Camarhynchus parvulus*)
D. sharp-beaked ground finch (*Geospiza difficilis*) and large ground finch (*Geospiza magnirostris*)
E. No such predictions are possible.



COMMON ANCESTOR
Warbler finches
Insect-eaters
Seed-eater
Bud-eater
Tree finches
Insect-eaters
Ground finches
Seed-eaters
Cactus-flower-eaters
Green warbler finch
Certhidea olivacea
Gray warbler finch
Certhidea fusca
Sharp-beaked ground finch
Geospiza difficilis
Vegetarian finch
Platyspiza crassirostris
Mangrove finch
Cactospiza heliobates
Woodpecker finch
Cactospiza pallida
Medium tree finch
Camarhynchus pauper
Large tree finch
Camarhynchus psittacula
Small tree finch
Camarhynchus parvulus
Large cactus ground finch
Geospiza conirostris
Cactus ground finch
Geospiza scandens
Small ground finch
Geospiza fuliginosa
Medium ground finch
Geospiza fortis
Large ground finch
Geospiza magnirostris

Which of the following is an activity that would not reflect the practice of science?

A. Science is typically performed alone in the lab.
B. Data are typically collected by teams of students and experienced researchers.
C. Scientists typically reexamine conclusions or repeat experiments from other large, famous labs.
D. Scientists who work in forests studying ecology often collaborate closely with geneticists who work only in the lab.
E. The practice of science results in a discovery that lends new insight, and technology involves how this new insight will be applied to develop a new drug.

Overview: A Chemical Connection to Biology

- Biology is a multidisciplinary science
- Living organisms are subject to basic laws of physics and chemistry

Matter consists of chemical elements in pure form and in combinations called compounds

- Organisms are composed of **matter**
- Matter is anything that takes up space and has mass

Elements and Compounds

- Matter is made up of elements
- An **element** is a substance that cannot be broken down to other substances by chemical reactions
- A **compound** is a substance consisting of two or more elements in a fixed ratio
- A compound has emergent properties, characteristics different from those of its elements

The Elements of Life

- Of 92 natural elements, about 20–25% are **essential elements**, needed by an organism to live a healthy life and reproduce
- **Trace elements** are required in only minute quantities
- For example, in vertebrates, iodine (I) is required for normal activity of the thyroid gland
- In humans, an iodine deficiency can cause goiter

Evolution of Tolerance to Toxic Elements

- Some naturally occurring elements are toxic to organisms
- In humans, arsenic is linked to many diseases and can be lethal
- Some species have become adapted to environments containing elements that are usually toxic
  - For example, sunflower plants can take up lead, zinc, and other heavy metals in concentrations lethal to most organisms
  - Sunflower plants were used to detoxify contaminated soils after Hurricane Katrina

An element's properties depend on the structure of its atoms

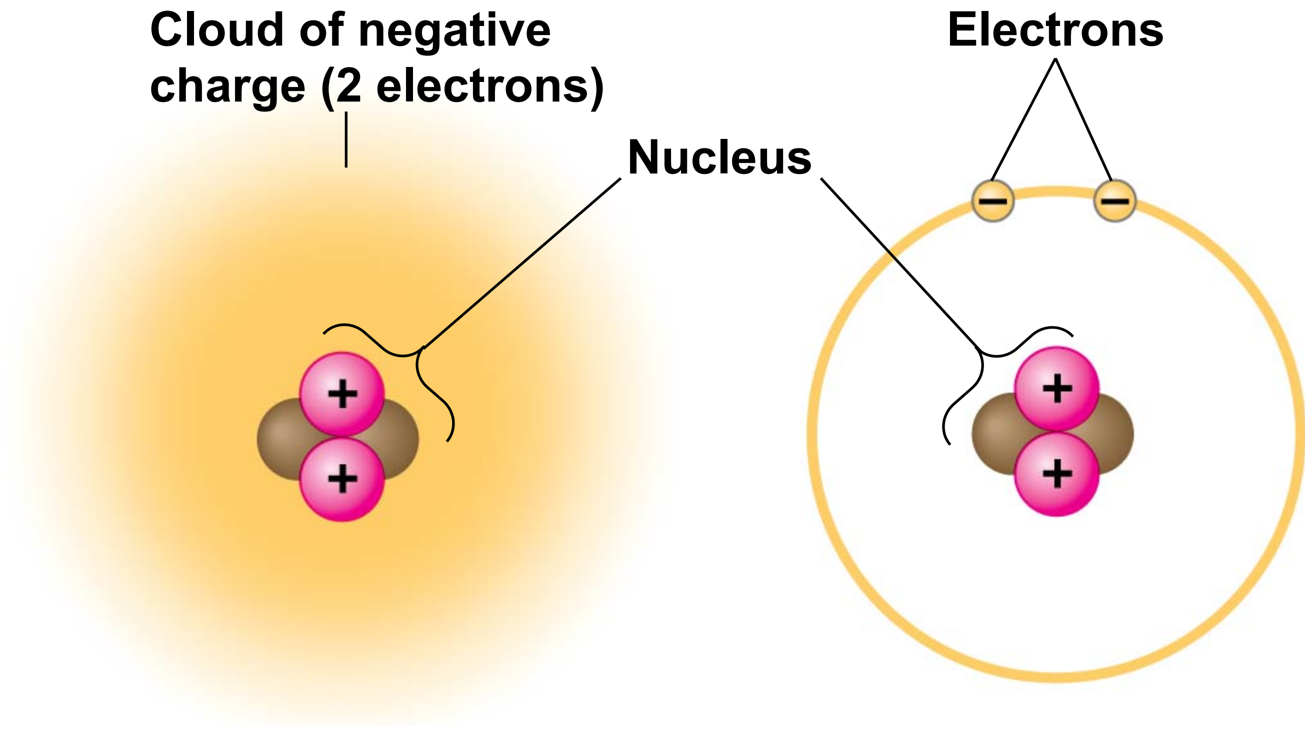
- Each element consists of a certain type of atom, different from the atoms of any other element
- An **atom** is the smallest unit of matter that still retains the properties of an element

Subatomic Particles

- Atoms are composed of smaller parts called subatomic particles
- Relevant subatomic particles include
  - **Neutrons** (no electrical charge)
  - **Protons** (positive charge)
  - **Electrons** (negative charge)

- Neutrons and protons form the **atomic nucleus**
- Electrons form a cloud around the nucleus
- Neutron mass and proton mass are almost identical and are measured in **daltons**

Simplified models of a helium (He) atom



Atomic Number and Atomic Mass

- Atoms of the various elements differ in number of subatomic particles
- An element's **atomic number** is the number of protons in its nucleus
- An element's **mass number** is the sum of protons plus neutrons in the nucleus
- **Atomic mass**, the atom's total mass, can be approximated by the mass number

Mass number = number of protons + neutrons
= 23 for sodium

$^{23}_{11}\text{Na}$

Atomic number = number of protons
= 11 for sodium

Because neutrons and protons each have a mass of approximately 1 dalton, we can estimate the **atomic mass** (total mass of one atom) of sodium as 23 daltons

Isotopes

- All atoms of an element have the same number of protons but may differ in number of neutrons
- **Isotopes** are two atoms of an element that differ in number of neutrons
- **Radioactive isotopes** decay spontaneously, giving off particles and energy

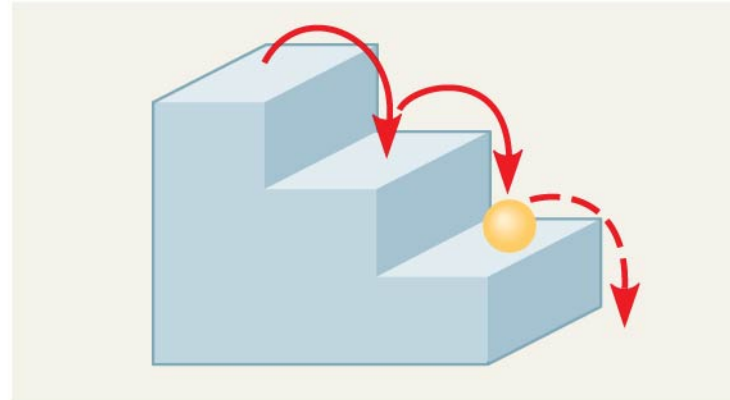
- Some applications of radioactive isotopes in biological research are
  - Dating fossils
  - Tracing atoms through metabolic processes
  - Diagnosing medical disorders

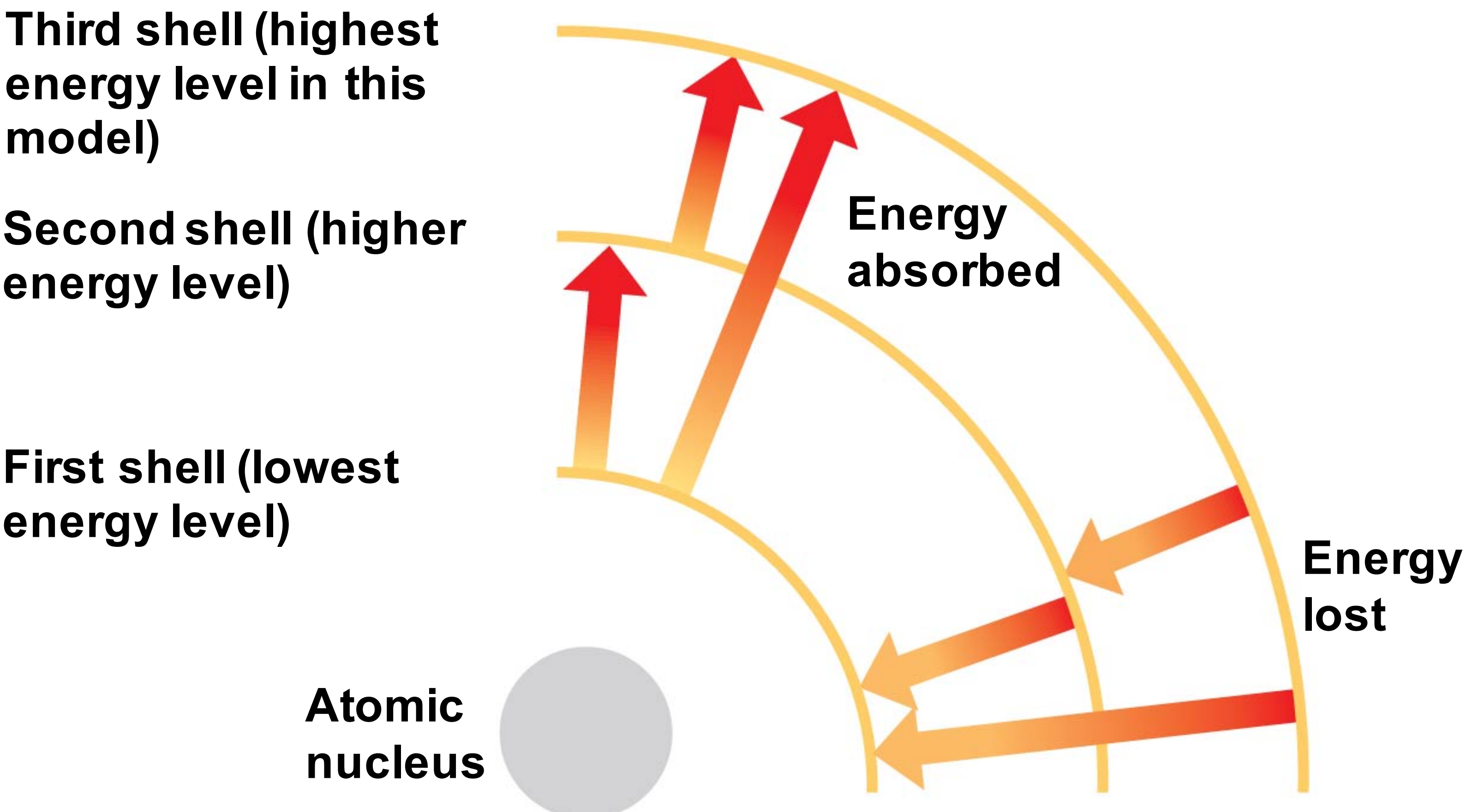
The Energy Levels of Electrons

- **Energy** is the capacity to cause change
- **Potential energy** is the energy that matter has because of its location or structure
- The electrons of an atom differ in their amounts of potential energy
- Changes in potential energy occur in steps of fixed amounts
- An electron's state of potential energy is called its energy level, or **electron shell**

- Electrons are found in different **electron shells,** each with a characteristic average distance from the nucleus
- The energy level of each shell increases with distance from the nucleus
- Electrons can move to higher or lower shells by absorbing or releasing energy, respectively

A ball bouncing down a flight of stairs provides an analogy for energy levels of electrons.

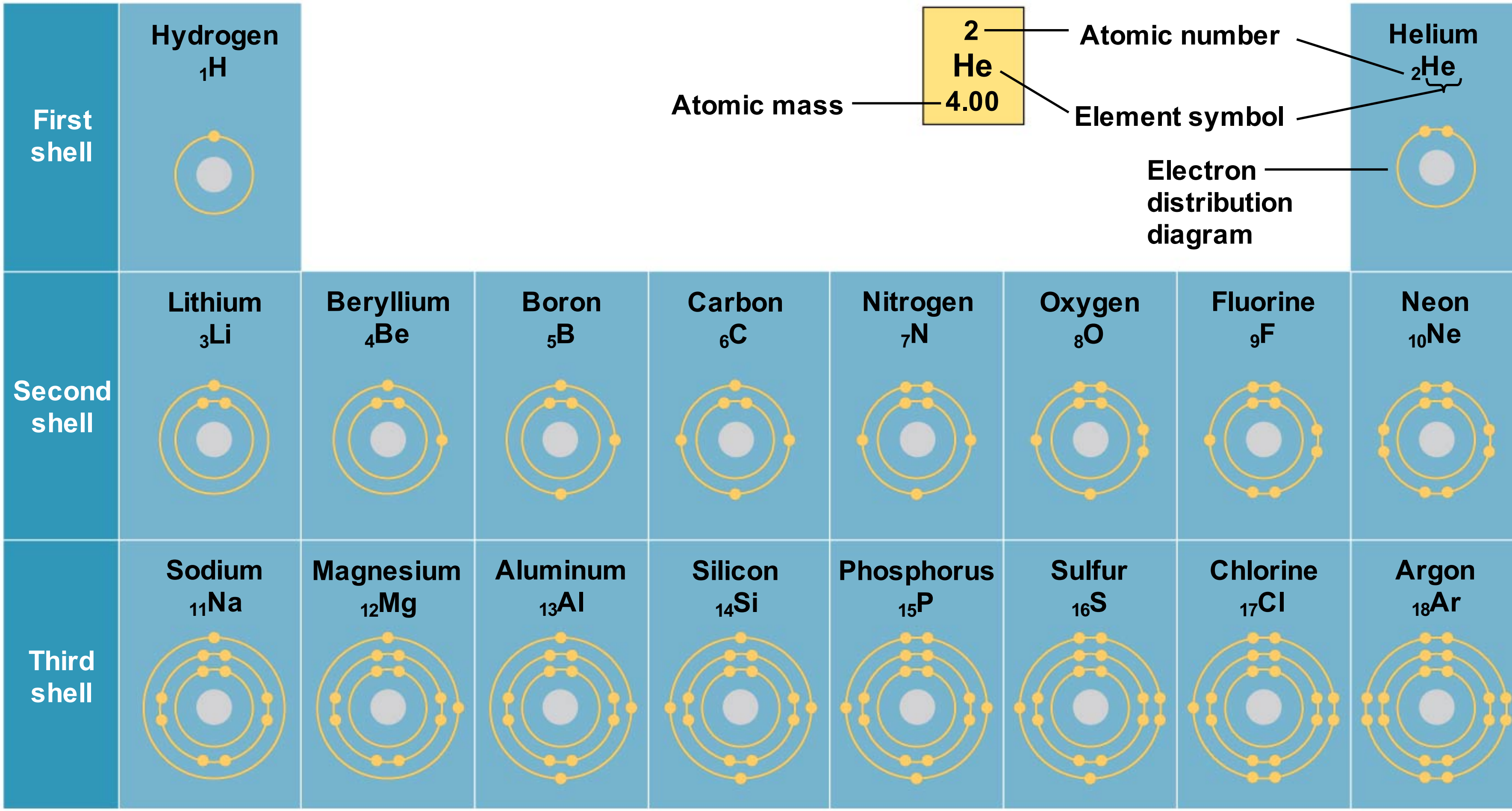




Electron Distribution and Chemical Properties

- The chemical behavior of an atom is determined by the distribution of electrons in electron shells
- The periodic table of the elements shows the electron distribution for each element

Figure 2.6



First shell
Second shell
Third shell
Hydrogen
$_1H$
2
He
4.00
Atomic mass
Atomic number
Element symbol
Electron distribution diagram
Helium
$_2He$
Lithium
$_3Li$
Beryllium
$_4Be$
Boron
$_5B$
Carbon
$_6C$
Nitrogen
$_7N$
Oxygen
$_8O$
Fluorine
$_9F$
Neon
$_{10}Ne$
Sodium
$_{11}Na$
Magnesium
$_{12}Mg$
Aluminum
$_{13}Al$
Silicon
$_{14}Si$
Phosphorus
$_{15}P$
Sulfur
$_{16}S$
Chlorine
$_{17}Cl$
Argon
$_{18}Ar$

- Chemical behavior of an atom depends mostly on the number of electrons in its outermost shell, or **valence shell**
- **Valence electrons** are those that occupy the valence shell
- The reactivity of an atom arises from the presence of one or more unpaired electrons in the valence shell
- Atoms with completed valence shells are unreactive, or inert

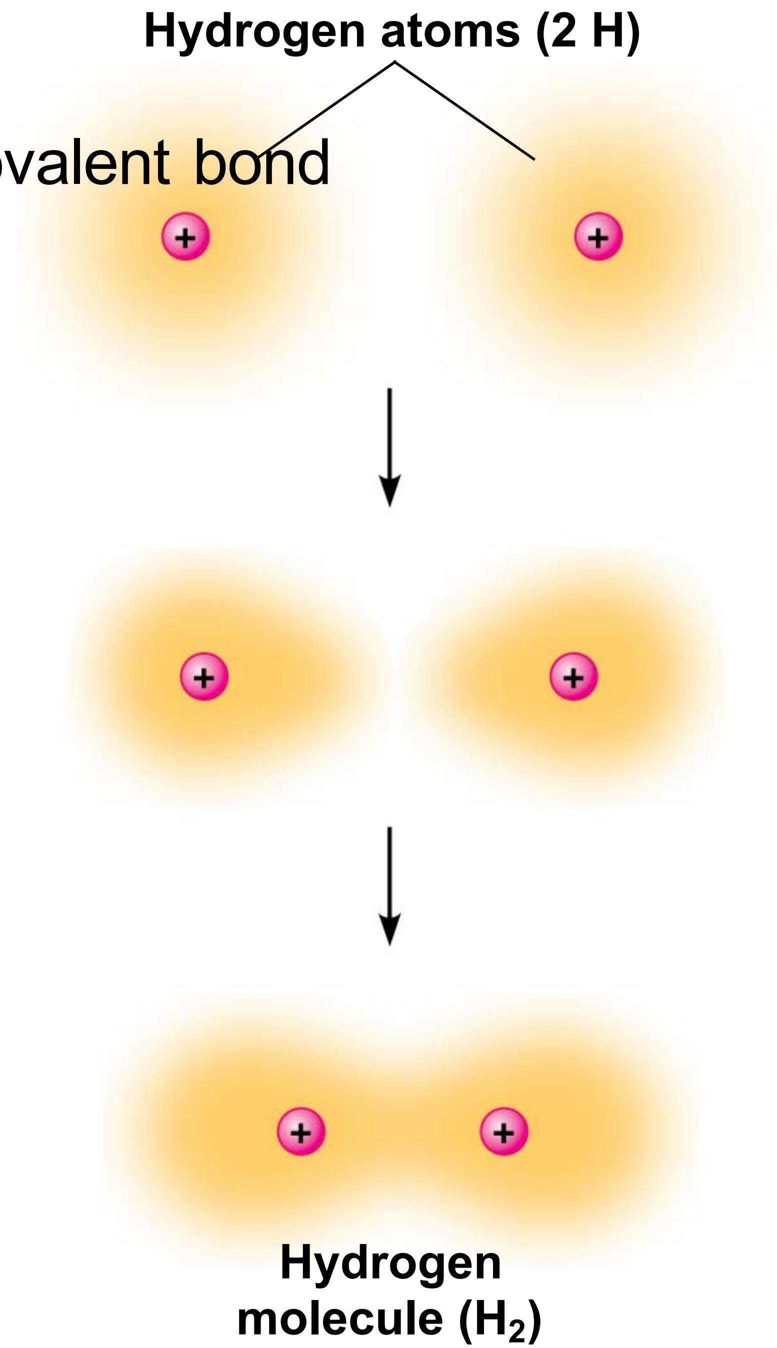
The formation and function of molecules depend on chemical bonding between atoms

- Atoms with incomplete valence shells can share or transfer valence electrons with certain other atoms
- This usually results in atoms staying close together, held by attractions called **chemical bonds**

Covalent Bonds

- A **covalent bond** is the sharing of a pair of valence electrons by two atoms
- In a covalent bond, the shared electrons count as part of each atom's valence shell
- Two or more atoms held together by valence bonds constitute a **molecule**

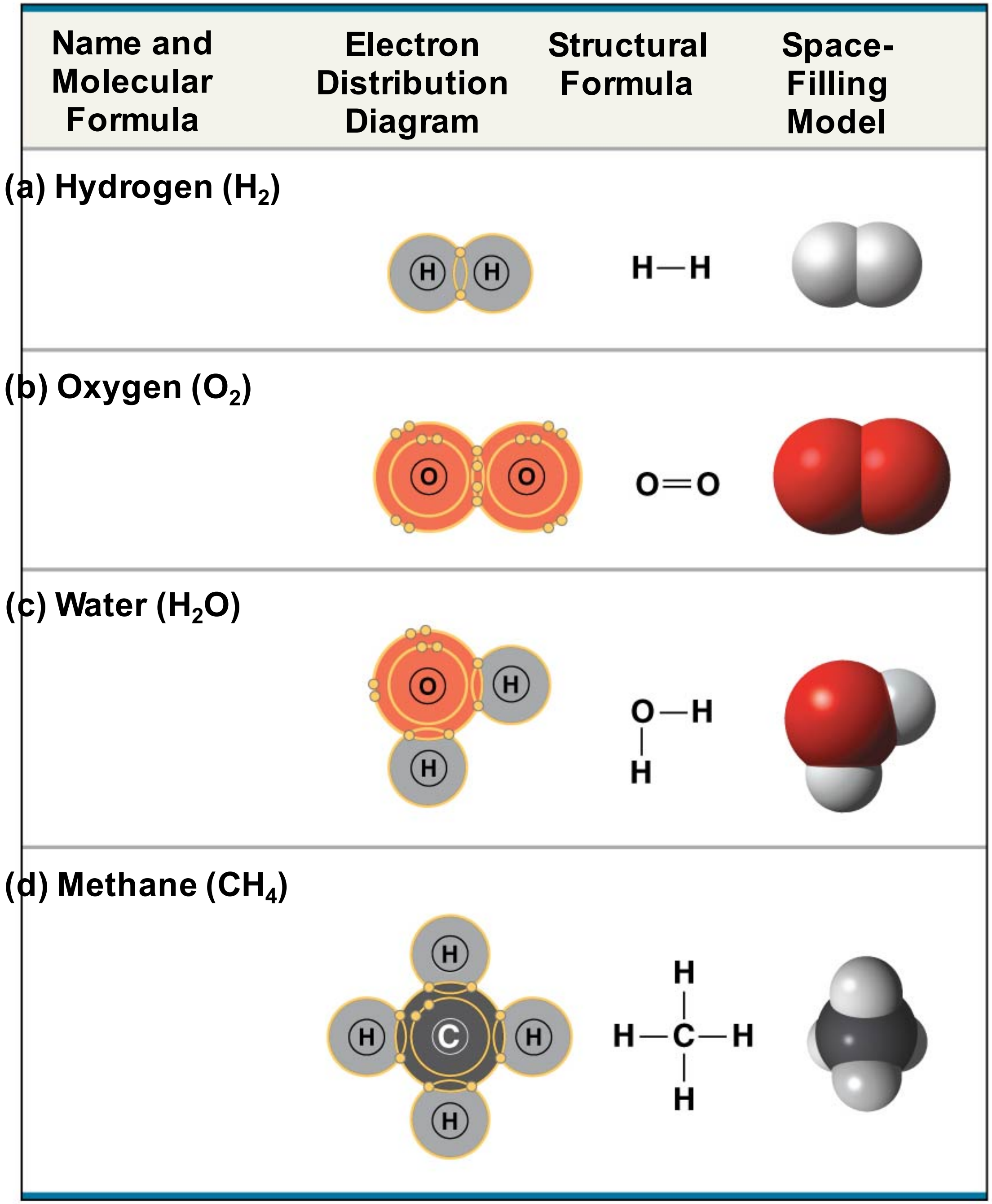
Formation of a covalent bond



- The notation used to represent atoms and bonding is called a structural formula
  - For example, H—H
- This can be abbreviated further with a molecular formula
  - For example, H_2

- In a structural formula, a single bond, the sharing of one pair of electrons, is indicated by a single line between the atoms
  - For example, H—H
- A double bond, the sharing of two pairs of electrons, is indicated by a double line between atoms
  - For example, O═O

Covalent bonding in four molecules



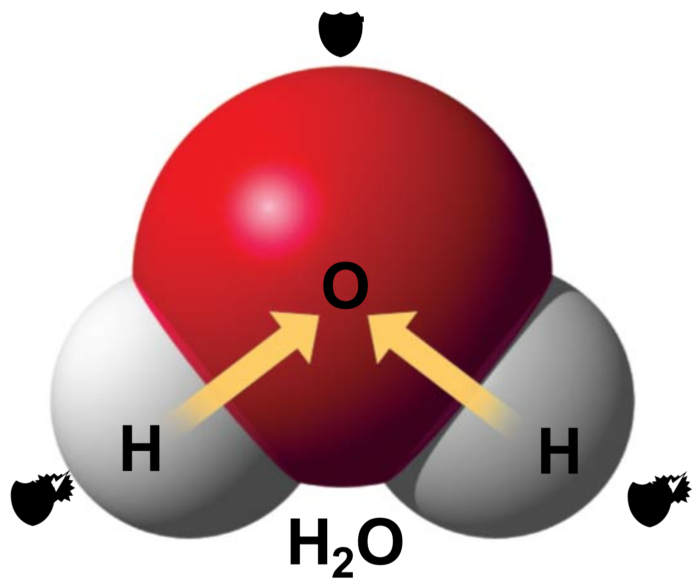
- Each atom that can share valence electrons has a bonding capacity, the number of bonds that the atom can form
- Bonding capacity, or **valence**, usually corresponds to the number of electrons required to complete the atom

- Pure elements are composed of molecules of one type of atom, such as H_2 and O_2
- Molecules composed of a combination of two or more types of atoms are called compounds, such as H_2O or CH_4

