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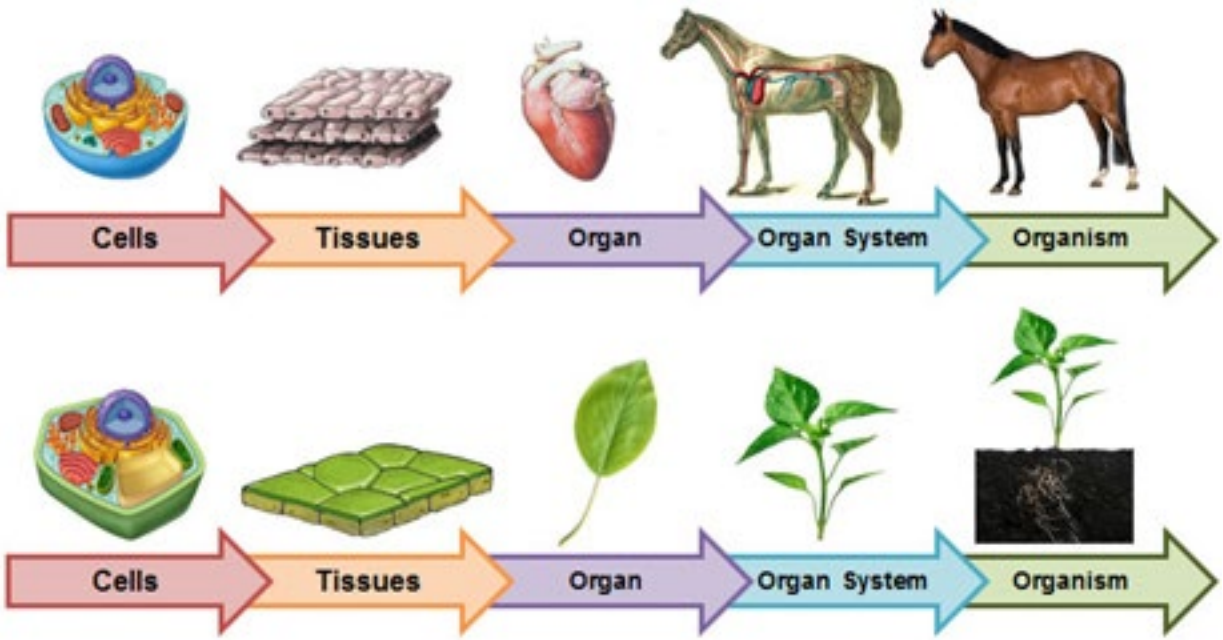


Chemistry of Life

Maxine Mowe

Office at S2-04

dbsmadm@nus.edu.sg

Tel: 65161614

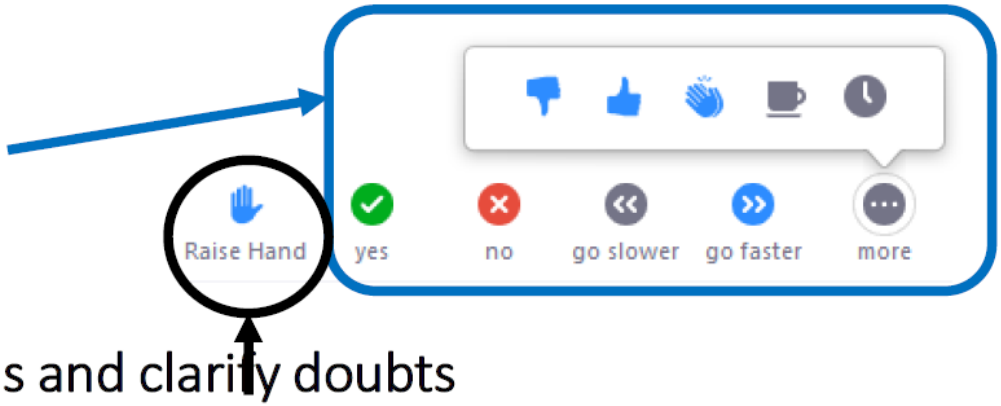
Lecture participation/ asking questions

Before I start...

Please ensure you are muted.

There are several ways you can interact with me during this lecture:

- Non-verbal.



Click on the **participants** icon on the lower bar

- Ask questions and clarify doubts

I will pause at certain points throughout the lecture to address any queries via Q&A

Topics and Assignments

This is a temporary plan, and is subject to change.

- **Introduction (1 Lecture Session)**

- **Dr. NP Lectures/labs/Museum (6 Lects, 2 Labs, 1 Museum, 1 Tutorials)**
  - **Assignments (20%)**

Today

- **Chemistry of Life (1 Lect + 1 Lab)**
  - **Macromolecules and food: Lab Assignment (5%)**
- **Cell Structure and Function (1 Lect + 1 Lab)**
  - **Living Cells: Lab assignment (5%)**
- **Energy and Life (1 Lect + 1 Lab)**
  - **Energy release: Lab Assignment (10%)**
- **DNA and Gene Expression (2 Lect +1 Lab)**
  - **Moelcular Biology: Lab Assignment (10%)**
- **Biotechnology (1 Lect)**

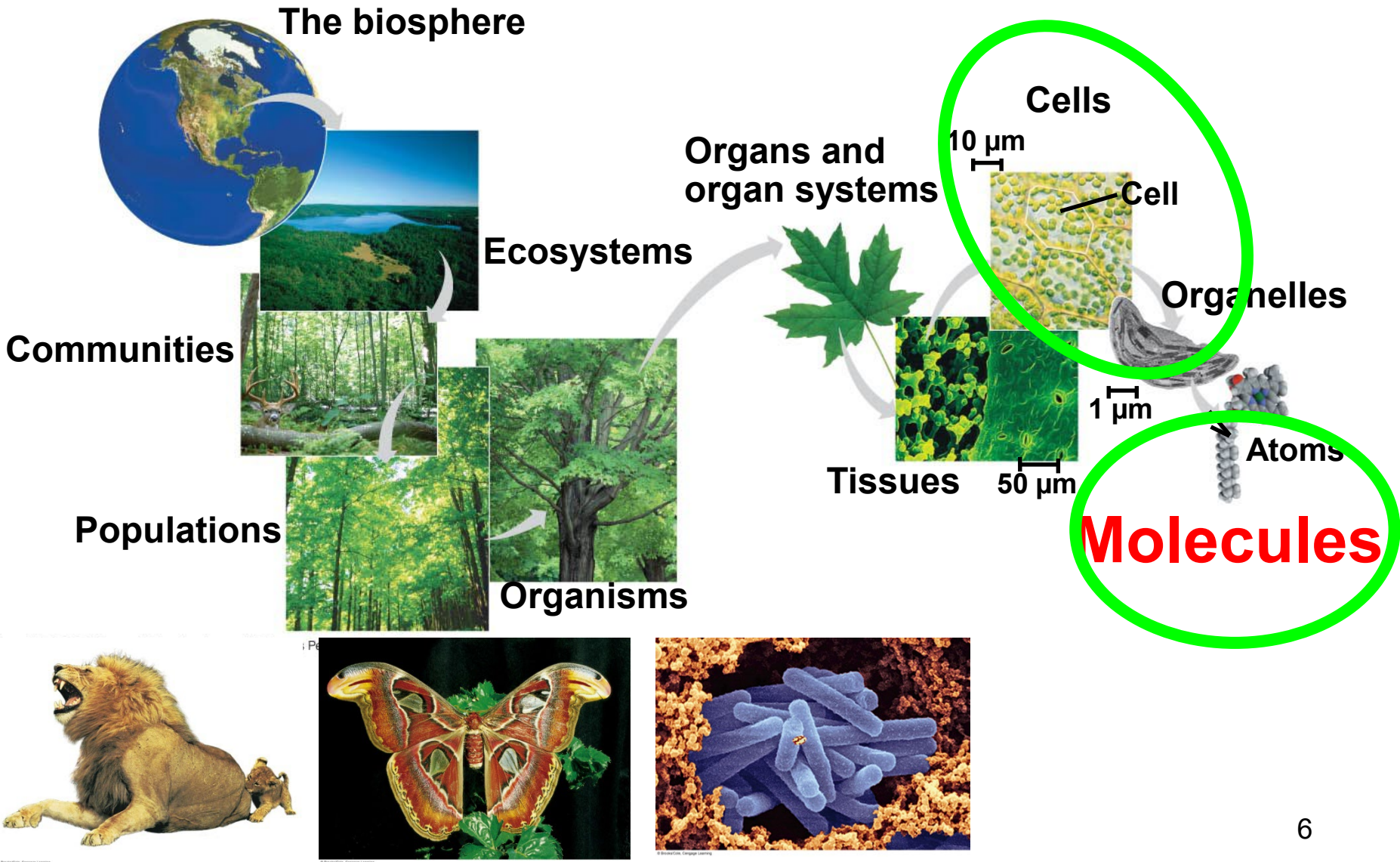
- **Summary & Tutorial (1 Session)**

All lectures are webcasted: https://luminus.nus.edu.sg

Learning Plan (Chemistry of Life)

Topic	Learning outcomes for the WK	Activities for online session	Activities for face-to-face session	Assignments/Assessments
Chemistry of life	• *Explain monomer and polymer, dehydration synthesis and hydrolysis* • *Describe the general structure and function of carbohydrates, lipids and proteins* • *Connect the protein structure with mad cow disease* • *Illustrate phospholipids organisation on cell membranes* • *Compare the structures of cellulose and starch; trans and cis lipids; saturated and unsaturated fats; explain how they function differentially in our daily life*	• *Read lecture notes to know monomer and polymer, dehydration synthesis and hydrolysis* • *Watch video: Carbohydrates https://www.youtube.com/watch?v=M6ZLDJluj6I (9 min)* • *Watch video: Lipids https://www.youtube.com/watch?v=VGHD9e3yRIU (8 min)* • *Write down key points learnt from video on the relevant part of lecture note*	• *Discuss differences of starch, cellulose and glycogen, and how they related to their functions.* • *Demonstration how assignment questions are linked to online and f2f learning.* • *Demonstrate how lipids (trans and cis) affect our daily life to enhance learning* • *Discuss the differences between lipids, fats and oils (triglycerides)* • *Focus on protein compositions, structures and functions* • *Illustrate how structure and function are associated using mad cow disease as an example*	• *Track Learning questions will be given (MCQs).*

Chemistry of Life



Outline

- Organic Molecules
  - Functional groups
  - Synthesis and breakdown
- Carbohydrates
  - Monosaccharides
  - Oligosaccharides
  - Polysaccharides
- Proteins
  - Amino acids
  - Protein structure
- Lipids
  - Triglycerides
  - Phospholipids
  - Waxes
  - Steroids

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  - Phospholipids
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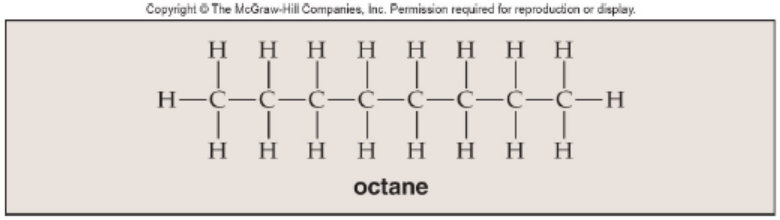
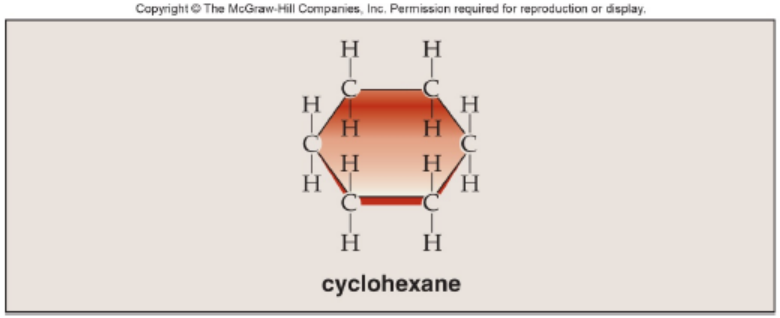
  - Steroids

Organic Molecules

- Contain both carbon and hydrogen atoms
  - Linked by covalent bonds
  - May also be bonded to other atoms
- Each carbon atom
  - Able to bond with up to four other atoms
  - By single, double or triple bonds
- Carbon atoms
  - Able to form chains or rings

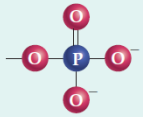
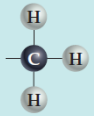




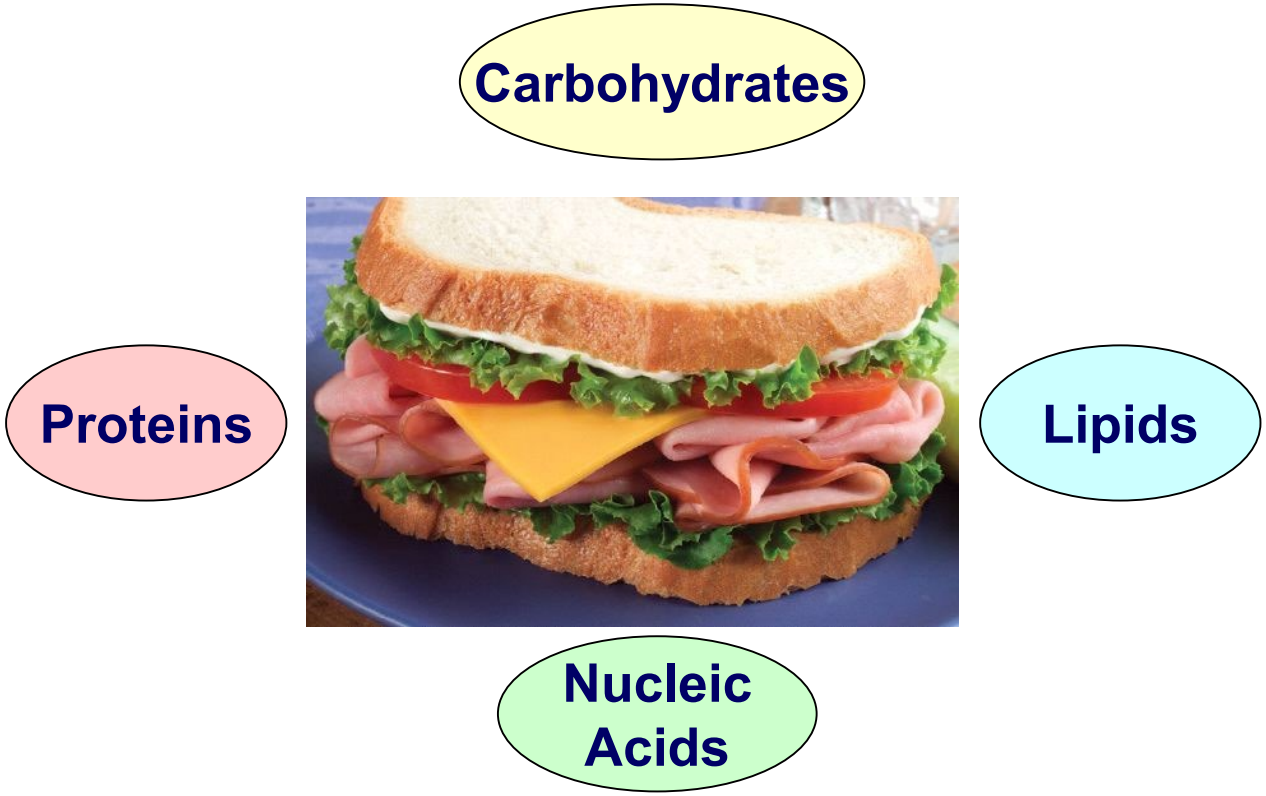
Functional groups

- Clusters of atoms linked to carbon skeleton
- Confer specific chemical properties to molecules
  - Reactivity
  - Polarity

TABLE 3-1 Important Functional Groups in Biological Molecules

Group	Structure	Properties	Found In
Hydroxyl		Polar; involved in dehydration and hydrolysis reactions; forms hydrogen bonds	Sugars, polysaccharides, nucleic acids, alcohols, some amino acids, steroids
Carbonyl		Polar; makes parts of molecules hydrophilic (water soluble)	Sugars (linear forms), steroid hormones, peptides and proteins, some vitamins
Carboxyl (ionized form)		Polar and acidic; the negatively charged oxygen may bond H^+, forming carboxylic acid (—COOH); involved in peptide bonds	Amino acids, fatty acids, carboxylic acids (such as acetic and citric acids)
Amino		Polar and basic; may become ionized by binding a third H^+; involved in peptide bonds	Amino acids, nucleic acids, some hormones
Sulfhydryl		Nonpolar; forms disulfide bonds in proteins	Cysteine (an amino acid), many proteins
Phosphate (ionized form)		Polar and acidic; links nucleotides in nucleic acids; forms high-energy bonds in ATP (ionized form occurs in cells)	Phospholipids, nucleotides, nucleic acids
Methyl		Nonpolar; may be attached to nucleotides in DNA (methylation), changing gene expression	Steroids, methylated nucleotides in DNA

The Four Types of Organic Molecules



1. A molecule that is normally found in or produced by living systems.

2. A molecule that typically consists of carbon atoms in rings or long chains, where other atoms (e.g. hydrogen, oxygen, and nitrogen) are attached.

