FISH270

Lecture 4

Reminders

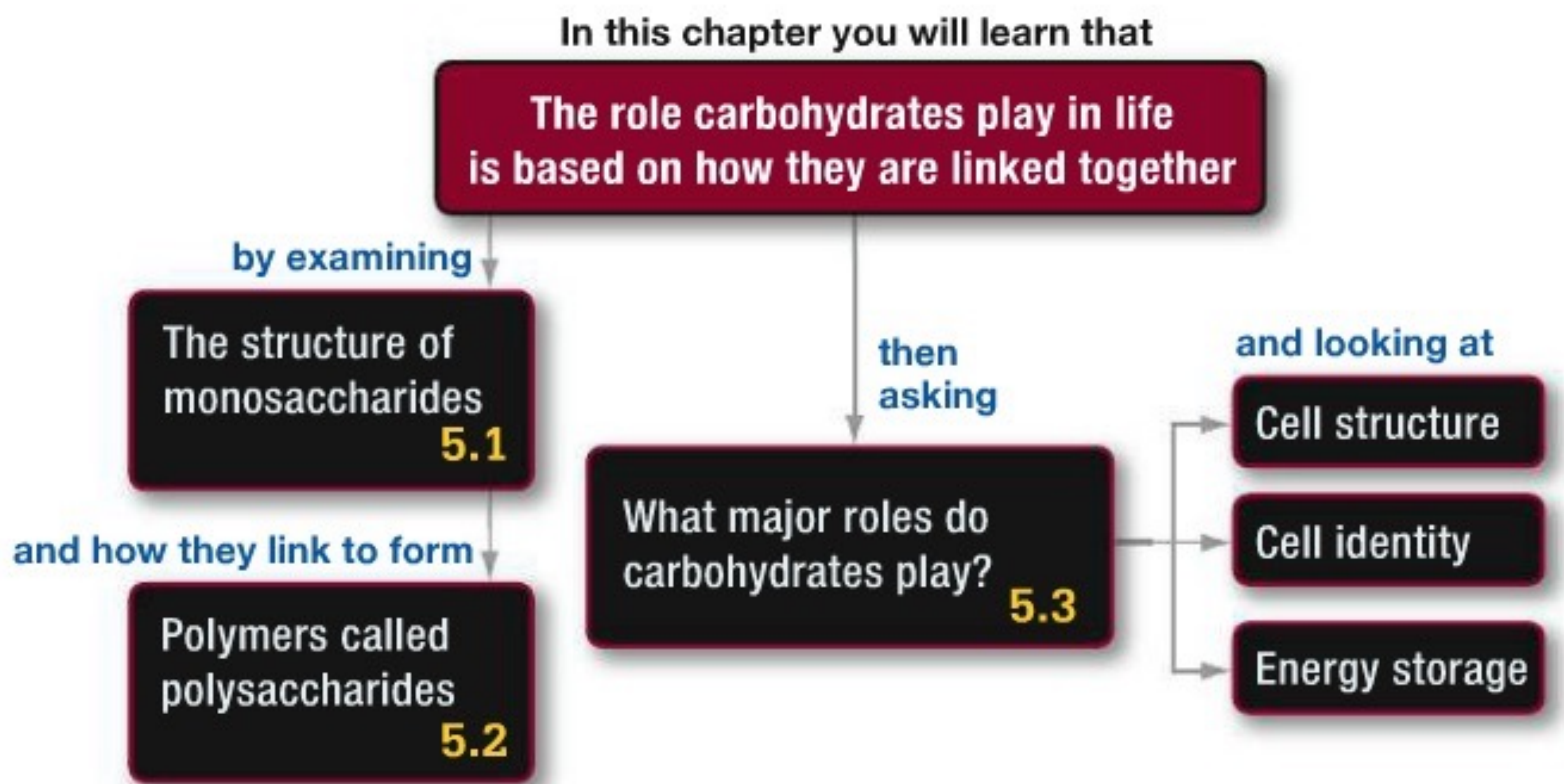
- Discussion Board
- Question Sets

Building blocks

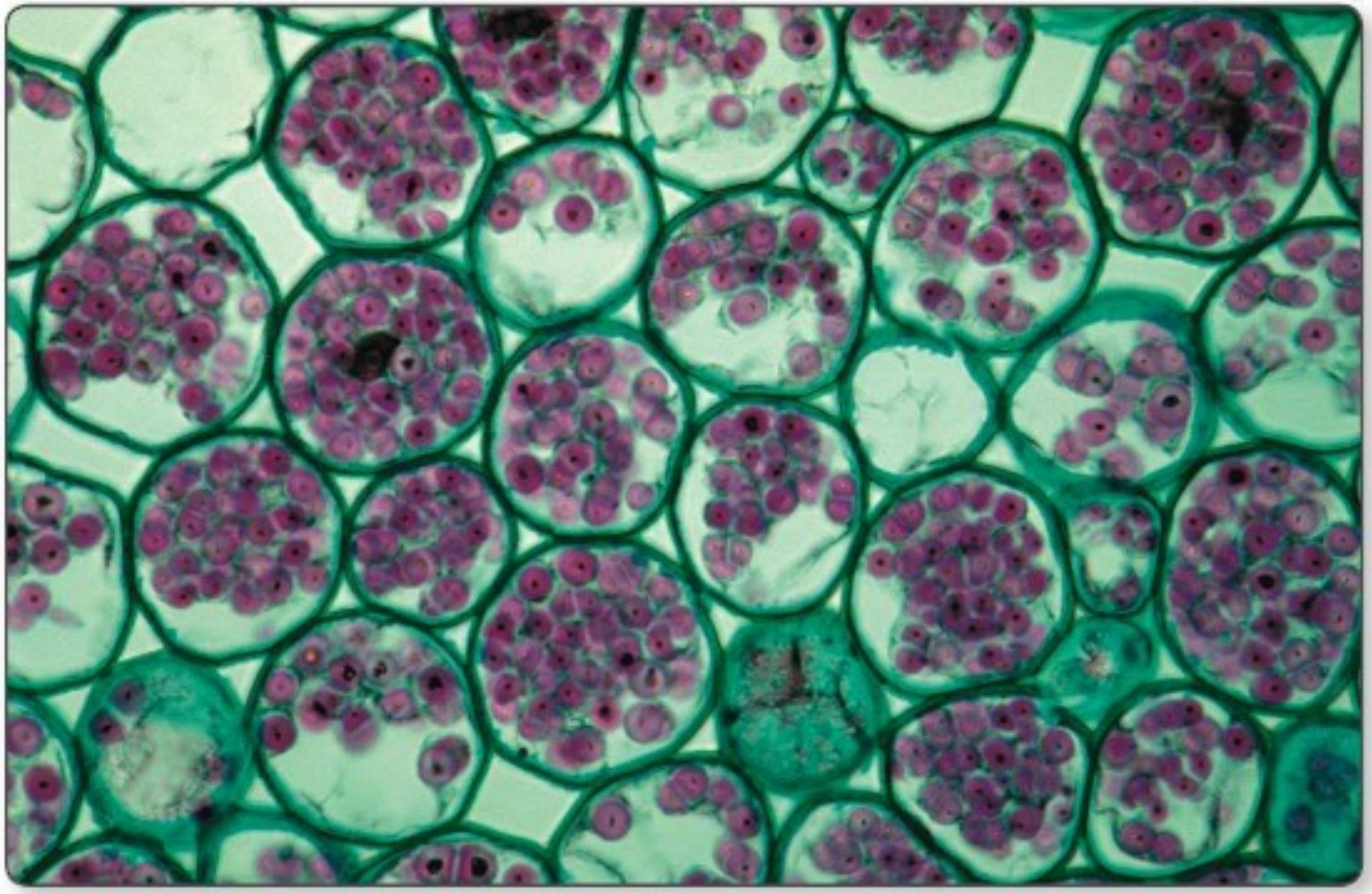
The week ahead

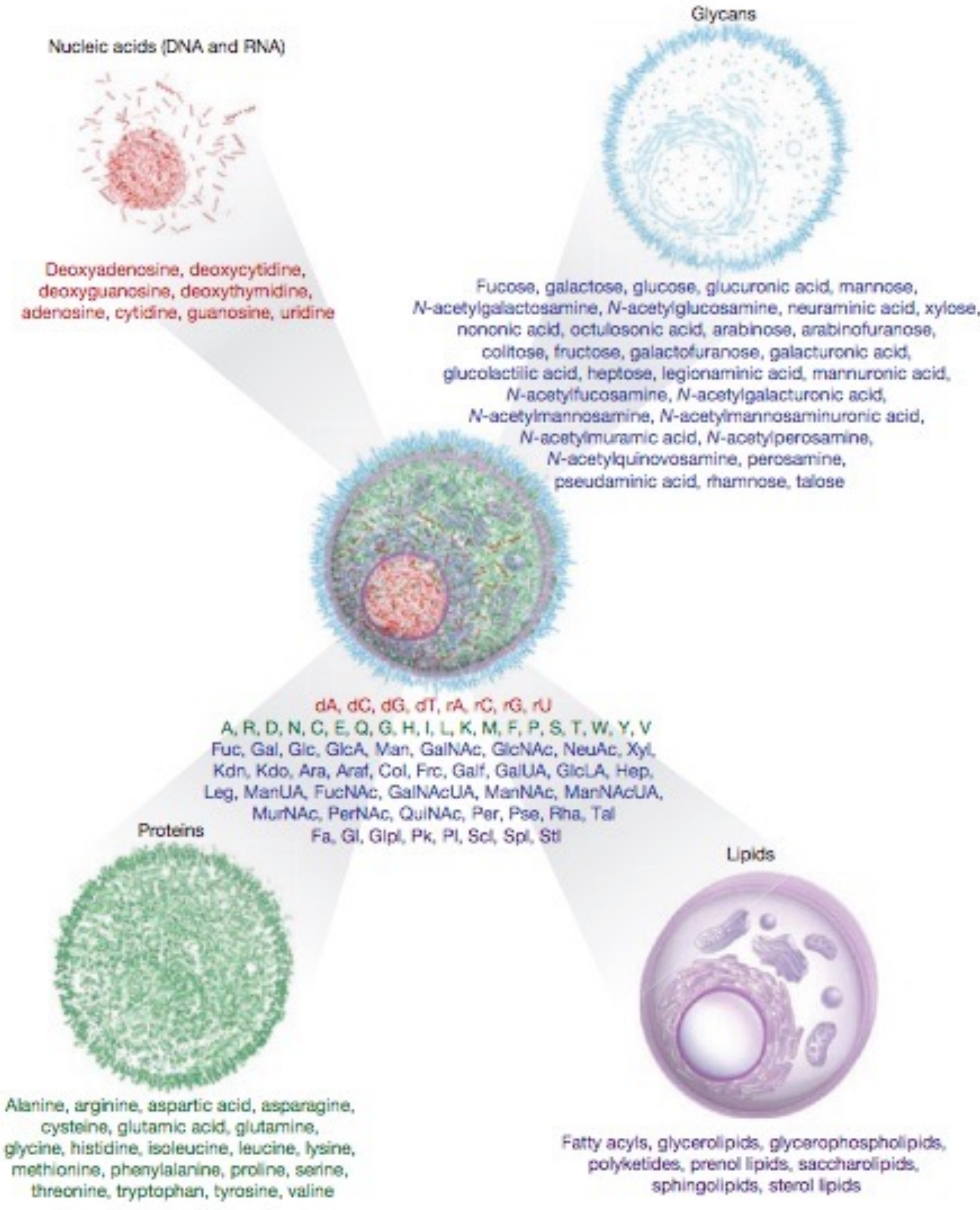
- Carbohydrates
- Animal Nutrition
- Photosynthesis