- Atoms in a molecule attract electrons to varying degrees
- **Electronegativity** is an atom's attraction for the electrons in a covalent bond
- The more electronegative an atom, the more strongly it pulls shared electrons toward itself

- In a **nonpolar covalent bond**, the atoms share the electron equally
- In a **polar covalent bond**, one atom is more electronegative, and the atoms do not share the electron equally
- Unequal sharing of electrons causes a partial positive or negative charge for each atom or molecule

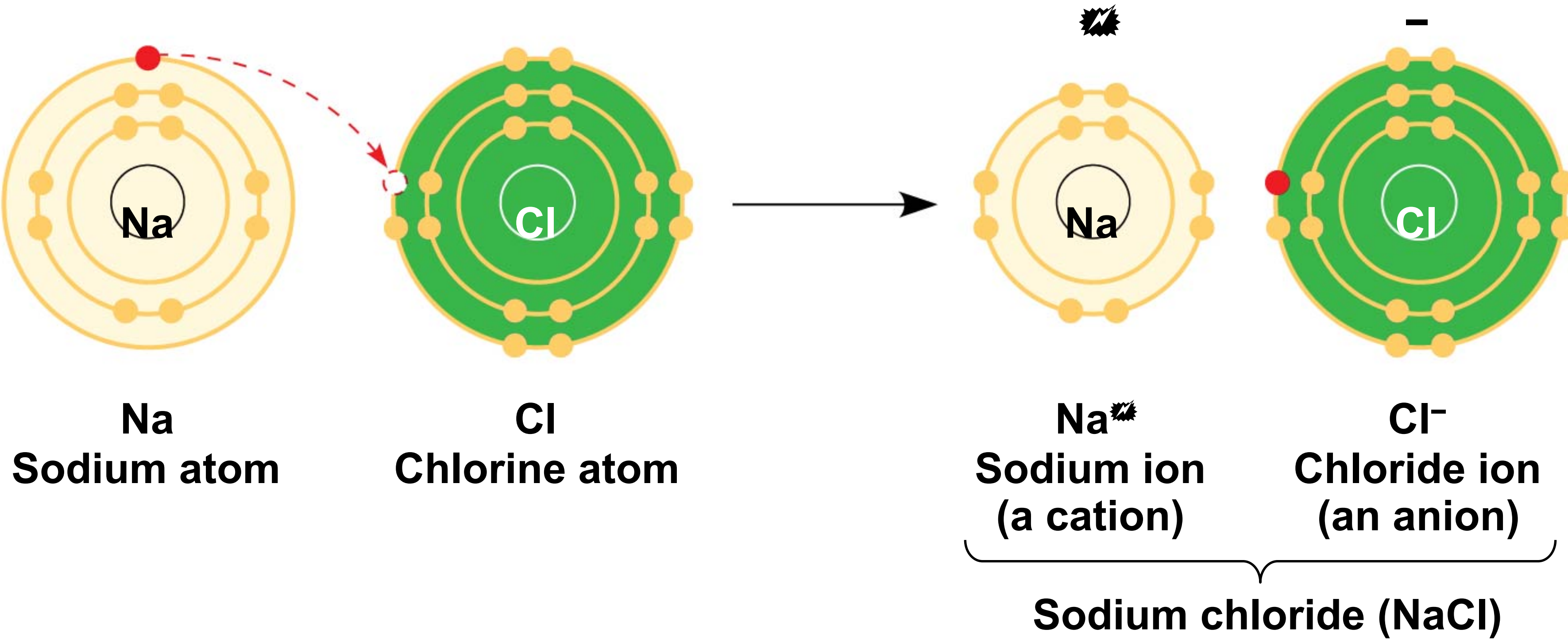
Polar covalent bonds in a water molecule



Ionic Bonds

- Atoms sometimes strip electrons from their bonding partners
- An example is the transfer of an electron from sodium to chlorine
- After the transfer of an electron, both atoms have charges
- Both atoms also have complete valence shells

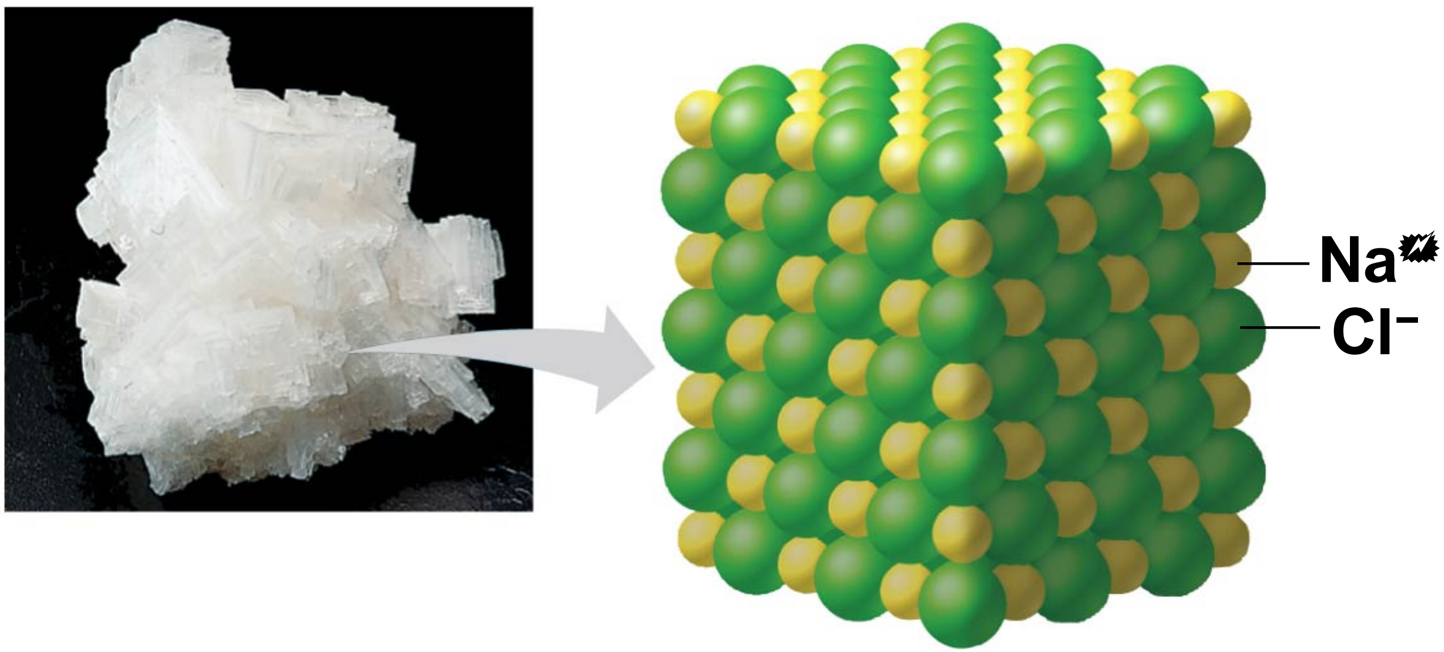
Electron transfer and ionic bonding



- A **cation** is a positively charged ion
- An **anion** is a negatively charged ion
- An **ionic bond** is an attraction between an anion and a cation

- Compounds formed by ionic bonds are called **ionic compounds**, or **salts**
- Salts, such as sodium chloride (table salt), are often found in nature as crystals

A sodium chloride (NaCl) crystal

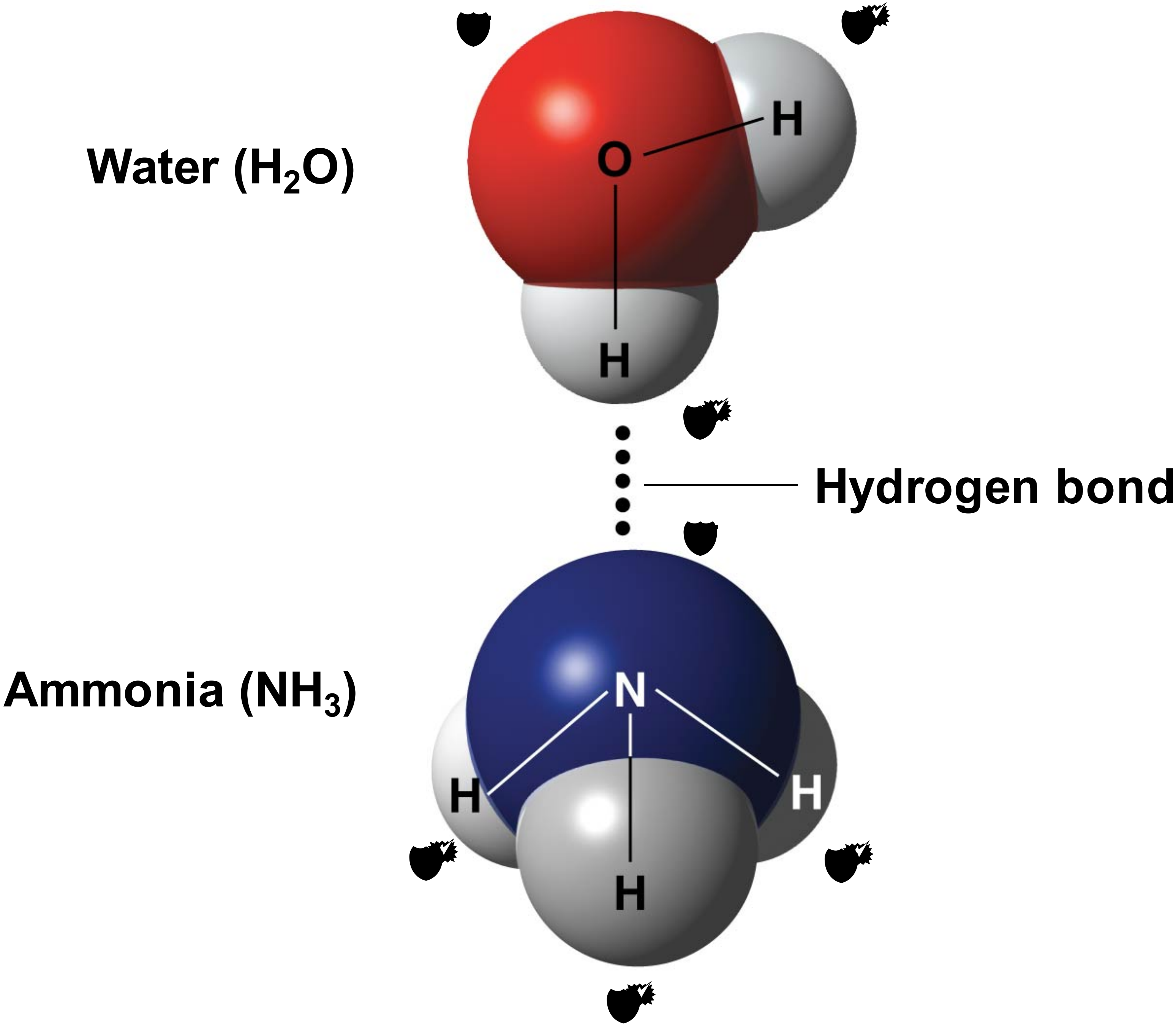


Weak Chemical Bonds

- Most of the strongest bonds in organisms are covalent bonds that form a cell's molecules
- Weak chemical bonds, such as ionic bonds and hydrogen bonds, are also important
- Many large biological molecules are held in their functional form by weak bonds

Hydrogen Bonds

- A **hydrogen bond** forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom
- In living cells, the electronegative partners are usually oxygen or nitrogen atoms


Water (H_2O)
O
H
H
Hydrogen bond
Ammonia (NH_3)
N
H
H
H

Van der Waals Interactions

- If electrons are distributed asymmetrically in molecules or atoms, they can result in "hot spots" of positive or negative charge
- **Van der Waals interactions** are attractions between molecules that are close together as a result of these charges

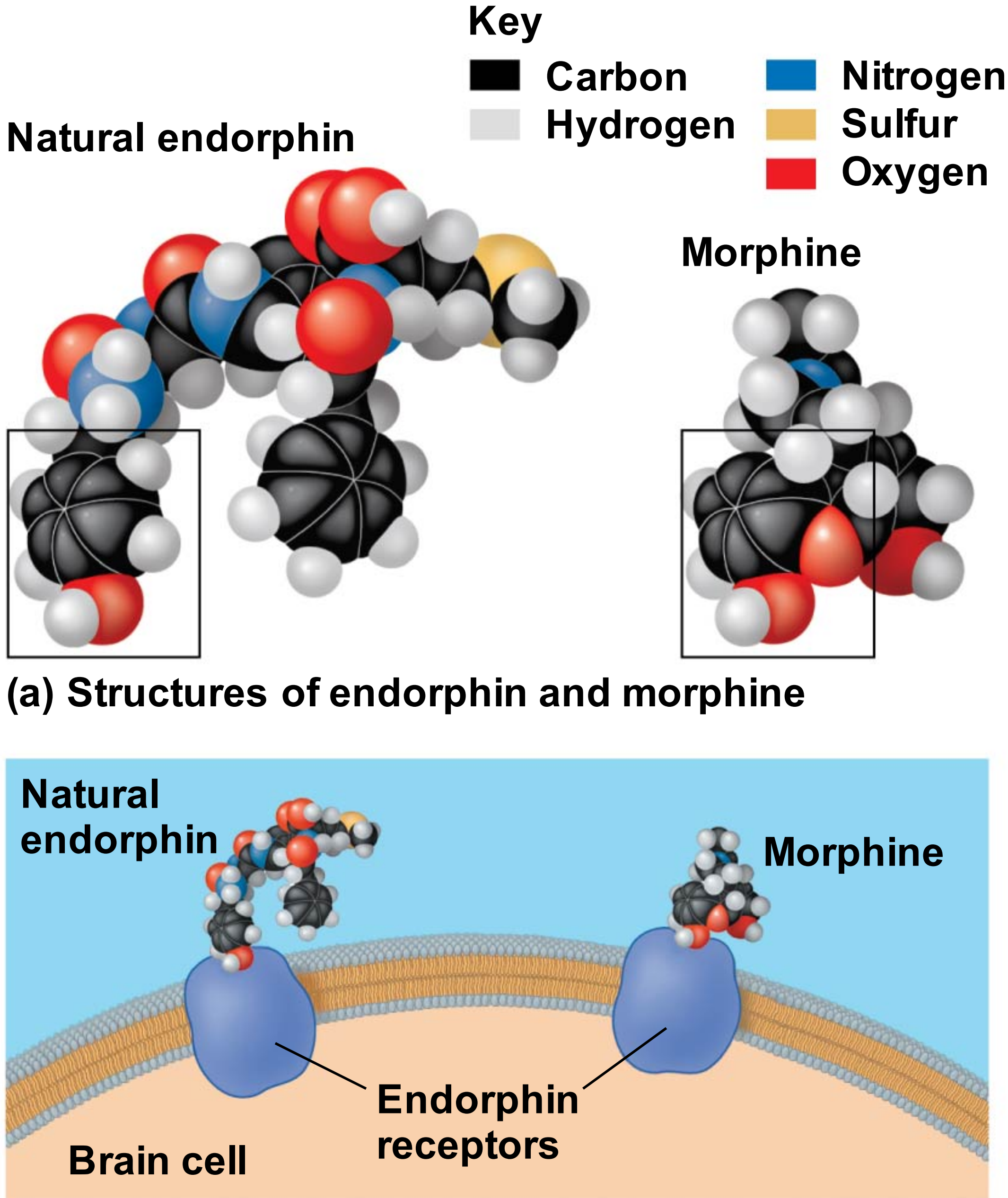
- Van der Waals interactions are individually weak and occur only when atoms and molecules are very close together
- Collectively, such interactions can be strong, as between molecules of a gecko's toe hairs and a wall surface

Molecular Shape and Function

- A molecule's shape is usually very important to its function
- Molecular shape determines how biological molecules recognize and respond to one another

- Biological molecules recognize and interact with each other with a specificity based on molecular shape
- Molecules with similar shapes can have similar biological effects

Figure 2.14



(a) Structures of endorphin and morphine

(b) Binding to endorphin receptors

Chemical reactions make and break chemical bonds

- **Chemical reactions** are the making and breaking of chemical bonds
- The starting molecules of a chemical reaction are called **reactants**
- The final molecules of a chemical reaction are called **products**

- Photosynthesis is an important chemical reaction
- Sunlight powers the conversion of carbon dioxide and water to glucose and oxygen

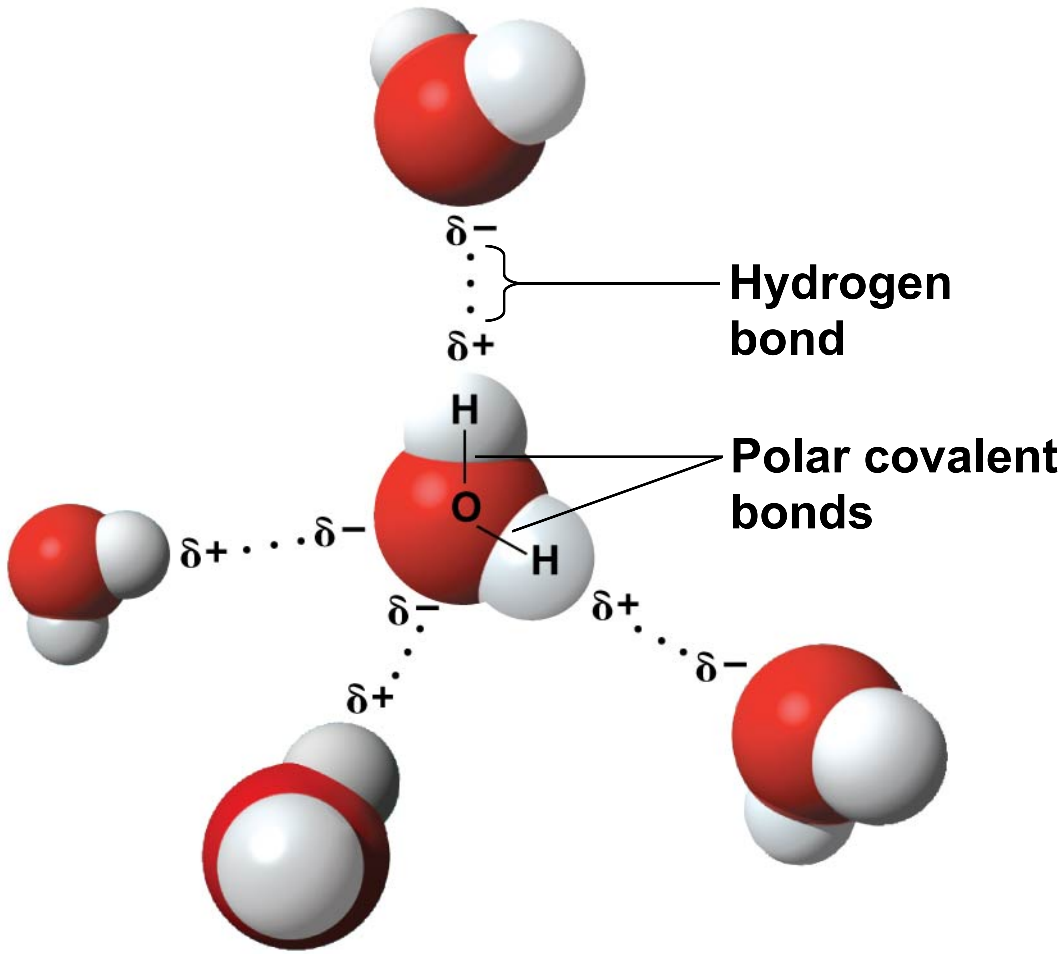
$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

- All chemical reactions are reversible: Products of the forward reaction become reactants for the reverse reaction
- **Chemical equilibrium** is reached when the forward and reverse reaction rates are equal

Hydrogen bonding gives water properties that help make life possible on Earth

- All organisms are made mostly of water and live in an environment dominated by water
- Water molecules are polar, with the oxygen region having a partial negative charge ($\delta-$) and the hydrogen region a slight positive charge ($\delta+$)
- Two water molecules are held together by a hydrogen bond

Hydrogen bonds between water molecules



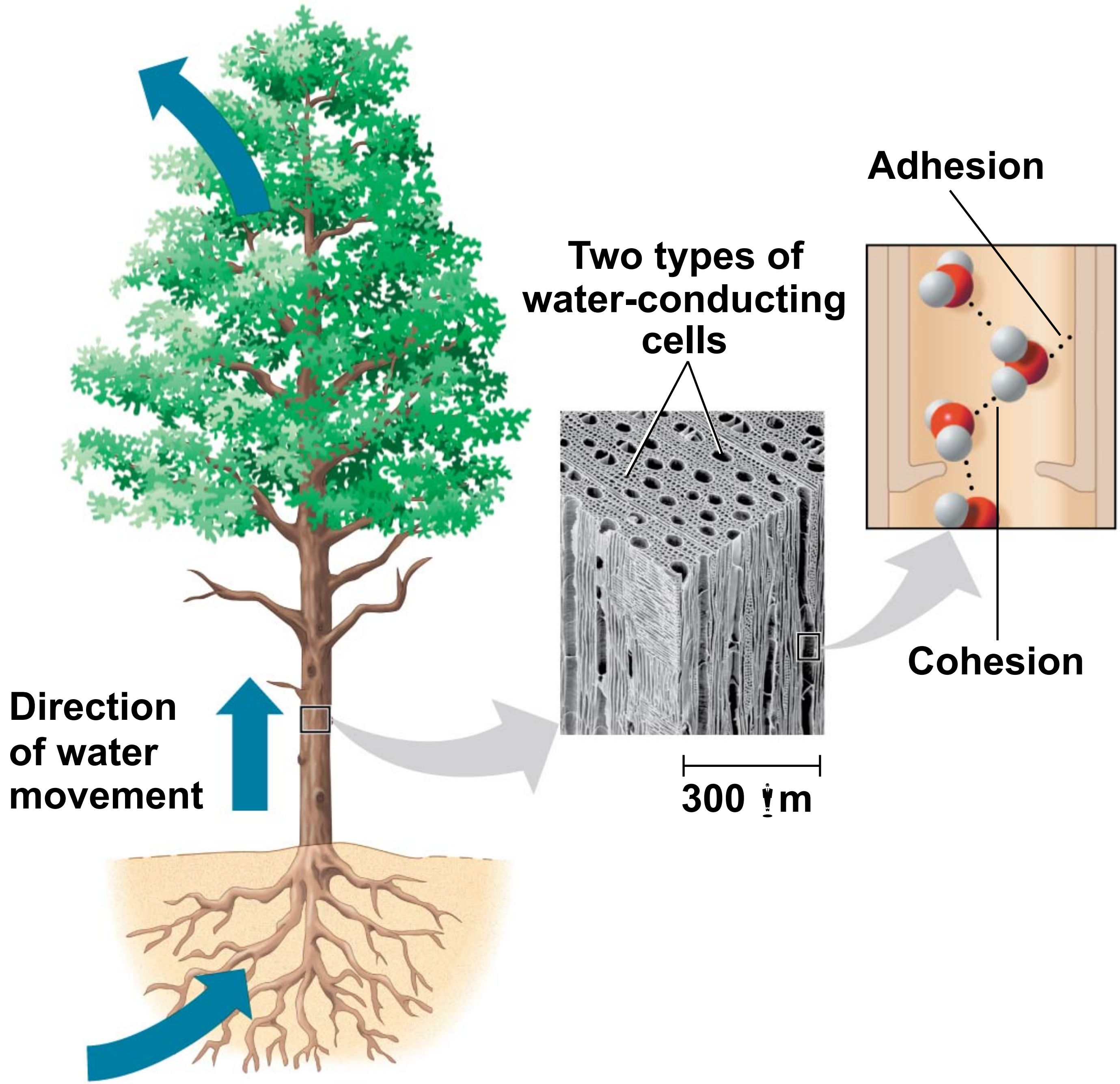
****

- Four emergent properties of water contribute to Earth's suitability for life:
  - Cohesive behavior
  - Ability to moderate temperature
  - Expansion upon freezing
  - Versatility as a solvent

Cohesion of Water Molecules

- Water molecules are linked by multiple hydrogen bonds
- The molecules stay close together because of this; it is called **cohesion**

- Cohesion due to hydrogen bonding contributes to the transport of water and nutrients against gravity in plants
- **Adhesion**, the clinging of one substance to another, also plays a role


Adhesion
Two types of water-conducting cells
Cohesion
Direction of water movement
300 μm

- **Surface tension** is a measure of how hard it is to break the surface of a liquid
- Surface tension is related to cohesion

Moderation of Temperature by Water

- Water absorbs heat from warmer air and releases stored heat to cooler air
- Water can absorb or release a large amount of heat with only a slight change in its own temperature

Temperature and Heat

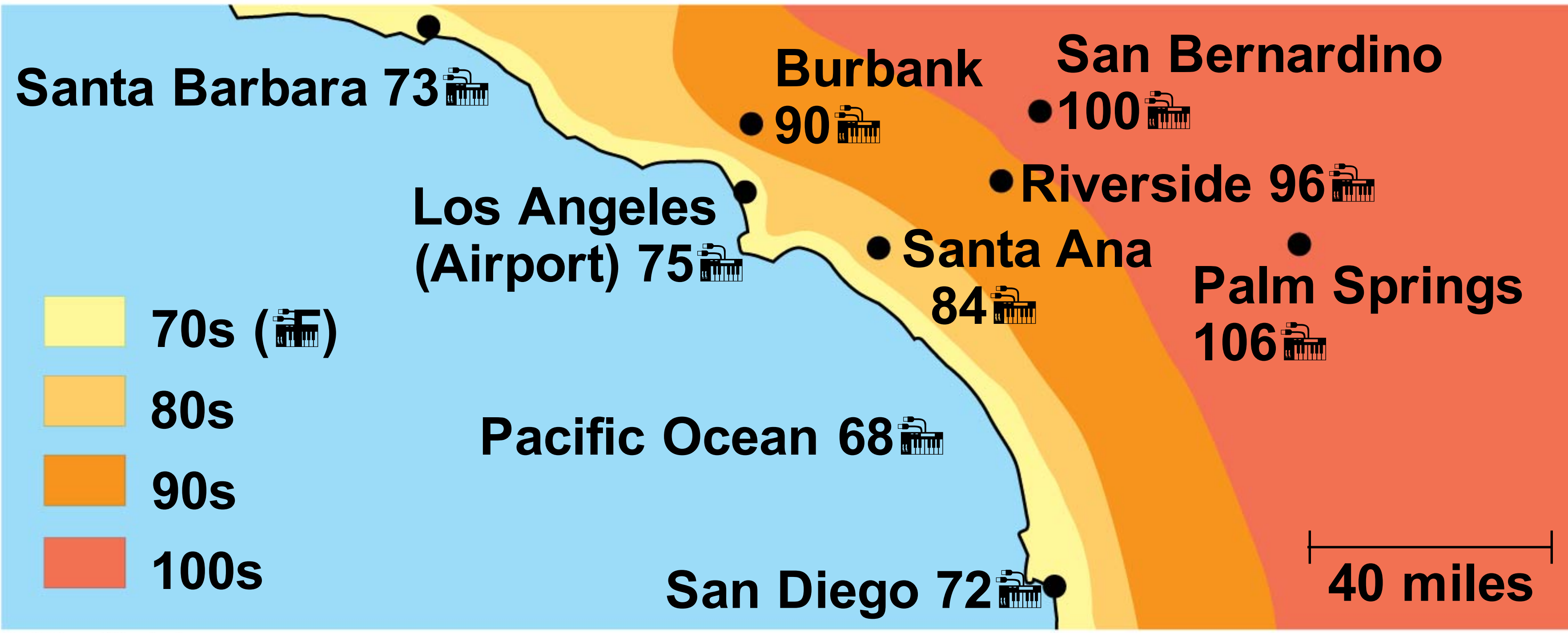
- **Kinetic energy** is the energy of motion
- **Thermal energy** is a measure of the total amount of kinetic energy due to molecular motion
- **Temperature** represents the average kinetic energy of molecules
- Thermal energy in transfer from one body of matter to another is defined as **heat**