How can life arise from non-life?

One important aspect of Chemistry of Life

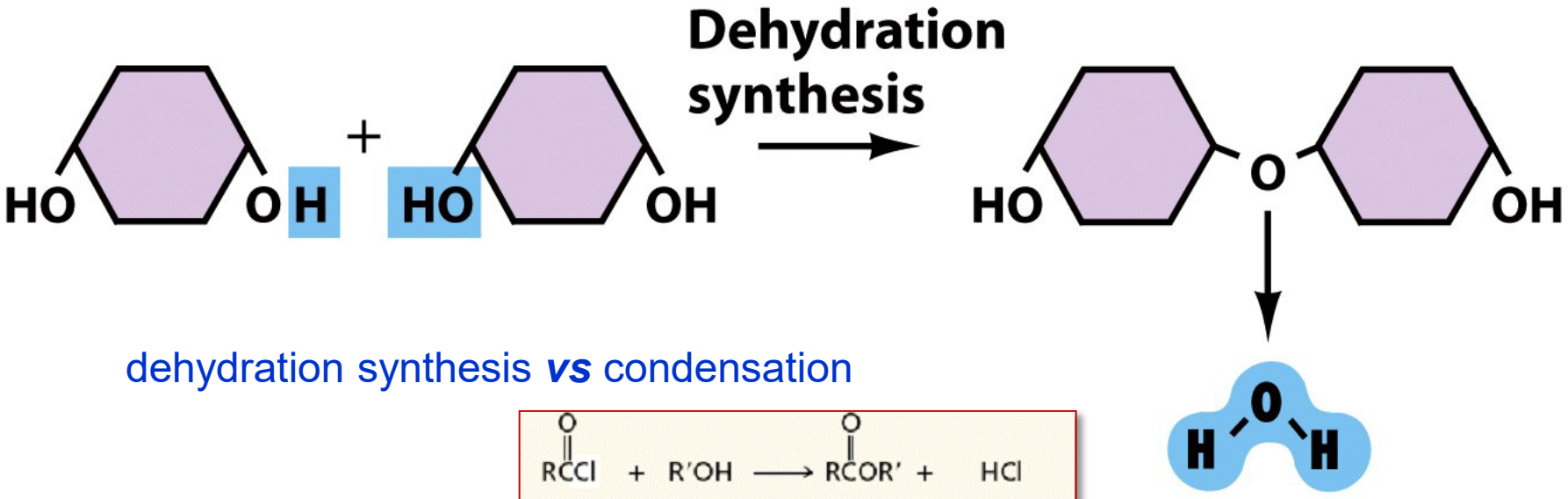
https://www.youtube.com/watch?v=dySwrhMQdX4

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**
- Three of the four classes of life's organic molecules are polymers:
  - Carbohydrates
  - Proteins
  - Nucleic acids

Synthesis of Polymers

- Monomers are joined together through **dehydration synthesis**
  - An H and an OH are removed, resulting in the loss of a water molecule (H_2O)



dehydration synthesis ***vs*** condensation

Figure 3-1 Biology: Life on Earth, 8/e

Breakdown of Polymers

- Polymers are broken apart through **hydrolysis** ("*splitting water*" in Greek)
  - Water is broken into H and OH and used to break the bond between monomers

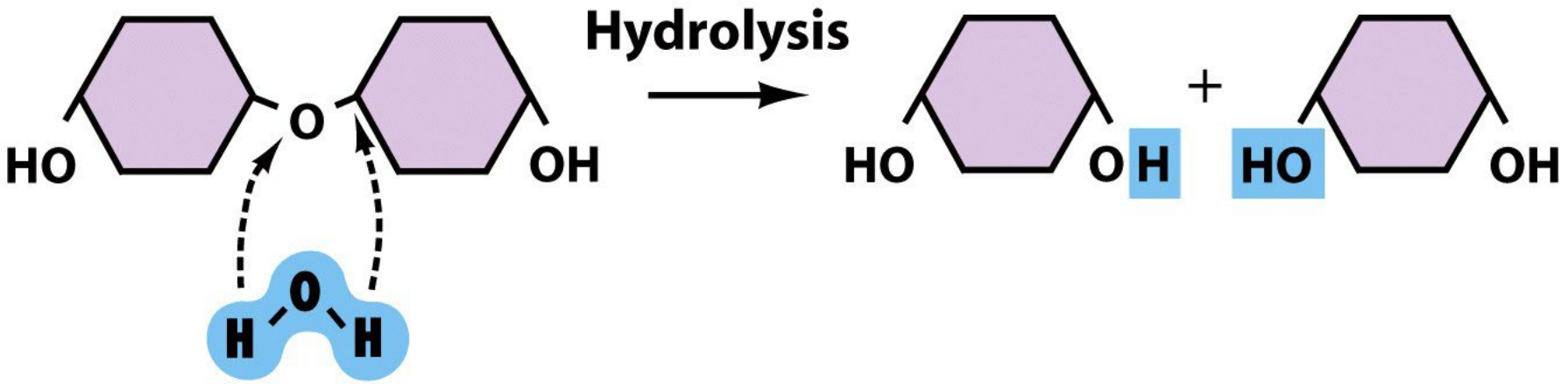


Figure 3-2 Biology: Life on Earth, 8/e

Outline

- Organic Molecules
  - Functional groups
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- Carbohydrates
  - Monosaccharides
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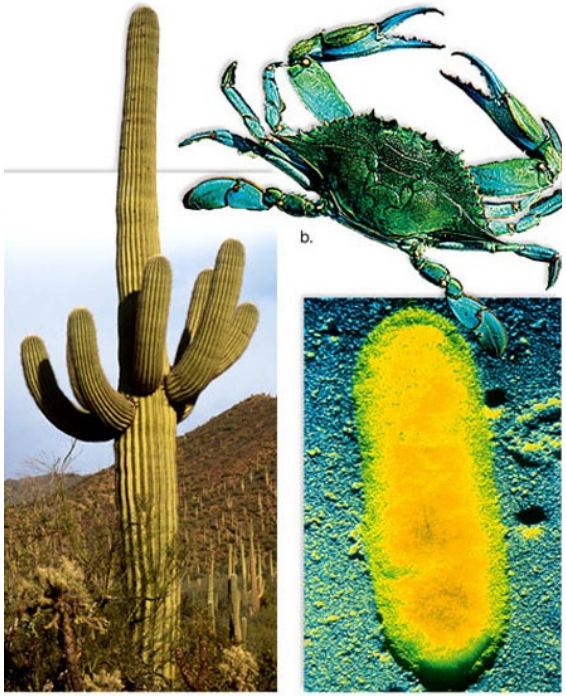
  - Polysaccharides
- Proteins
  - Amino acids
  - Protein structure
- Lipids
  - Triglycerides
  - Phospholipids
  - Waxes
  - Steroids

Carbohydrates

Charles D. Winters/Photo Researchers.



What are they? Why do we need them?

Carbohydrates

Composition

- C, H, and O in ratio of 1:2:1
- Chemical formula $(CH_2O)_n$ "Carbon + Water"

  n is the number of carbons in the backbone

- Single sugar – monosaccharide
- Two sugars – disaccharide
- Several (3-10) sugars – oligosaccharide
- Many sugars – polysaccharide

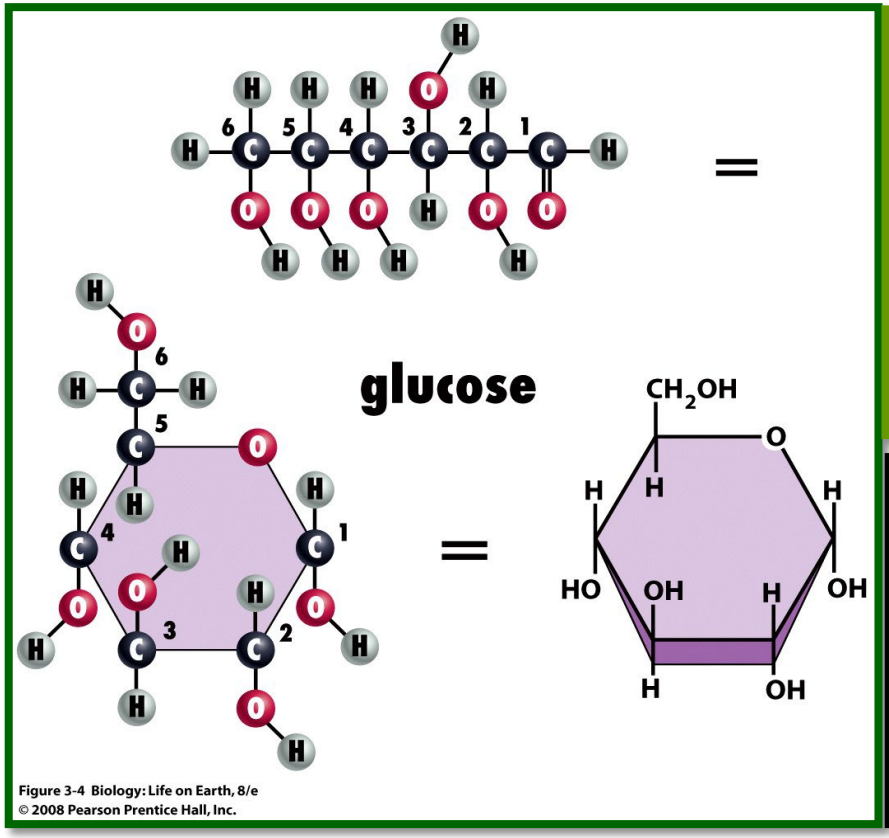
Function

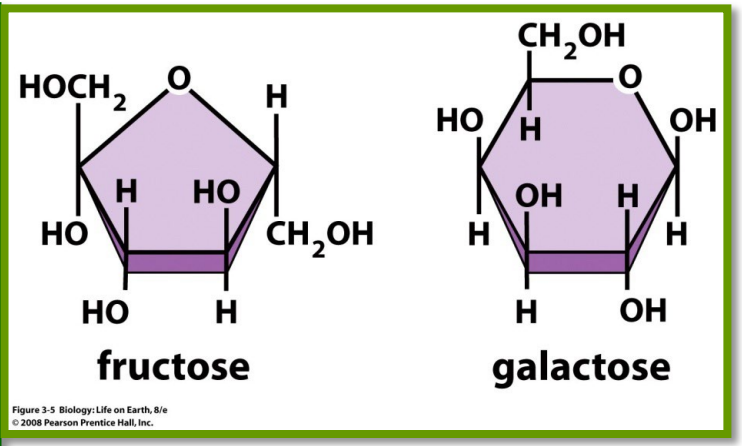
- Energy source and structural support

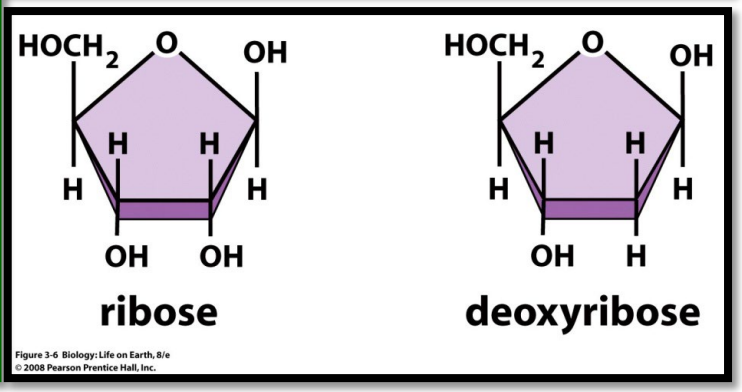
Monosaccharides

- **Single sugar molecule**
  - E.g. Glucose (blood sugar), ribose, deoxyribose
- Most have 5- or 6-carbon backbone
  - 5-carbon sugars – pentoses
  - 6-carbon sugars – hexoses
- Usually in ring form in cells
- Soluble in water
- Most have a distinctly sweet taste.

Monosaccharides



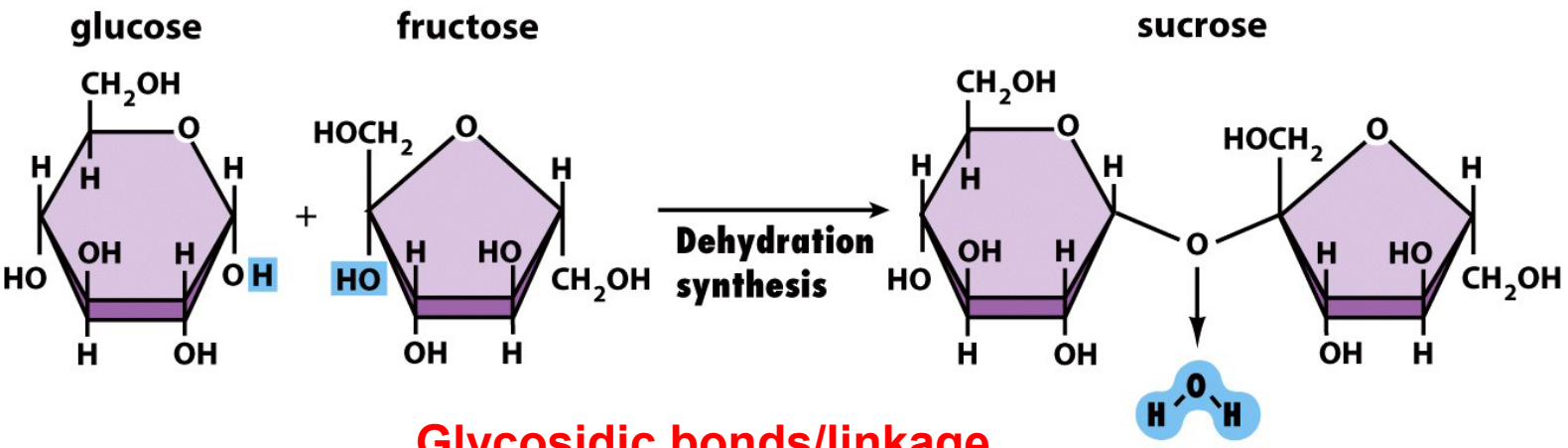




Isomers: are molecules with the same molecular formula, but different arrangements of atoms.