Carbohydrates



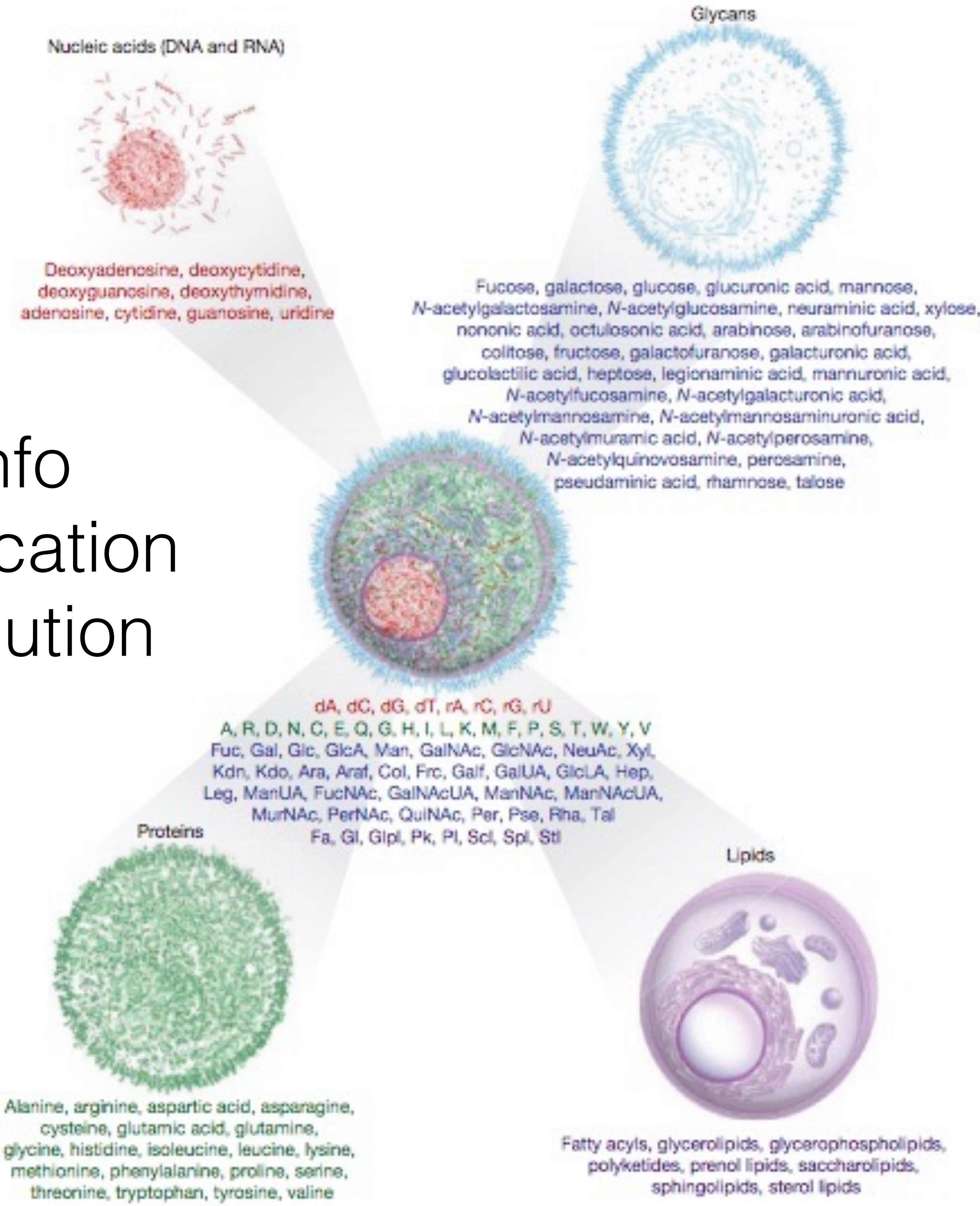
A cross section through a buttercup root. Cellulose-rich cell walls are stained green; starch-filled structures are stained purple. Cellulose is a structural carbohydrate; starch is an energy-storage carbohydrate.



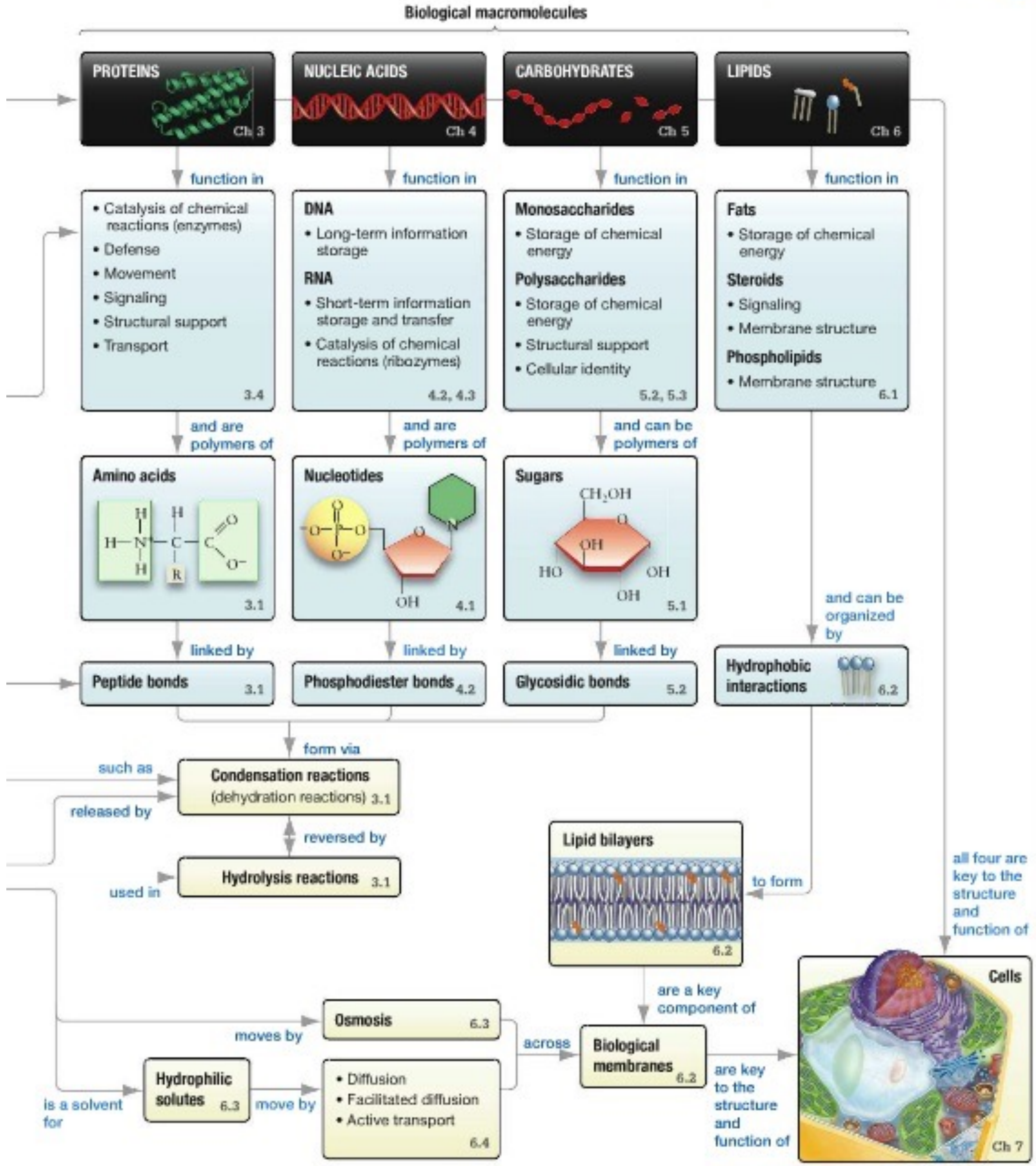

Nucleic acids (DNA and RNA)
Deoxyadenosine, deoxycytidine, deoxyguanosine, deoxythymidine, adenosine, cytidine, guanosine, uridine
Glycans
Fucose, galactose, glucose, glucuronic acid, mannose, N-acetylgalactosamine, N-acetylglucosamine, neuraminic acid, xylose, nononic acid, octulosonic acid, arabinose, arabinofuranose, colitose, fructose, galactofuranose, galacturonic acid, glucolactilic acid, heptose, legionaminic acid, mannuronic acid, N-acetylfucosamine, N-acetylgalacturonic acid, N-acetylmannosamine, N-acetylmannosaminuronic acid, N-acetylmuramic acid, N-acetylperosamine, N-acetylquinovosamine, perosamine, pseudaminic acid, rhamnose, talose
dA, dC, dG, dT, rA, rC, rG, rU
A, R, D, N, C, E, Q, G, H, I, L, K, M, F, P, S, T, W, Y, V
Fuc, Gal, Glc, GlcA, Man, GalNAc, GlcNAc, NeuAc, Xyl, Kdn, Kdo, Ara, Araf, Col, Frc, Galf, GalUA, GlcLA, Hep, Leg, ManUA, FucNAc, GalNAcUA, ManNAc, ManNAcUA, MurNAc, PerNAc, QuiNAc, Per, Pse, Rha, Tal
Fa, Gl, Glpl, Pk, Pl, Scl, Spl, Stl
Proteins
Lipids
Alanine, arginine, aspartic acid, asparagine, cysteine, glutamic acid, glutamine, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine, valine
Fatty acyls, glycerolipids, glycerophospholipids, polyketides, prenol lipids, saccharolipids, sphingolipids, sterol lipids