- The **Celsius scale** is a measure of temperature using Celsius degrees (^oC)
- A **calorie (cal)** is the amount of heat required to raise the temperature of 1 g of water by 1^oC
- The "**C**alories" on food packages are actually **kilocalories (kcal)**, where 1 kcal = 1,000 calories
- The **joule (J)** is another unit of energy, where 1 J = 0.239 cal, or 1 cal = 4.184 J

Water's High Specific Heat

- The **specific heat** of a substance is the amount of heat that must be absorbed or lost for 1 g of that substance to change its temperature by 1^{o}C
- The specific heat of water is 1 cal/g/^{o}C
- Water resists changing its temperature because of its high specific heat

- Water's high specific heat can be traced to hydrogen bonding
  - Heat is absorbed when hydrogen bonds break
  - Heat is released when hydrogen bonds form
- The high specific heat of water keeps temperature fluctuations within limits that permit life



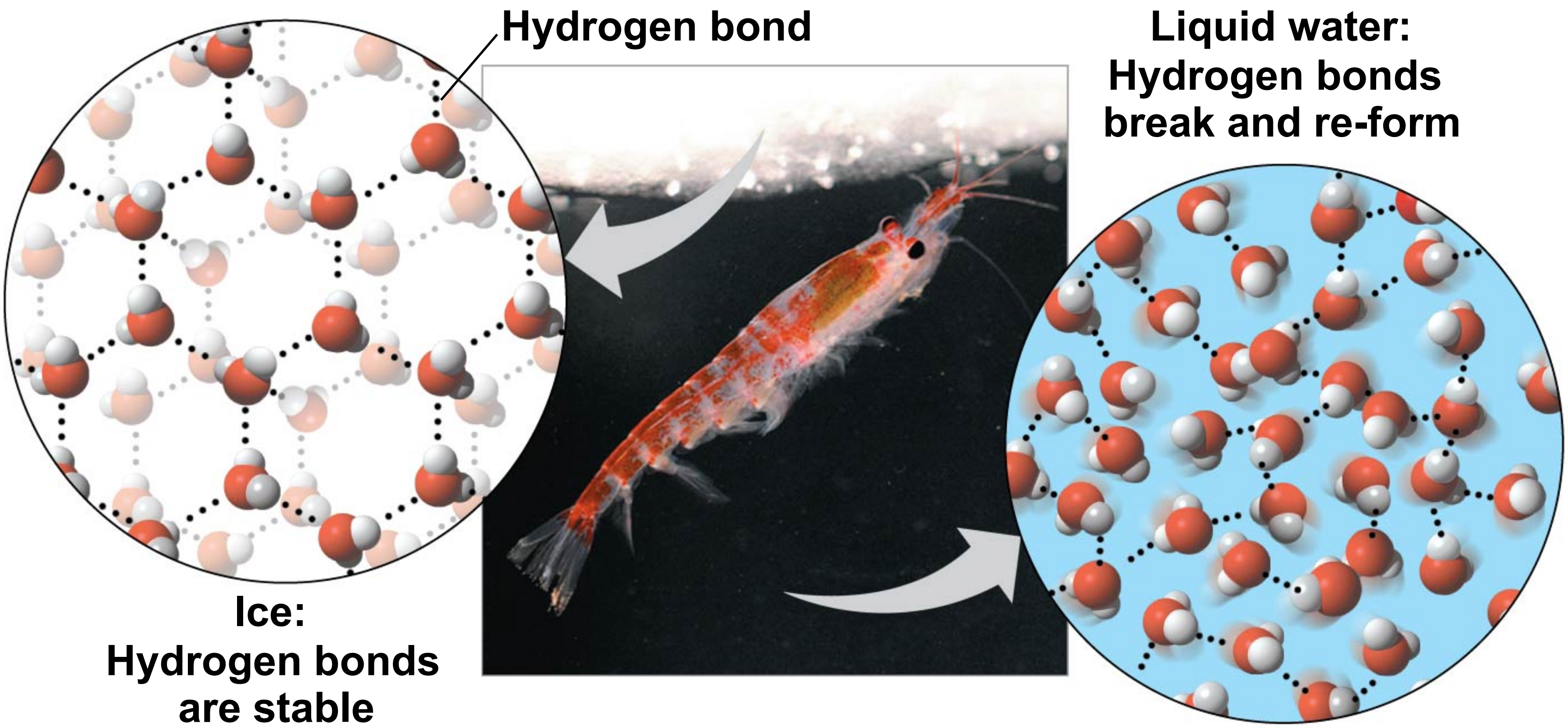
Santa Barbara 73°
Burbank
90°
San Bernardino
100°
Riverside 96°
Los Angeles
(Airport) 75°
Santa Ana
84°
Palm Springs
106°
70s (°F)
80s
90s
100s
Pacific Ocean 68°
San Diego 72°
40 miles

Evaporative Cooling

- Evaporation is transformation of a substance from liquid to gas
- **Heat of vaporization** is the heat a liquid must absorb for 1 g to be converted to gas
- As a liquid evaporates, its remaining surface cools, a process called **evaporative cooling**
- Evaporative cooling of water helps stabilize temperatures in organisms and bodies of water

Floating of Ice on Liquid Water

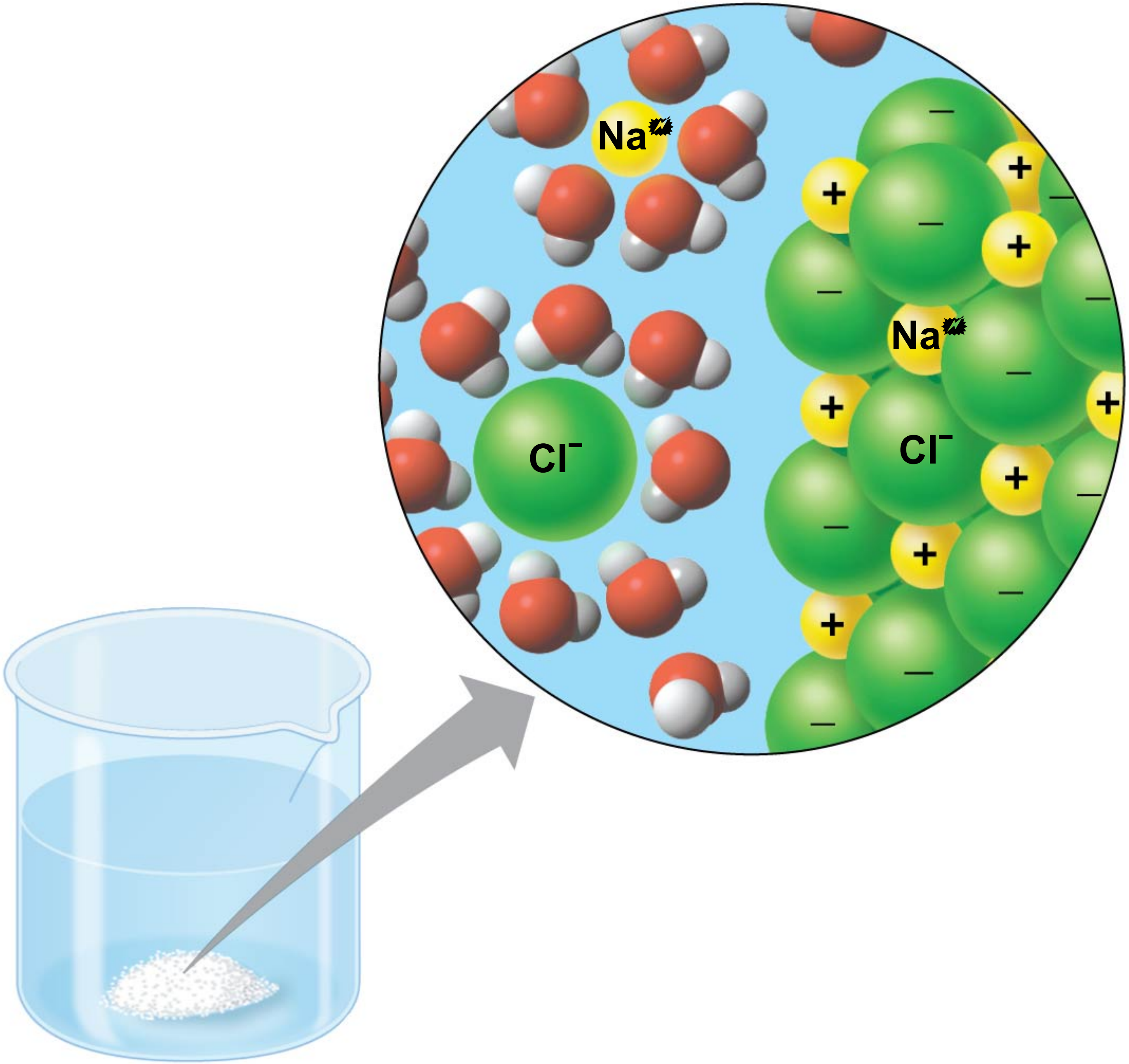
- Ice floats in liquid water because hydrogen bonds in ice are more "ordered," making ice less dense
- Water reaches its greatest density at 4°C
- If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth


Hydrogen bond
Liquid water:
Hydrogen bonds
break and re-form
Ice:
Hydrogen bonds
are stable

Water: The Solvent of Life

- A **solution** is a liquid that is a homogeneous mixture of substances
- A **solvent** is the dissolving agent of a solution
- The **solute** is the substance that is dissolved
- An **aqueous solution** is one in which water is the solvent

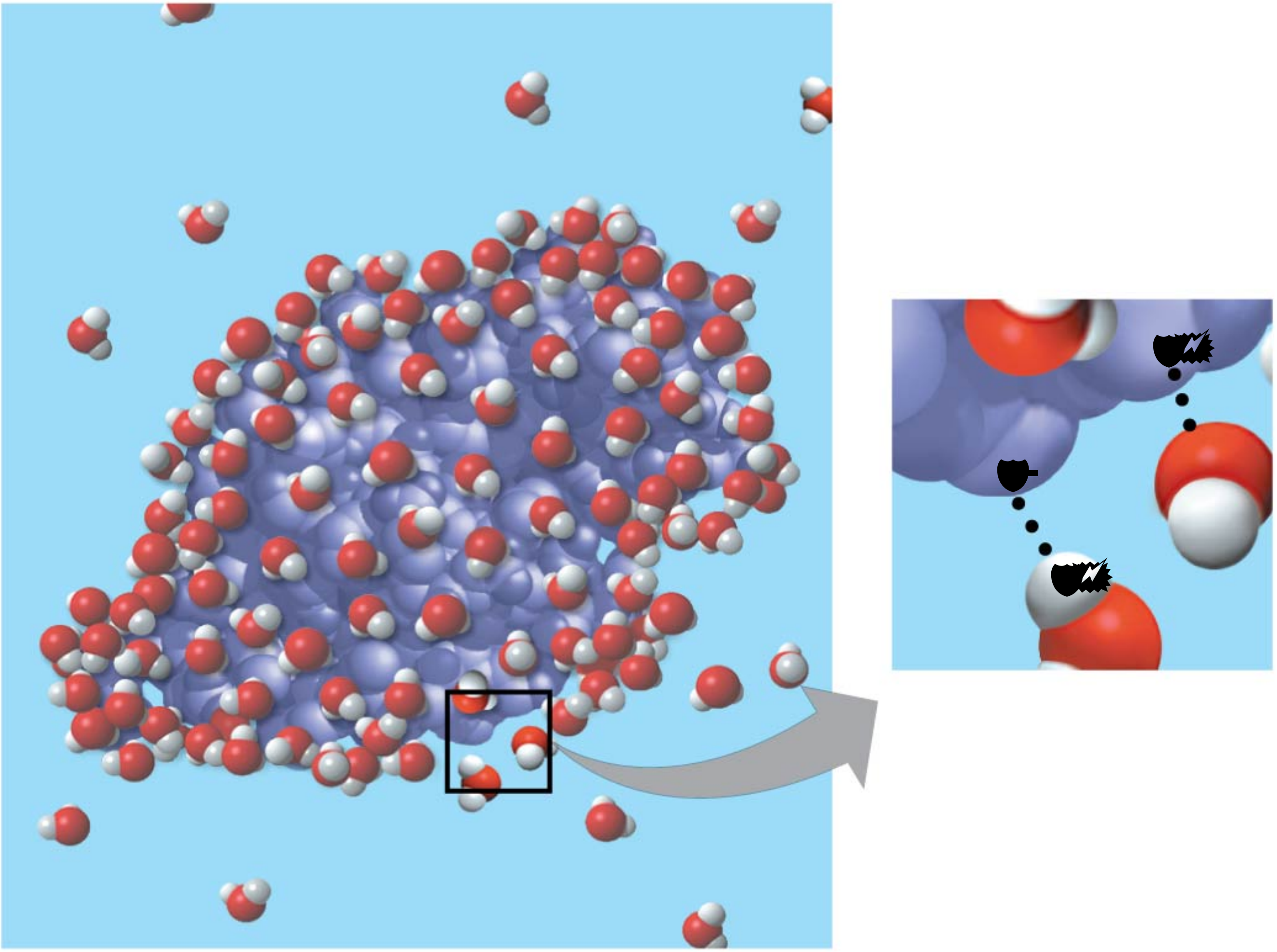
- Water is a versatile solvent due to its polarity, which allows it to form hydrogen bonds easily
- When an ionic compound is dissolved in water, each ion is surrounded by a sphere of water molecules called a **hydration shell**



Na+
Cl−
Na+
Cl−

- Water can also dissolve compounds made of nonionic polar molecules
- Even large polar molecules such as proteins can dissolve in water if they have ionic and polar regions

A water-soluble protein



Hydrophilic and Hydrophobic Substances

- A **hydrophilic** substance is one that has an affinity for water
- A **hydrophobic** substance is one that does not have an affinity for water
- Oil molecules are hydrophobic because they have relatively nonpolar bonds
- A **colloid** is a stable suspension of fine particles in a liquid

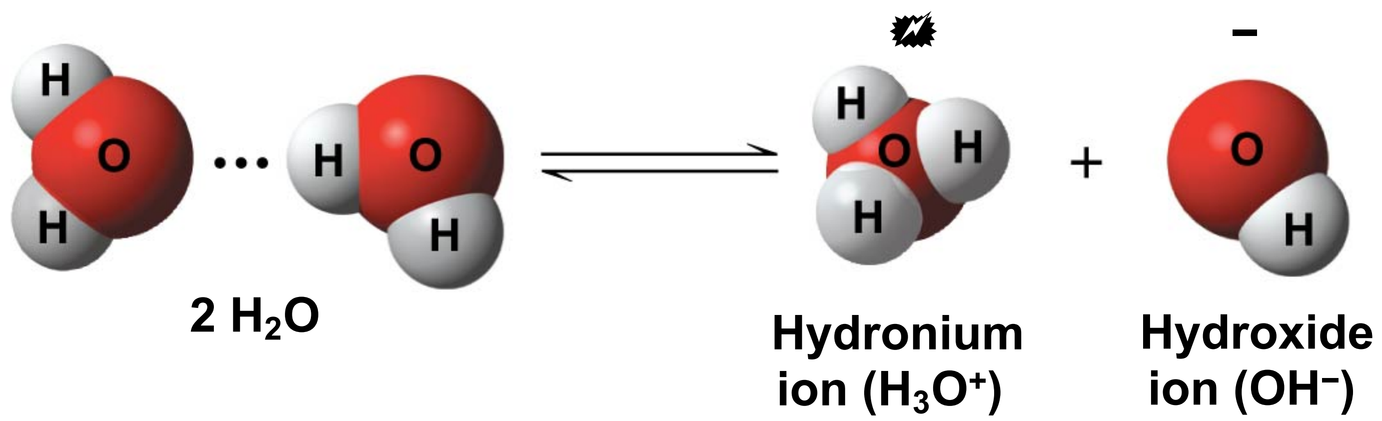
Solute Concentration in Aqueous Solutions

- Most biochemical reactions occur in water
- Chemical reactions depend on collisions of molecules and therefore on the concentration of solutes in an aqueous solution

- **Molecular mass** is the sum of all masses of all atoms in a molecule
- Numbers of molecules are usually measured in moles, where 1 **mole (mol)** = 6.02×10^{23} molecules
- Avogadro's number and the unit *dalton* were defined such that 6.02×10^{23} daltons = 1 g
- **Molarity (*M*)** is the number of moles of solute per liter of solution

Acids and Bases

- Sometimes a **hydrogen ion** (H^+) is transferred from one water molecule to another, leaving behind a **hydroxide ion** (OH^-)
- The proton (H^+) binds to the other water molecule, forming **a hydronium ion** (H_3O^+)
- By convention, H^+ is used to represent the hydronium ion


H
O
H
H
O
H
H
O
H
H
O
H
+
–
2 H2O
Hydronium ion (H3O+)
Hydroxide ion (OH−)

- Though water dissociation is rare and reversible, it is important in the chemistry of life
- H^+ and OH^- are very reactive
- Solutes called acids and bases disrupt the balance between H^+ and OH^- in pure water
- **Acids** increase the H^+ concentration in water, while **bases** reduce the concentration of H^+

- An **acid** is any substance that increases the H^+ concentration of a solution
- A **base** is any substance that reduces the H^+ concentration of a solution

- A strong acid like hydrochloric acid, HCl, dissociates completely into H^+ and Cl^- in water:

$$HCl \rightarrow H^+ + Cl^-$$

- Sodium hydroxide, NaOH, acts as a strong base indirectly by dissociating completely to form hydroxide ions

- These combine with H^+ ions to form water:

$$NaOH \rightarrow Na^+ + OH^-$$

- Ammonia, NH_3, acts as a relatively weak base when it attracts an H^+ ion from the solution and forms ammonium, NH_4^+
- This is a reversible reaction, as shown by the double arrows:

$$NH_3 + H^+ \rightleftharpoons NH_4^+$$

- Carbonic acid, H_2CO_3, acts as a weak acid, which can reversibly release and accept back H^+ ions:

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

The pH Scale

- In any aqueous solution at 25°C, the product of H^+ and OH^- is constant and can be written as

$$[H^+][OH^-] = 10^{-14}$$

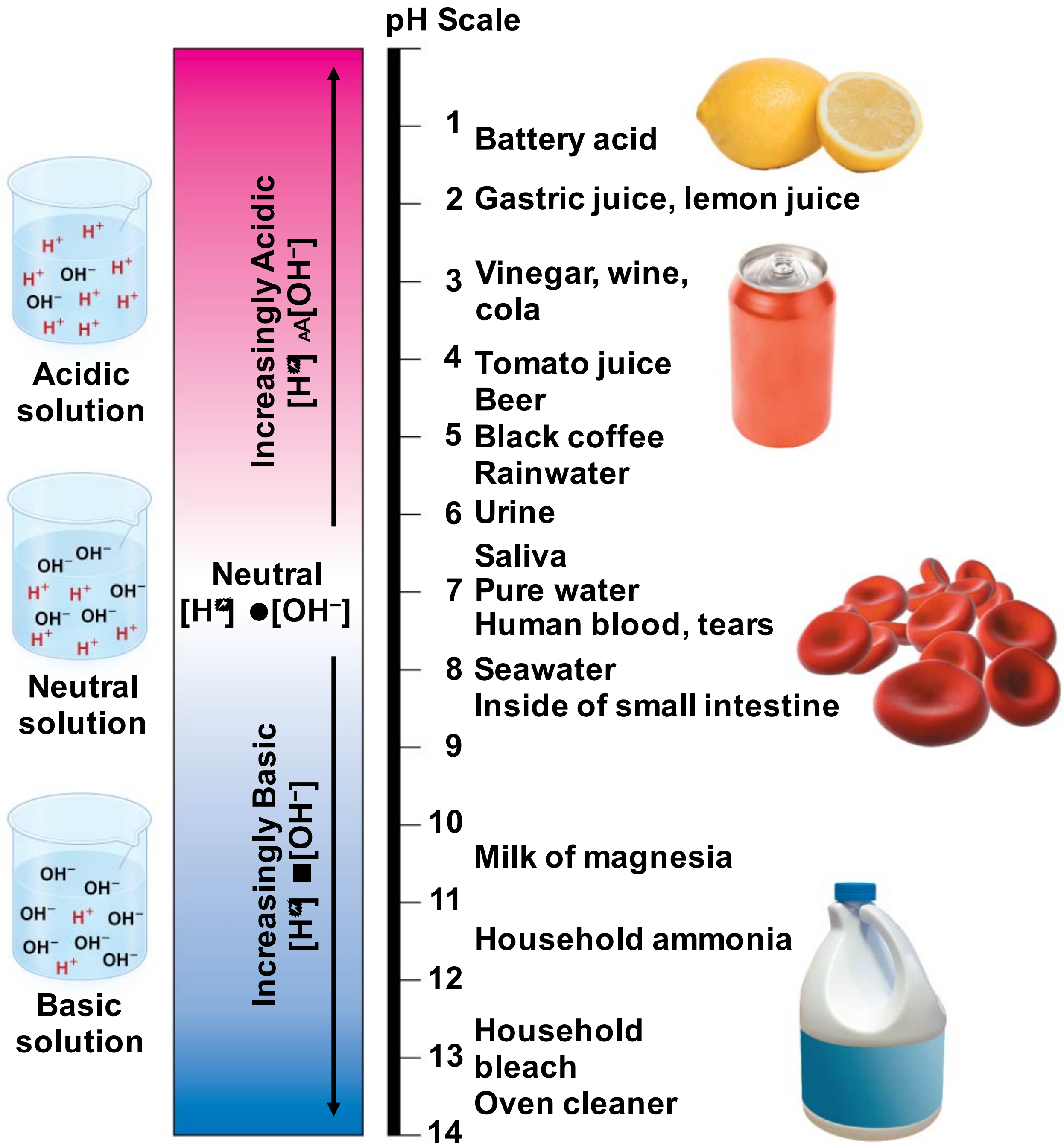
- The **pH** of a solution is defined by the negative logarithm of H^+ concentration, written as

$$pH = -\log [H^+]$$

- For a neutral aqueous solution, $[H^+]$ is 10^{-7}, so

$$-\log [H^+] = -(-7) = 7$$

- Acidic solutions have pH values less than 7
- Basic solutions have pH values greater than 7
- Most biological fluids have pH values in the range of 6 to 8


pH Scale
1 Battery acid
2 Gastric juice, lemon juice
3 Vinegar, wine, cola
4 Tomato juice
Beer
5 Black coffee
Rainwater
6 Urine
Saliva
7 Pure water
Human blood, tears
8 Seawater
Inside of small intestine
9
10
Milk of magnesia
11
Household ammonia
12
Household bleach
13
Oven cleaner
14
Increasingly Acidic
$[H^+]$ A $[OH^-]$
Neutral
$[H^+]$ ● $[OH^-]$
Increasingly Basic
$[H^+]$ ■ $[OH^-]$
Acidic solution
Neutral solution
Basic solution
H^+
OH^-

Buffers

- The internal pH of most living cells must remain close to pH 7
- **Buffers** are substances that minimize changes in concentrations of H^+ and OH^- in a solution
- Most buffers consist of an acid-base pair that reversibly combines with H^+

- Carbonic acid is a buffer that contributes to pH stability in human blood:

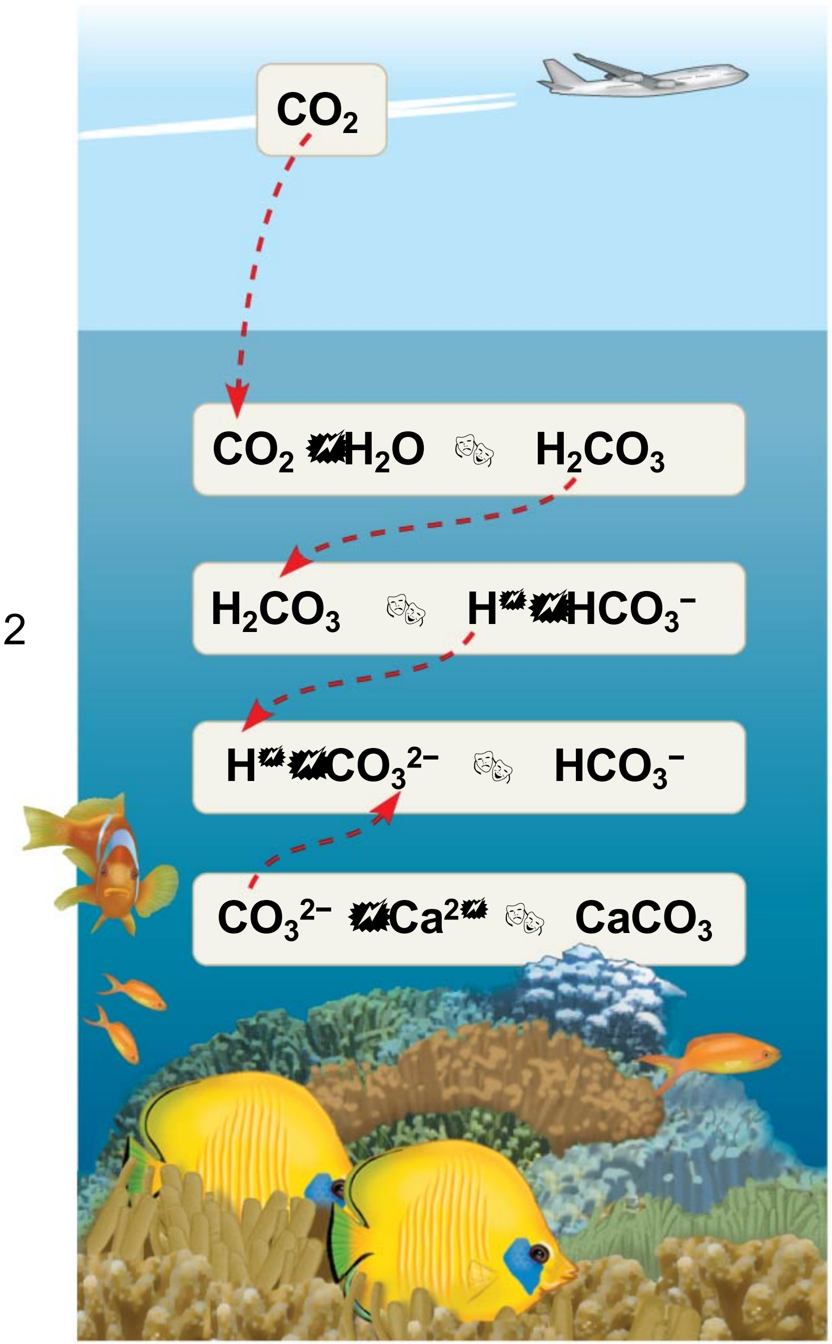
	Response to a rise in pH			
H_2CO_3	$\rightleftharpoons$	HCO_3^-	+	H^+
H^+ donor (acid)	Response to a drop in pH	H^+ acceptor (base)		Hydrogen ion

Acidification: A Threat to Our Oceans

- Human activities such as burning fossil fuels threaten water quality
- CO_2 is the main product of fossil fuel combustion
- About 25% of human-generated CO_2 is absorbed by the oceans
- CO_2 dissolved in seawater forms carbonic acid; this causes ocean acidification

- As seawater acidifies, H^+ ions combine with CO_3^{2-} ions to form bicarbonate ions (HCO_3^-)
- It is predicted that carbonate ion concentrations will decline by 40% by the year 2100
- This is a concern because organisms that build coral reefs or shells require carbonate ions

Atmospheric CO_2 from human activities and its fate in the ocean



Please indicate your answers to the following Questions and save this document- Review of content and submission of answers will be discussed the first week of class.