http://faculty.lacitycollege.edu/boanta/LAB102/Organic%20Isomers.htm

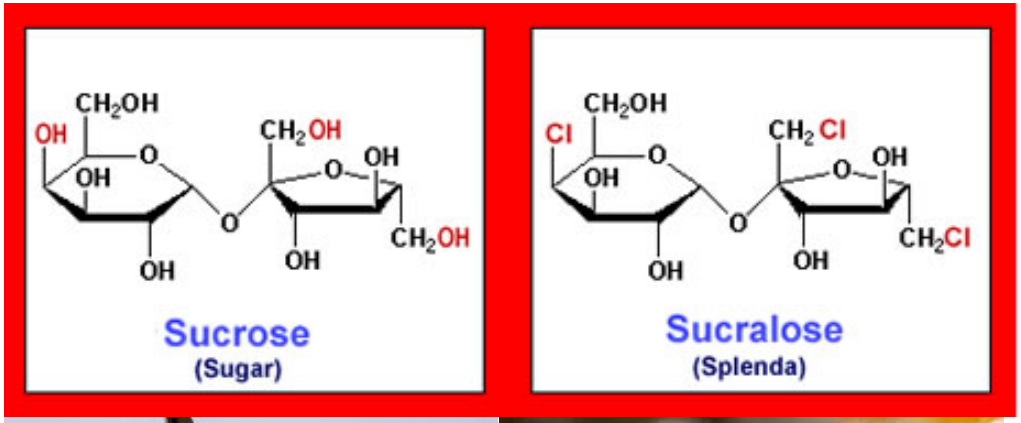
Disaccharides



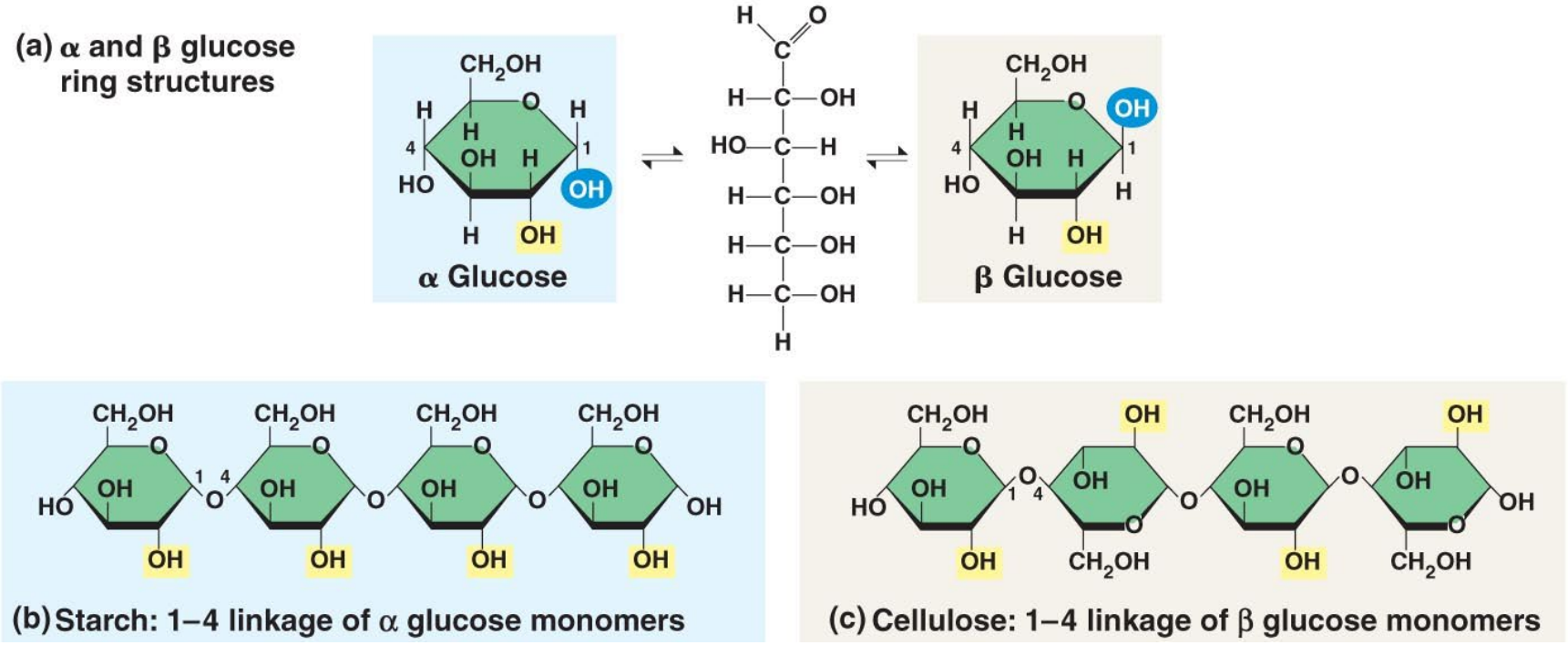
Glycosidic bonds/linkage

- Sucrose (table sugar) = glucose + fructose
- Lactose (milk sugar) = glucose + galactose
- Maltose (malt sugar) = glucose + glucose

Case study: Natural sugar *vs* Artificial sugar



Polysaccharides



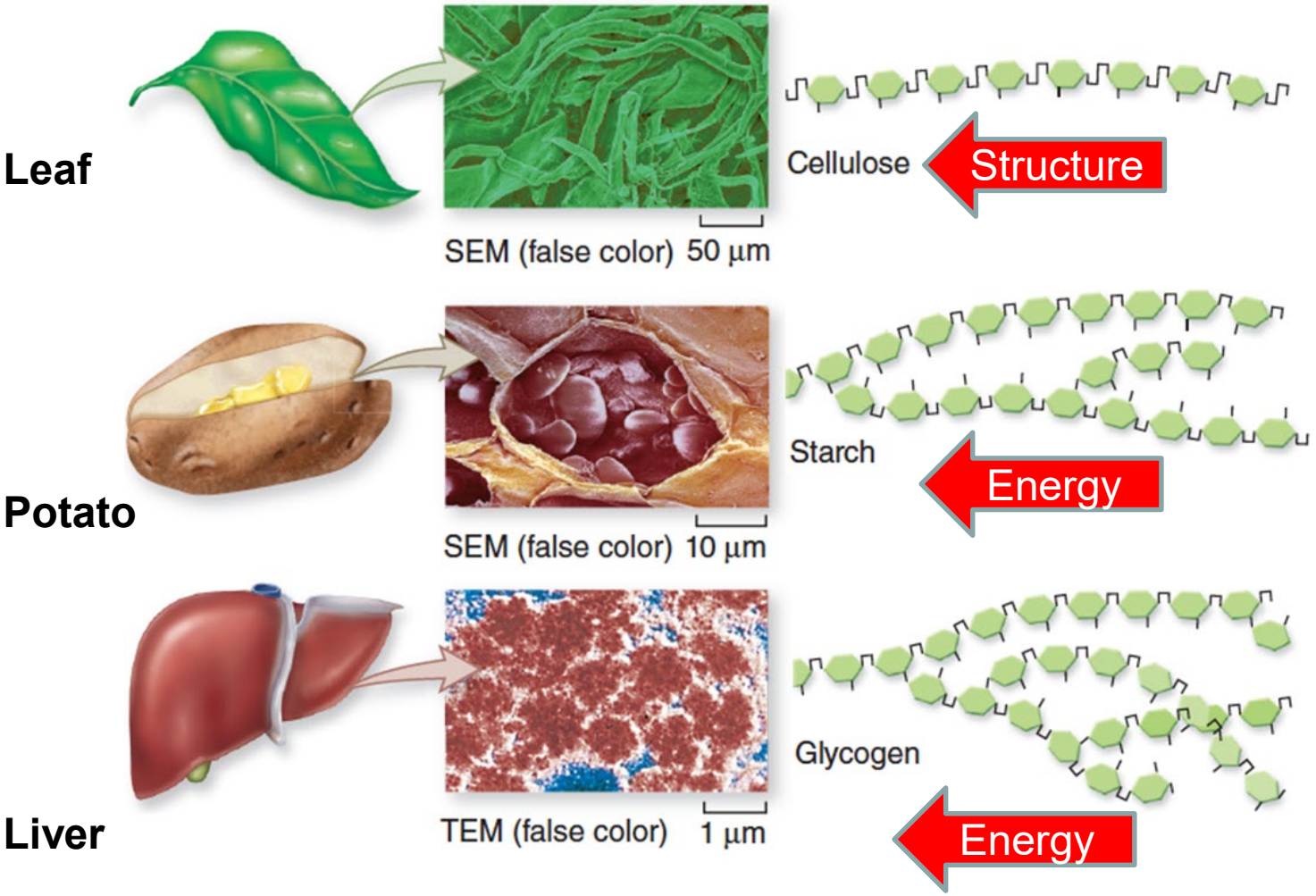
The designation ‘α’ means that the hydroxyl group attached to C-1 and the -CH_2OH group at C-5 lies on opposite sides of the ring's plane (a trans arrangement), while 'β' means that they are on the same side of the plane (a cis arrangement).

Dual view for comparison of α glucose and β glucose

http://www.biotopics.co.uk/JmolApplet/alphabetajglucose2.html

Polysaccharides

Polysaccharides are long chains of carbohydrates.

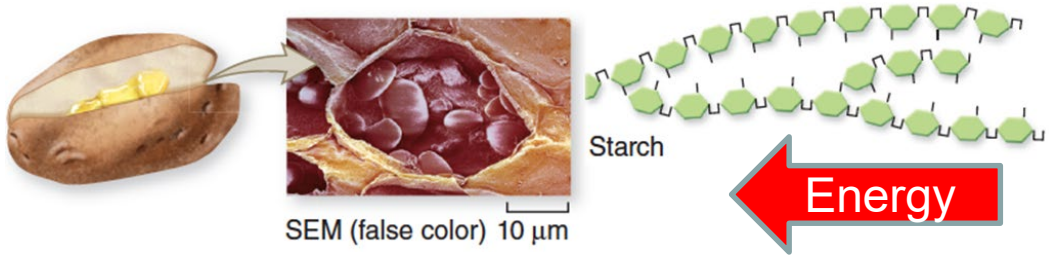


Polysaccharides

Starches

- Starches hydrolyze easily in water and acid to give smaller saccharides: Dextrins
- Hydrolyze to maltose and finally glucose
- In our bodies, these complex carbs are digested by the enzymes amylase in saliva and maltase in the intestine

Potato

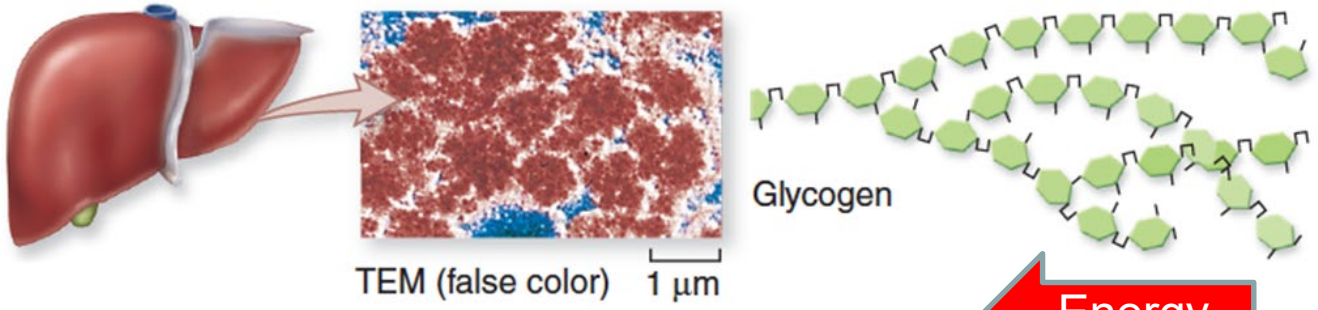


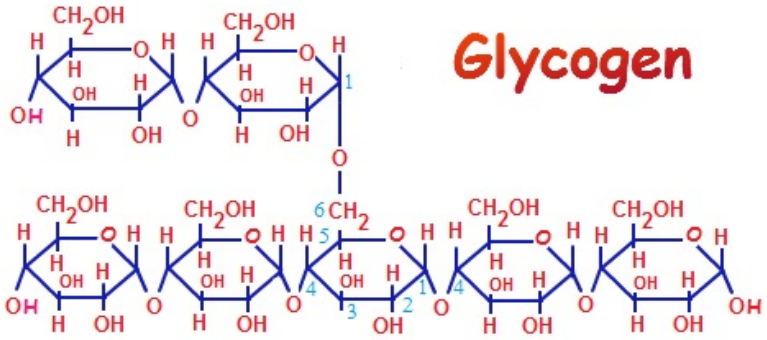
Polysaccharides

Glycogen

- Animal starch, polymer of glucose that is stored in the liver and muscle of animals
- It is hydrolyzed in our cells and maintains the blood level of glucose and provides energy between meals
- In glycogen, the glucose units are joined by alpha 1,4 glycosidic bond (linkage): highly branched.

Liver

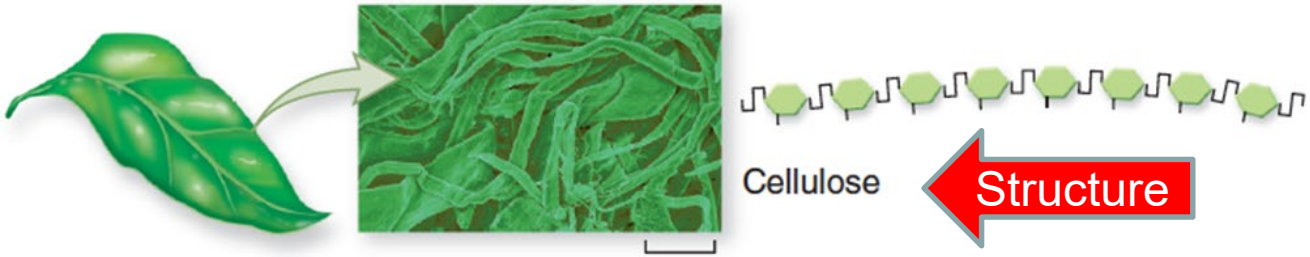


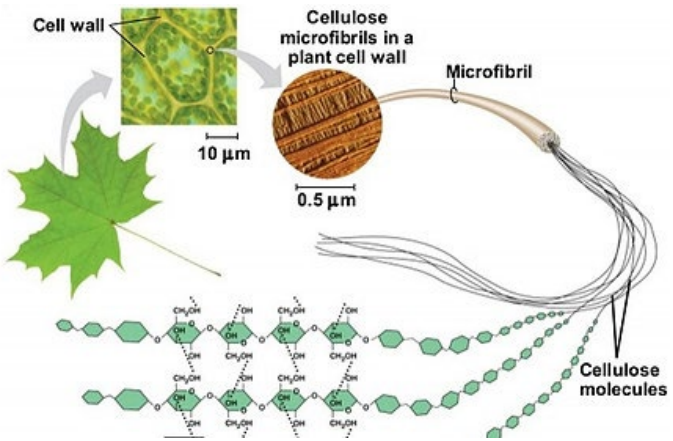


Polysaccharides

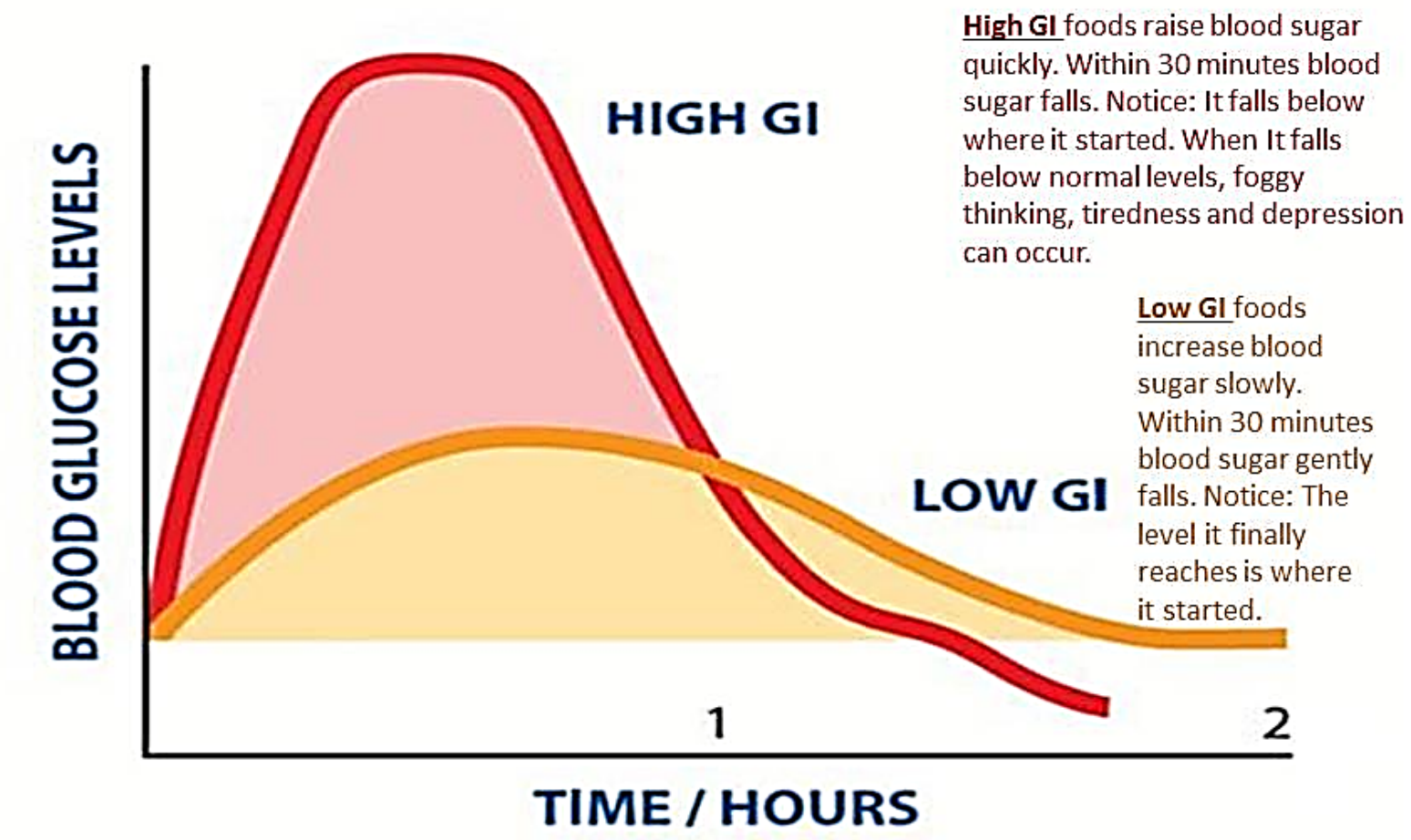
Cellulose

- Major structural material of wood and plants, cotton
- In cellulose, glucose molecules form a long, unbranched chain, however the glucose units in cellulose are linked by beta-1,4 glycosidic bonds (linkage)
- Cellulose chains are aligned in parallel rows held in place by hydrogen bonds between hydroxyl groups in adjacent chains, making cellulose insoluble in water--this gives a rigid structure to the cell walls in wood and fiber that is more resistant to hydrolysis compared to starch