ENERGY!

info
replication
evolution



Big Picture



105

Monosaccharides Vary in Structure

- Monosaccharide monomers are simple sugars that structurally vary in four primary ways:

  1. Location of the carbonyl group
     - **Aldose**: found at the end of the monosaccharide
     - **Ketose**: found in the middle of the monosaccharide

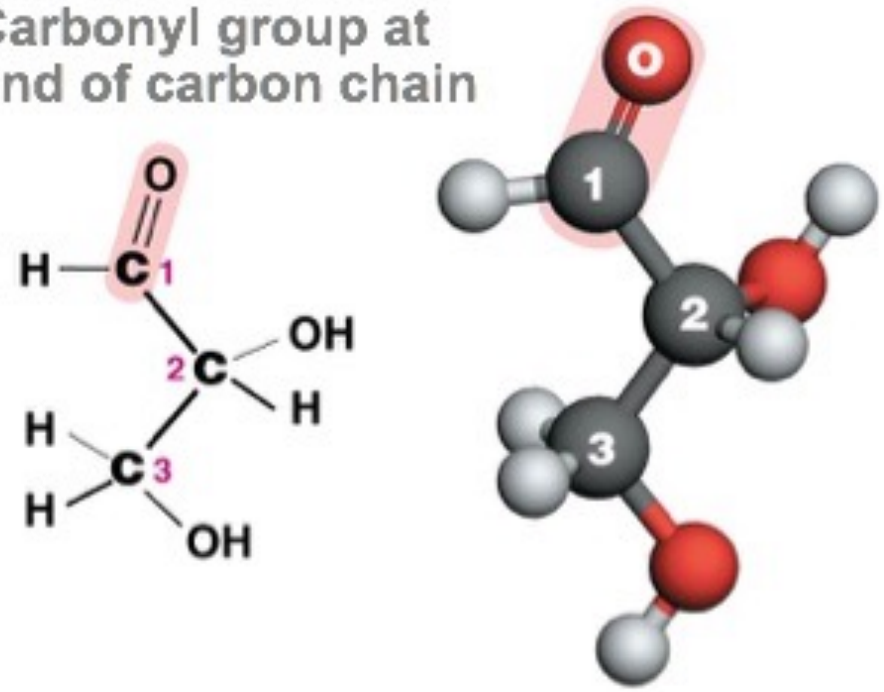
  2. Number of carbon atoms present
     - **Triose**: three
     - **Pentose**: five
     - **Hexose**: six

Monosaccharides Vary in Structure

3. Spatial arrangement of their atoms
   - Different arrangement of the hydroxyl groups
4. Linear and alternative ring forms
   - Sugars tend to form ring structures in aqueous solutions

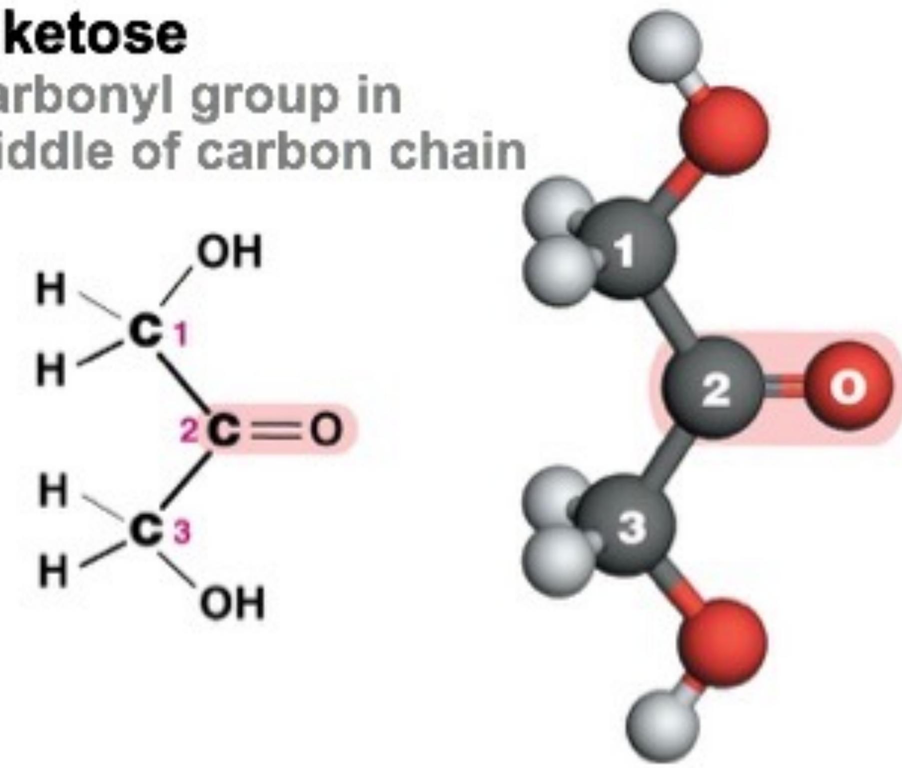
An aldose

Carbonyl group at end of carbon chain



A ketose

Carbonyl group in middle of carbon chain



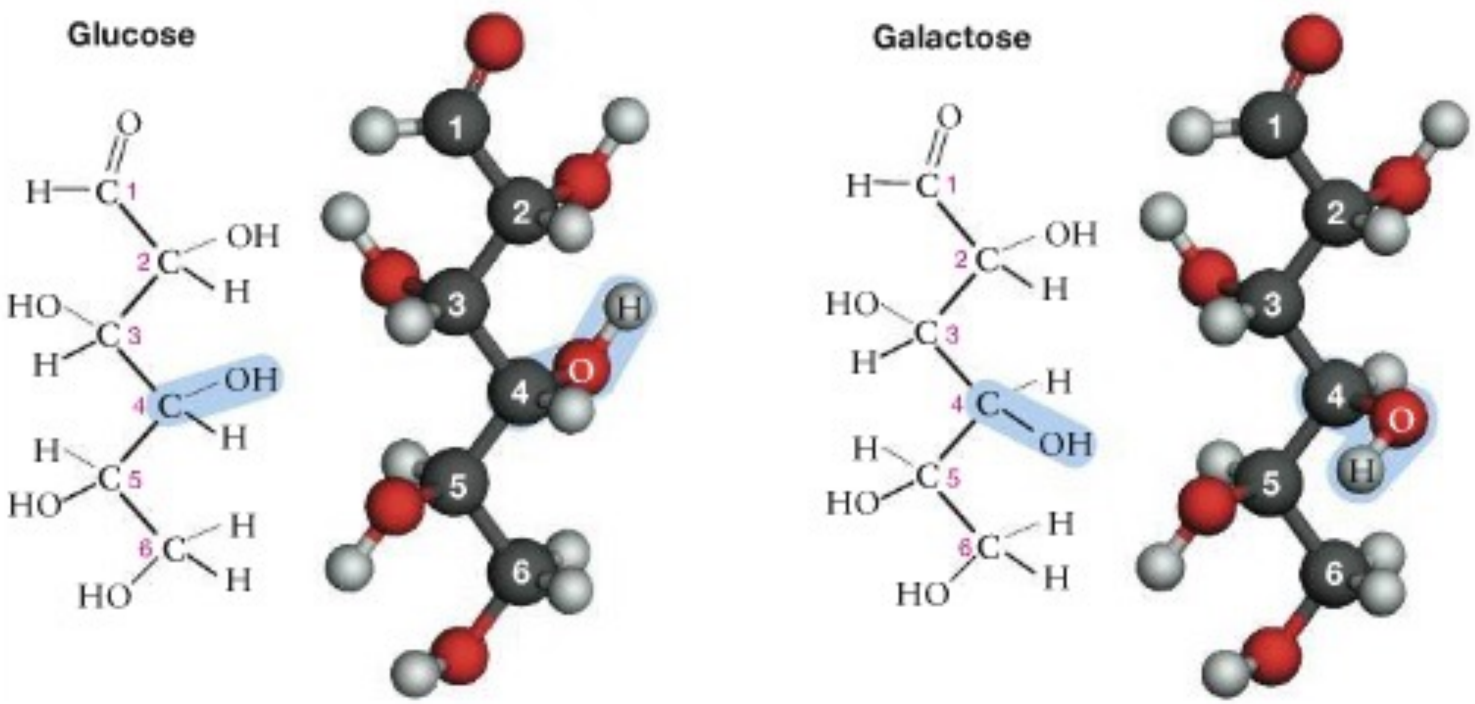
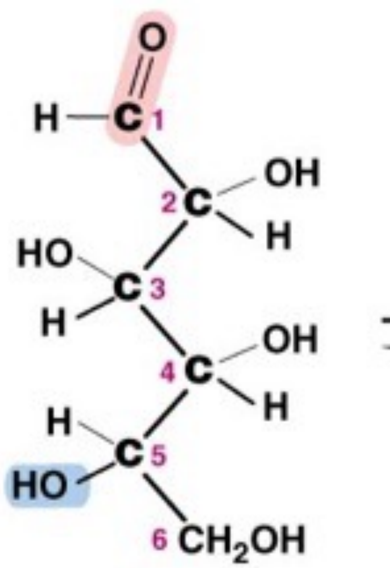


FIGURE 5.2 Sugars May Vary in the Configuration of Their Hydroxyl Groups. The two six-carbon sugars shown here vary only in the spatial orientation of their hydroxyl groups on carbon number 4.