Based on the periodic table shown here, which elements will most likely form an ionic bond?

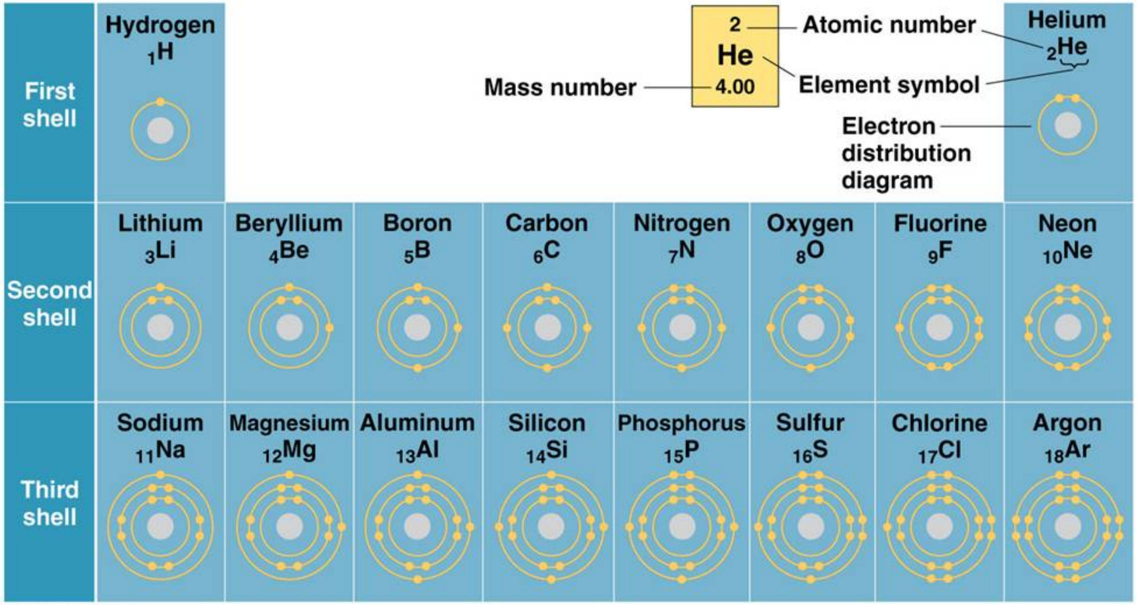
A. Na and Cl, and Li and F

B. C and O

C. N and O

D. Si and Cl

E. all of the above



Based on the periodic table shown here, which elements will most likely form a covalent bond?

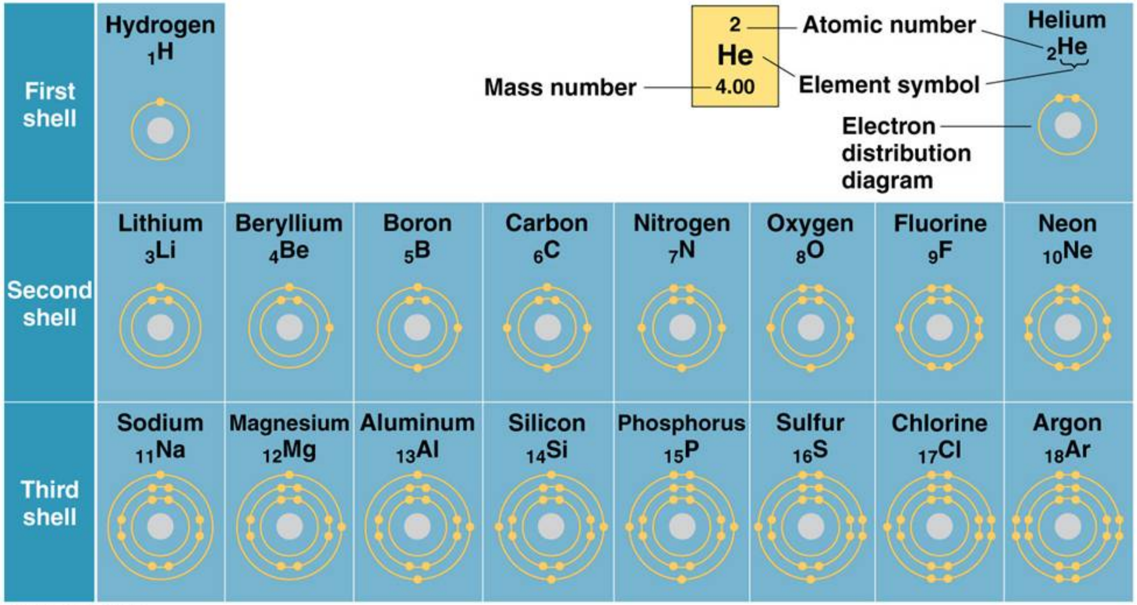
A. Na and Cl

B. C and O

C. N and O

D. Si and Cl

E. H and H



What do elements with atomic numbers 6, 14, and 22 have in common?

A. same number of electrons
B. same atomic mass
C. same valence and will form the same number of covalent bonds
D. all of the above
E. none of the above

What type of bond is very prevalent in lipids and gives lipids their properties?

A. polar covalent
B. nonpolar covalent
C. strong ionic bond
D. weak ionic bond
E. hydrogen bond

Water shows high cohesion and surface tension and can absorb large amounts of heat because of large numbers of which of the following bonds between water molecules? Solutions of other molecules have much less bonding between molecules.

A. strong ionic bonds
B. nonpolar covalent bonds
C. polar covalent bonds
D. hydrogen bonds
E. weak ionic bonds

Which of the following observations would distinguish between the alternative hypotheses that geckos walk on vertical surfaces via either hydrogen bonding or van der Waals interactions?

A. Geckos can walk up dry surfaces.
B. Geckos can walk up smooth glass surfaces—silicon dioxide is a polar, hydrophilic compound.
C. Geckos can walk up smooth plastic surfaces—plastics are hydrophobic.

What are the four emergent properties of water that are important for life?

A. cohesion, expansion upon freezing, high heat of evaporation, capillarity
B. cohesion, moderation of temperature, expansion upon freezing, solvent properties
C. moderation of temperature, solvent properties, high surface tension, capillarity
D. heat of vaporization, high specific heat, high surface tension, capillarity
E. polarity, hydrogen bonding, high specific heat, high surface tension

Water has an unusually high specific heat. This is directly related to which one of the following?

A. At its boiling point, water changes from liquid to vapor.
B. More heat is required to raise the temperature of water.
C. Ice floats in liquid water.
D. Salt water freezes at a lower temperature than pure water.
E. Floating ice can insulate bodies of water.

Surfactants reduce surface tension of a liquid. Which of the following would result if water was treated with surfactants?

A. Surfactant-treated water droplets will form a thin film instead of beading on a waxed surface.
B. Surfactant-treated water will form smaller droplets when dripping from a sink.
C. Water striders will sink.
D. All of the above will occur.
E. Only A and C will occur.

Overview: Carbon Compounds and Life

- Aside from water, living organisms consist mostly of carbon-based compounds
- Carbon is unparalleled in its ability to form large, complex, and diverse molecules
- A compound containing carbon is said to be an **organic compound**

- Critically important molecules of all living things fall into four main classes
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids
- The first three of these can form huge molecules called **macromolecules**

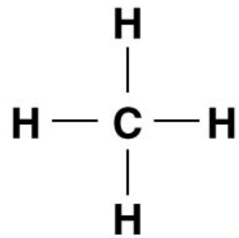
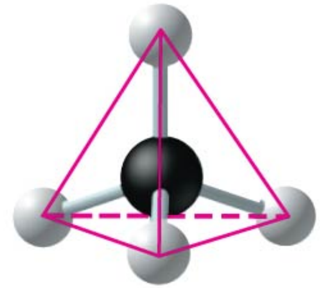
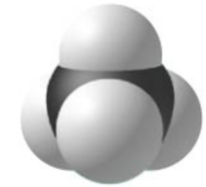
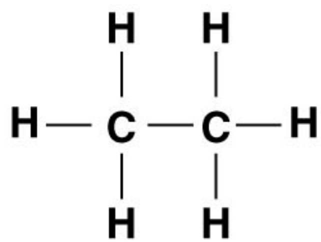
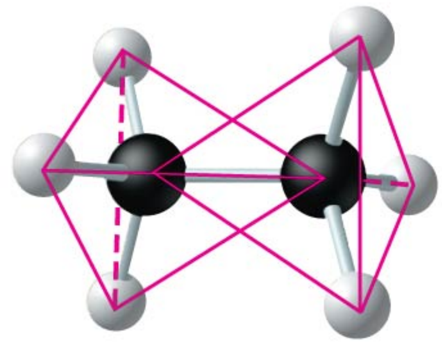
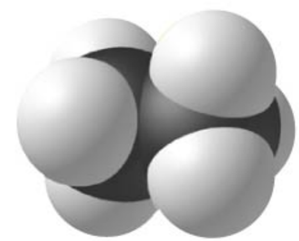
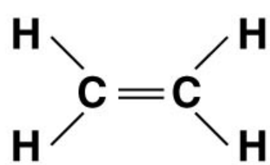
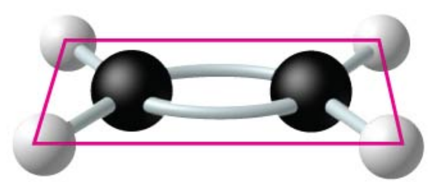
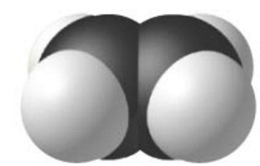
Carbon atoms can form diverse molecules by bonding to four other atoms

- An atom's electron configuration determines the kinds and number of bonds the atom will form with other atoms
- This is the source of carbon's versatility

The Formation of Bonds with Carbon

- With four **valence** electrons, carbon can form four covalent bonds with a variety of atoms
- This ability makes large, complex molecules possible
- In molecules with multiple carbons, each carbon bonded to four other atoms has a tetrahedral shape
- However, when two carbon atoms are joined by a double bond, the atoms joined to the carbons are in the same plane as the carbons

- When a carbon atom forms four single covalent bonds, the bonds angle toward the corners of an imaginary tetrahedron
- When two carbon atoms are joined by a double bond, the atoms joined to those carbons are in the same plane as the carbons

Name	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
Methane				
Ethane				
Ethene (ethylene)				

- The electron configuration of carbon gives it covalent compatibility with many different elements
- The valences of carbon and its most frequent partners (hydrogen, oxygen, and nitrogen) are the "building code" that governs the architecture of living molecules

Valences of the major elements of organic molecules

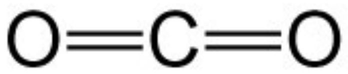
Hydrogen (valence ●1)

Oxygen (valence ●2)

Nitrogen (valence ●3)

Carbon (valence ●4)

- Carbon atoms can partner with atoms other than hydrogen; for example:
  - Carbon dioxide: CO_2



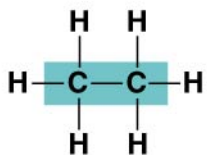
  - Urea: $CO(NH_2)_2$

Molecular Diversity Arising from Variation in Carbon Skeletons

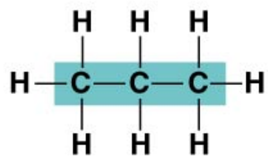
- Carbon chains form the skeletons of most organic molecules
- Carbon chains vary in length and shape

Four ways that carbon skeletons can vary

(a) Length

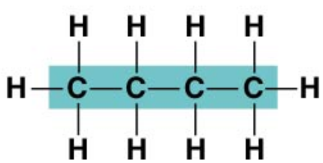


Ethane

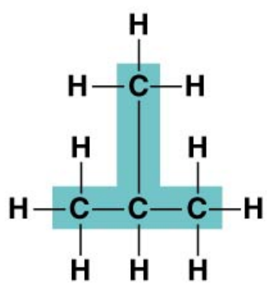


Propane

(b) Branching

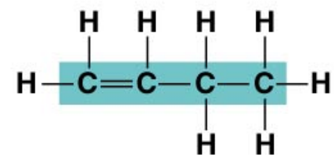


Butane

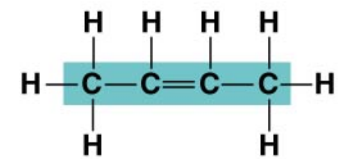


2-Methylpropane
(isobutane)

(c) Double bond position

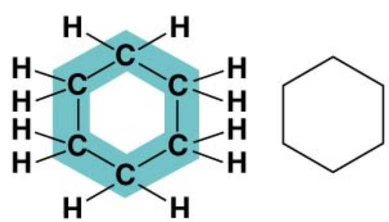


1-Butene

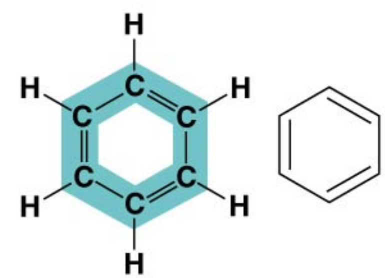


2-Butene

(d) Presence of rings

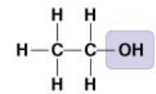
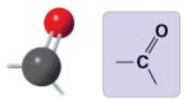
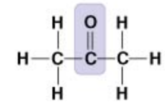
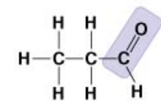
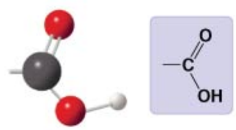
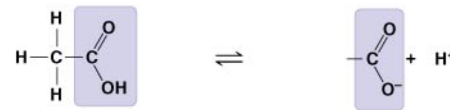
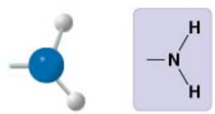
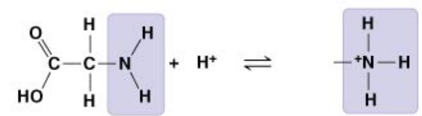
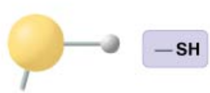
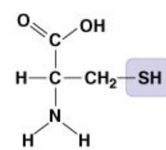
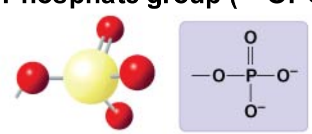
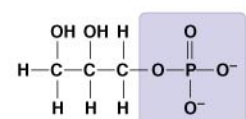
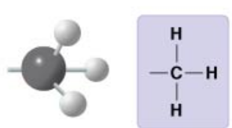
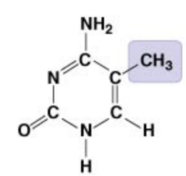


Cyclohexane

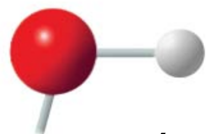


Benzene

*****Some biologically important chemical groups**

Chemical Group	Compound Name	Examples
Hydroxyl group (—OH) 	Alcohol	 Ethanol
Carbonyl group (>C=O) 	Ketone Aldehyde	 Acetone  Propanal
Carboxyl group (—COOH) 	Carboxylic acid, or organic acid	 Acetic acid
Amino group ($—NH_2$) 	Amine	 Glycine
Sulfhydryl group (—SH) 	Thiol	 Cysteine
Phosphate group ($—OPO_3^{2-}$) 	Organic phosphate	 Glycerol phosphate
Methyl group ($—CH_3$) 	Methylated compound	 5-Methyl cytosine

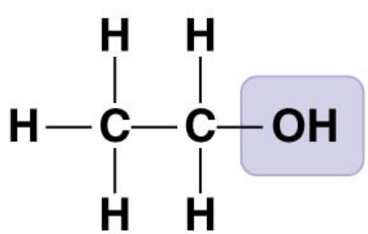
Hydroxyl group (—OH)



—OH

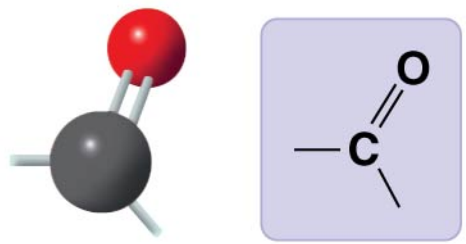
(may be written HO—)

Alcohol
(The specific name usually ends in *-ol*.)



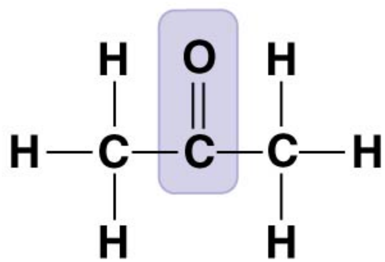
Ethanol, the alcohol present in alcoholic beverages

Carbonyl group ($>C=O$)

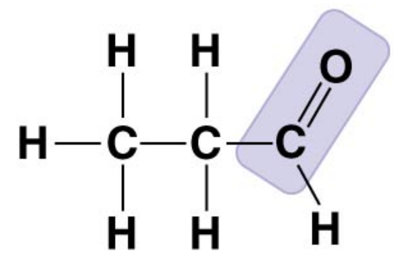


Ketone if the carbonyl group is within a carbon skeleton

Aldehyde if the carbonyl group is at the end of a carbon skeleton

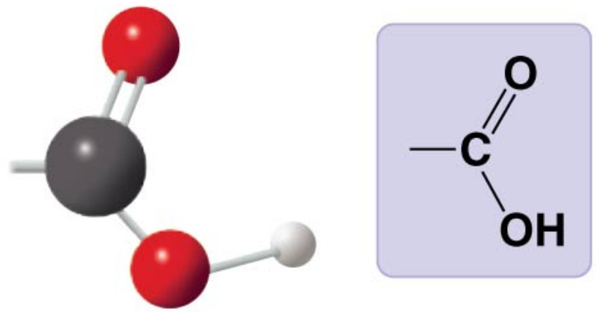


Acetone, the simplest ketone

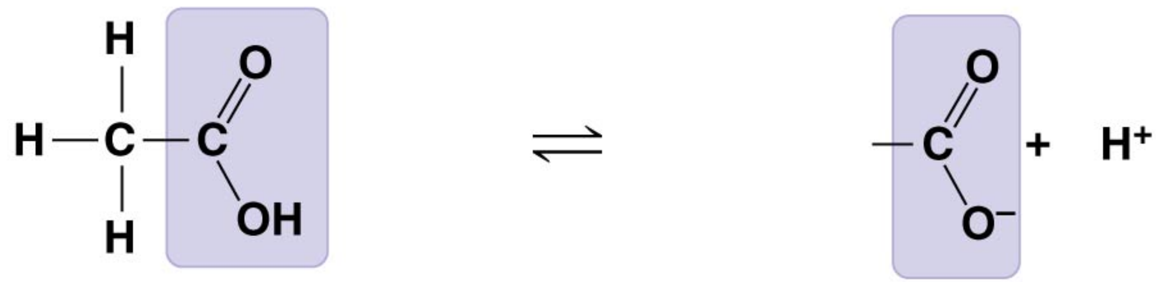


Propanal, an aldehyde

Carboxyl group (—COOH)



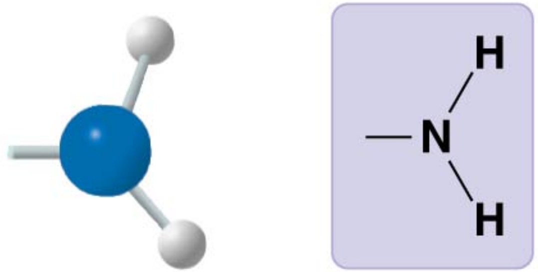
Carboxylic acid, or organic acid



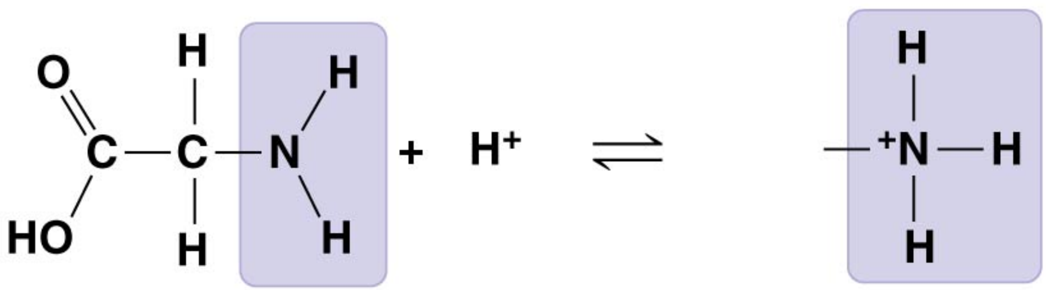
Acetic acid, which gives vinegar its sour taste

Ionized form of —COOH (carboxylate ion), found in cells

Amino group ($-NH_2$)



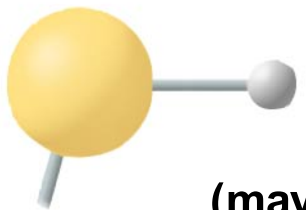
Amine



Glycine, an amino acid (note its carboxyl group)

Ionized form of $-NH_2$ found in cells

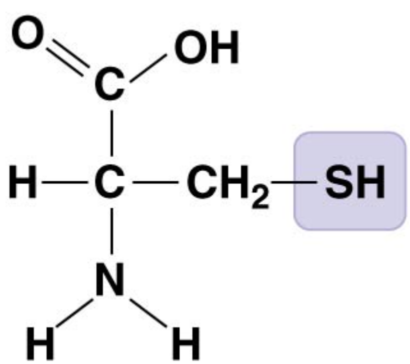
Sulfhydryl group (—SH)



—SH

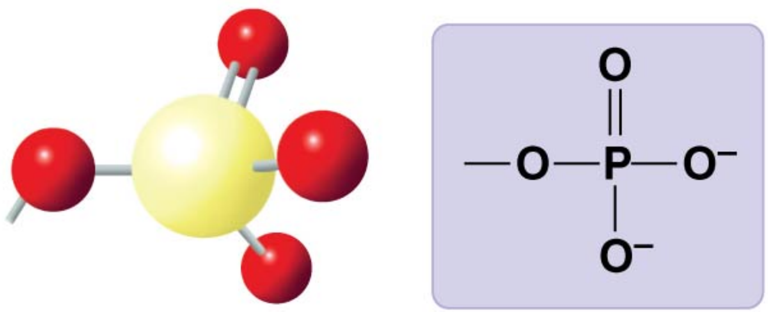
(may be written HS—)

Thiol

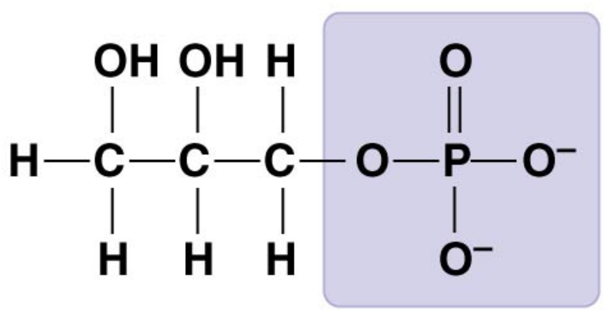


Cysteine, a sulfur-containing amino acid

Phosphate group ($—OPO_3^{2-}$)

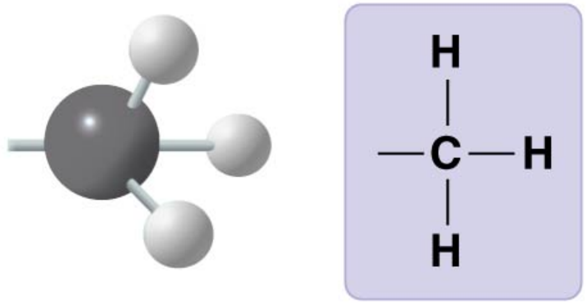


Organic phosphate

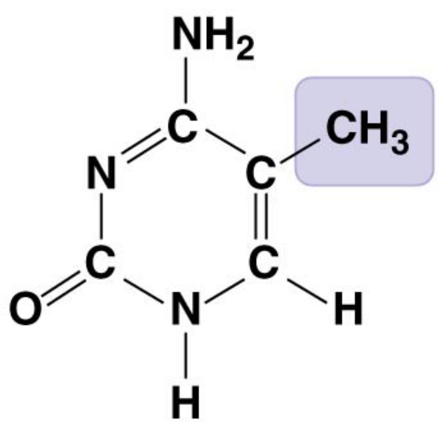


Glycerol phosphate, which takes part in many important chemical reactions in cells

Methyl group ($—CH_3$)



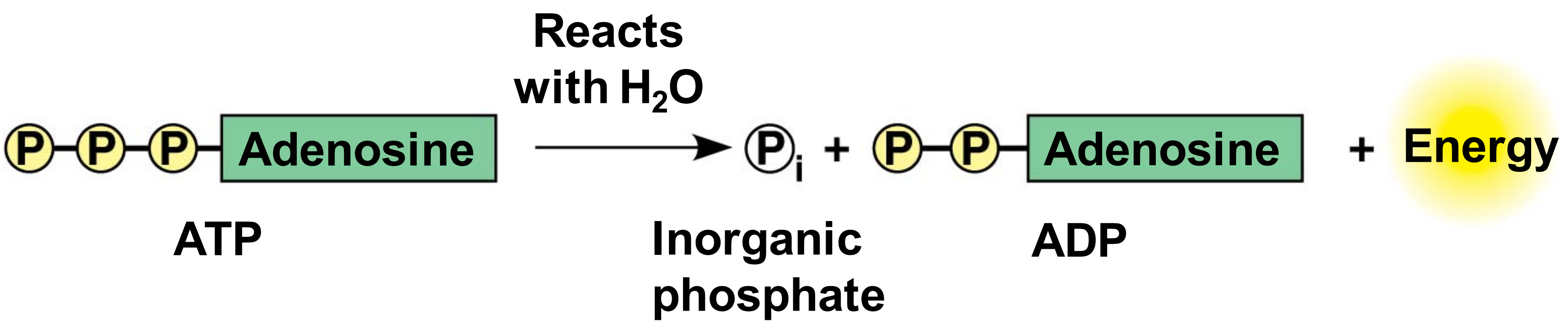
Methylated compound



5-Methyl cytosine, a component of DNA that has been modified by addition of a methyl group