Case study: Glycemic Index



http://lowglycemichappiness.com/Glycemic-Index-chart.html

Further learning: https://www.youtube.com/watch?v=Zpb2VHgjCQs

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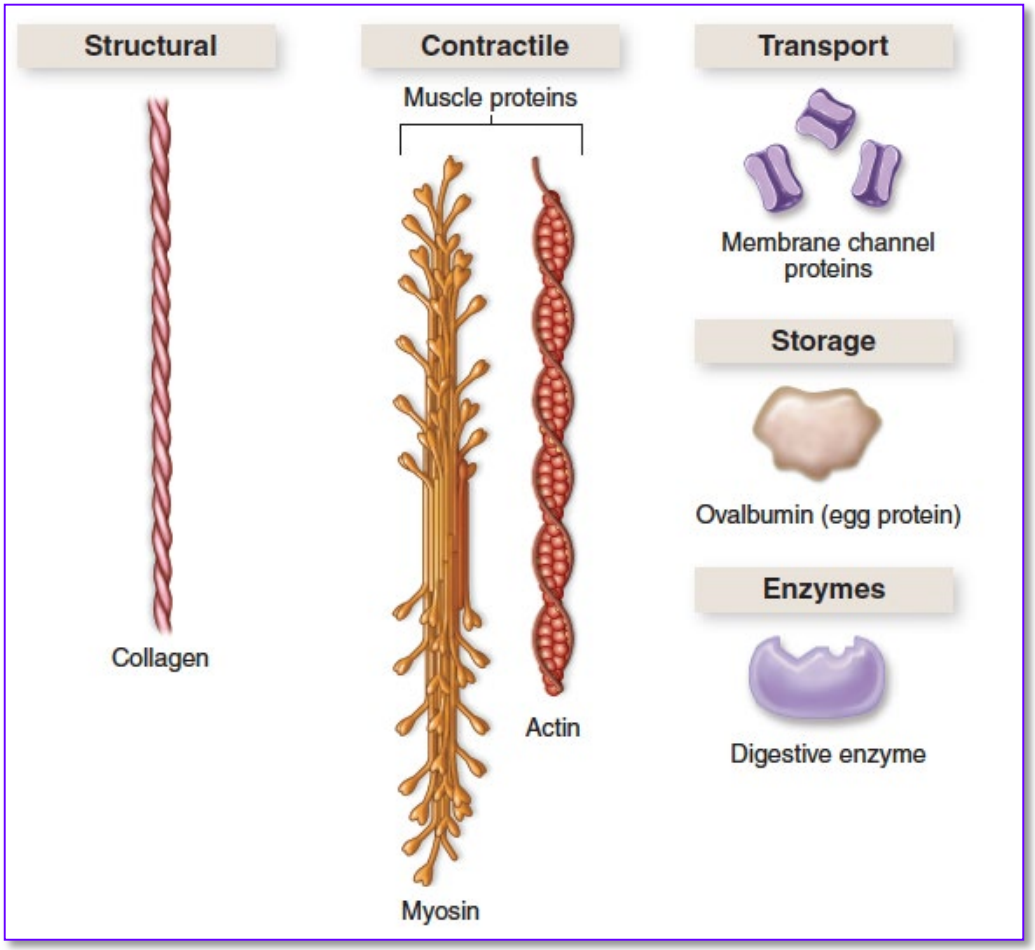
- Lipids
  - Triglycerides
  - Phospholipids
  - Waxes
  - Steroids

Proteins

Proteins
are polymers com
posed of building
blocks called
amino acids.

They have more variable structures and functions than any of the other organic molecules.



Spider silk, hemoglobin, keratin in your nails and hair, actin and myosin in muscle fibers – all these are proteins.

TABLE 3-3 Functions of Proteins

Function	Example(s)
Structural	Keratin (forms hair, nails, scales, feathers, and horns); silk (forms webs and cocoons)
Signaling	Insulin (secreted by the pancreas; promotes glucose uptake into cells)
Catalyzing reactions	Amylase (found in saliva and the small intestine; digests carbohydrates)

(a) Hair

(b) Horn

(c) Silk

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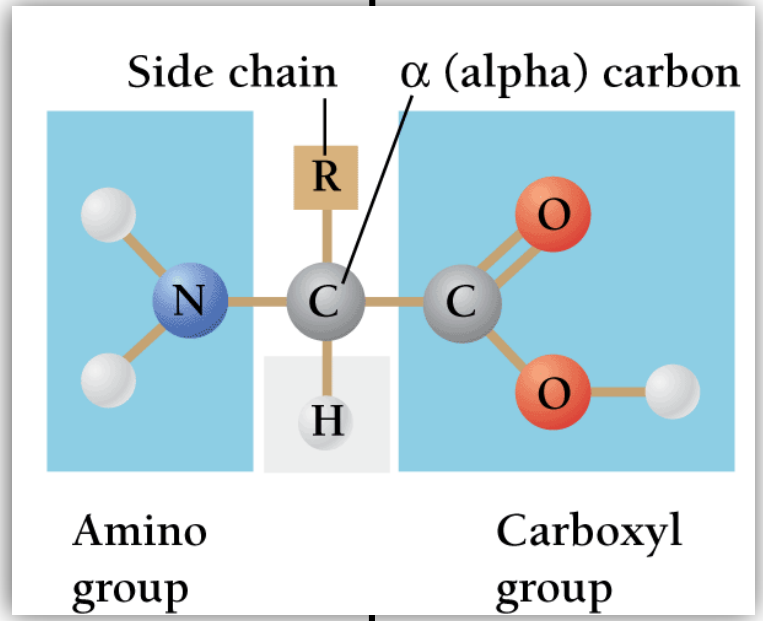
(b) Horn

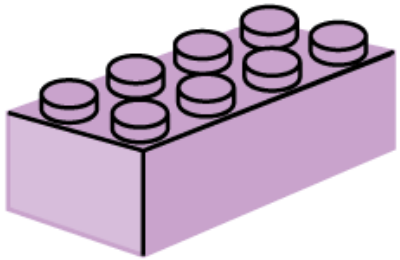
(c) Silk

Amino Acids

Central Carbon

- Hydrogen
- Amino
- Carboxyl
- "R"





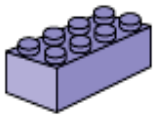
Polypeptide Chains

Proteins

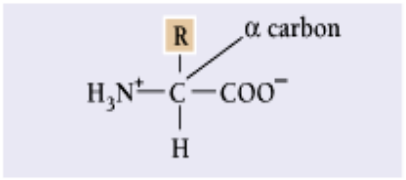
Amino Acids

- Subunits of proteins
- 20 different amino acids that make up proteins
- Structure
  - One central carbon (C_α) atom
  - One hydrogen atom
  - One amino ($-NH_2$) group
  - One carboxyl ($-COOH$) group
  - One "R" group, variable group
- "R" groups differ from one amino acid to another
  - 20 different types of "R" groups

AMINO ACIDS



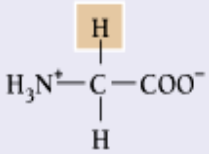
Amino acid



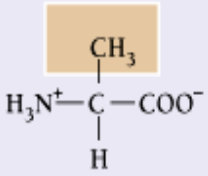
Essential amino acids

Amino acids with nonpolar side chains

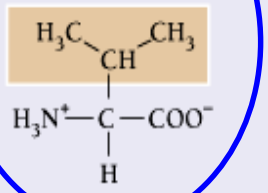
Glycine



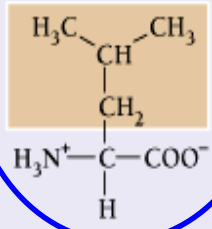
Alanine



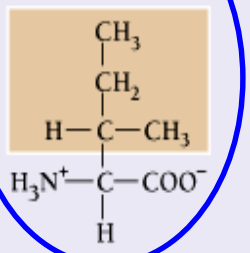
Valine



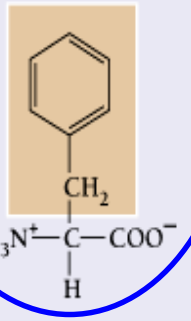
Leucine



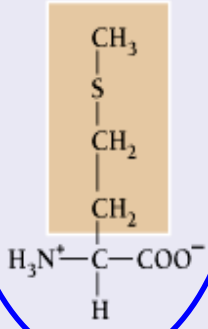
Isoleucine



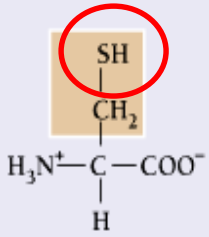
Phenylalanine



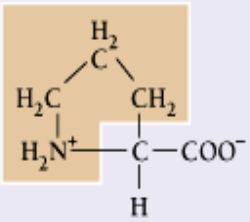
Methionine



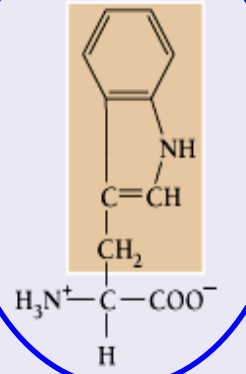
Cysteine



Proline



Tryptophan



Sulfhydryl group to produce disulfide linkages (-S-S-)

Case study: Curly hair

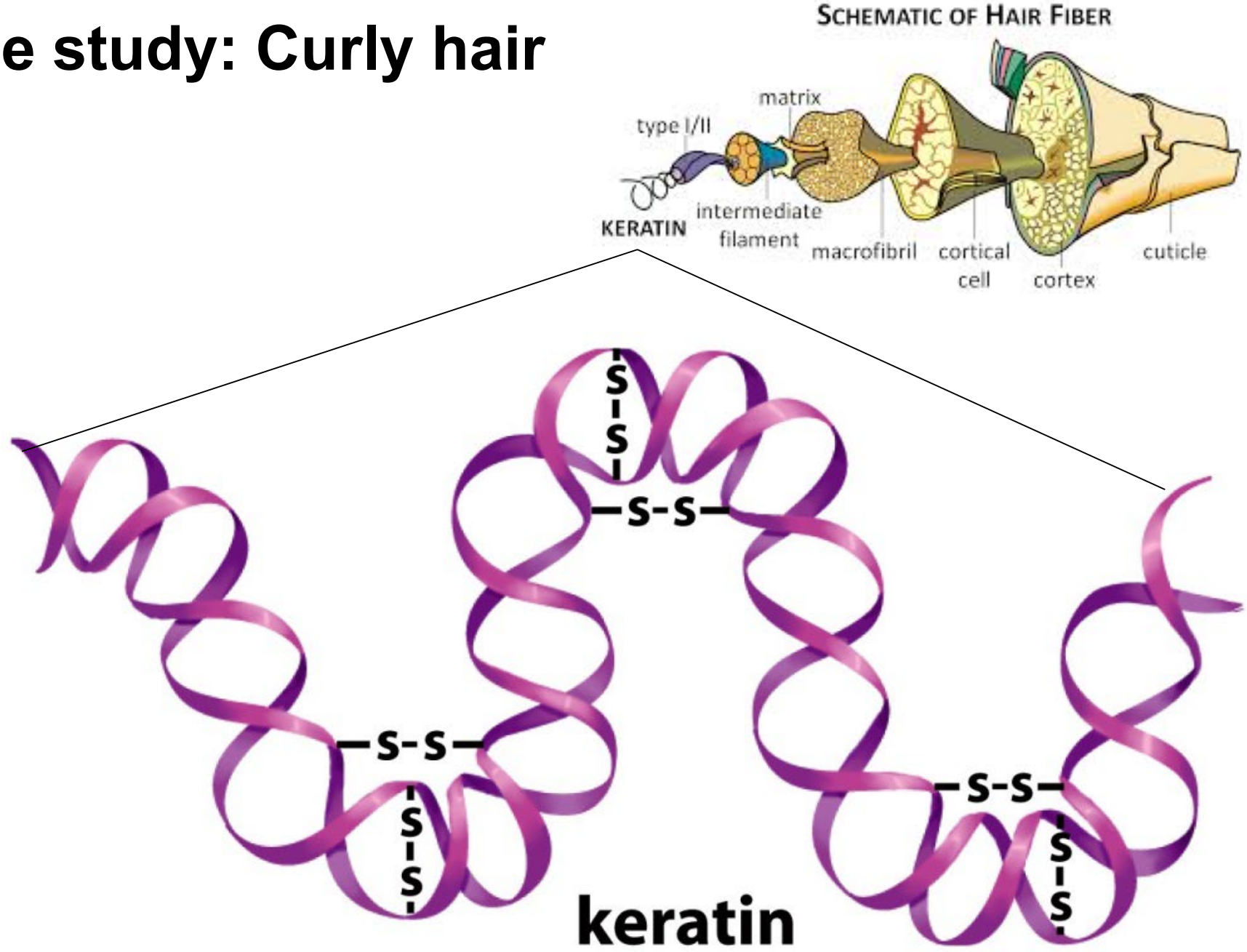
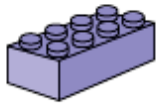
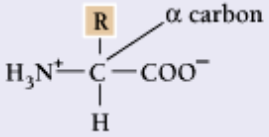


Figure 3-23 Biology: Life on Earth, 8/e

AMINO ACIDS

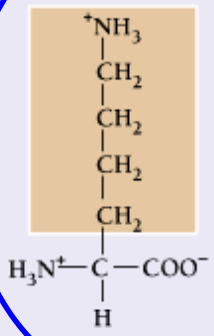


Amino acid

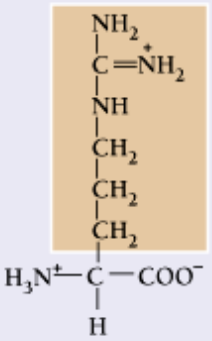


Amino acids with basic side chains

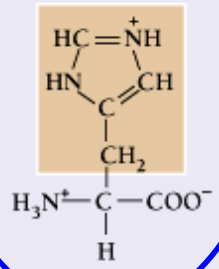
Lysine



Arginine

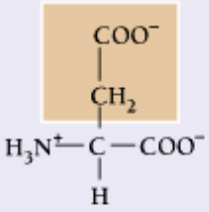


Histidine

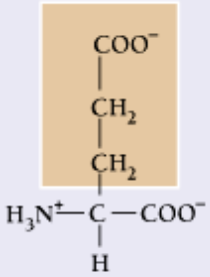


Amino acids with acidic side chains

Aspartic acid

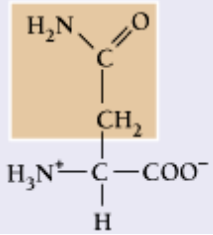


Glutamic acid

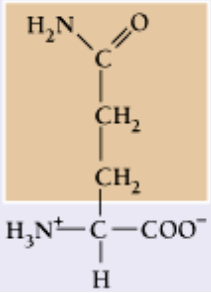


Amino acids with polar uncharged side chains

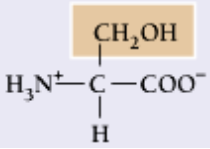
Asparagine



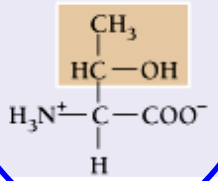
Glutamine



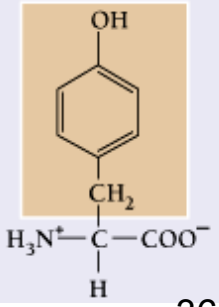
Serine



Threonine

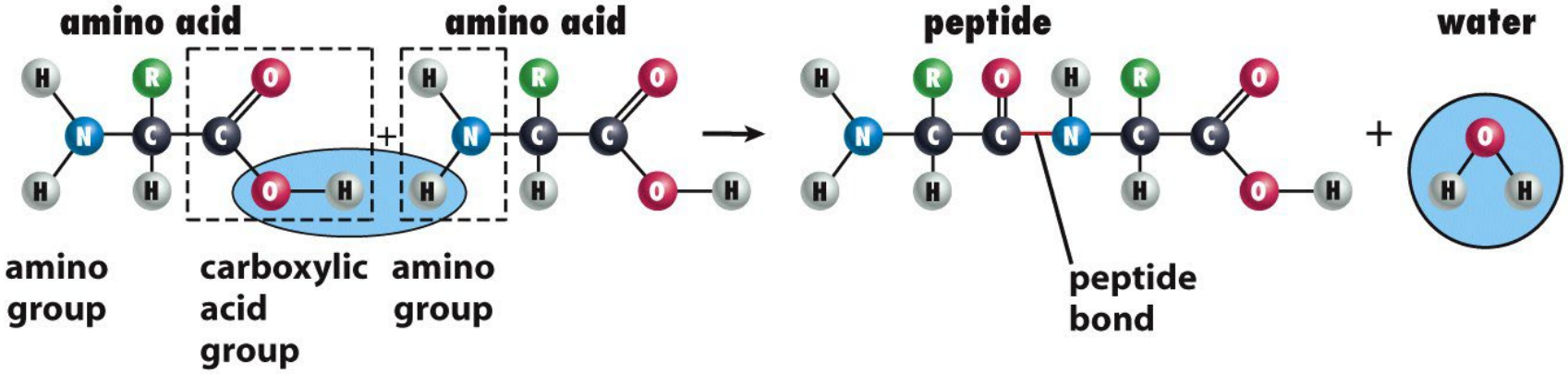


Tyrosine



Protein Synthesis

- Joined by condensation
  - Carboxyl (–COOH) group of one amino acid with amino ($–NH_2$) group of the next amino acid
  - H_2O formed as by-product
- Result in peptide bond