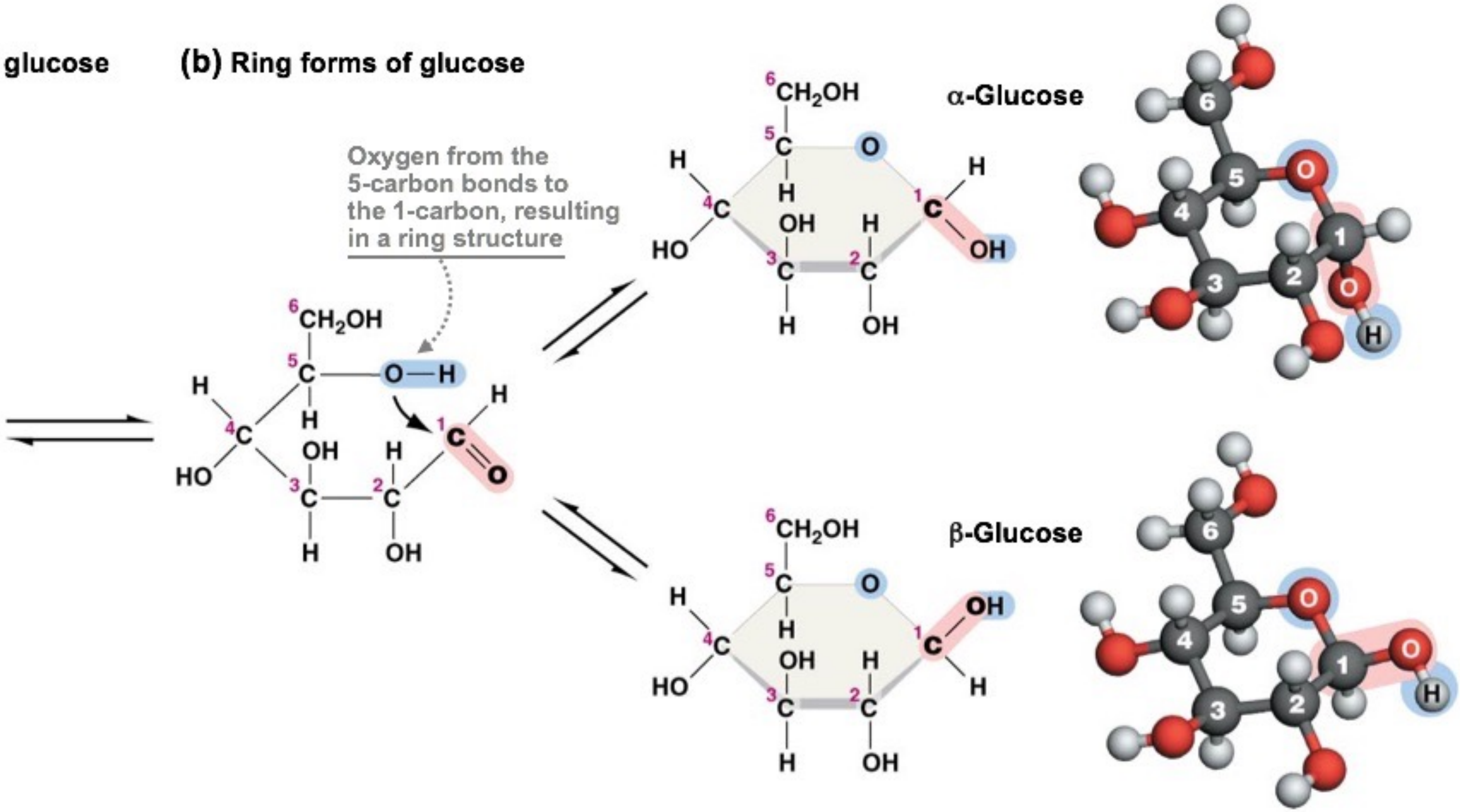
✔ **EXERCISE** Mannose is a six-carbon sugar that is identical to glucose, except that the hydroxyl (–OH) group on carbon number 2 is switched in orientation. Circle carbon number 2 in glucose and galactose; then draw the structural formula of mannose.

catalyzed reaction. This example underscores a general theme: Even seemingly simple changes in structure—like the location of a single hydroxyl group—can have enormous consequences for function. This is because molecules interact in precise ways, based on their shape.

(a) Linear form of glucose



(b) Ring forms of glucose



Summary of Monosaccharide Structure

- Distinct monosaccharides exist
- Because so many aspects of their structure are variable
  - Aldose or ketose placement of the carbonyl group
  - Variation in carbon number
  - Different arrangements of hydroxyl groups in space
  - Alternative ring forms
- Each monosaccharide has a unique structure and function

check your understanding

C Y U

If you understand that . . .

- Simple sugars differ from each other in three respects:
  1. the location of their carbonyl group,
  2. the number of carbon atoms present, and
  3. the spatial arrangement of their atoms—particularly the relative positions of hydroxyl (−OH) groups.

✔ You should be able to . . .

Draw the structural formula of a three-carbon monosaccharide ($C_3H_6O_3$) in linear form and then draw three other sugars that illustrate the three differences listed above.

Answers are available in Appendix A.

The Structure of Polysaccharides

- **Polysaccharides**, or **complex carbohydrates**, are polymers of monosaccharide monomers
- The simplest polysaccharides are **disaccharides**
  - Comprised of two monosaccharide monomers
  - The monomers can be identical or different
- Simple sugars polymerize when
  - A **condensation reaction** occurs
    - Between two hydroxyl groups
    - Resulting in a covalent bond called a **glycosidic linkage**

Polysaccarides

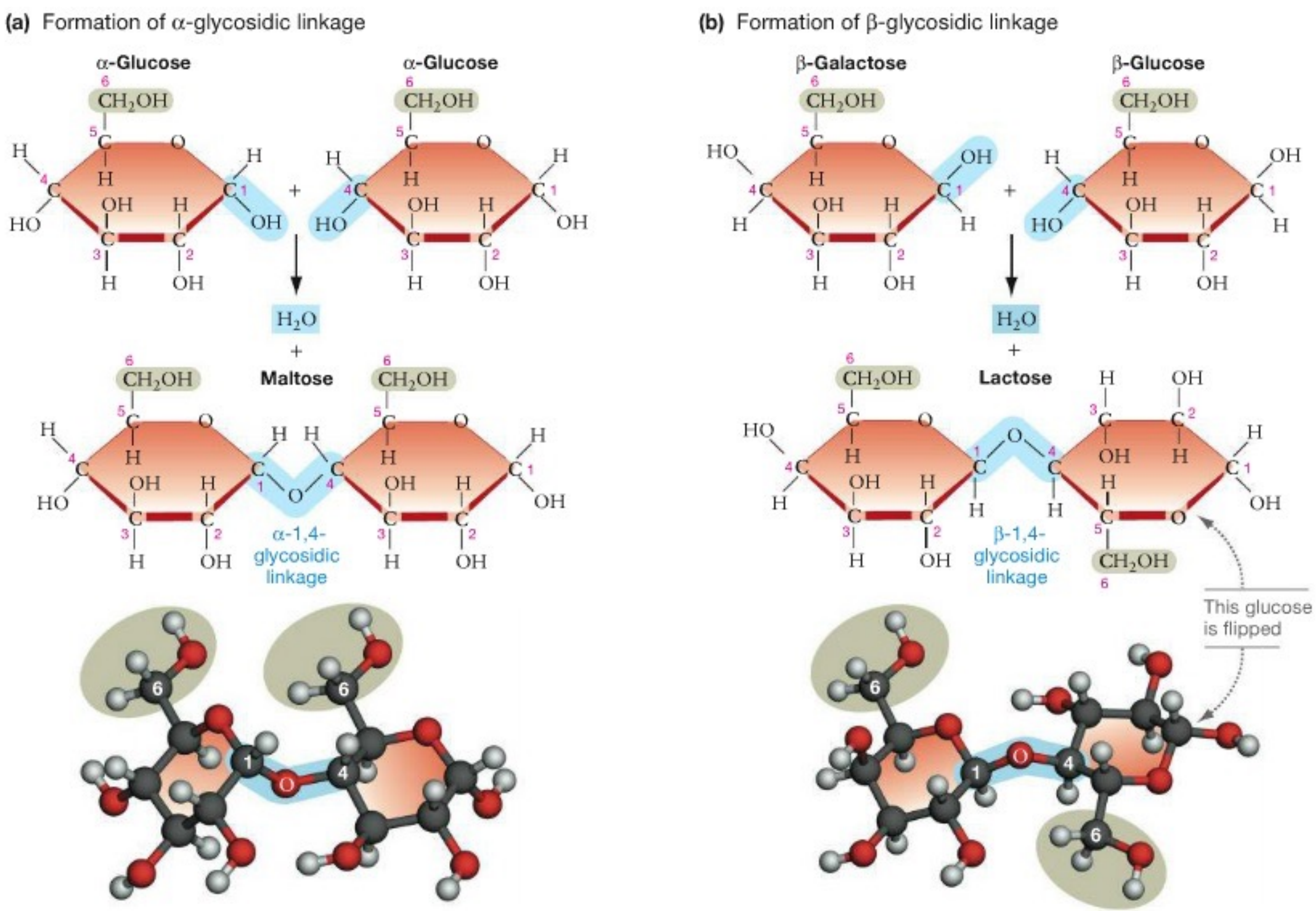


FIGURE 5.4 Monosaccharides Polymerize through Formation of Glycosidic Linkages. A glycosidic linkage occurs when hydroxyl groups on two monosaccharides undergo a condensation reaction. Maltose and lactose are disaccharides.