ATP: An Important Source of Energy for Cellular Processes

- One organic phosphate molecule, **adenosine triphosphate** (**ATP**), is the primary energy-transferring molecule in the cell
- ATP consists of an organic molecule called adenosine attached to a string of three phosphate groups



P
P
P
Adenosine
ATP
Reacts
with H_2O
P_i
Inorganic
phosphate
+
P
P
Adenosine
ADP
+
Energy

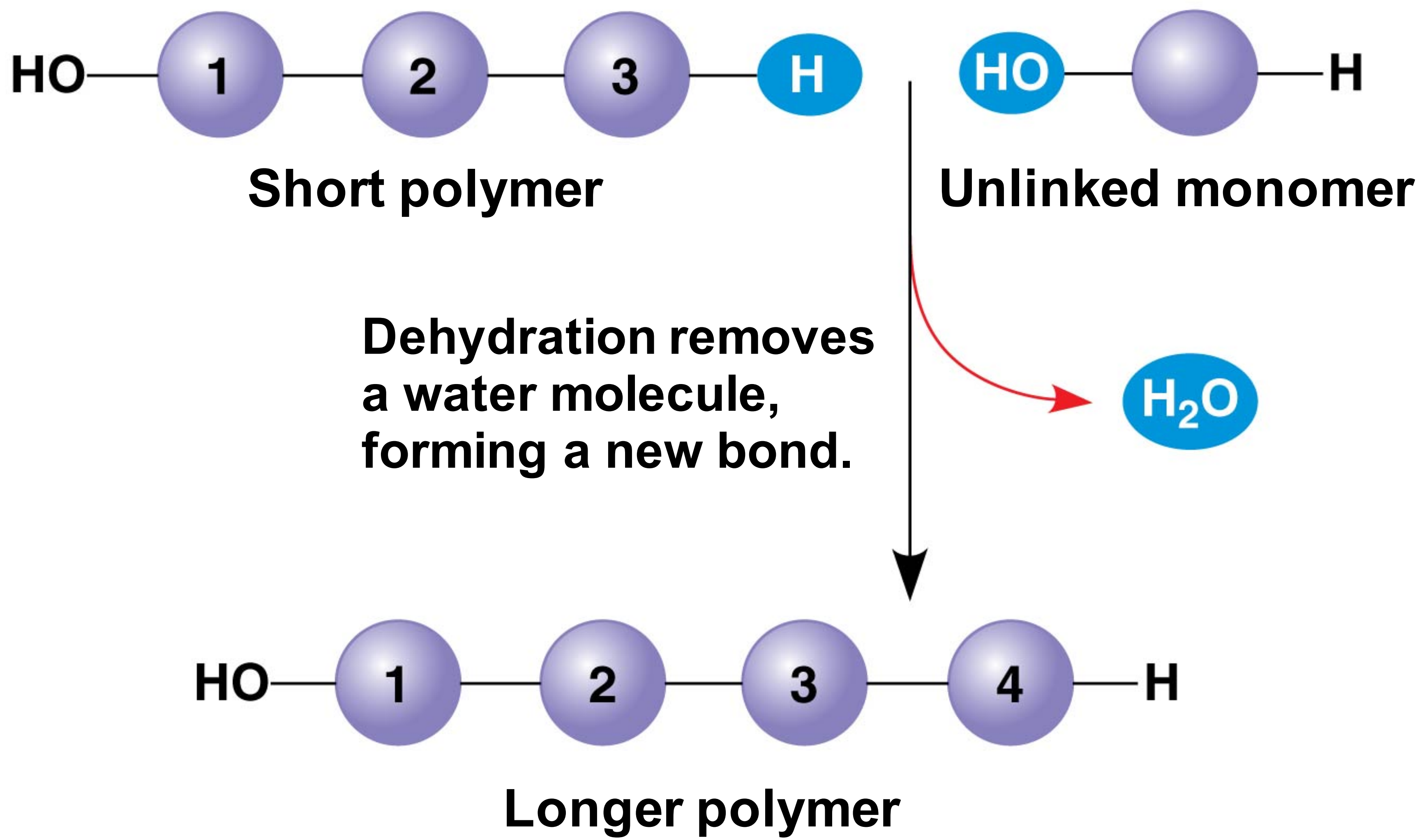
Macromolecules are polymers, built from monomers

- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**
- Some molecules that serve as monomers also have other functions of their own

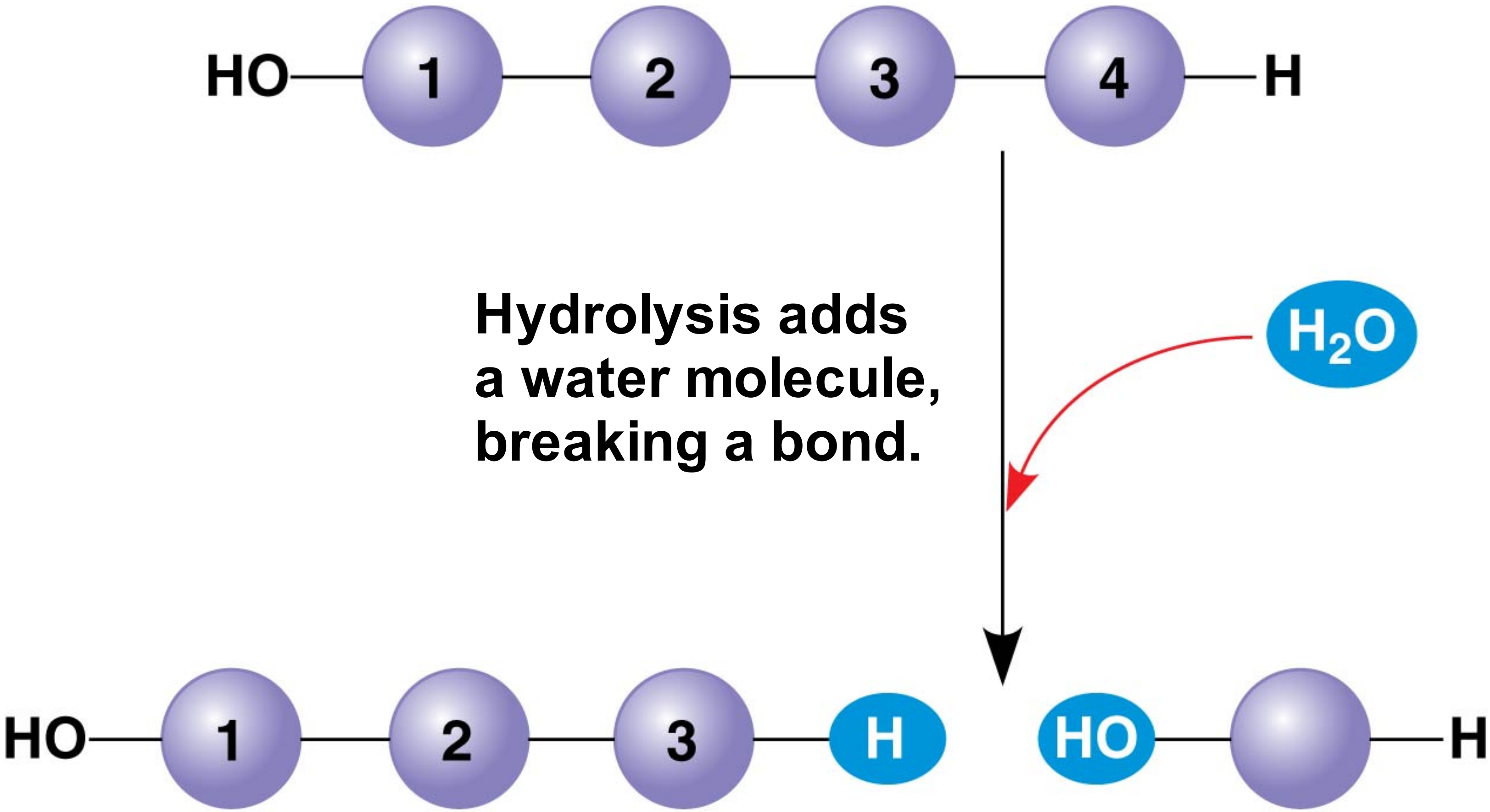
The Synthesis and Breakdown of Polymers

- Cells make and break down polymers by the same process
- A **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction
- These processes are facilitated by **enzymes**, which speed up chemical reactions

Dehydration reaction: synthesizing a polymer



Hydrolysis: breaking down a polymer



The Diversity of Polymers

- Each cell has thousands of different macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- An immense variety of polymers can be built from a small set of monomers

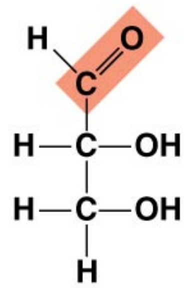
Carbohydrates serve as fuel and building material

- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are monosaccharides, or simple sugars
- Carbohydrate macromolecules are polysaccharides, polymers composed of many sugar building blocks

Sugars

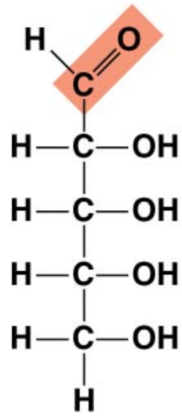
- **Monosaccharides** have molecular formulas that are usually multiples of CH_2O
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides are classified by the number of carbons in the carbon skeleton and the placement of the carbonyl group ($C{=}O$)

Triose: 3-carbon sugar ($C_3H_6O_3$)



Glyceraldehyde
An initial breakdown product of glucose in cells

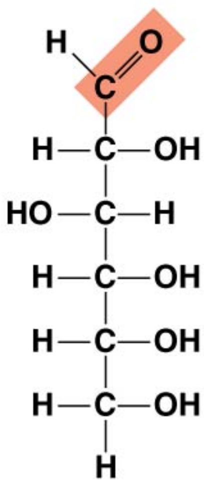
Pentose: 5-carbon sugar ($C_5H_{10}O_5$)



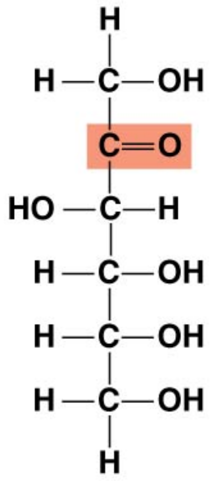
Ribose
A component of RNA

Examples of monosaccharides

Hexoses: 6-carbon sugars ($C_6H_{12}O_6$)



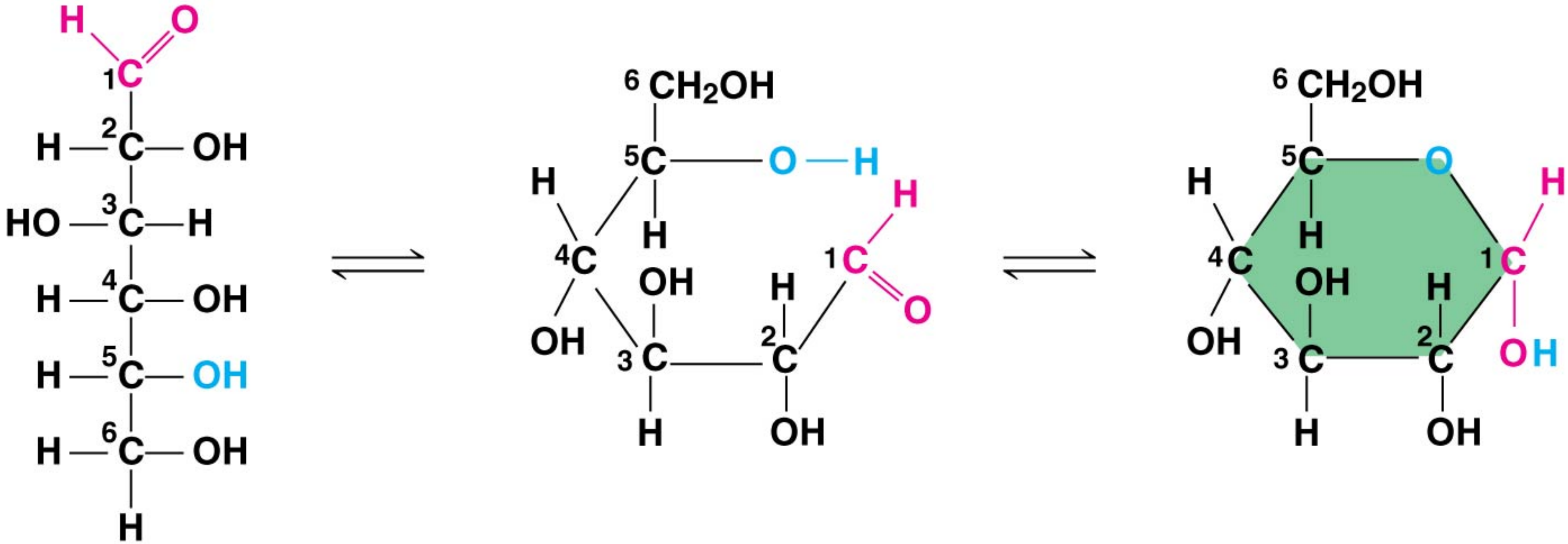
Glucose



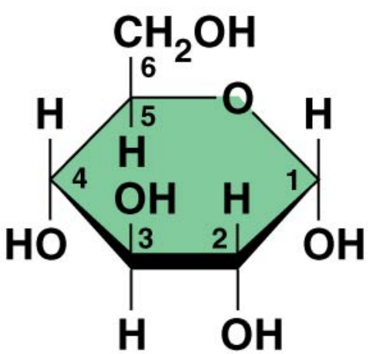
Fructose

Energy sources for organisms

- Though often drawn as linear skeletons, in aqueous solutions many sugars form rings
- Monosaccharides serve as a major fuel for cells and as raw material for building molecules

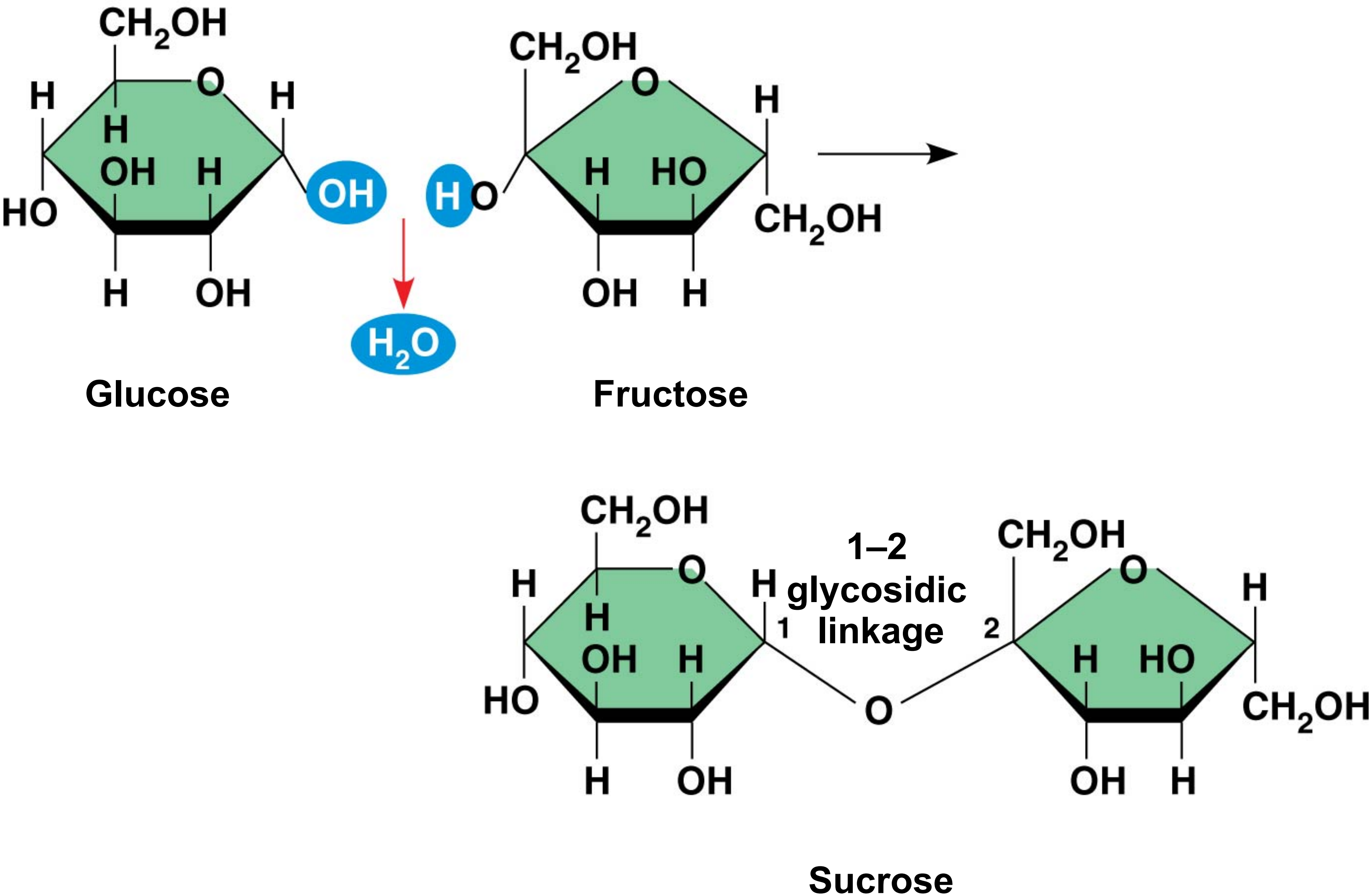


Linear and ring forms



Abbreviated ring structure

- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**



Glucose
Fructose
H_2O
Sucrose
1–2 glycosidic linkage

Polysaccharides

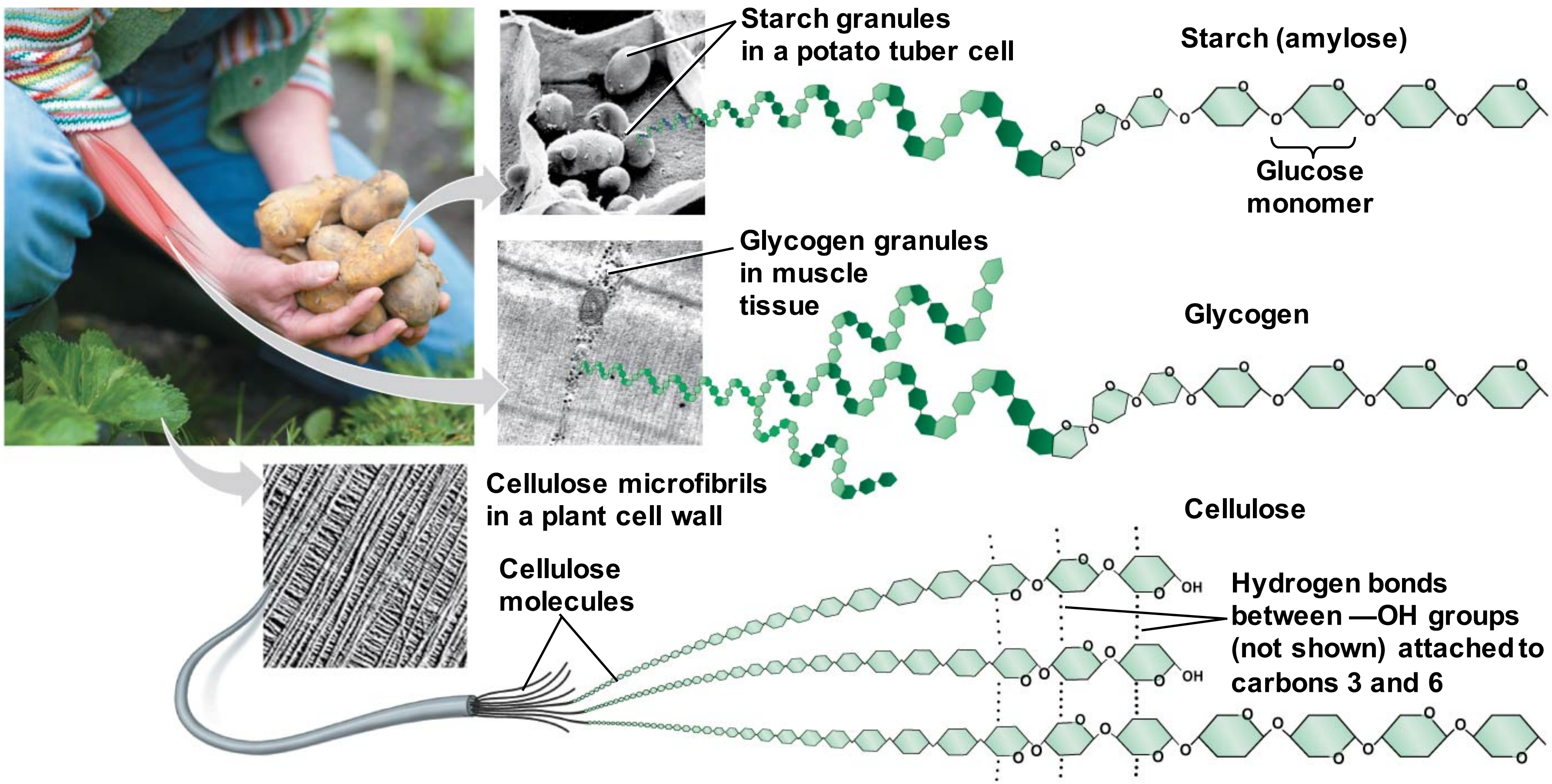
- **Polysaccharides**, the polymers of sugars, have storage and structural roles
- The structure and function of a polysaccharide are determined by its sugar monomers and the positions of glycosidic linkages

Storage Polysaccharides

- **Starch**, a storage polysaccharide of plants, consists entirely of glucose monomers
- Plants store surplus starch as granules
- The simplest form of starch is amylose

- **Glycogen** is a storage polysaccharide in animals
- Humans and other vertebrates store glycogen mainly in liver and muscle cells

Figure 3.10



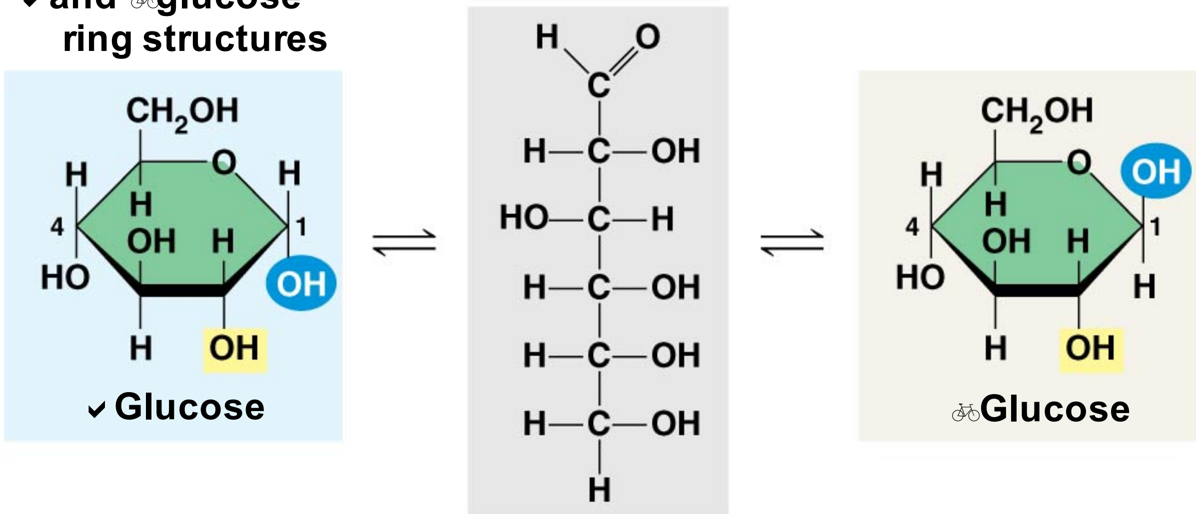
Starch granules in a potato tuber cell
Starch (amylose)
Glucose monomer
Glycogen granules in muscle tissue
Glycogen
Cellulose microfibrils in a plant cell wall
Cellulose
Cellulose molecules
Hydrogen bonds between —OH groups (not shown) attached to carbons 3 and 6
OH

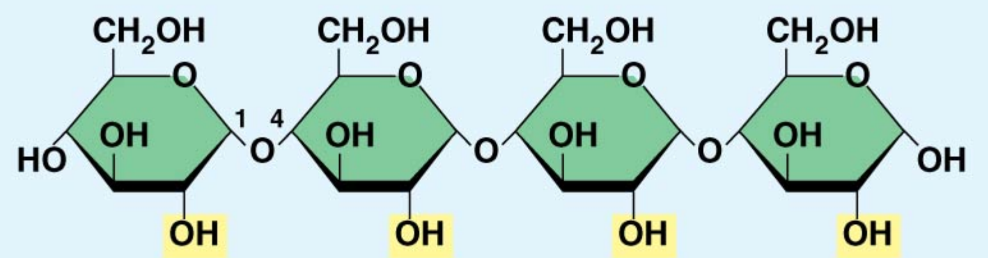
Structural Polysaccharides

- The polysaccharide **cellulose** is a major component of the tough wall of plant cells
- Like starch and glycogen, cellulose is a polymer of glucose, but the glycosidic linkages in cellulose differ
- The difference is based on two ring forms for glucose

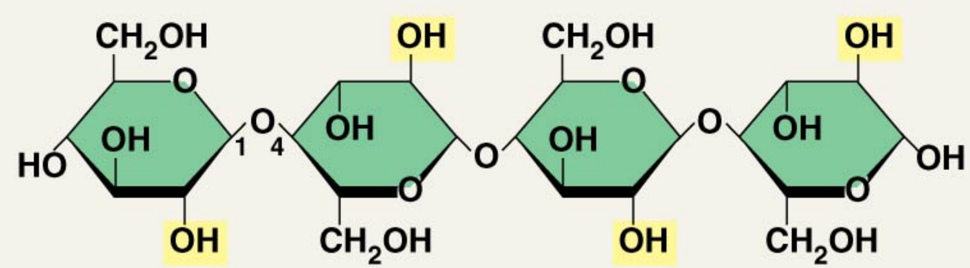
- In starch, the glucose monomers are arranged in the alpha (✔) conformation
- Starch (and glycogen) are largely helical
- In cellulose, the monomers are arranged in the beta (🚲) conformation
- Cellulose molecules are relatively straight

✔ and 🚲 glucose ring structures





Starch: 1–4 linkage of ✔ glucose monomers



Cellulose: 1–4 linkage of 🚲 glucose monomers

- In straight structures (cellulose), H atoms on one strand can form hydrogen bonds with OH groups on other strands
- Parallel cellulose molecules held together this way are grouped into microfibrils, which form strong building materials for plants

- Enzymes that digest starch by hydrolyzing ✔ linkages can’t hydrolyze 🚲 linkages in cellulose
- Cellulose in human food passes through the digestive tract as insoluble fiber
- Some microbes use enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these microbes