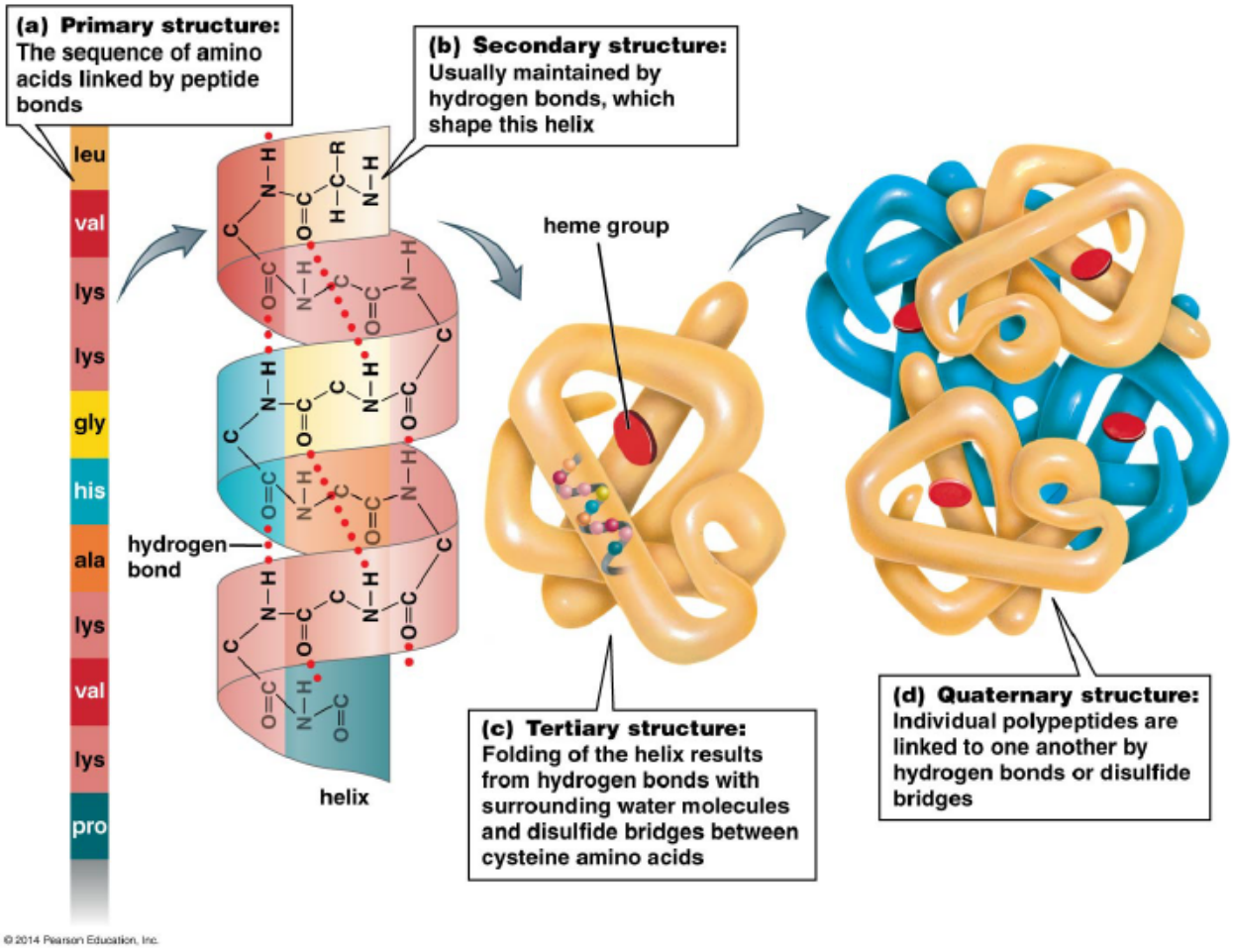
an amino end **(N-terminus**) and a carboxyl end **(C-terminus).**

Protein Structure

Four levels of protein structure

1. Primary – consists of a linear sequence of amino acids linked together by peptide bonds (a polypeptide chain)
2. Secondary – the chain twists into a coil (helix), or a pleated sheet held by **hydrogen bonds**
3. Tertiary – refers to complex foldings of the protein chain held together by **hydrogen bonds**, **disulfide bridges**, and other bonds
4. Quaternary – in which two or more *multiple* polypeptide chains associate as linked together by hydrogen bonds or disulfide bridges.

Protein Structure

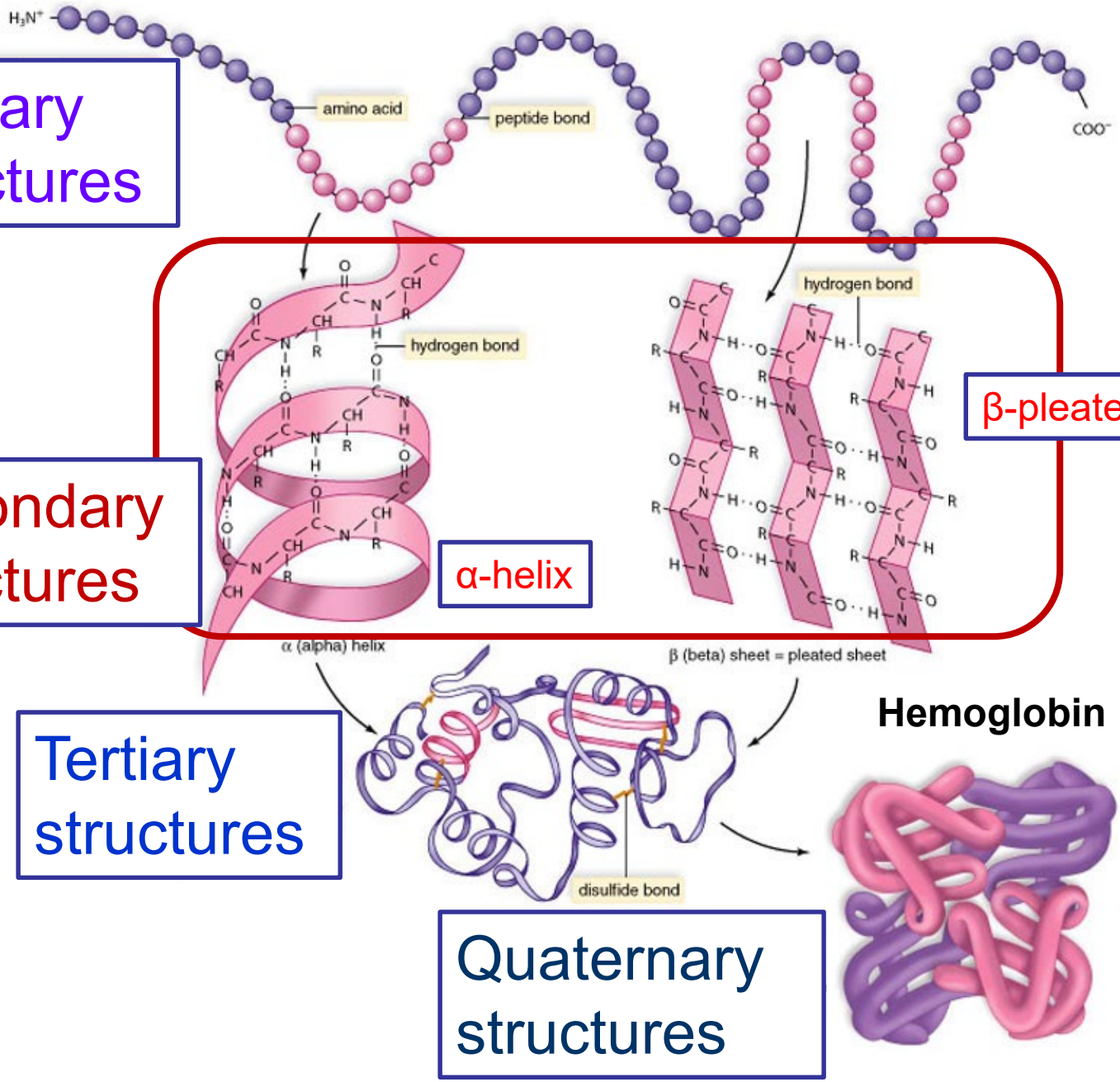


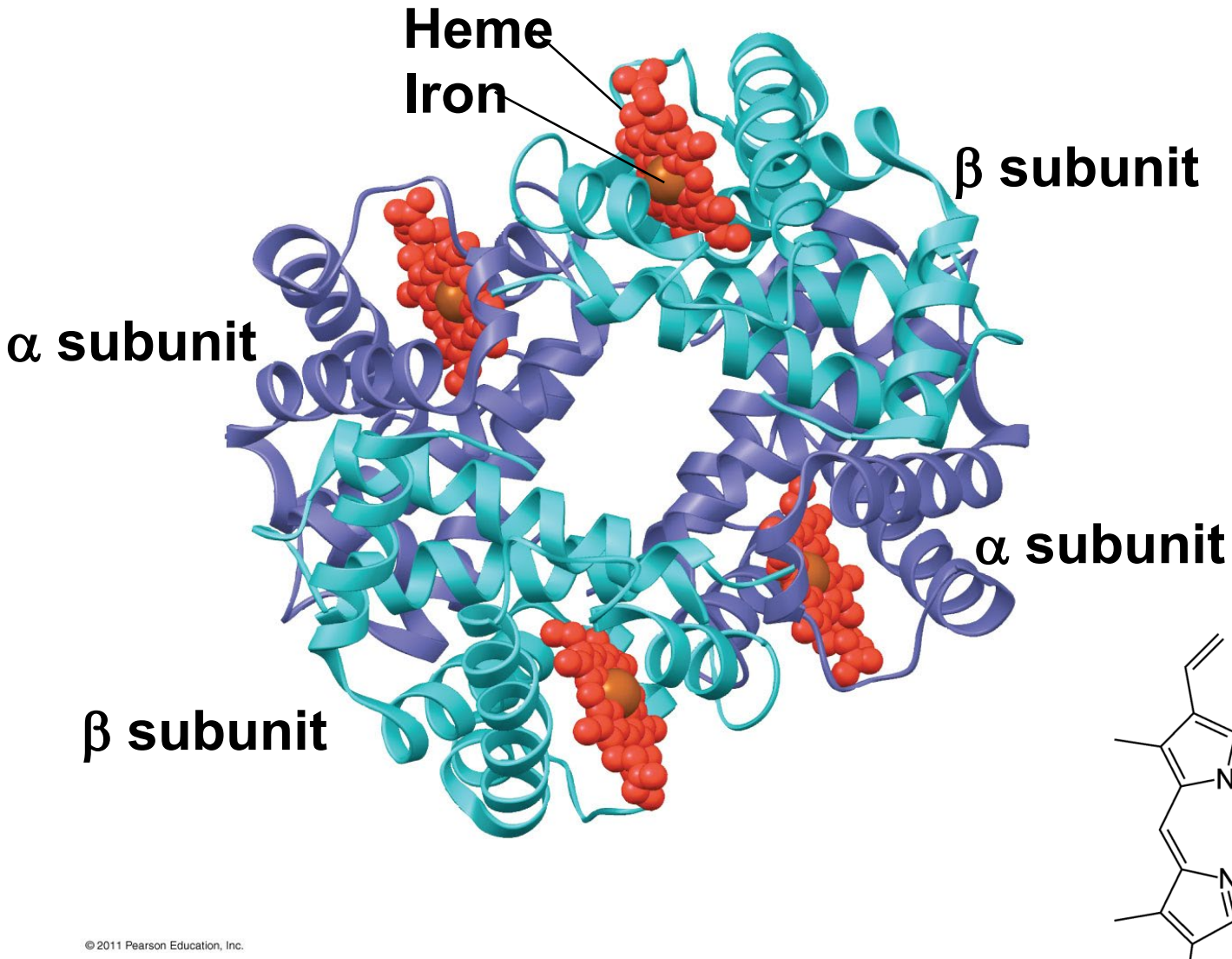
Primary structures

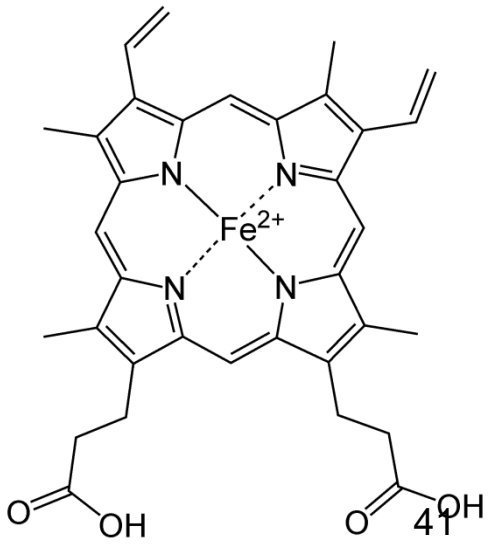
Secondary structures

Tertiary structures

Quaternary structures







Quaternary structure of Hemoglobin

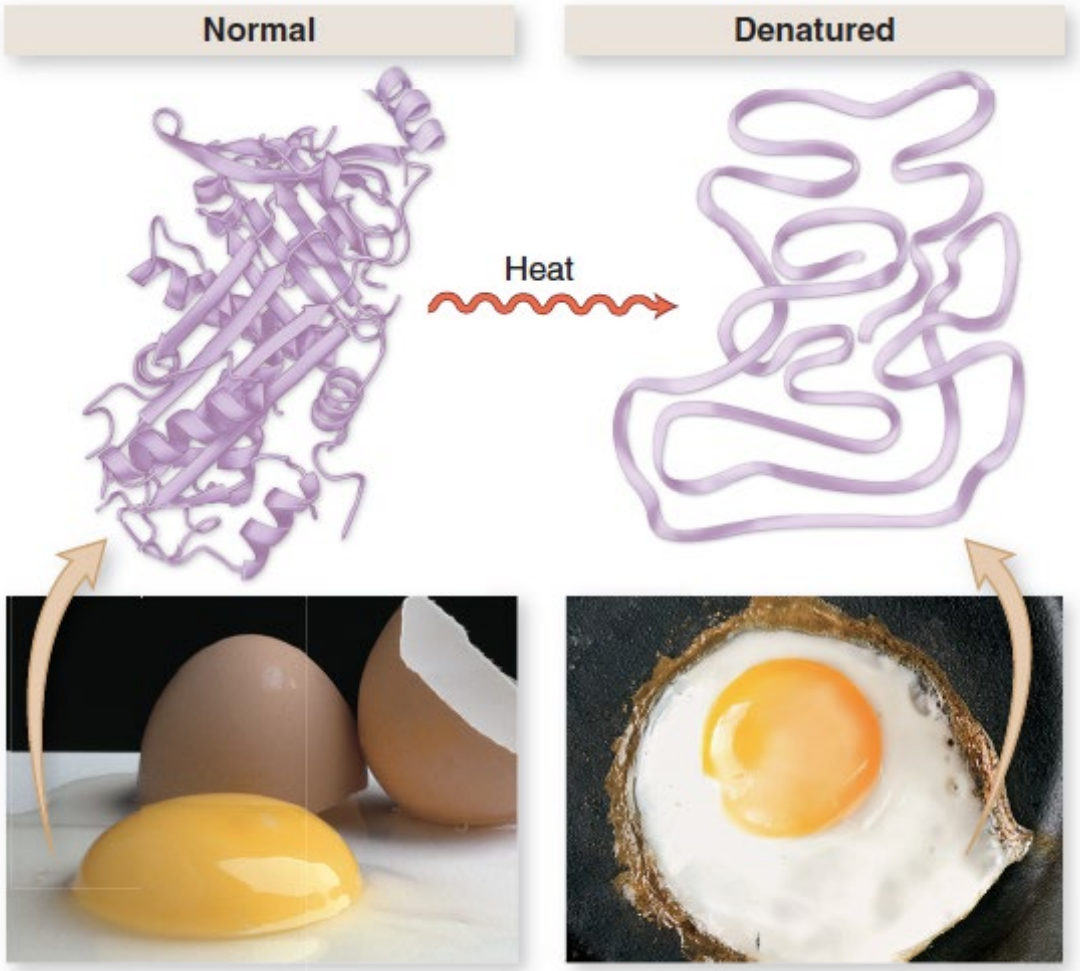
Protein Structure

The functions of proteins are linked to their three-dimensional structures

- Precise positioning of amino acid R groups leads to bonds that determine secondary and tertiary structure
- Disruption of secondary and tertiary bonds leads to **denatured** proteins and loss of function