Types of Polysaccharides

1. Plants store sugar as **starch**
   – Mixture of branched (**amylopectin**) and unbranched (**amylose**) α-glucose polymer
2. Animals store sugar as **glycogen**
   – Highly branched α-glucose polymer
3. **Cellulose**: a structural polymer found in plant **cell walls**
   – Polymer of β-glucose monomers

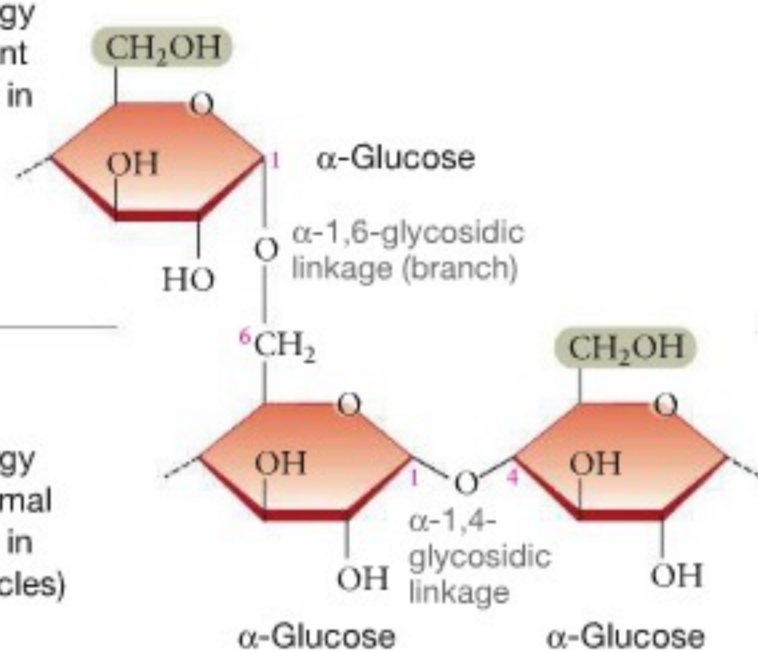
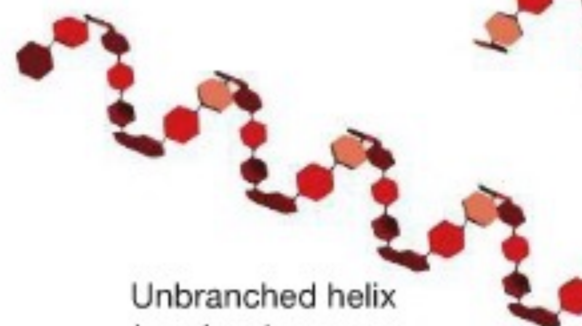
Types of Polysaccharides

4. **Chitin**: a structural polymer found in fungi cell walls, some algae, and many animal exoskeletons
   – Comprised of N-acetylglucosamine (NAc) monomers
5. **Peptidoglycan**: structural support for bacterial cell walls
   – Backbones of alternating monosaccharides

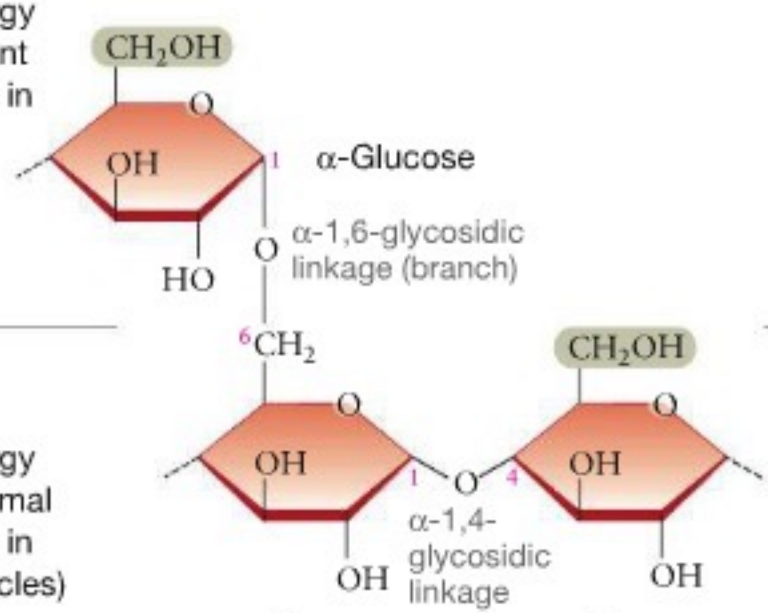
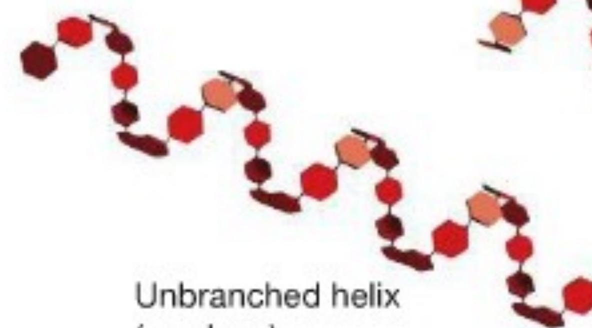
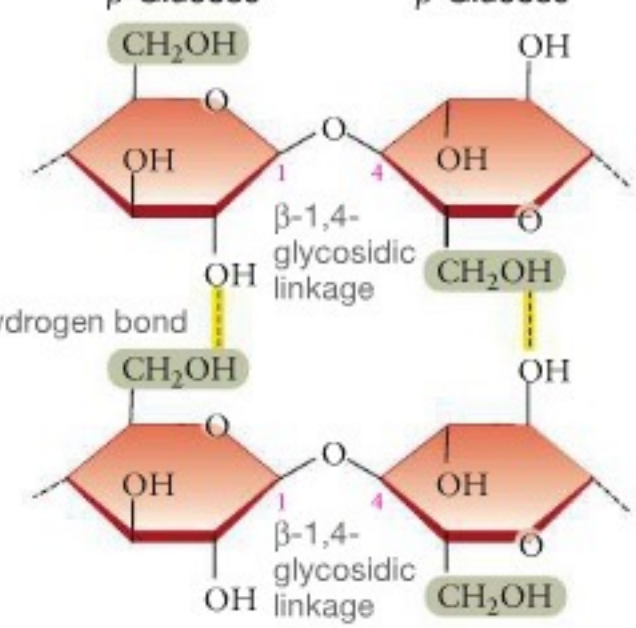
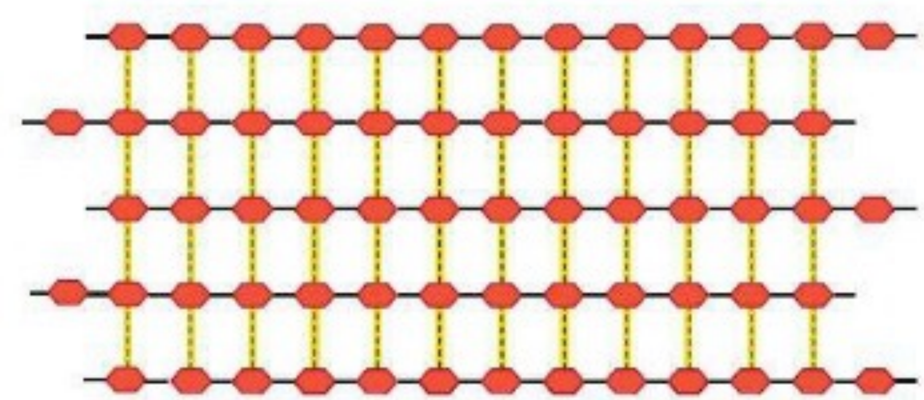
Polysaccharides

- Starch
- Glycogen
- Cellulose
- Chitin
- Peptidoglycan

SUMMARY TABLE 5.1 Polysaccharides Differ in Structure

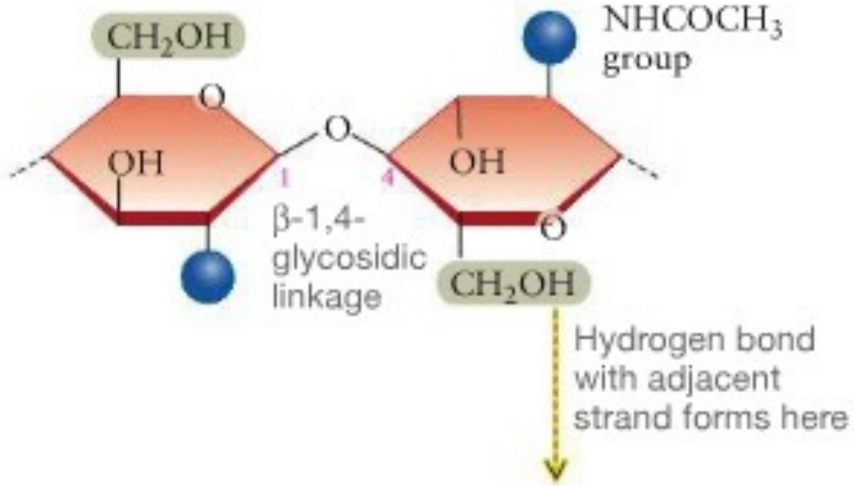
Polysaccharide	Chemical Structure	Three-dimensional Structure
Starch Used for energy storage in plant cells (such as in potatoes) 		 Unbranched helix (amylose)  Branched helices (amylopectin)
Glycogen Used for energy storage in animal cells (such as in liver and muscles) 		 Highly branched helices

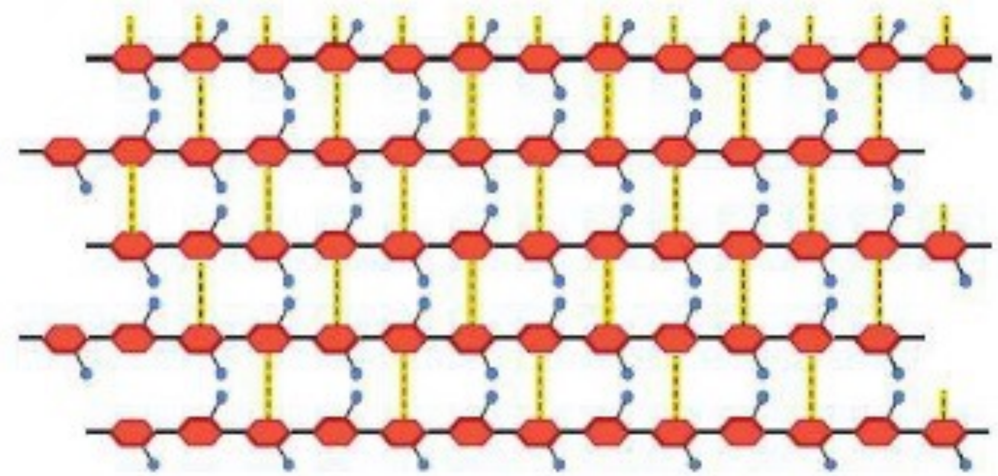
SUMMARY TABLE 5.1 Polysaccharides Differ in Structure

Polysaccharide	Chemical Structure	Three-dimensional Structure
Starch Used for energy storage in plant cells (such as in potatoes) 		 Unbranched helix (amylose)  Branched helices (amylopectin)
Glycogen Used for energy storage in animal cells (such as in liver and muscles) 		 Highly branched helices
Cellulose Used for structural support in cell walls of plants and many algae 		 Parallel strands joined by hydrogen bonds

Chitin

Used for structural support in the cell walls of fungi and the external skeletons of insects and crustaceans