- **Chitin**, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi

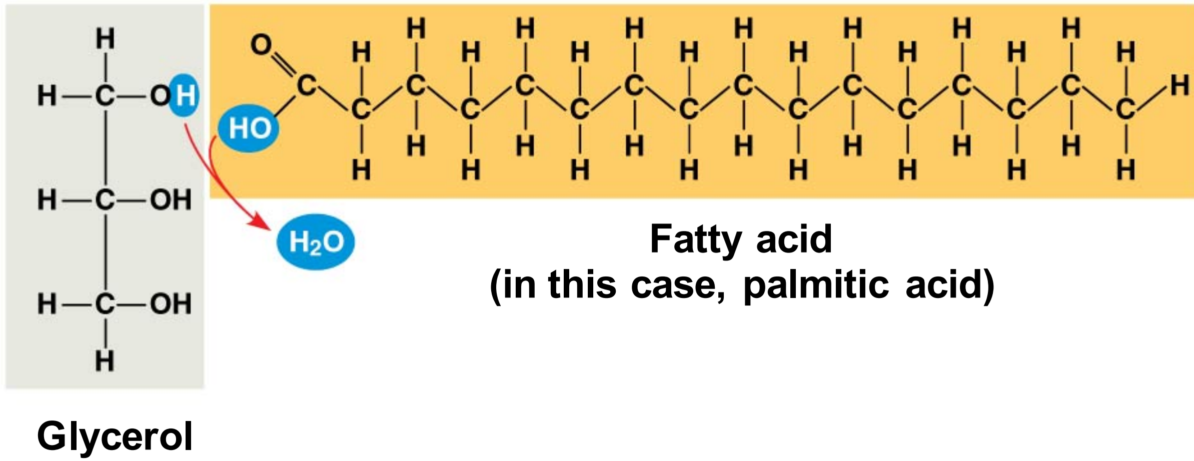
Lipids are a diverse group of hydrophobic molecules

- **Lipids** do not form true polymers
- The unifying feature of lipids is having little or no affinity for water
- Lipids are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds
- The most biologically important lipids are fats, phospholipids, and steroids

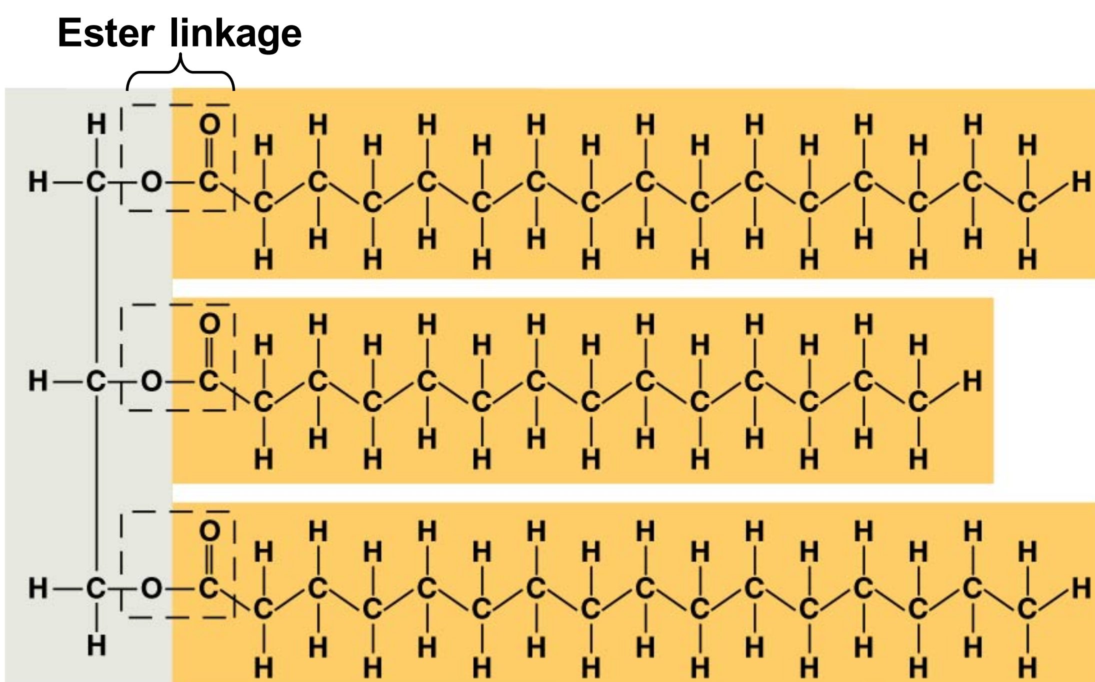
Fats

- **Fats** are constructed from two types of smaller molecules: glycerol and fatty acids
- Glycerol is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton

- Fats separate from water because water molecules hydrogen-bond to each other and exclude the fats
- In a fat, three fatty acids are joined to glycerol by an ester linkage, creating a **triacylglycerol**, or triglyceride

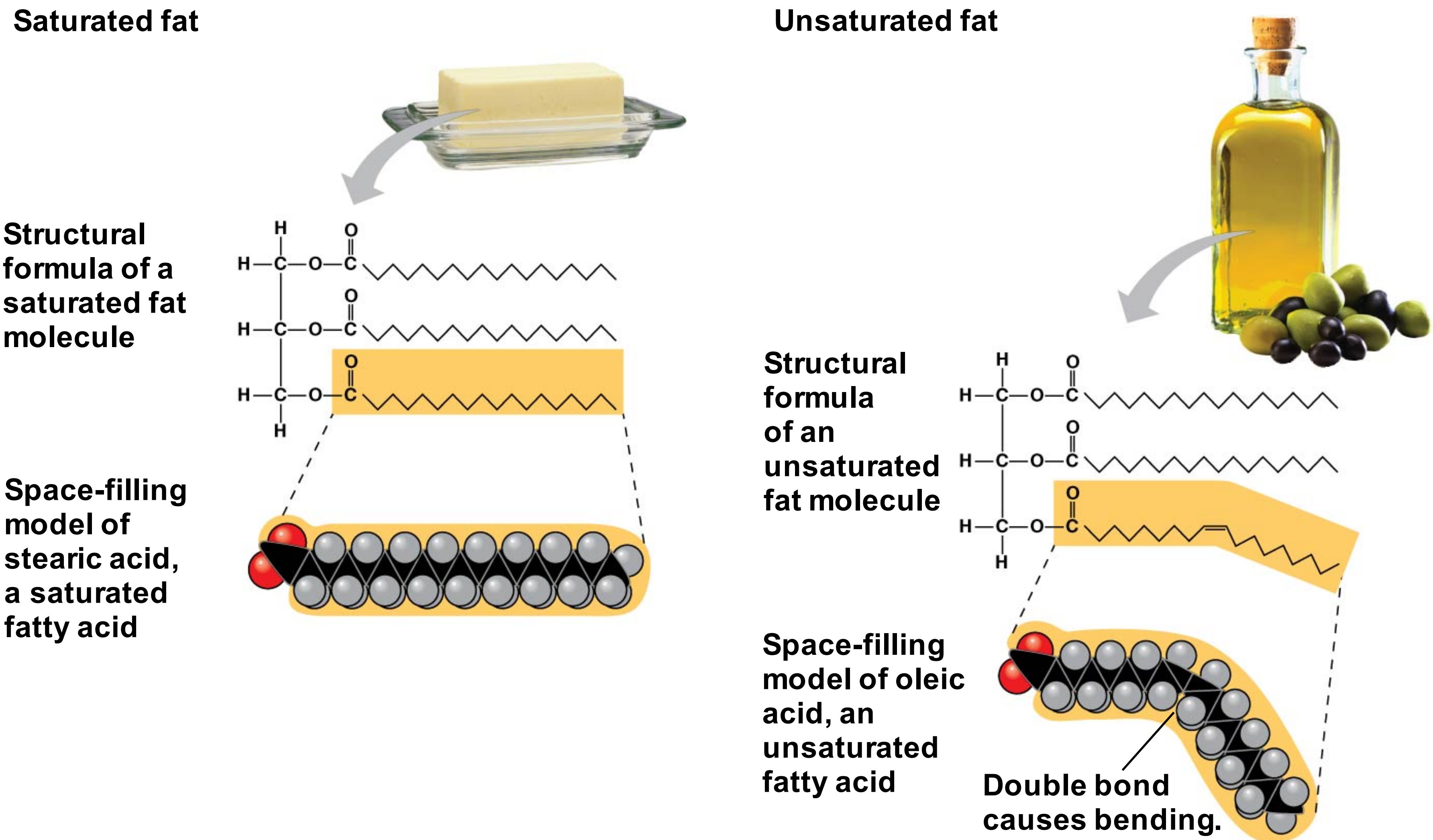


One of three dehydration reactions in the synthesis of a fat



(b) Fat molecule (triacylglycerol)

- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and no double bonds
- **Unsaturated fatty acids** have one or more double bonds


Saturated fat
Structural formula of a saturated fat molecule
H
H—C—O—C
O
H—C—O—C
O
H—C—O—C
O
H
Space-filling model of stearic acid, a saturated fatty acid
Unsaturated fat
Structural formula of an unsaturated fat molecule
Space-filling model of oleic acid, an unsaturated fatty acid
Double bond causes bending.

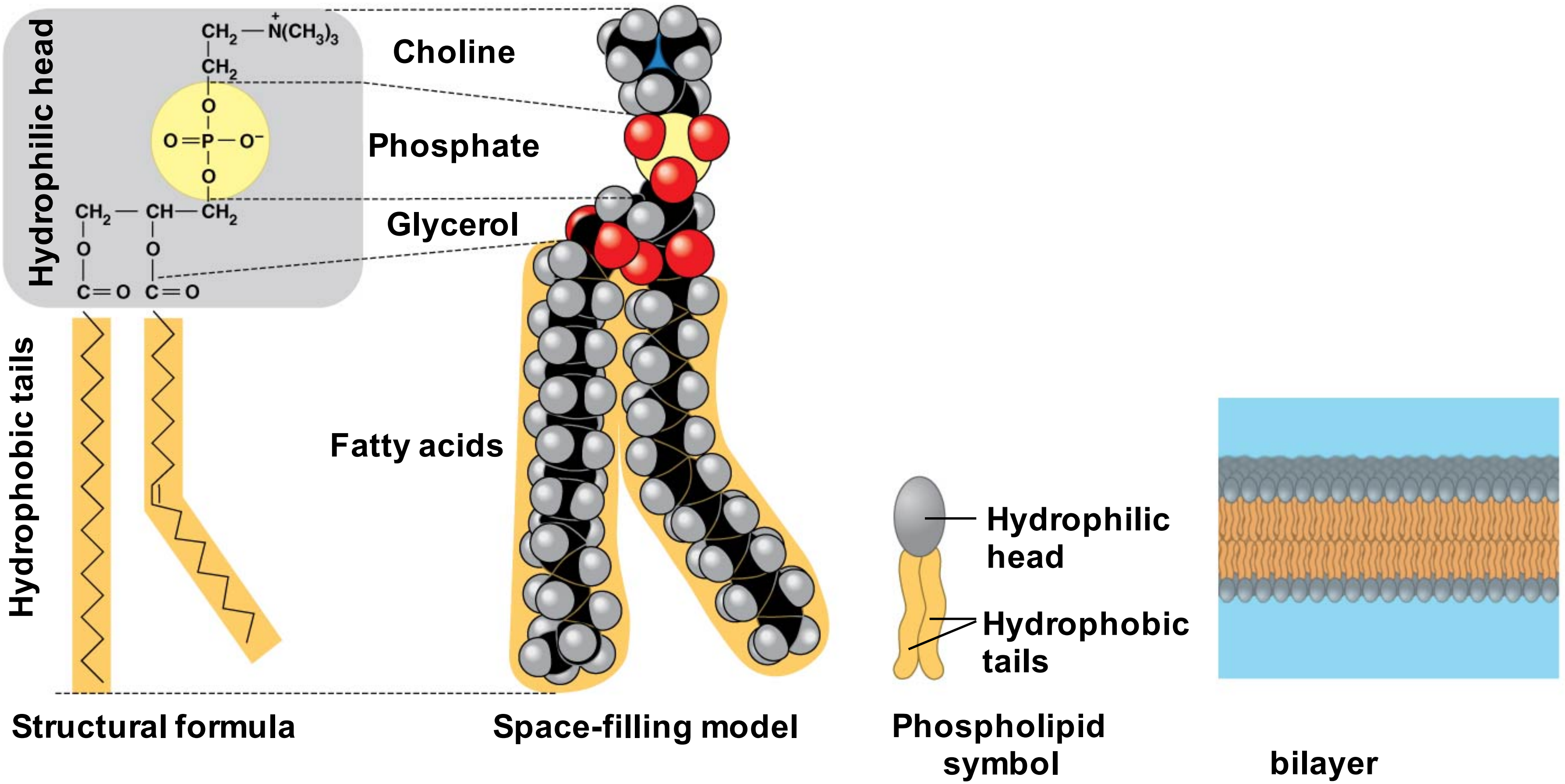
- Fats made from saturated fatty acids are called saturated fats and are solid at room temperature
- Most animal fats are saturated
- Fats made from unsaturated fatty acids, called unsaturated fats or oils, are liquid at room temperature
- Plant fats and fish fats are usually unsaturated

- The major function of fats is energy storage
- Fat is a compact way for animals to carry their energy stores with them

Phospholipids

- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head
- Phospholipids are major constituents of cell membranes

The structure of a phospholipid

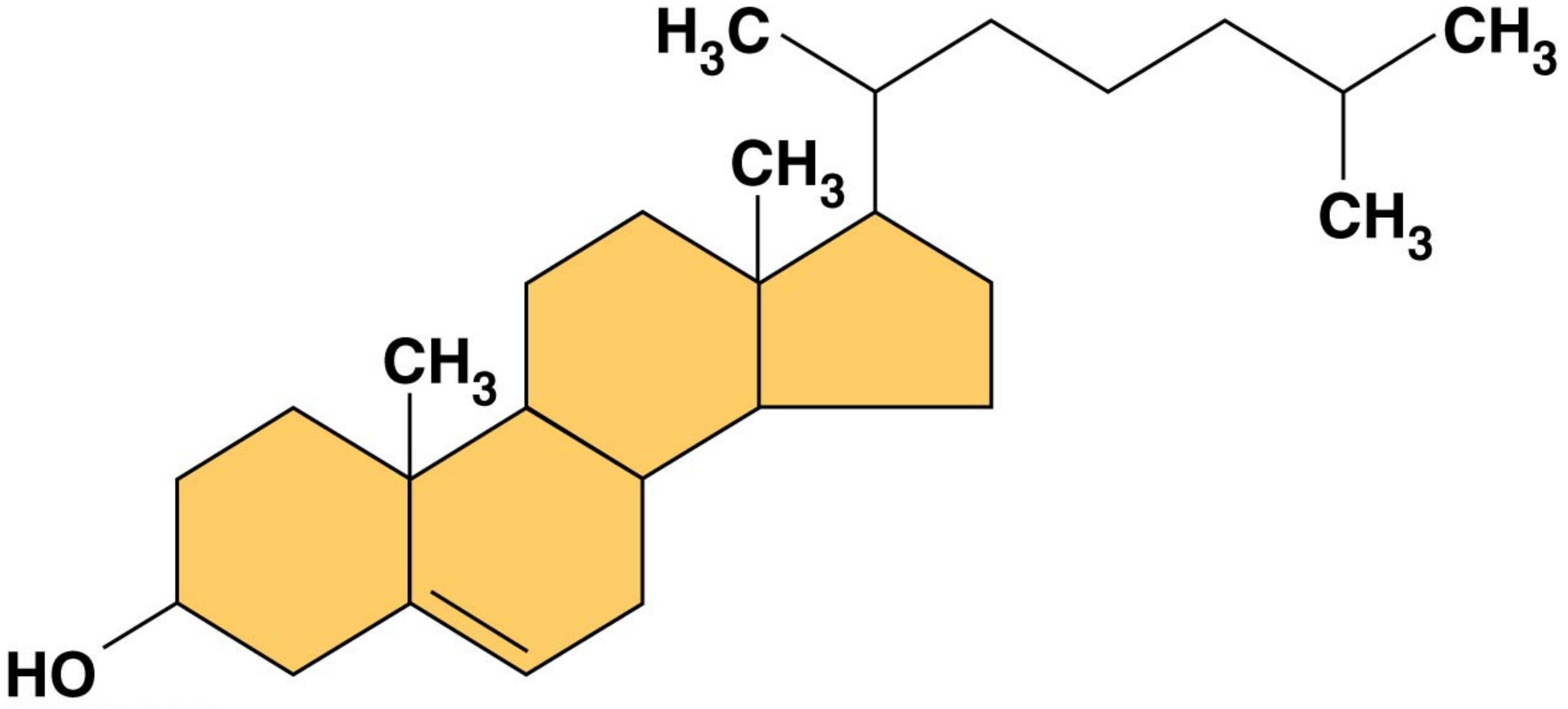


- When phospholipids are added to water, they self-assemble into a bilayer, with the hydrophobic tails pointing toward the interior
- This feature of phospholipids results in the bilayer arrangement found in cell membranes

Steroids

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings
- **Cholesterol**, an important steroid, is a component in animal cell membranes
- Although cholesterol is essential in animals, high levels in the blood may contribute to cardiovascular disease

Cholesterol, a steroid



*** Proteins include a diversity of structures, resulting in a wide range of functions

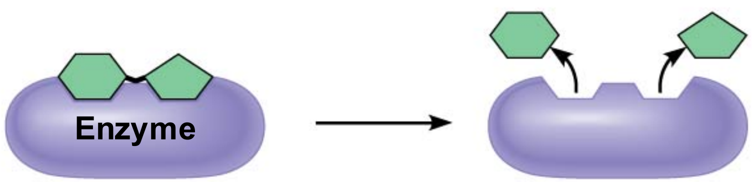
- Proteins account for more than 50% of the dry mass of most cells
- Protein functions include defense, storage, transport, cellular communication, movement, and structural support

Protein Functions: An Overview

Enzymatic proteins

Function: Selective acceleration of chemical reactions

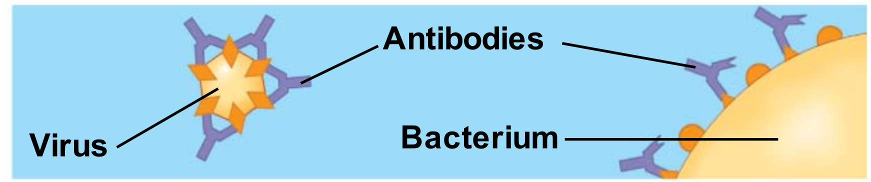
Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.



Defensive proteins

Function: Protection against disease

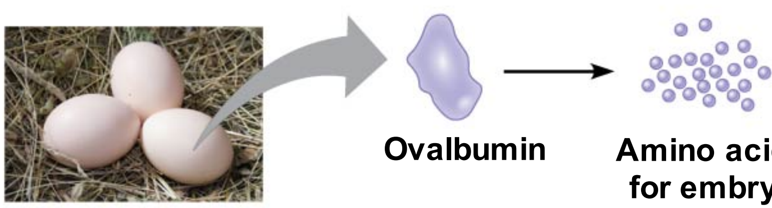
Example: Antibodies inactivate and help destroy viruses and bacteria.



Storage proteins

Function: Storage of amino acids

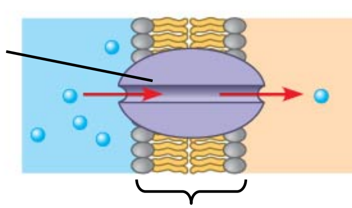
Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.



Transport proteins

Function: Transport of substances

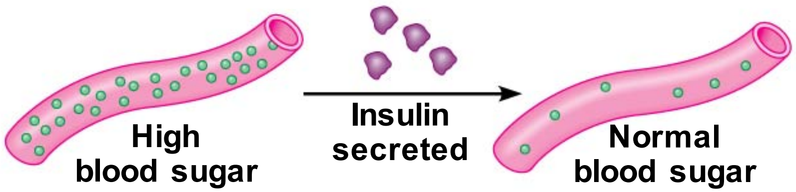
Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.



Hormonal proteins

Function: Coordination of an organism's activities

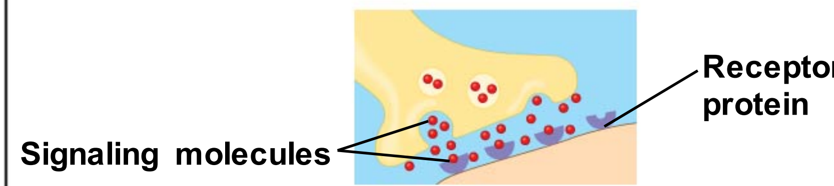
Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.



Receptor proteins

Function: Response of cell to chemical stimuli

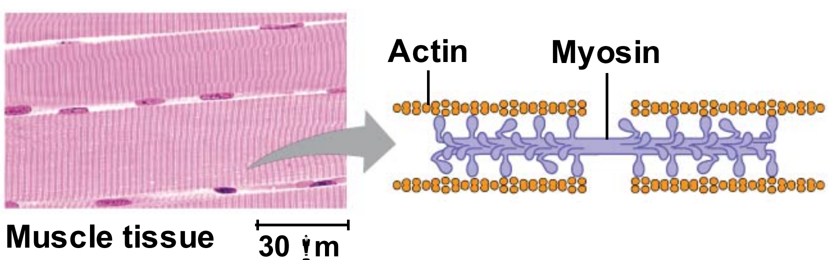
Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



Contractile and motor proteins

Function: Movement

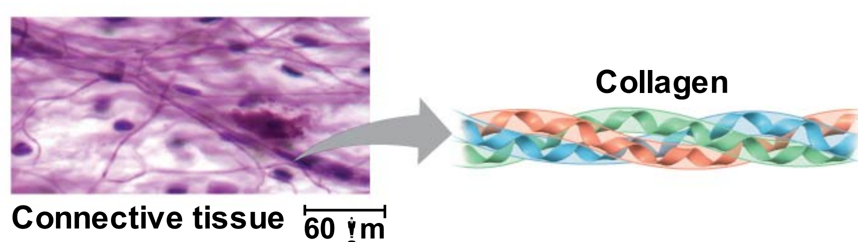
Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.



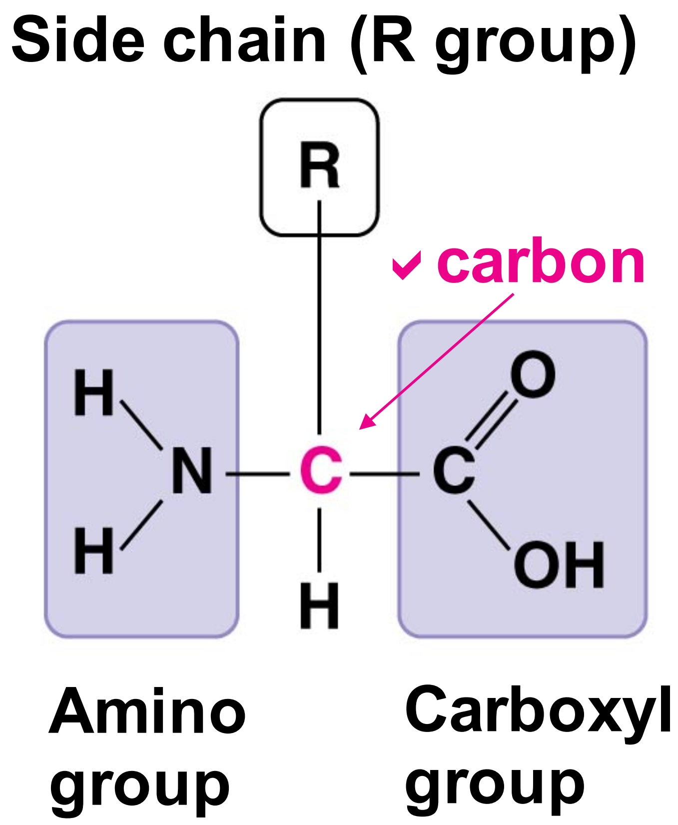
- Life would not be possible without enzymes
- Enzymatic proteins act as **catalysts**, to speed up chemical reactions without being consumed by the reaction

- **Polypeptides** are unbranched polymers built from the same set of 20 amino acids
- A **protein** is a biologically functional molecule that consists of one or more polypeptides

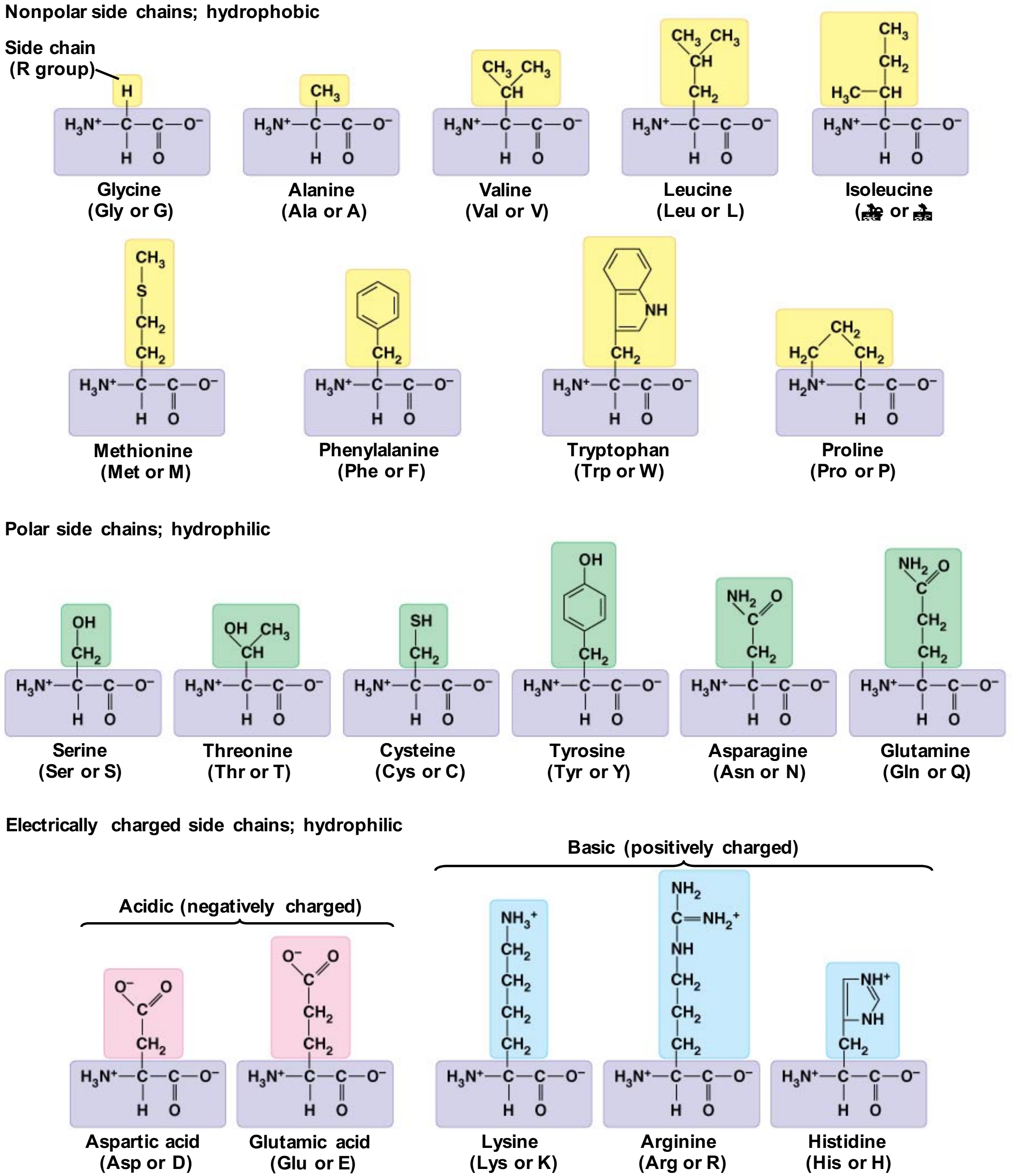
Amino Acids

- **Amino acids** are organic molecules with carboxyl and amino groups
- Amino acids differ in their properties due to differing side chains, called R groups