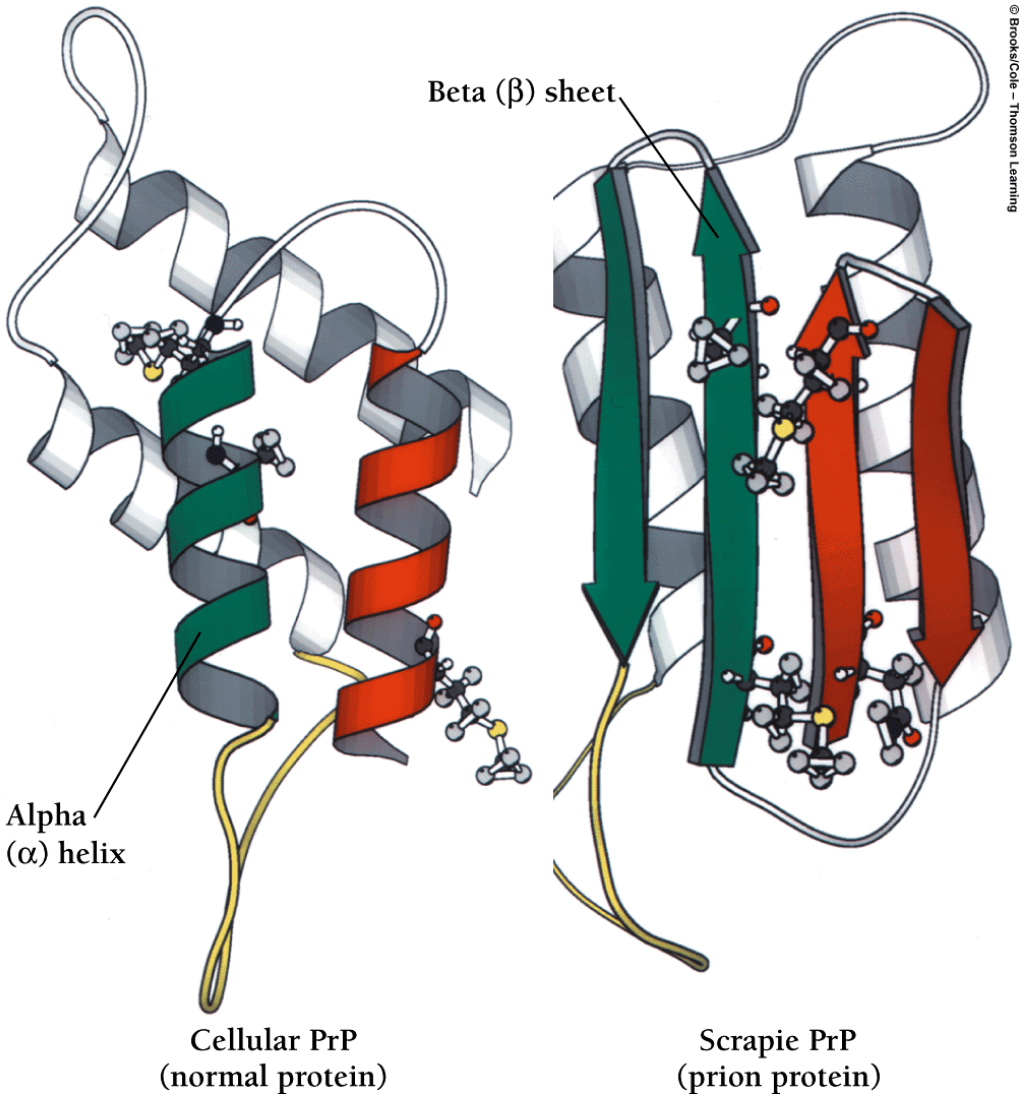
Protein Structure & Function

The function of a protein depends on its shape.
When protein structure is changed, its function is lost or changed.



Case study: What is mad cow disease? (video)

Case study:Prions and Mad Cow Disease



Stanley B. Prusiner

The Nobel Prize in Physiology or Medicine 1997

http://nobelprize.org/nobel_prizes/medicine/laureates/1997/prusiner-lecture.html

Proposed model for replication of prions

1. Prion protein is a normal part of nerve cells
2. Misfolded versions of the normal protein are the infectious particles
3. The misfolded proteins induce normal copies to misfold, too
4. A high concentration of prions in nerve tissue causes cell damage and degeneration

Case study: Curly hair

Eyelash curling set

a.

b.

c.

Outline

- Organic Molecules
  - Functional groups
  - Synthesis and breakdown
- Carbohydrates
  - Monosaccharides
  - Oligosaccharides
  - Polysaccharides
- Proteins
  - Amino acids
  - Protein structure
- Lipids
  - Triglycerides
  - Phospholipids
  - Waxes
  - Steroids

Lipids

Lipid is the collective name for fats, oils, waxes and fat-like molecules (such as steroids) found in the body.

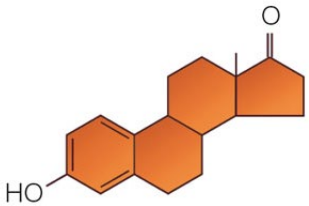
- **Features of lipids**
  - Composed mostly of hydrogen and carbon
  - Hydrophobic and insoluble in water
  - Do not form polymers
- **Variety of functions**
  - Components of cell membranes (phospholipids and cholesterol)
  - Energy storage
  - Chemical messengers (steroid as hormones)
  - Protection, waterproof and insulation

Lipids

Lipids: Organic substances which are insoluble in polar solvents, such as water. Include: triglycerides (fats and oils), phospholipids, waxes, and steroids

Lipids are classified into two major groups

1. Fatty acid lipids: containing fatty acids such as oils, fats, and waxes
2. Non-fatty acid lipids (Steroids) such as cholesterol containing 4 carbon rings



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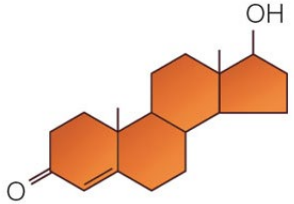

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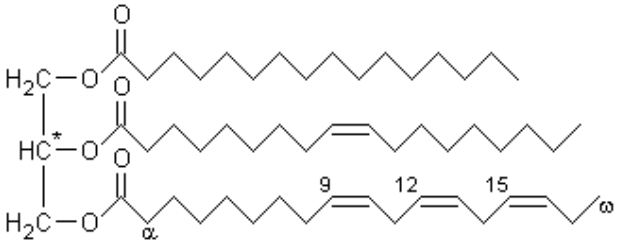
Lipids

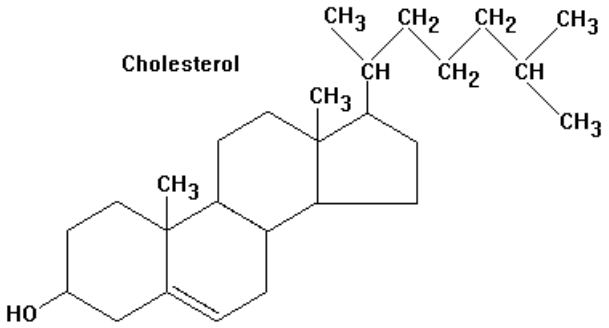


Fatty Acid Lipids

- Triglycerides
- Waxes
- Phospholipids

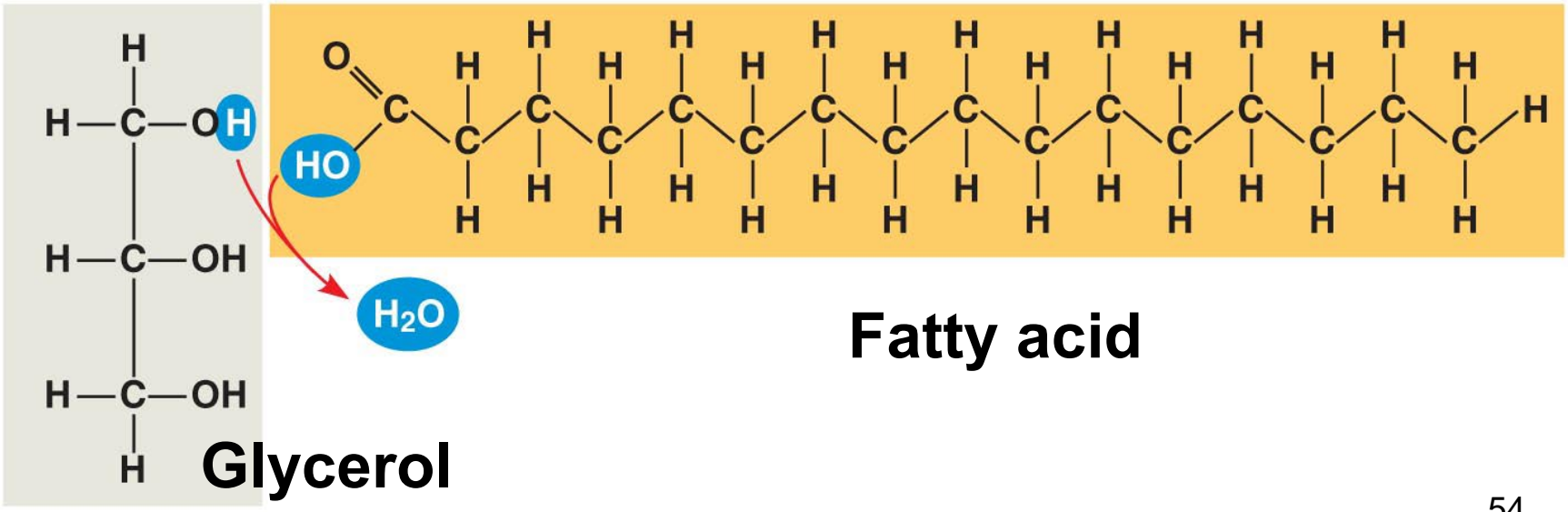
Non-Fatty Acid Lipids

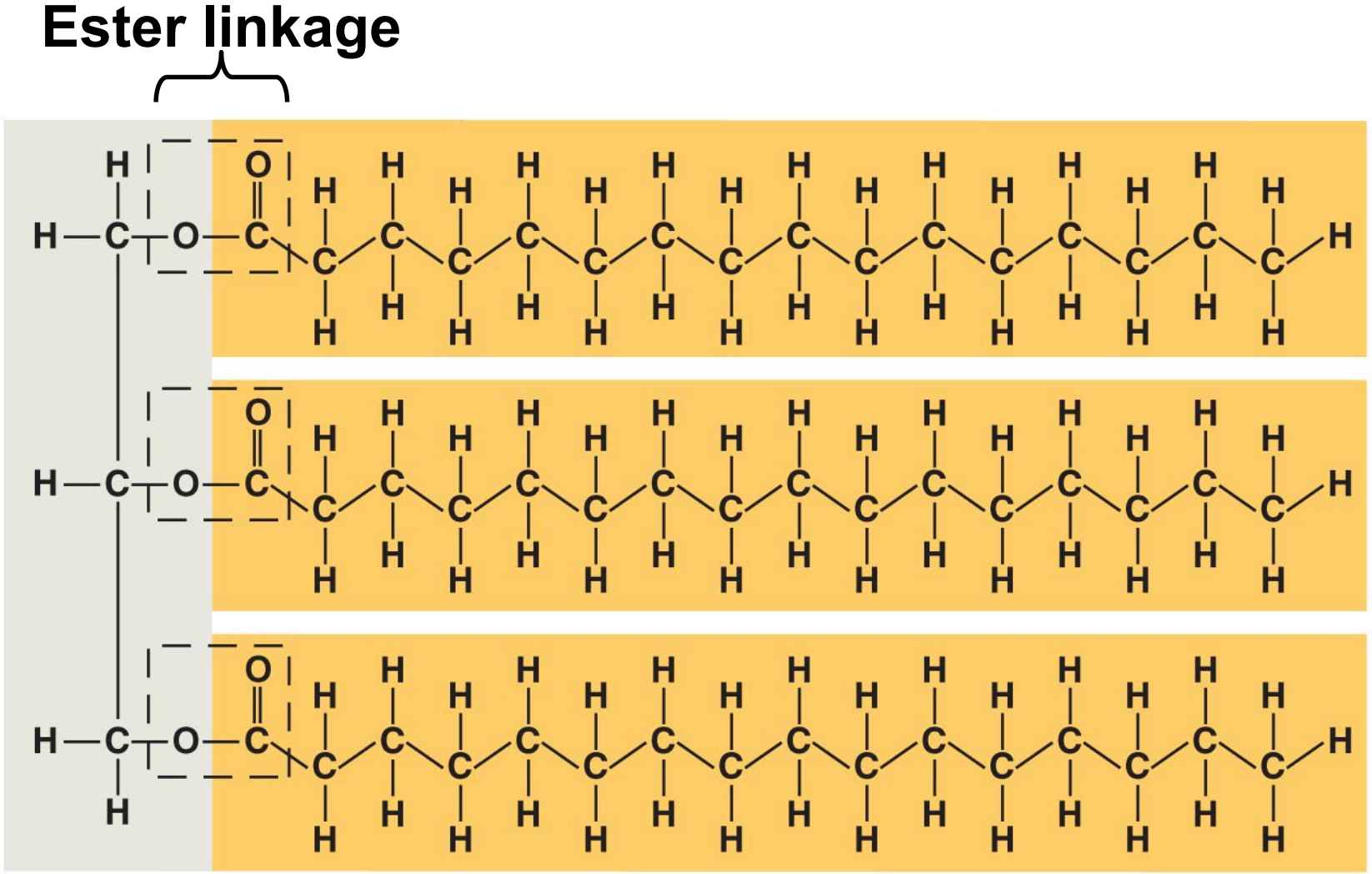
- Steroids



Triglycerids (Oils, Fats)