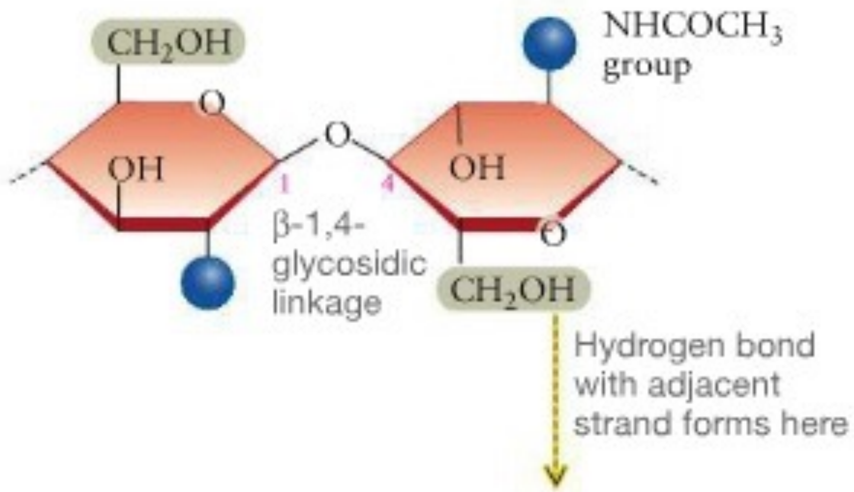


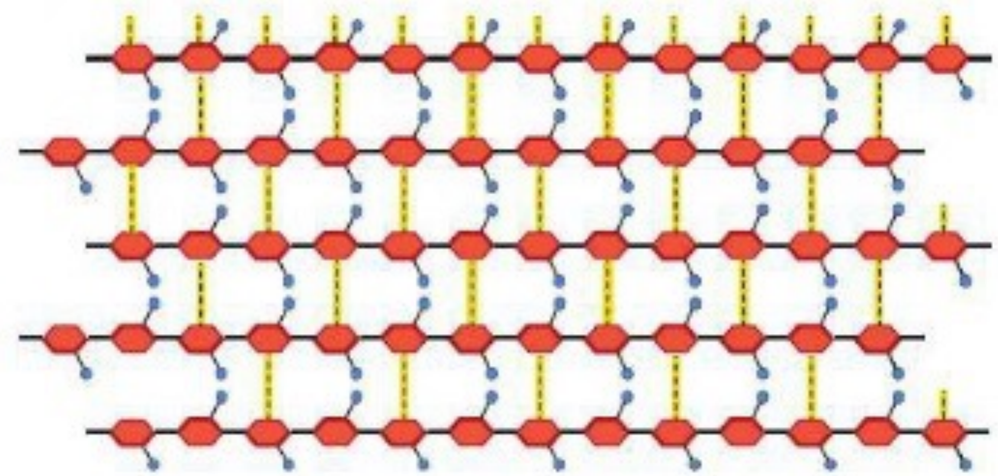


Parallel strands joined by hydrogen bonds

Chitin

Used for structural support in the cell walls of fungi and the external skeletons of insects and crustaceans

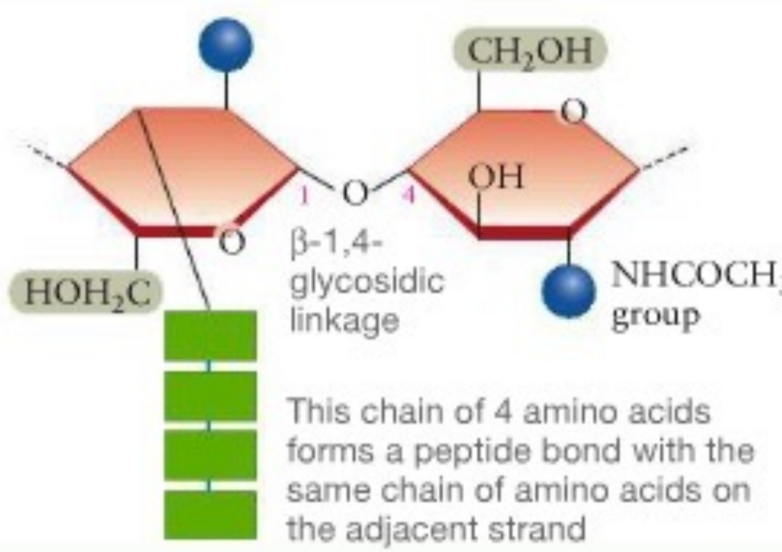


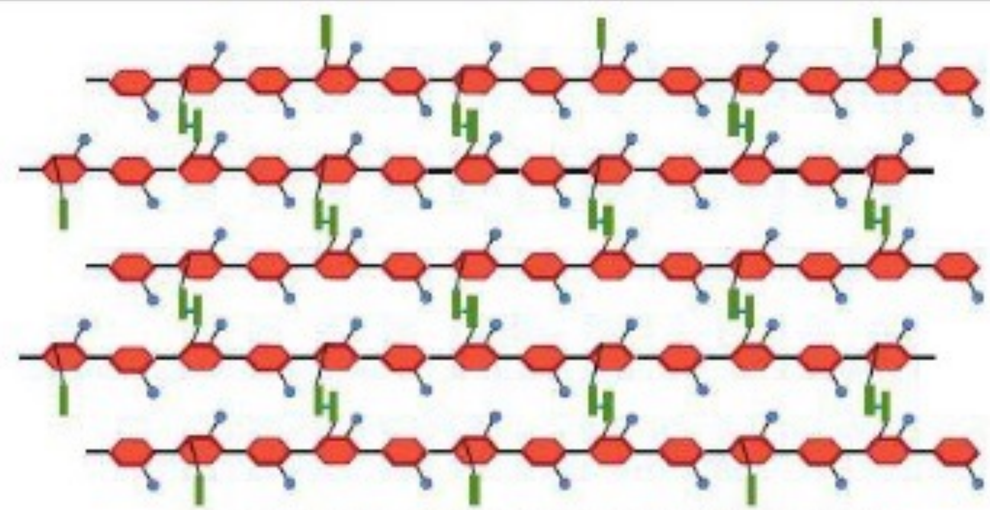


Parallel strands joined by hydrogen bonds

Peptidoglycan

Used for structural support in bacterial cell walls





Parallel strands joined by peptide bonds

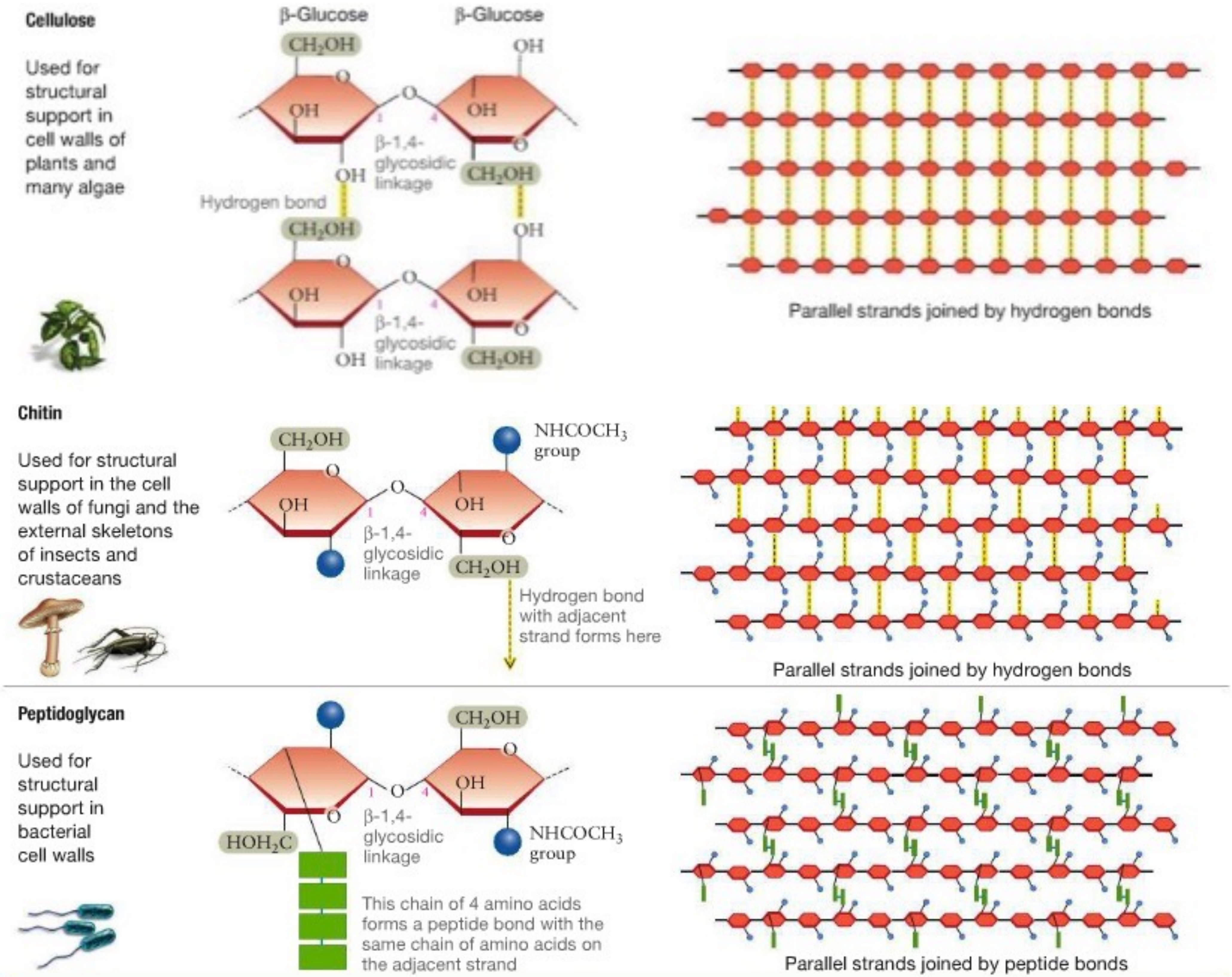
What Do Carbohydrates Do?