Amino acid structure



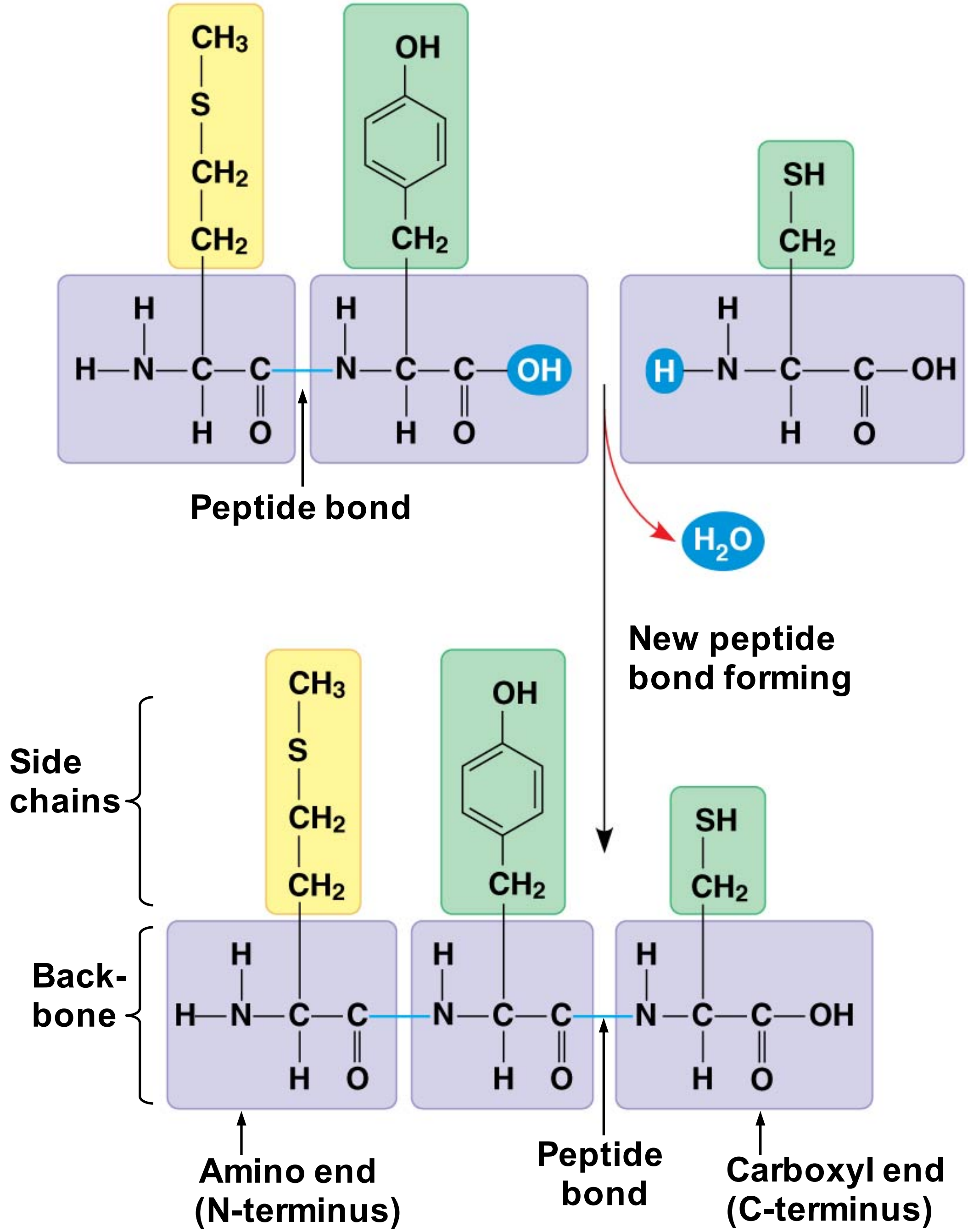
The 20 amino acids of proteins:



Polypeptides

- Amino acids are linked by **peptide bonds**
- A polypeptide is a polymer of amino acids
- Polypeptides range in length from a few to more than a thousand monomers
- Each polypeptide has a unique linear sequence of amino acids, with a carboxyl end (C-terminus) and an amino end (N-terminus)

Making a polypeptide chain

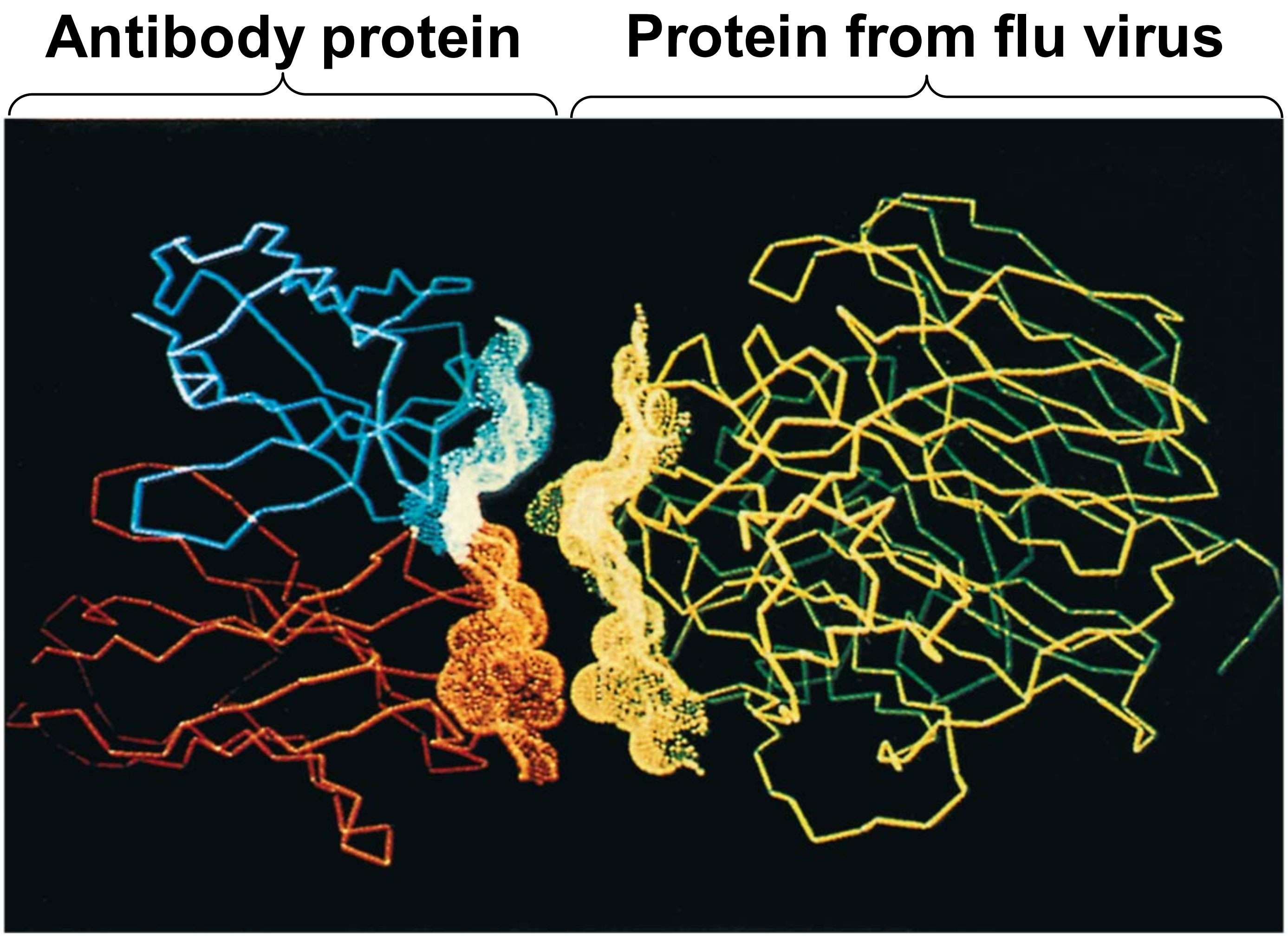


Protein Structure and Function

- A functional protein consists of one or more polypeptides precisely twisted, folded, and coiled into a unique shape

- The sequence of amino acids, determined genetically, leads to a protein’s three-dimensional structure
- A protein’s structure determines its function

An antibody binding to a protein from a flu virus

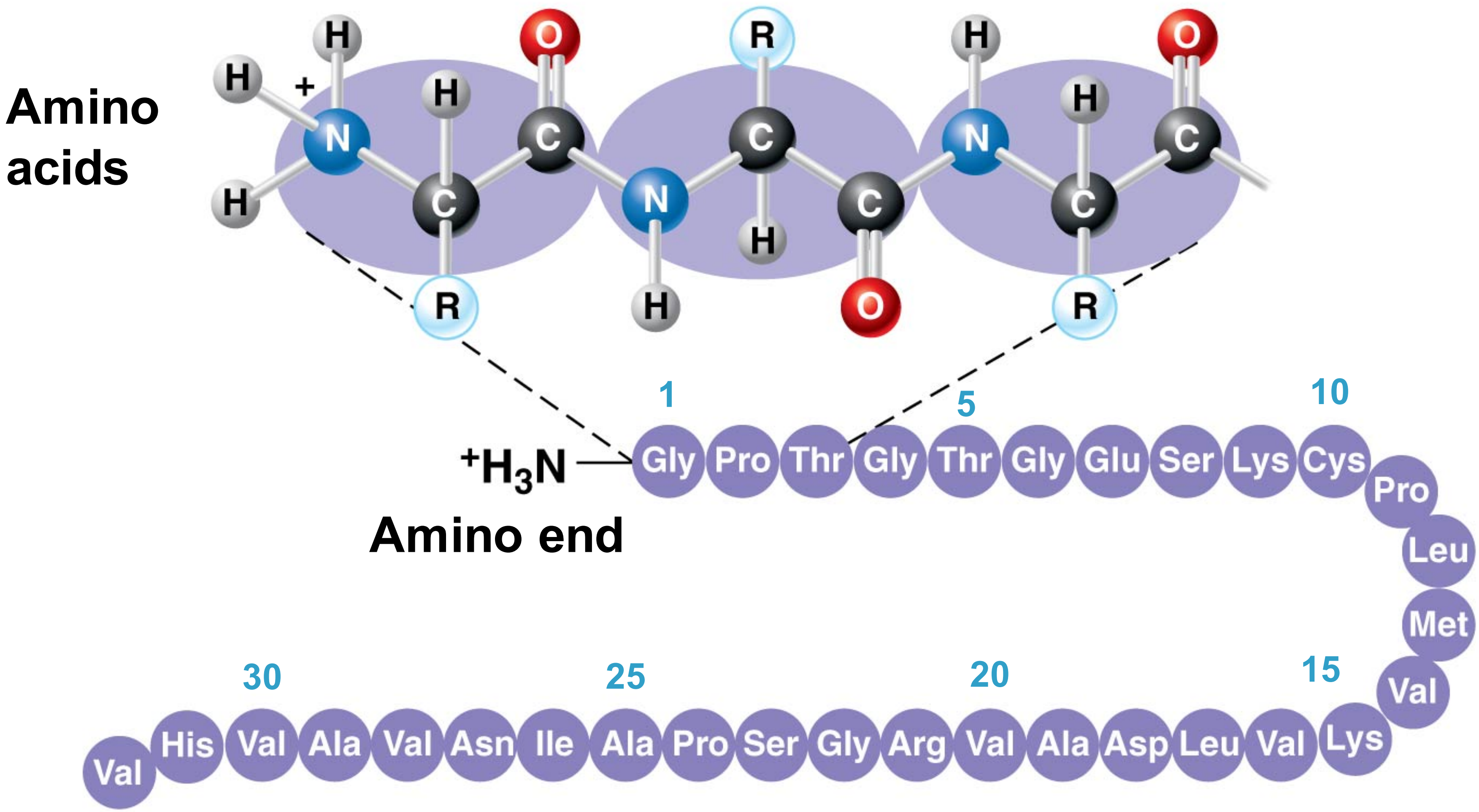


Four Levels of Protein Structure

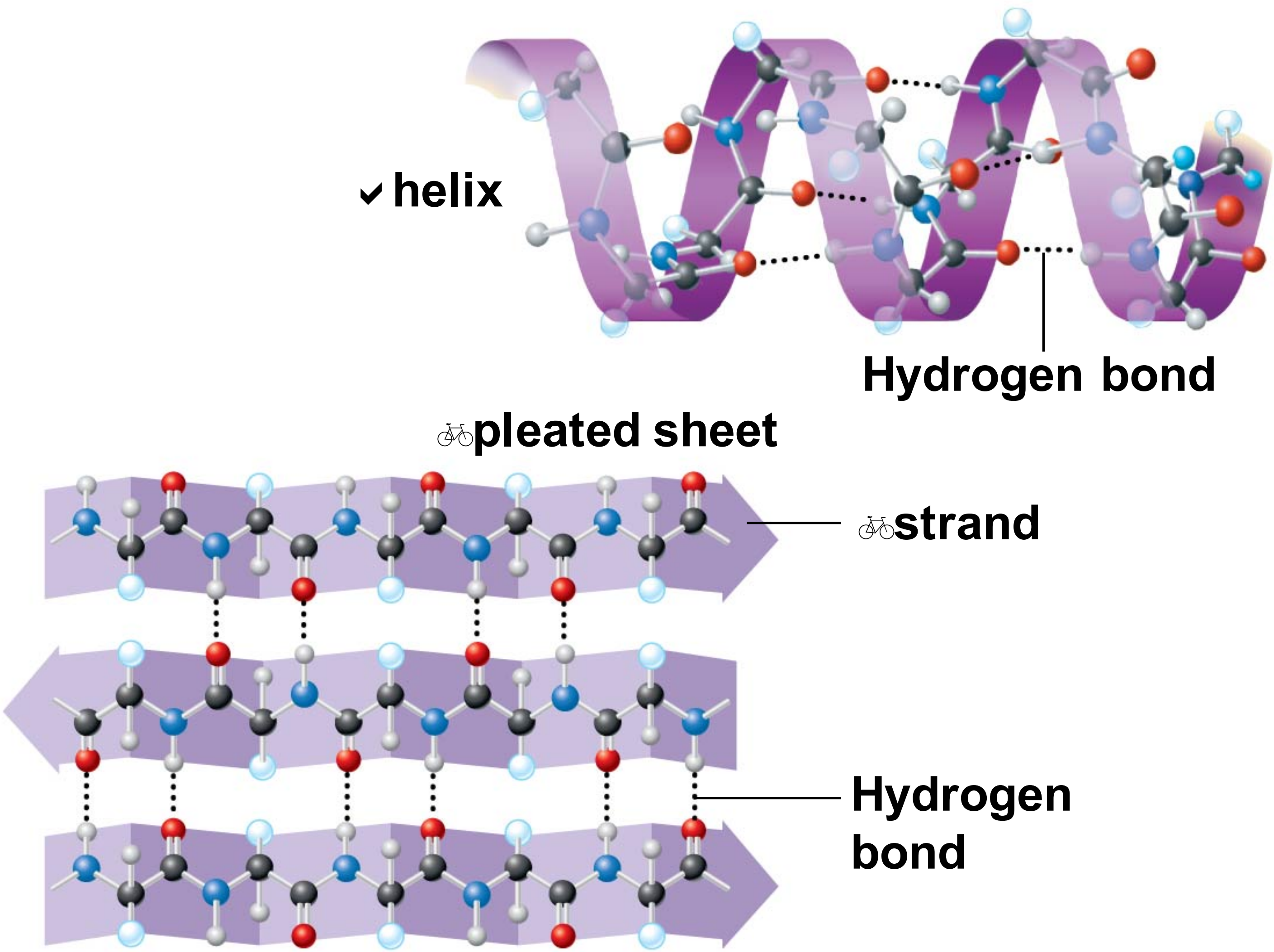
- Proteins are very diverse, but share three superimposed levels of structure called primary, secondary, and tertiary structure
- A fourth level, quaternary structure, arises when a protein consists of more than one polypeptide chain

- The primary structure of a protein is its unique sequence of amino acids
- Secondary structure, found in most proteins, consists of coils and folds in the polypeptide chain
- Tertiary structure is determined by interactions among various side chains (R groups)
- Quaternary structure results from interactions between multiple polypeptide chains