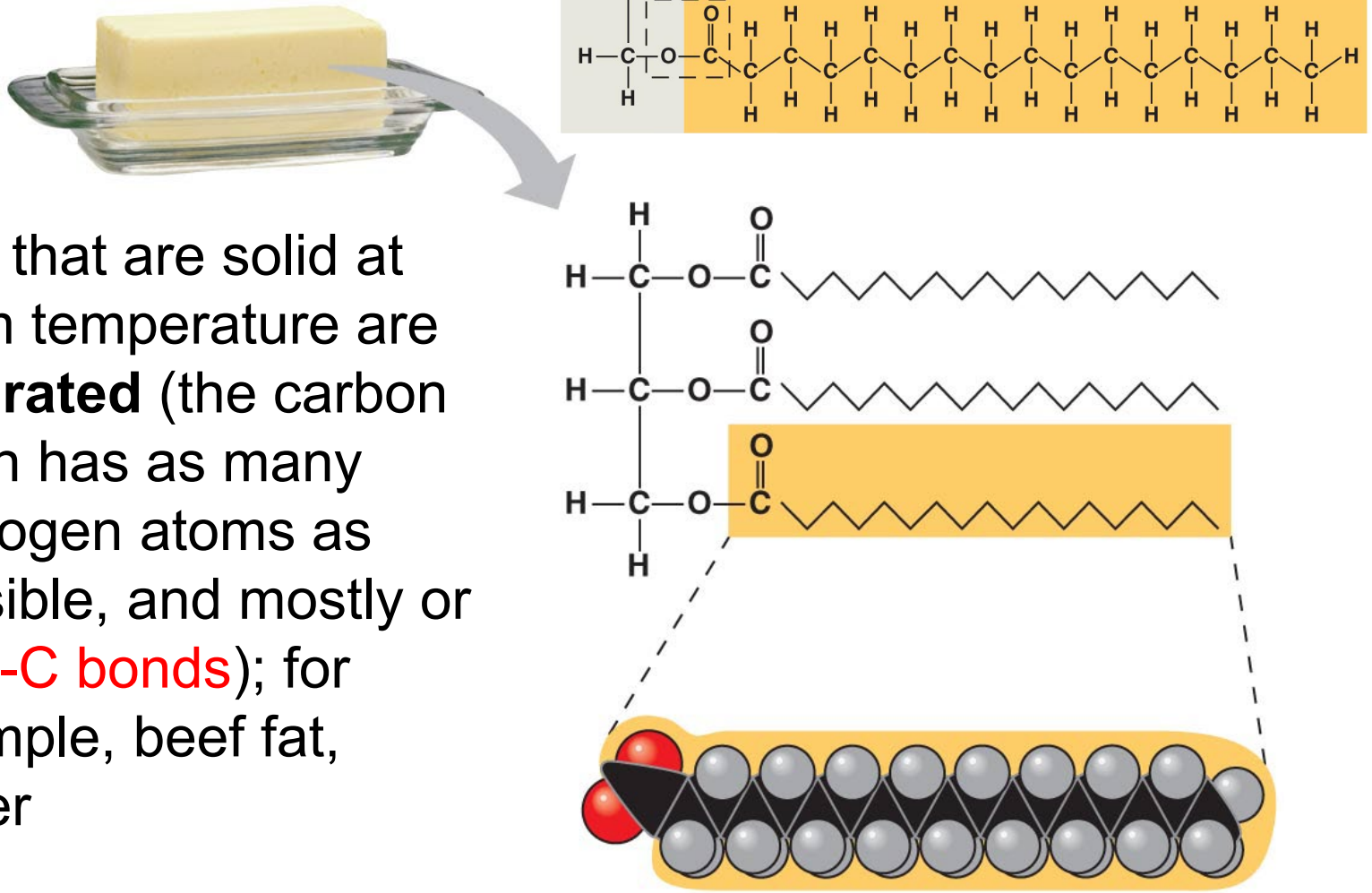
- Are used primarily as energy-storage molecules, containing twice as many calories per gram as carbohydrates and proteins
- Are formed by dehydration synthesis
  - Three fatty acids + **glycerol** → **triglyceride**



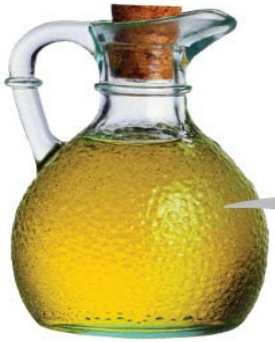


(b) Fat molecule (triglycerides)

Saturated fat

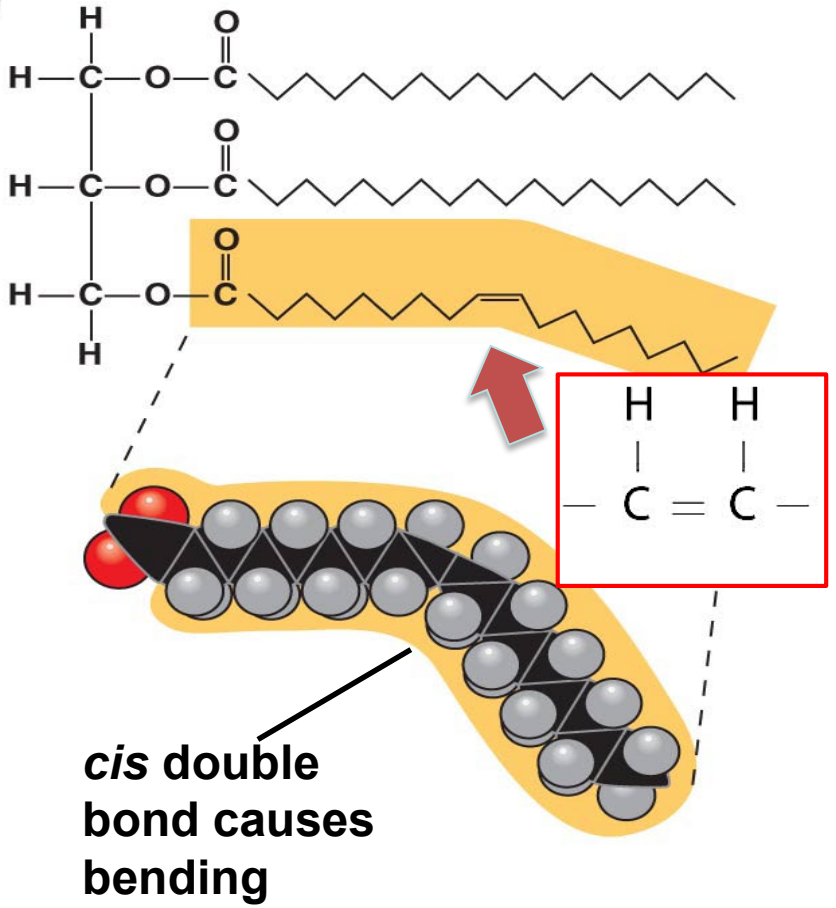


Fats that are solid at room temperature are **saturated** (the carbon chain has as many hydrogen atoms as possible, and mostly or all C-C bonds); for example, beef fat, butter

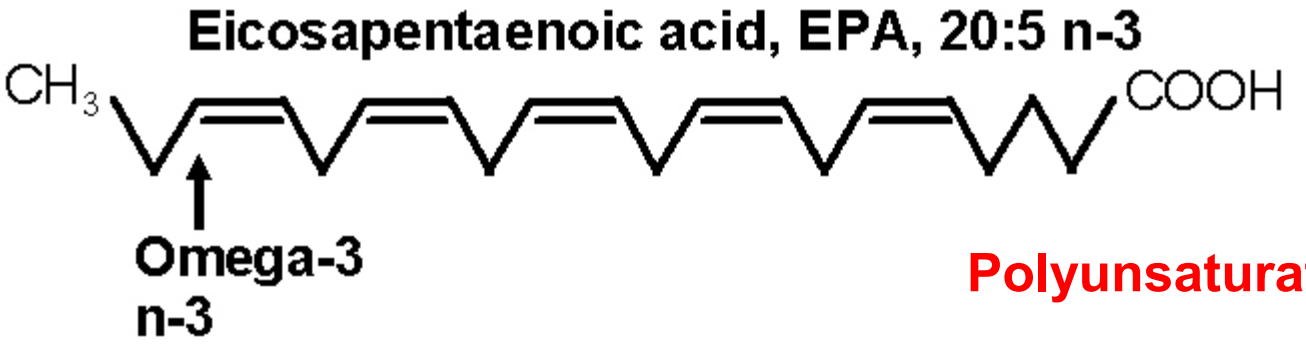


Unsaturated fat (oil)

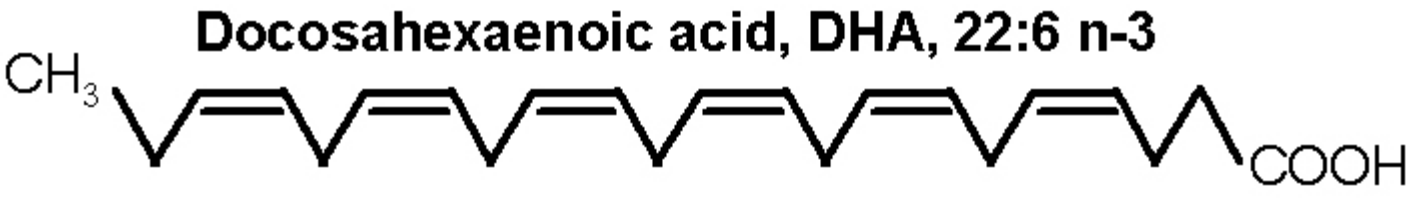
Fats that are liquid at room temperature are unsaturated (with fewer hydrogen atoms, and many **C=C bonds**); for example, corn oil
Unsaturated trans fats have been linked to heart disease

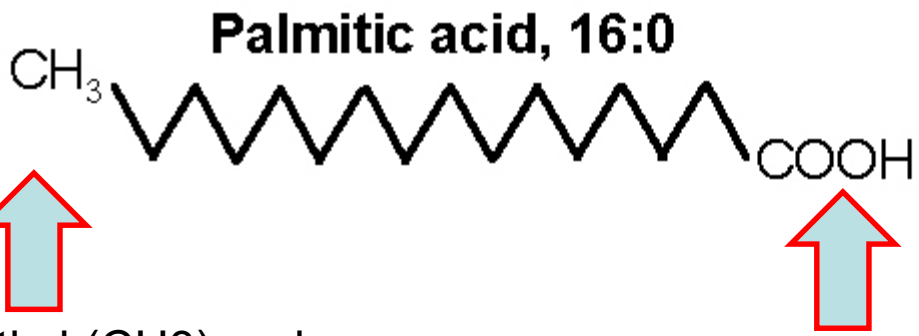


Omega-3 fatty acid ethyl esters



Polyunsaturated fats

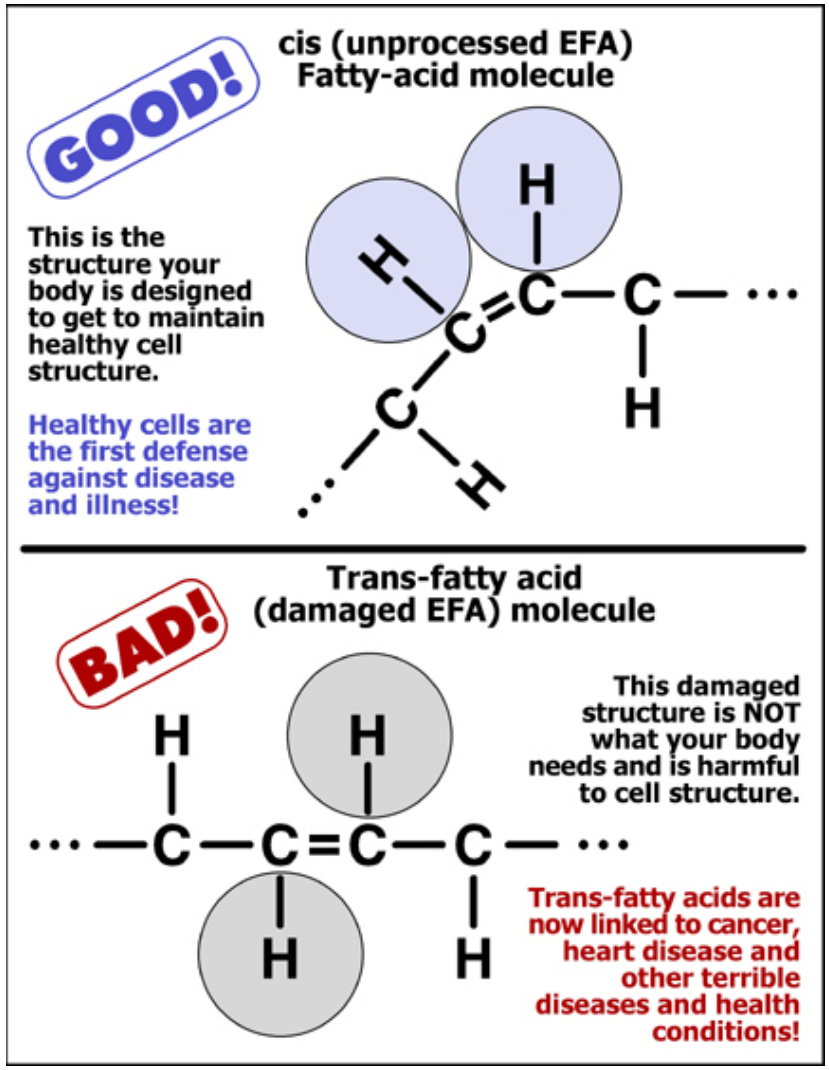




Methyl (CH3) end

carboxylic acid (-COOH) end

Case study: Cis *vs* Trans lipids



The oil has **zero grams of trans** fat per serving

http://www.scienceofhealthindex.com/distorted-efas.html

Case study: Fat Substitutes Linked to Weight Gain

Behavioral Neuroscience
Susan E et al. 2011

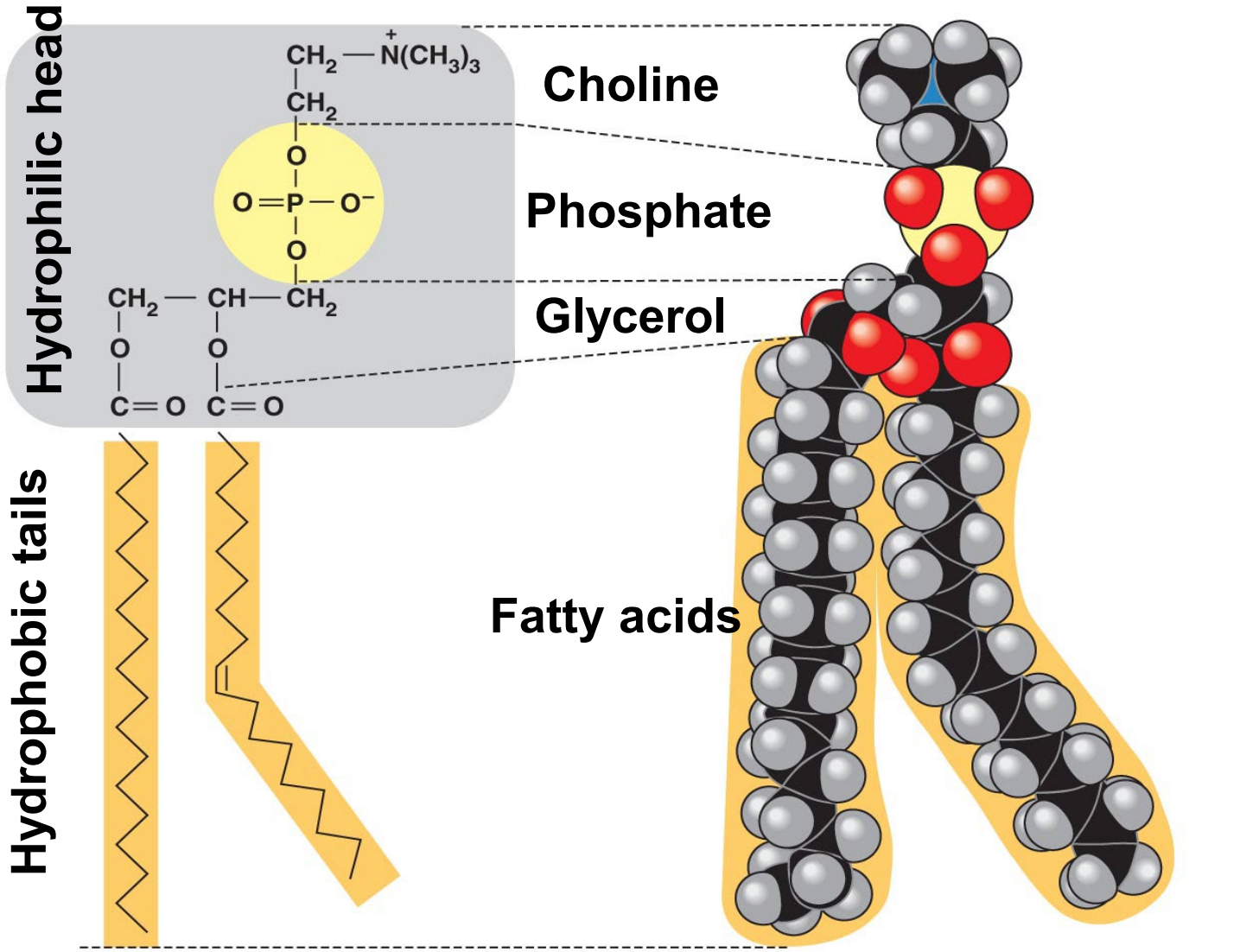
Synthetic fat substitutes used in low-calorie potato chips and other foods could backfire and contribute to weight gain and obesity.

The use of artificial sweeteners and fat substitutes has increased dramatically over the past 30 years, mirroring the increase in obesity in America.