- Precursors to larger molecules
- Provide fibrous structural materials
- Indicate cell identity
- Store chemical energy

Carbohydrates Can Provide Structural Support

- They provide fibrous structural materials
  - Water is excluded and the fibers tend to be insoluble
- Due to the strong interactions between strands consisting of β-1,4-glycosidic linkages
- The absence of water within these fibers makes their hydrolysis more difficult
- As a result, the structural polysaccharides are resistant to degradation and decay

Structure


Cellulose
Used for structural support in cell walls of plants and many algae
β-Glucose
β-Glucose
CH_2OH
OH
O
OH
OH
β-1,4-glycosidic linkage
CH_2OH
OH
Hydrogen bond
Parallel strands joined by hydrogen bonds
Chitin
Used for structural support in the cell walls of fungi and the external skeletons of insects and crustaceans
CH_2OH
$NHCOCH_3$ group
OH
β-1,4-glycosidic linkage
CH_2OH
Hydrogen bond with adjacent strand forms here
Parallel strands joined by hydrogen bonds
Peptidoglycan
Used for structural support in bacterial cell walls
CH_2OH
OH
HOH_2C
β-1,4-glycosidic linkage
$NHCOCH_3$ group
This chain of 4 amino acids forms a peptide bond with the same chain of amino acids on the adjacent strand
Parallel strands joined by peptide bonds

Carbohydrates: Cell Identity

- Carbohydrates indicate cell identity
- *Display* information on the outer surface of cells in the form of **glycoproteins**
  - Proteins joined to carbohydrates by covalent bonds
- Glycoproteins are key molecules in
  - Cell–cell recognition
    - Each cell in your body has glycoproteins on its surface
    - Identify it as part of your body
  - Cell–cell signaling

Cell Identity

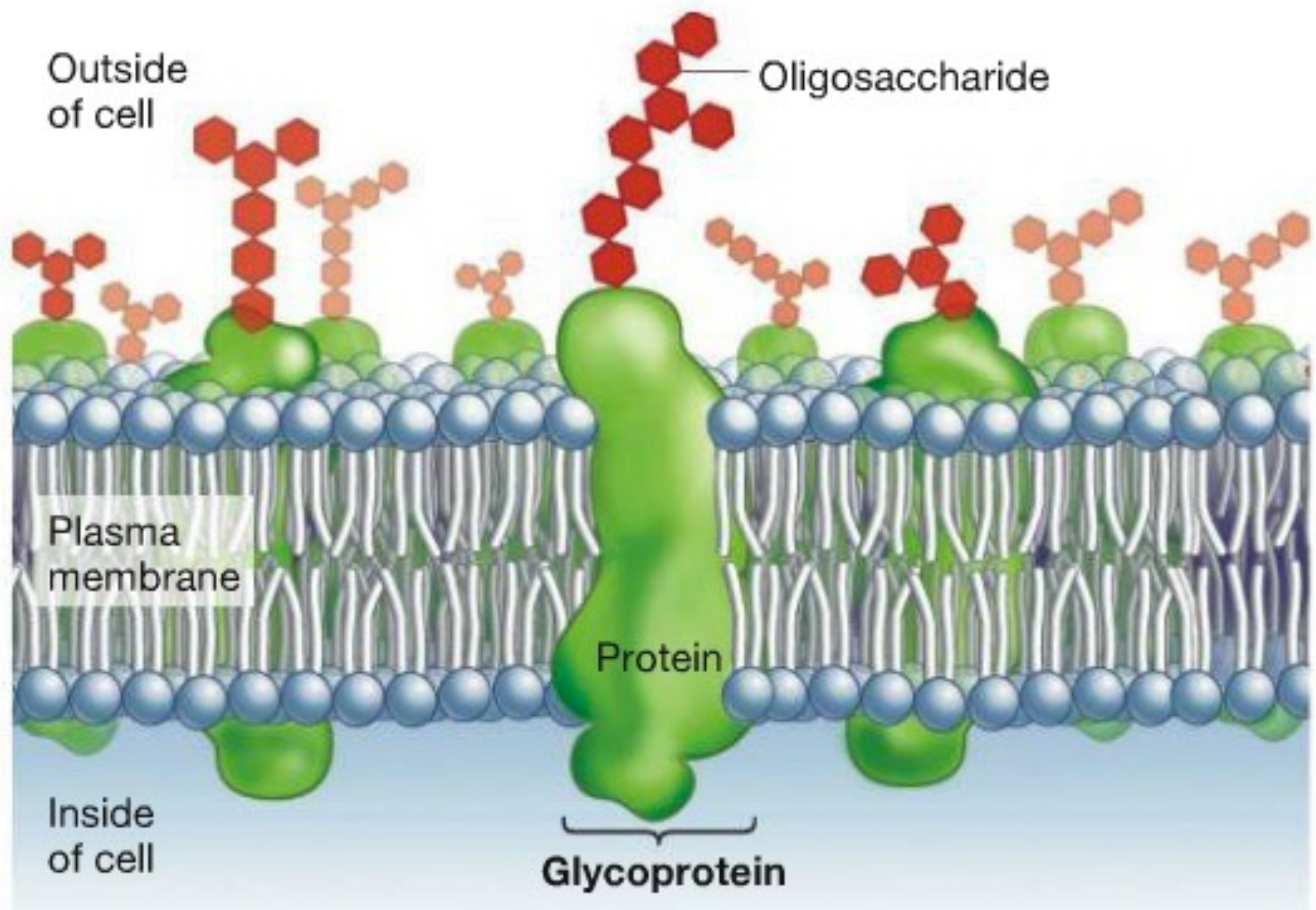


FIGURE 5.5 Carbohydrates Are an Identification Badge for Cells. Glycoproteins contain sugar groups that project outside the cell from the surface of the plasma membrane enclosing the cell. These sugar groups have distinctive structures that identify the type or species of the cell.

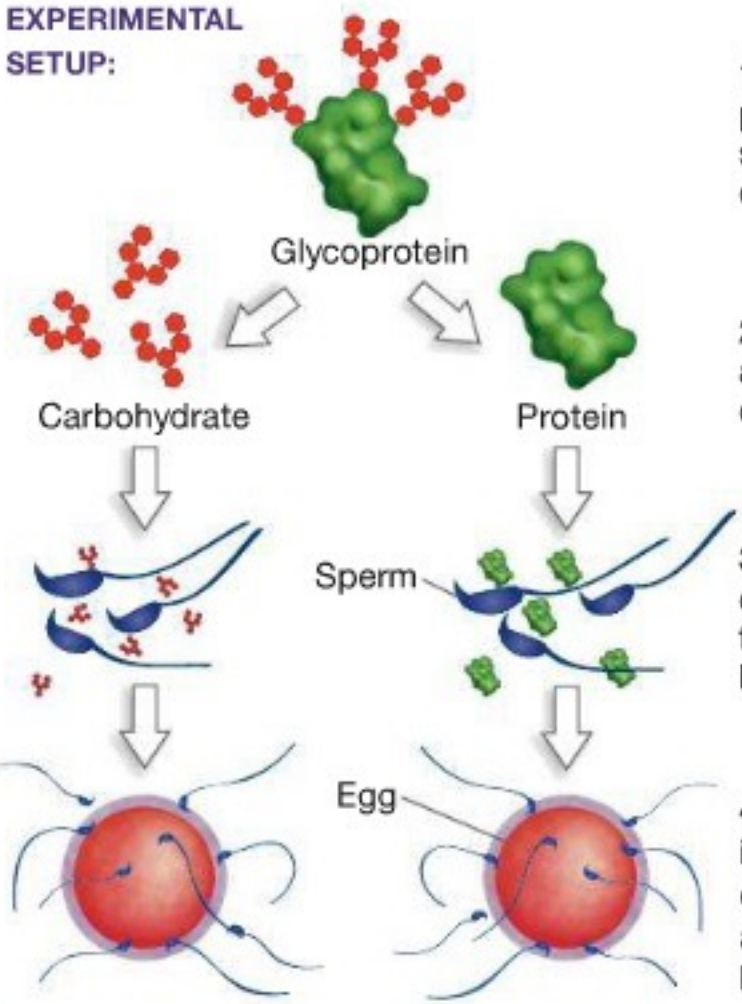
RESEARCH

QUESTION: What part of surface glycoproteins do sperm recognize when they attach to eggs?

HYPOTHESIS: Sperm attach to the carbohydrate component.

NULL HYPOTHESIS: Sperm attach to the protein component.

EXPERIMENTAL SETUP:



1. **Isolate glycoproteins** from the surface of a mouse egg.
2. **Separate protein and carbohydrate** components.
3. **Treat sperm** with components; allow time for component binding.
4. **Test attachment inhibition:** Add mouse eggs to treated sperm; allow time for sperm binding.

PREDICTION: The carbohydrate component of the glycoprotein will bind to sperm and block their attachment to eggs.

PREDICTION OF NULL HYPOTHESIS: The protein component of the glycoprotein will block sperm attachment to eggs.

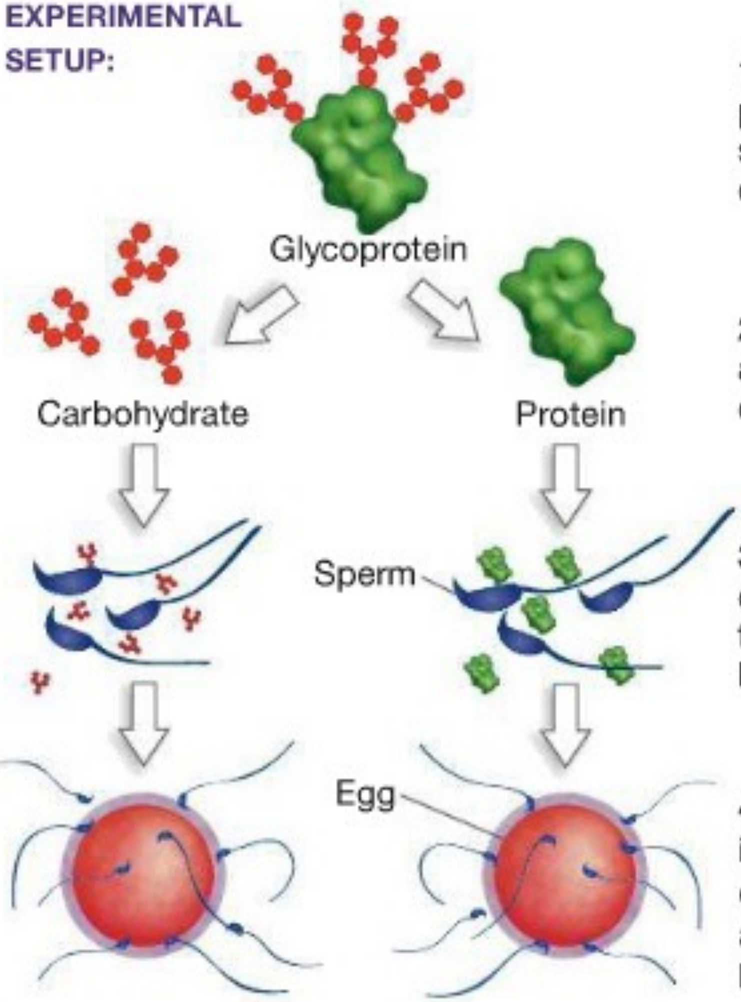
RESEARCH

QUESTION: What part of surface glycoproteins do sperm recognize when they attach to eggs?