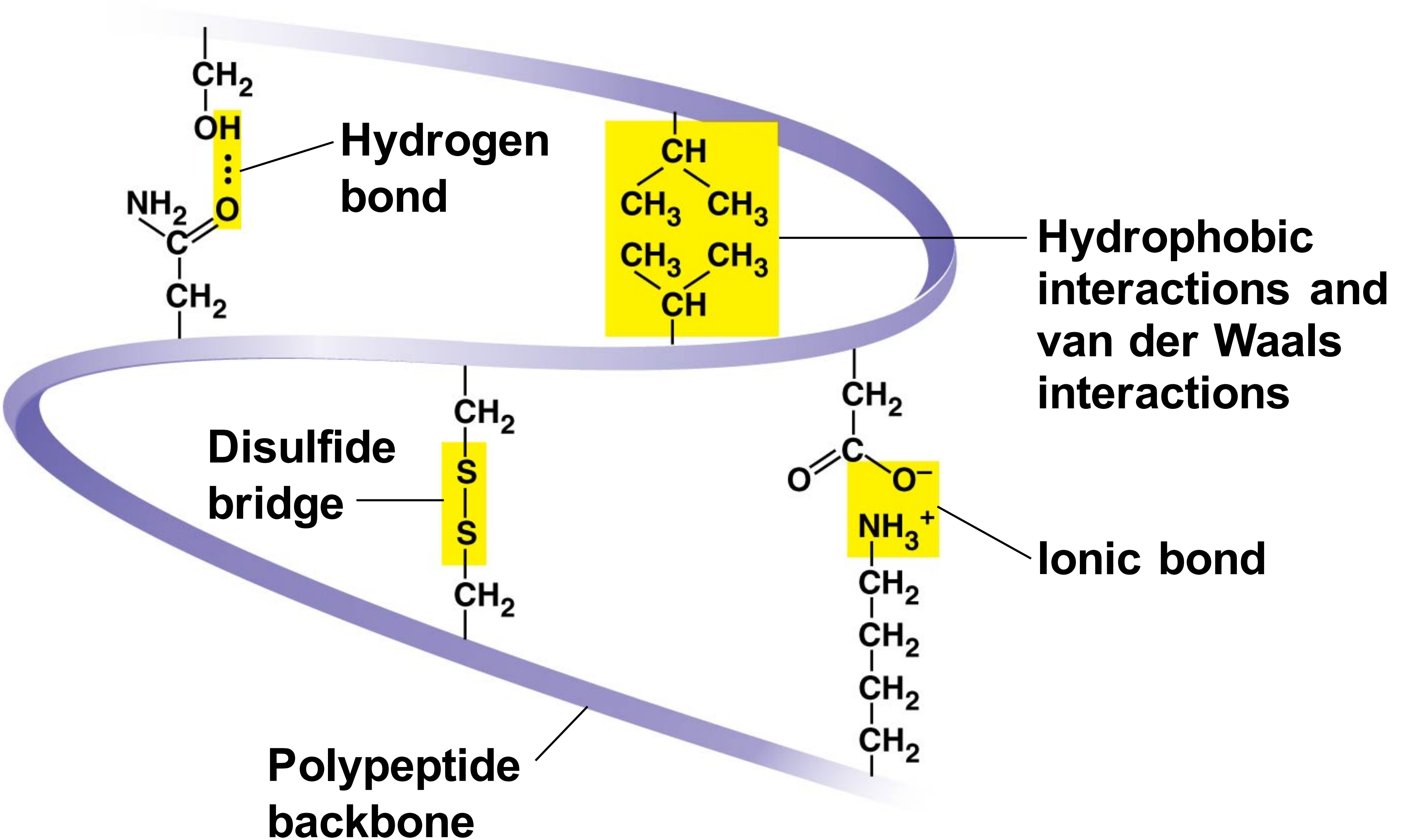
Primary structure



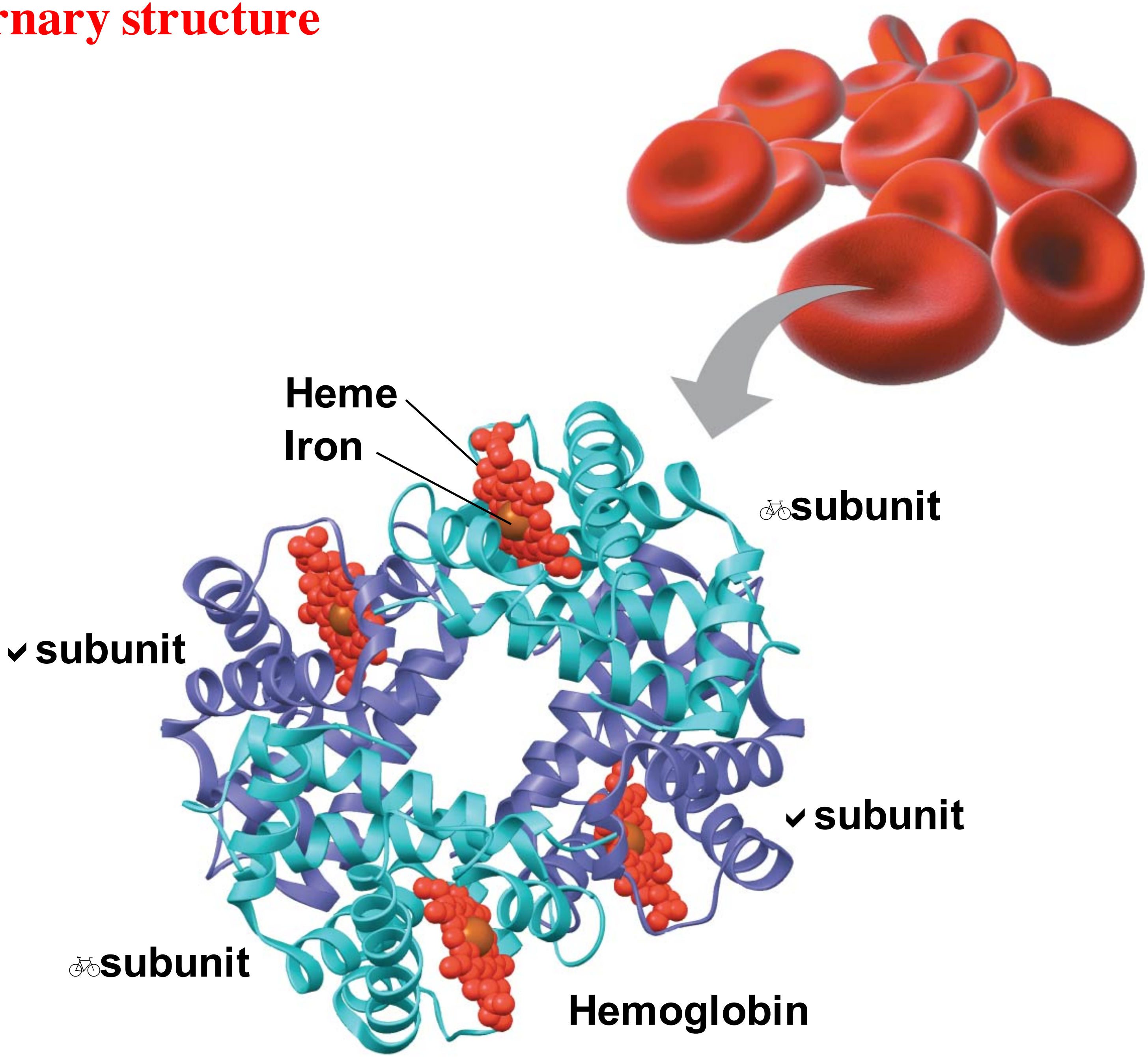
Secondary structure



Tertiary structure



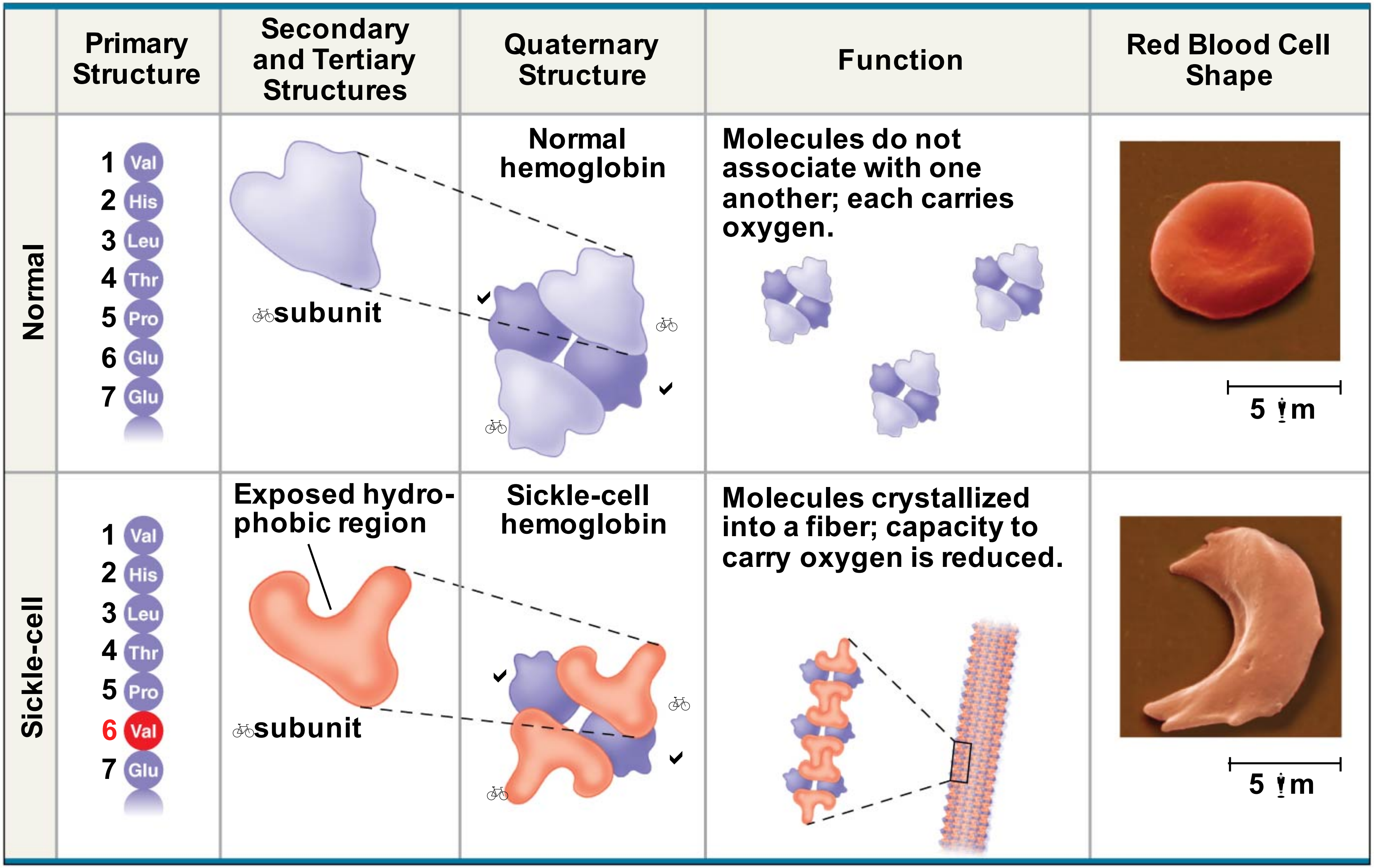
Quaternary structure



Sickle-Cell Disease: A Change in Primary Structure

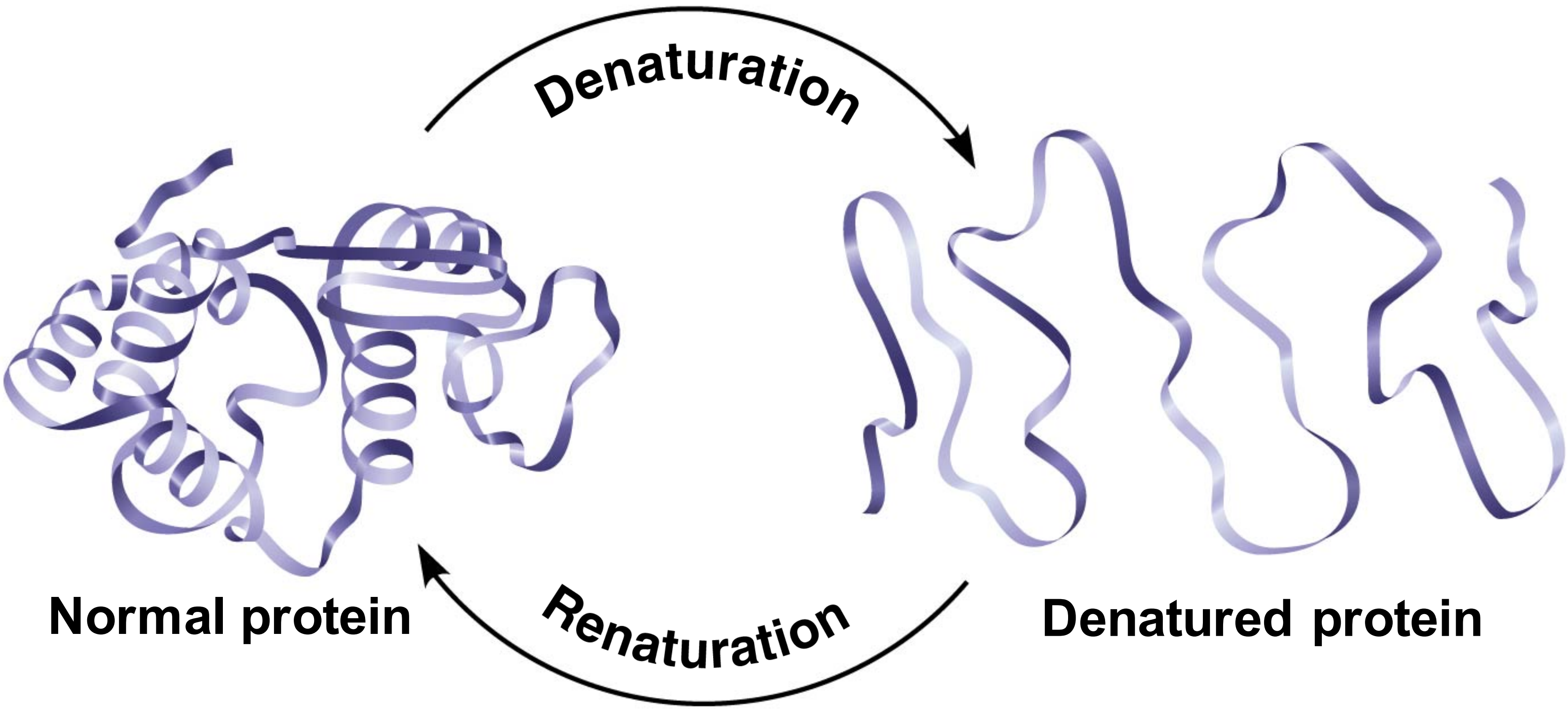
- Primary structure is the sequence of amino acids on the polypeptide chain
- A slight change in primary structure can affect a protein's structure and ability to function
- **Sickle-cell disease**, an inherited blood disorder, results from a single amino acid substitution in the protein hemoglobin

A single amino acid substitution in a protein causes sickle-cell disease.



What Determines Protein Structure?

- In addition to primary structure, physical and chemical conditions can affect structure
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel
- This loss of a protein's native structure is called **denaturation**
- A denatured protein is biologically inactive


Denaturation
Normal protein
Renaturation
Denatured protein

Protein Folding in the Cell

- It is hard to predict a protein’s structure from its primary structure
- Most proteins probably go through several intermediate structures on their way to their final, stable shape
- Scientists use **X-ray crystallography** to determine 3-D protein structure based on diffractions of an X-ray beam by atoms of the crystalized molecule

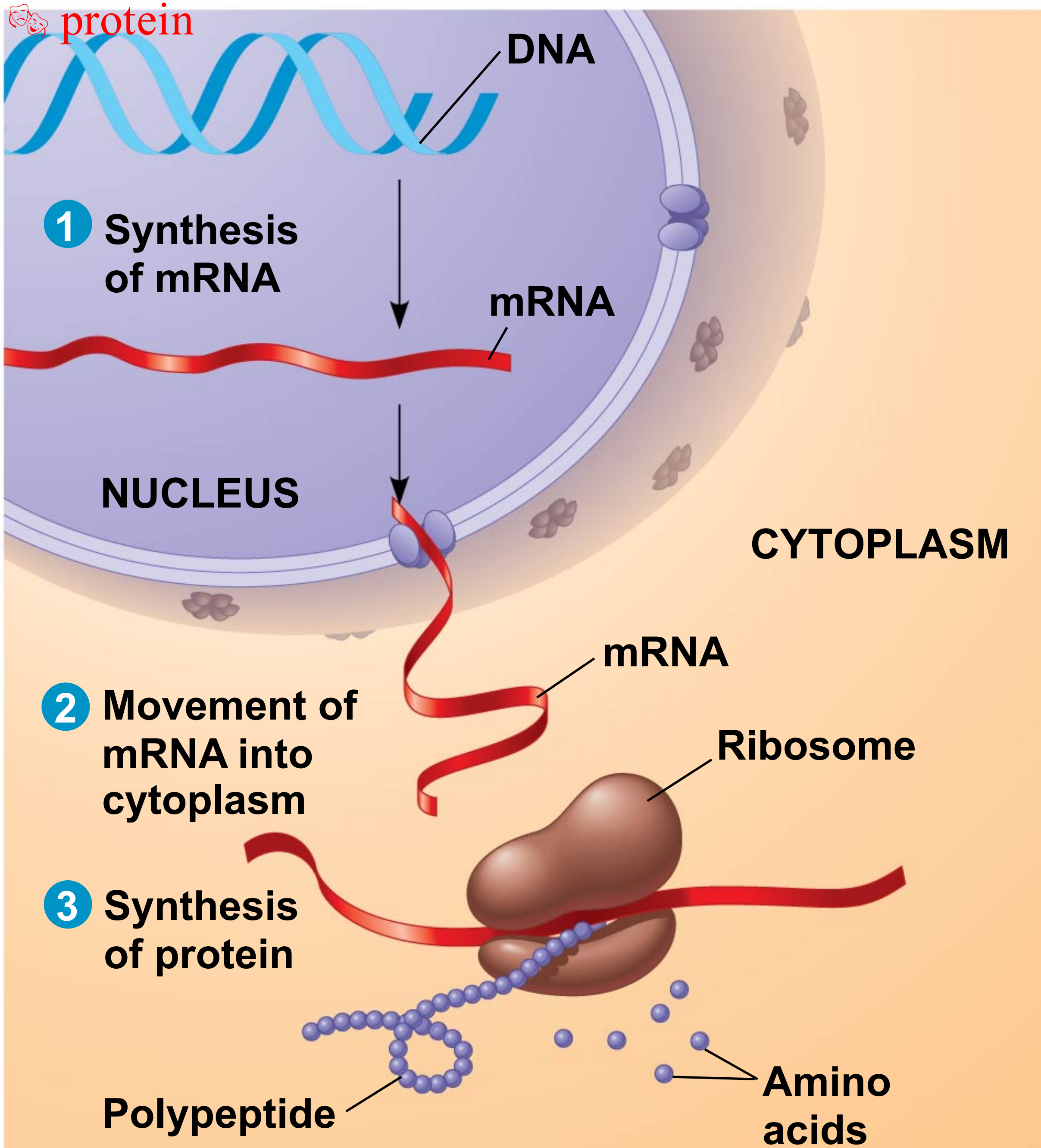
Nucleic acids store, transmit, and help express hereditary information

- The amino acid sequence of a polypeptide is programmed by a unit of inheritance called a **gene**
- Genes are made of DNA, a **nucleic acid** made of monomers called nucleotides

The Roles of Nucleic Acids

- There are two types of nucleic acids
  - **Deoxyribonucleic acid (DNA)**
  - **Ribonucleic acid (RNA)**
- DNA provides directions for its own replication
- DNA directs synthesis of messenger RNA (mRNA) and, through mRNA, controls protein synthesis

DNA 🎭 RNA 🎭 protein

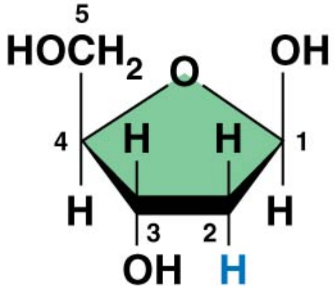


The Components of Nucleic Acids

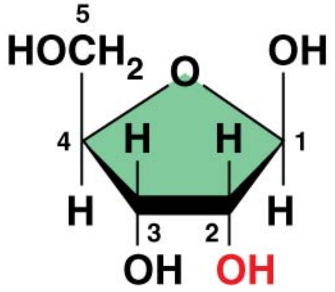
- Nucleic acids are polymers called **polynucleotides**
- Each polynucleotide is made of monomers called **nucleotides**
- Each nucleotide consists of a nitrogenous base, a pentose sugar, and one or more phosphate groups
- The portion of a nucleotide without the phosphate group is called a nucleoside

- The sugar in DNA is **deoxyribose**; in RNA it is **ribose**
- A prime (′) is used to identify the carbon atoms in the ribose, such as the 2′ carbon or 5′ carbon
- A nucleoside with at least one phosphate attached is a nucleotide

Sugars



Deoxyribose (in DNA)

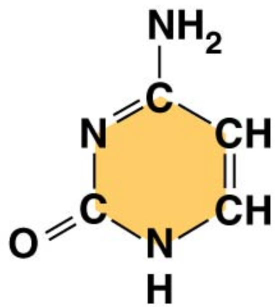


Ribose (in RNA)

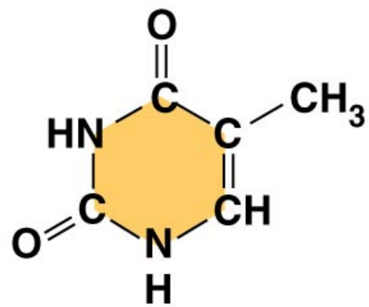
- Each nitrogenous base has one or two rings that include nitrogen atoms
- The nitrogenous bases in nucleic acids are called cytosine (C), thymine (T), uracil (U), adenine (A), and guanine (G)
- Thymine is found only in DNA, and uracil only in RNA; the rest are found in both DNA and RNA

Nitrogenous bases

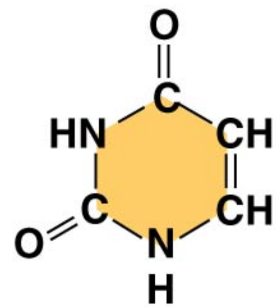
Pyrimidines



Cytosine (C)

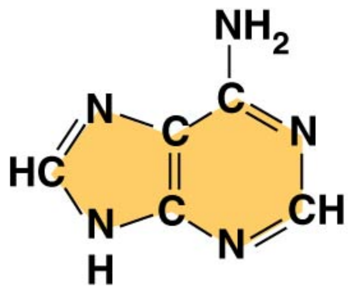


Thymine
(T, in DNA)

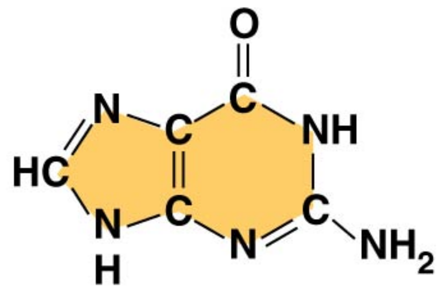


Uracil
(U, in RNA)

Purines



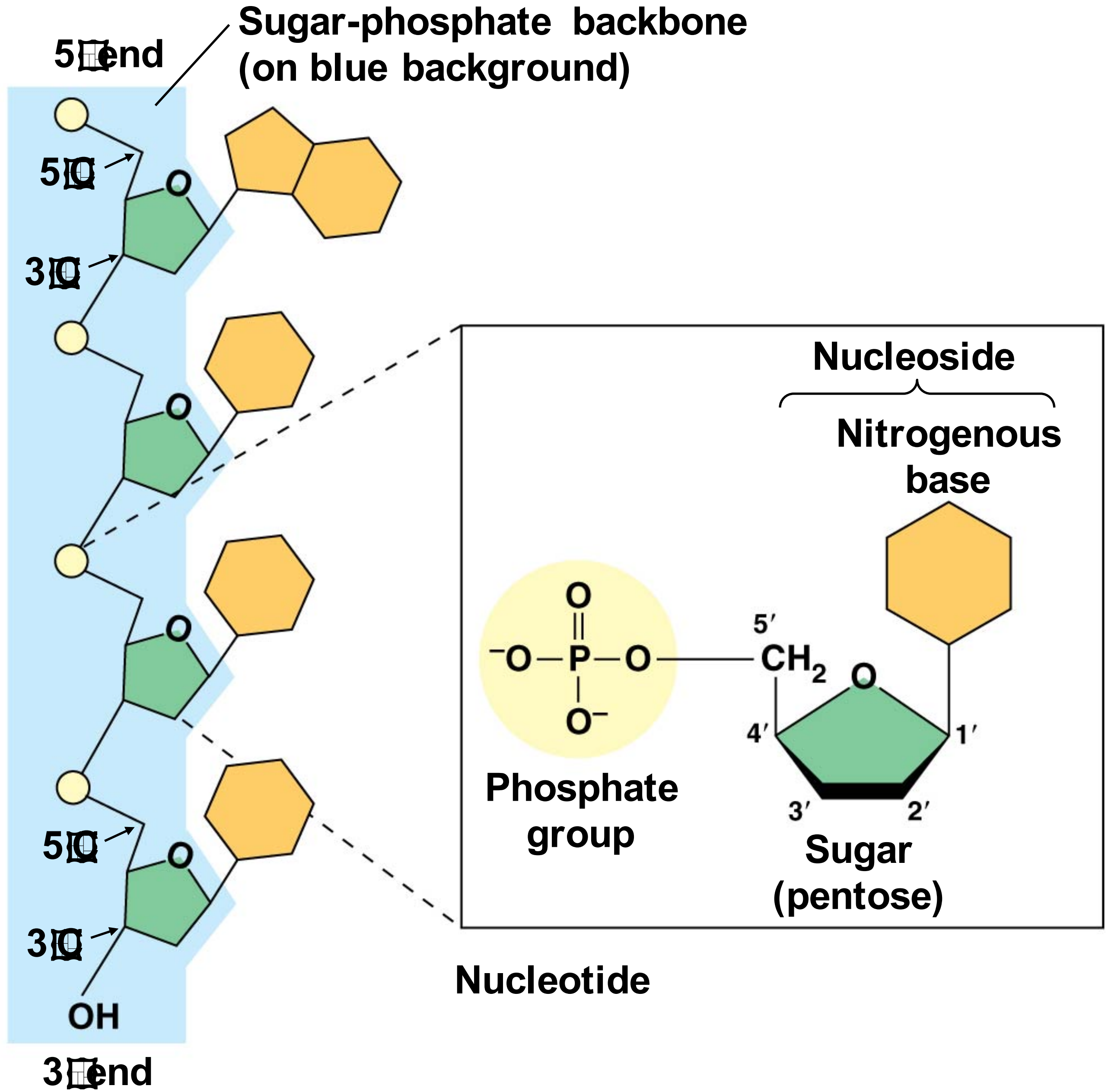
Adenine (A)



Guanine (G)

Nucleotide Polymers

- Adjacent nucleotides are joined by covalent bonds that form between the —OH group on the 3′ carbon of one nucleotide and the phosphate on the 5′ carbon of the next
- These links create a backbone of sugar-phosphate units with nitrogenous bases as appendages
- The sequence of bases along a DNA or mRNA polymer is unique for each gene



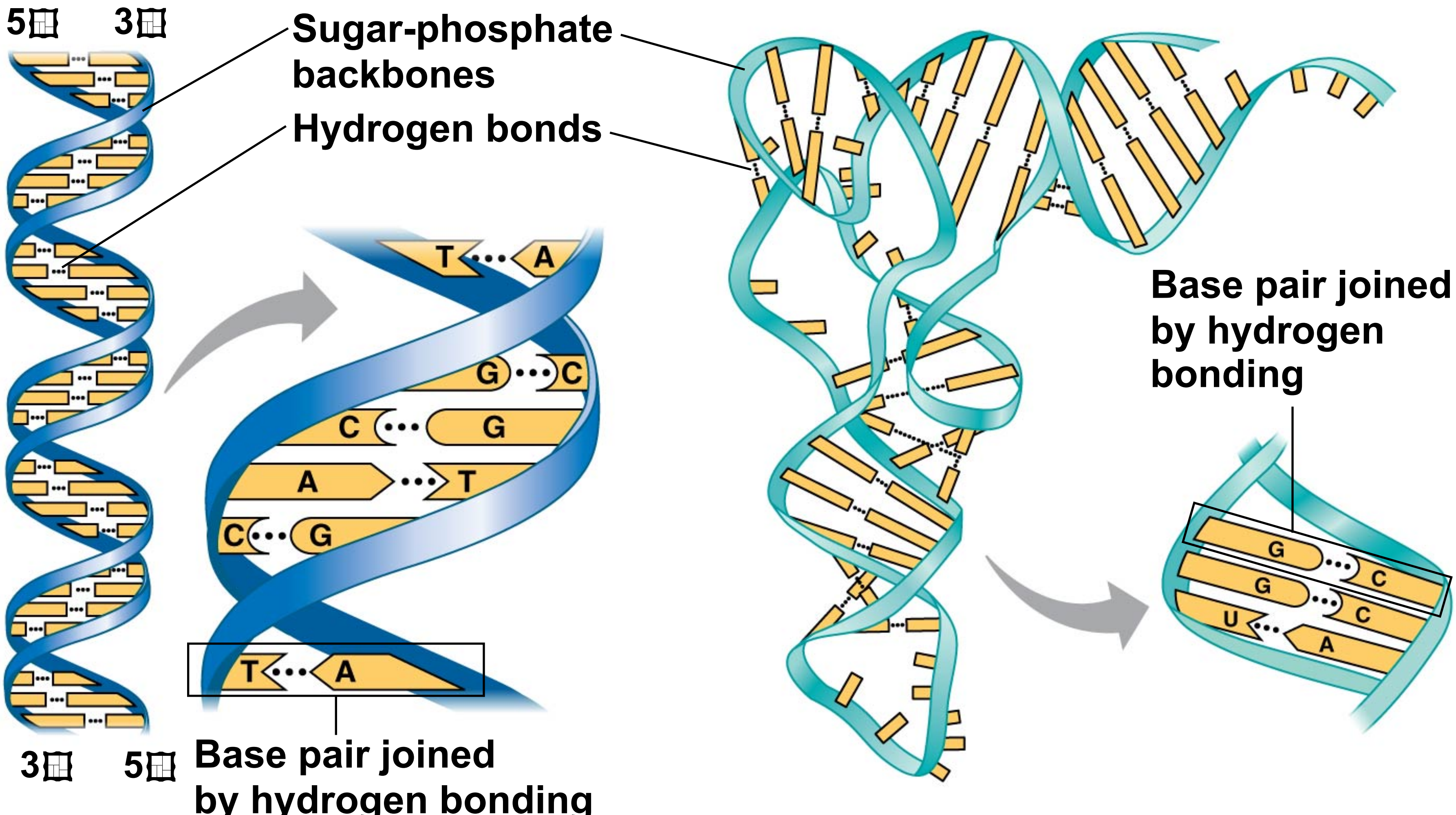
(a) Polynucleotide, or nucleic acid

The Structures of DNA and RNA Molecules

- RNA molecules usually exist as single polypeptide chains
- DNA molecules have two polynucleotides spiraling around an imaginary axis, forming a **double helix**
- In the DNA double helix, the two backbones run in opposite $5' \rightarrow 3'$ directions from each other, an arrangement referred to as **antiparallel**
- One DNA molecule includes many genes

- The nitrogenous bases in DNA pair up and form hydrogen bonds: adenine (A) always with thymine (T), and guanine (G) always with cytosine (C)
- This is called complementary base pairing
- Complementary pairing can also occur between two RNA molecules or between parts of the same molecule
- In RNA, thymine is replaced by uracil (U), so A and U pair

The structures of DNA and tRNA molecules



(a) DNA

(b) Transfer RNA

DNA and Proteins as Tape Measures of Evolution

- The linear sequences of nucleotides in DNA molecules are passed from parents to offspring
- Two closely related species are more similar in DNA than are more distantly related species
- Molecular biology can be used to assess evolutionary kinship

Please indicate your answers to the following Questions and save this document- Review of content and submission of answers will be discussed the first week of class.

The type of bonds present in a molecule determine its properties. Which type of bond is associated with molecules that are soluble in water (i.e., molecules that do not precipitate)?

A. strong ionic bond
B. polar covalent bond
C. nonpolar covalent bond
D. hydrophobic interaction (force between hydrophobic molecules that causes oil to separate from vinegar solutions)

The chemical bonds present in a molecule contribute to the properties of the molecule. Carbon is an unusual atom in that it can form multiple bonds. Which statement is not true?

A. A carbon-to-carbon *cis* double bond is the type found in nature and is associated with cardiovascular health.

B. A carbon-to-carbon *trans* double bond is made artificially in food processing and is associated with poor cardiovascular health.

C. Multiple carbon-to-carbon double bonds located near each other can absorb light, so they are found in molecules in the eye or in chloroplasts.

D. Multiple carbon-to-carbon bonds are stronger than single bonds.

E. Saturated fats are those that have a carbon-to-carbon double bond and are associated with good health.

Silicon (atomic number 14, atomic weight 28) is in the same column as carbon in the periodic table of the elements (Group IV). Why isn't life on Earth based on silicon, instead of carbon?

A. Silicon is far more rare in the Earth's crust than carbon.
B. Silicon cannot form polar covalent bonds with oxygen.
C. Silicon has a different valence than carbon.
D. Silicon compounds often have very different physico-chemical properties than the analogous carbon compounds.

Which polysaccharide has the greatest number of branches?

A. cellulose
B. chitin
C. amylose
D. amylopectin
E. glycogen

Given a chemical formula for an organic molecule (e.g., $C_6H_{12}O_6$), what can one usually deduce?

A. structure

B. its molecular weight

C. its solubility in water

D. all of the above

E. its molecular weight and solubility in water

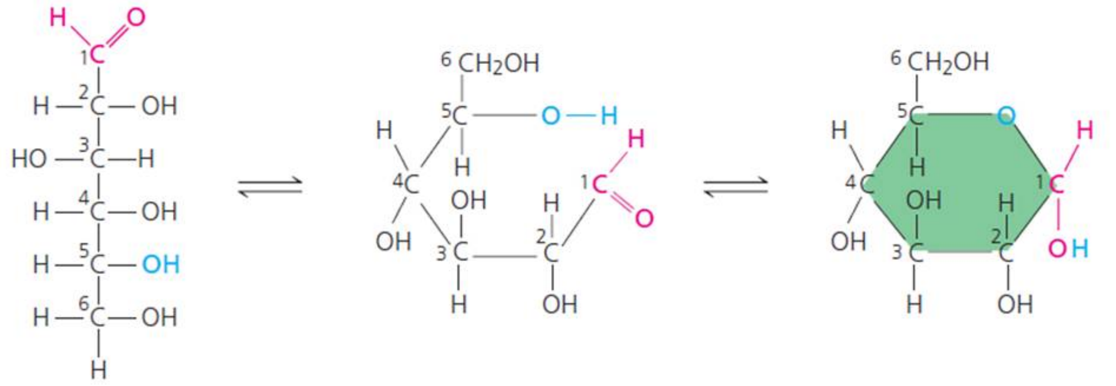
High-glucose diets result in glucose-binding tendon proteins, making them yellow and stiff. Treatment of diabetes and high blood sugar is quantified by measuring the amount of glucose-bound hemoglobin. The reaction involved is the formation of a new bond between the carbonyl group of glucose and the amino group of proteins. Which of the following is true?

A. The linear form of glucose is unhealthy.

B. The ring form of glucose is unhealthy.

C. The —O—H group of proteins is important in this reaction.

D. In blood, the linear form is more common than the ring form.



All lipids

A. are made from glycerol and fatty acids.

B. contain nitrogen.

C. have low energy content.

D. are acidic when mixed with water.

E. do not dissolve well in water.

Sickle-cell disease is caused by a mutation in the beta-hemoglobin gene that changes a charged amino acid, glutamic acid, to valine, a hydrophobic amino acid. Where in the protein would you expect to find glutamic acid?

A. on the exterior surface of the protein
B. in the interior of the protein, away from water
C. at the active site, binding oxygen
D. at the heme-binding site

Which is not a function of proteins?

A. help make up membranes
B. carry the code for translation from the nucleus to the ribosome
C. bind to hormones (hormone receptor)
D. can be hormones
E. speed chemical reactions

How does RNA differ from DNA?

A. DNA encodes hereditary information; RNA does not.
B. DNA forms duplexes; RNA does not.
C. DNA contains thymine; RNA contains uracil.
D. all of the above