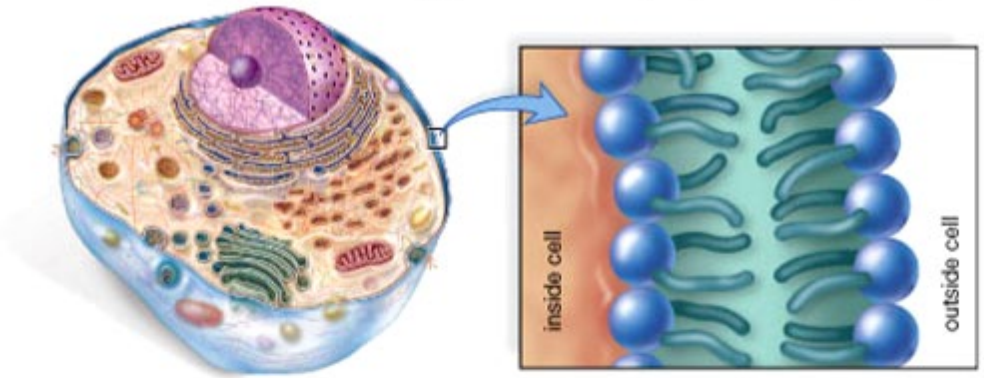
April 29, 2014 ScienceDaily® Your source for the latest research news

Phospholipids

- The major component of all cell membranes
- Subunits
  - One glycerol
  - Two fatty acids (non-polar and hydrophobic)
  - "Head" with phosphate group (polar and hydrophilic)
- Formed by condensation

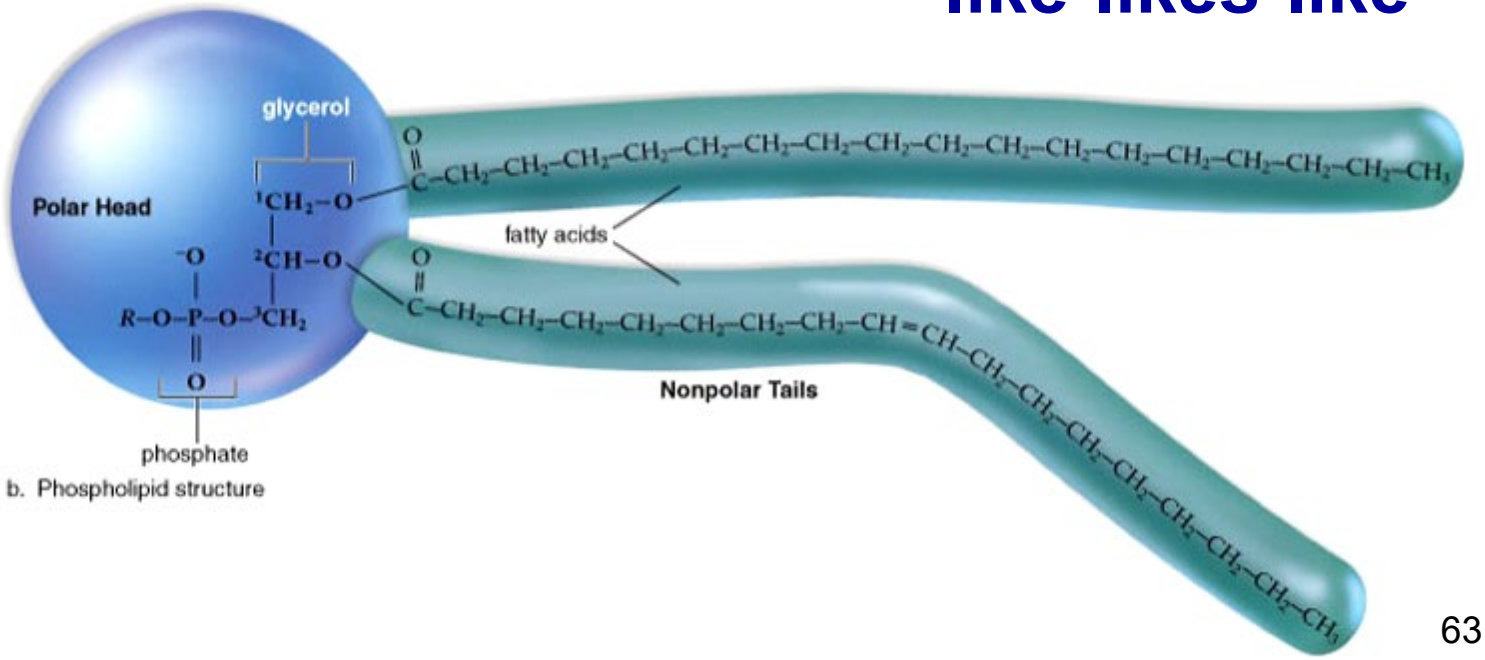


Lipid bilayer of cell membranes



a. Plasma membrane of a cell

like-likes-like

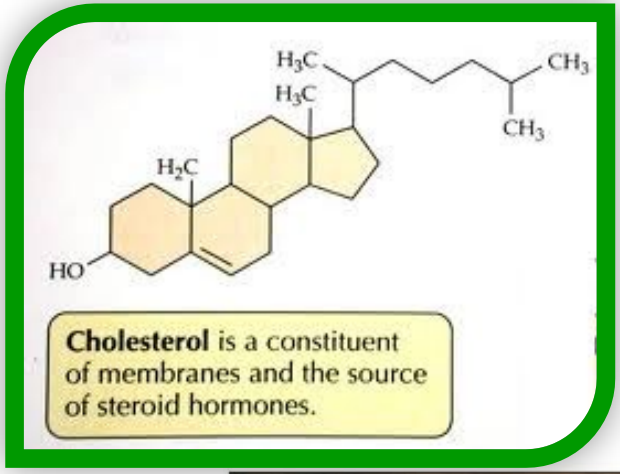


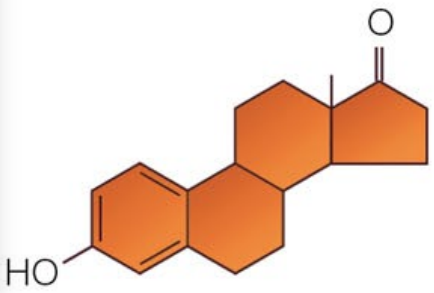
b. Phospholipid structure

Steroids

- Steroids are composed of four carbon rings fused together, with various functional groups protruding from them
- Examples of steroids include:
  - Cholesterol
    - Vital component of the membranes of animal cells
    - The precursor from which the body synthesizes vitamin D
    - Excessive cholesterol contributes to cardiovascular disease
    - Makes up 2% of human brain
  - Male and female sex hormones

Steroids





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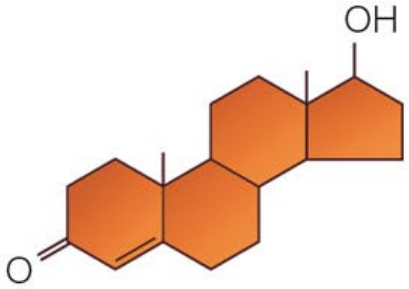

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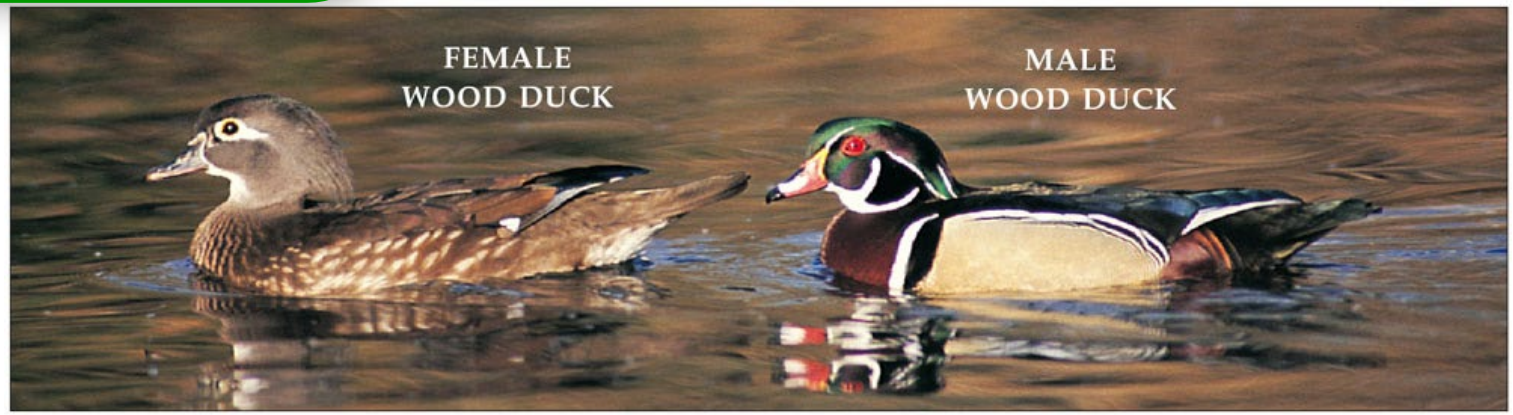
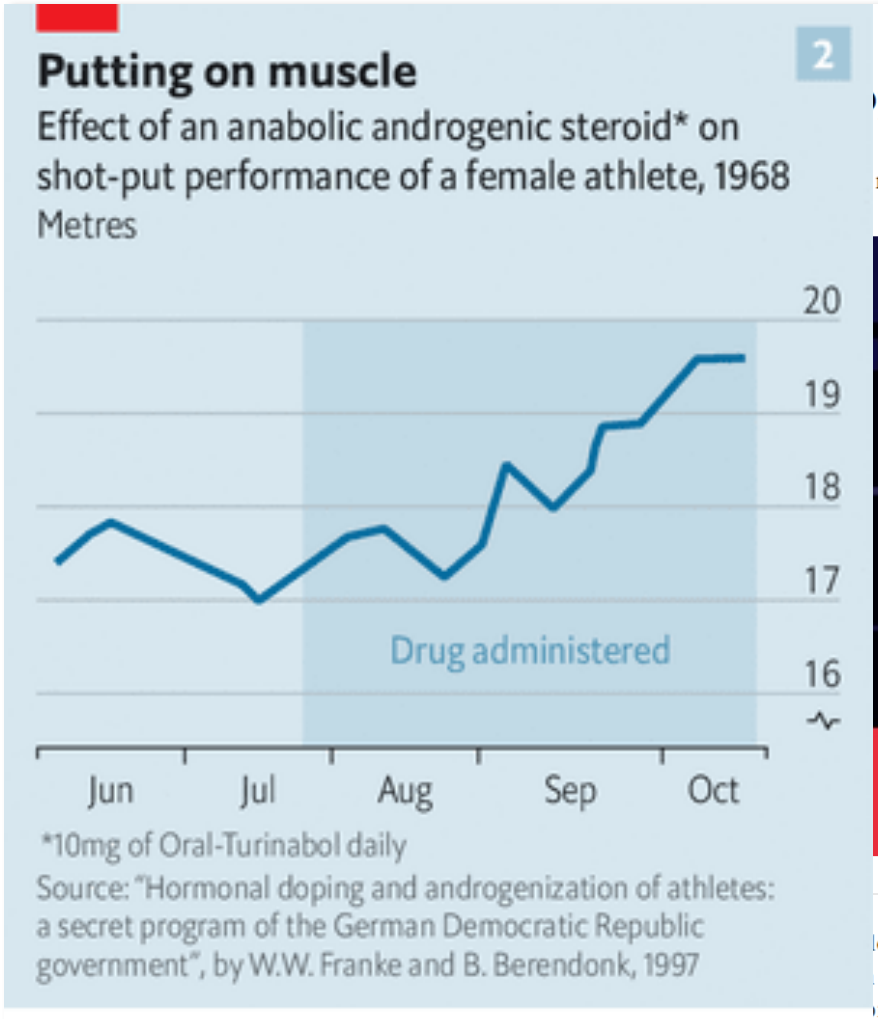


Case study: Steroids in sports

Anabolic steroids help build muscle tissue and increase body mass by acting like the body's natural male hormone, testosterone. However, **steroids cannot improve an athlete's agility or skill**.



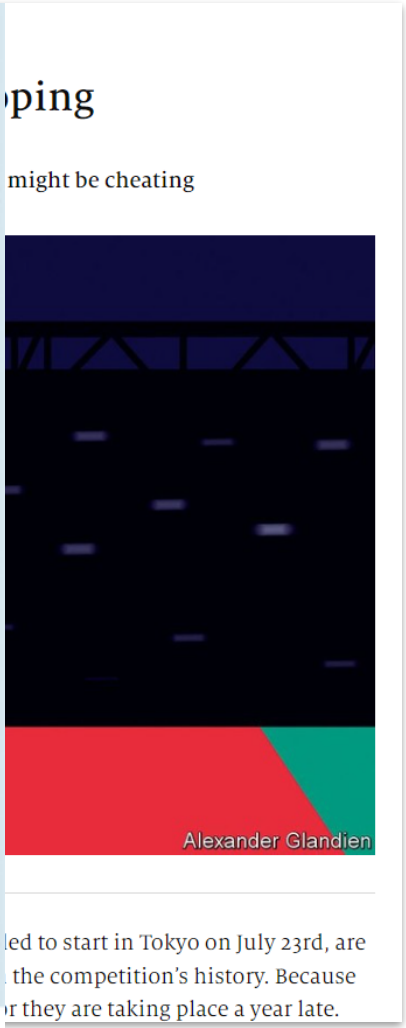


TABLE 3.3

Lipids

Type	*Functions*	*Human Uses*
Fats	Long-term energy storage and insulation in animals	Butter, lard
Oils	Long-term energy storage in plants and their seeds	Cooking oils
Phospholipids	Component of plasma membrane	—
Steroids	Component of plasma membrane (cholesterol), sex hormones	Medicines
Waxes	Protection, prevent water loss (cuticle of plant surfaces), beeswax, earwax	Candles, polishes

Outline

- Organic Molecules
  - Functional groups
  - Synthesis and breakdown
- Carbohydrates
  - Monosaccharides
  - Oligosaccharides
  - Polysaccharides
- Proteins
  - Amino acids
  - Protein structure
- Lipids
  - Triglycerides
  - Phospholipids
  - Waxes
  - Steroids

Key Terms and Key Concepts

Key Terms

dehydration synthesis, hydrolysis, monomer, polymer, monosaccharide, disaccharide, polysaccharide, lipid, phospholipid, steroid, trans fat, cis fat, amino acid, peptide bond, protein primary structure, secondary structure (helix and pleated sheet), tertiary structure, quaternary structure

Key Concepts

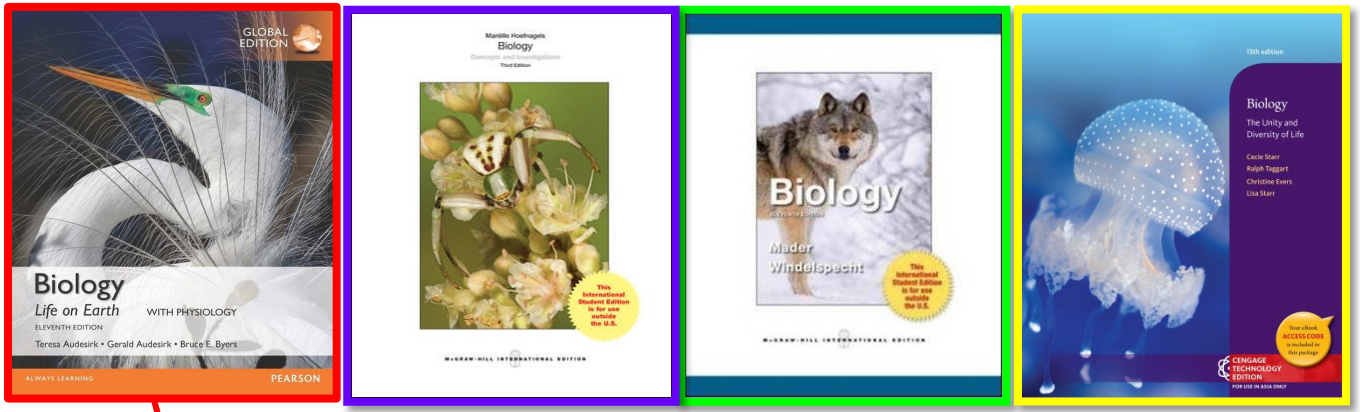
- How are large biological molecules synthesized?
- What are carbohydrates and their functions?
- What are lipids and their functions?
- What are proteins and the 4 levels of structure?
- What is the denaturation of protein, how is the protein structure related to its function?

Further questions

- Albumin in eggs coagulates when heat is applied, but keratin in hair does not. Both keratin and albumin are proteins.
  - What then makes them respond to heat in different ways?

- In an alternate universe where people could digest cellulose molecules, how might this affect our way of life?

Text Books/References



The main textbook I am using

Today's Lecture

Chapter 3	Chapter 2	Chapter 2,3	Chapter 2,3

Next Lecture

Chapters 4, 5	Chapter 3	Chapters 4,5	Chapters 4

Reminders

- Please attempt the quiz on today's lecture topic
  - I will go through any questions about the quiz on the Forum or during my review tutorial in Week 12