HYPOTHESIS: Sperm attach to the carbohydrate component.

NULL HYPOTHESIS: Sperm attach to the protein component.

EXPERIMENTAL SETUP:

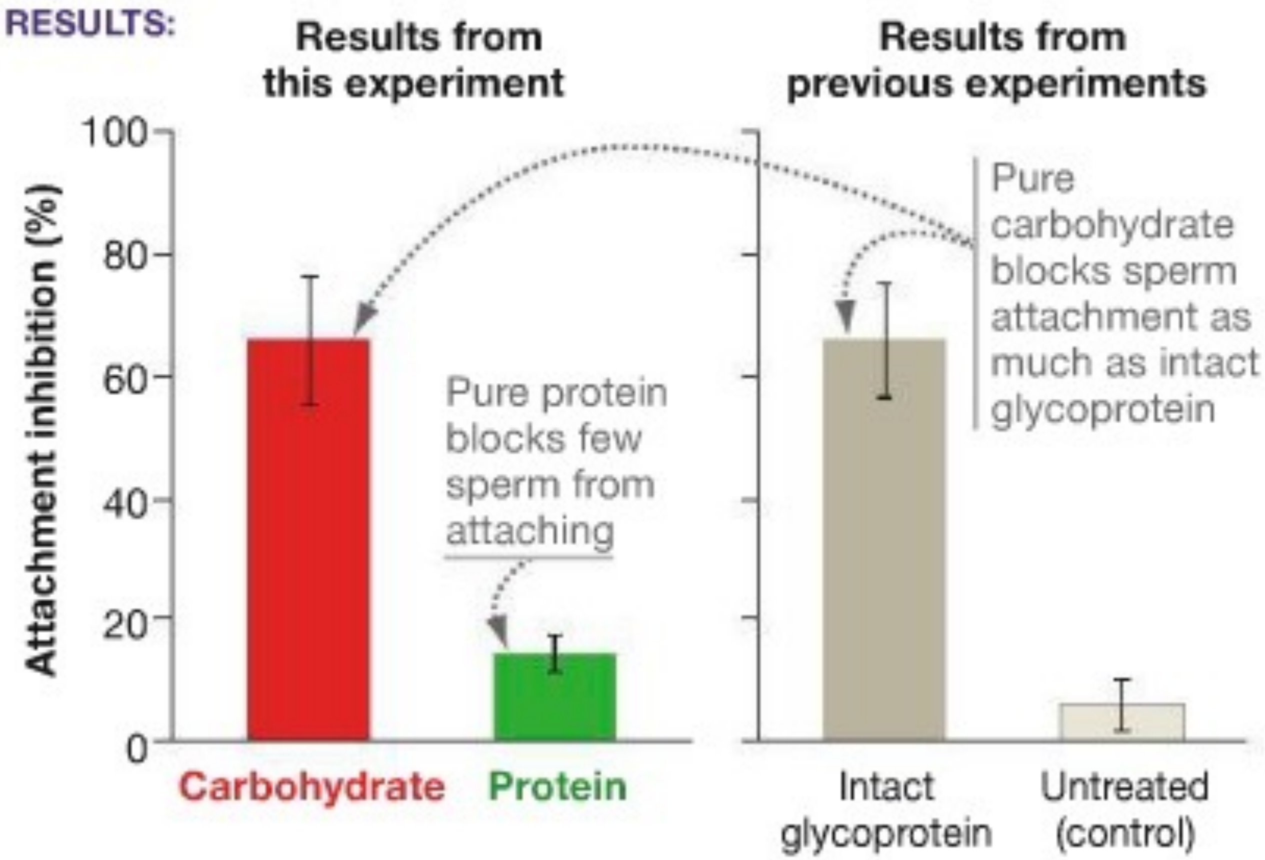


1. **Isolate glycoproteins** from the surface of a mouse egg.
2. **Separate protein and carbohydrate** components.
3. **Treat sperm** with components; allow time for component binding.
4. **Test attachment inhibition:** Add mouse eggs to treated sperm; allow time for sperm binding.

PREDICTION: The carbohydrate component of the glycoprotein will bind to sperm and block their attachment to eggs.

PREDICTION OF NULL HYPOTHESIS: The protein component of the glycoprotein will block sperm attachment to eggs.

RESULTS:



CONCLUSION: Sperm recognize and bind to the carbohydrates of egg-surface glycoproteins when they attach to egg cells.

FIGURE 5.6 Carbohydrates Are Required for Cellular Recognition and Attachment.

SOURCES: Florman, H. M., K. B. Bechtol, and P. M. Wassarman. 1984. Enzymatic dissection of the functions of the mouse egg's receptor for sperm. *Developmental Biology* 106: 243–255. Also Florman, H. M., and P. M. Wassarman. 1985. O-linked oligosaccharides of mouse egg ZP3 account for its sperm receptor activity. *Cell* 41: 313–324.

✔ **QUANTITATIVE** How would the bars change in the graph if sperm attachment required only the protein portion of egg glycoproteins?

Energy Storage

Carbohydrates and Energy Storage

- Carbohydrates store chemical energy
- They also provide chemical energy in cells
- In chemical evolution
  - Kinetic energy of sunlight and heat were converted into chemical energy stored in the bonds of H_2CO and HCN
  - Today, most sugars are produced via photosynthesis
    - A key process that transforms the energy of sunlight into the chemical energy of C–H bonds in carbohydrates

Carbohydrates and Energy Storage

- Carbohydrates have more free energy than CO_2
  - Electrons in C–H bonds and C–C bonds are shared more equally
  - Held less tightly than they are in C–O bonds

Energy Storage

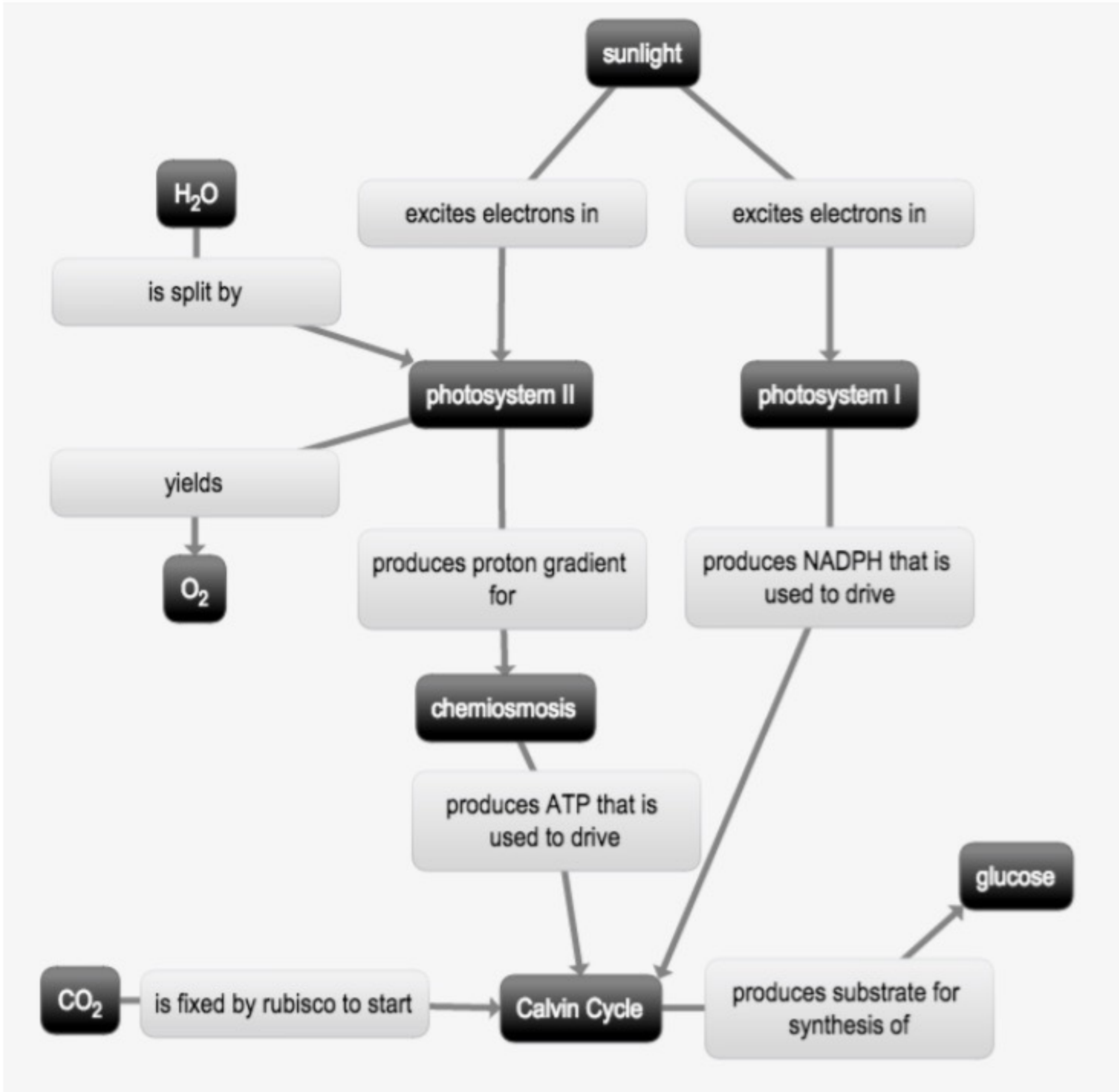
Photosynthesis

$$CO_2 + H_2O + \text{sunlight} \longrightarrow (CH_2O)_n + O_2$$

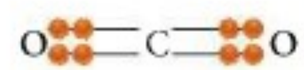
where $(CH_2O)_n$ represents a carbohydrate. The key to understanding the energy conversion that is taking place in this reaction is to compare the positions of the electrons in the reactants to those in the products.

1. The electrons in the C=O bonds of carbon dioxide and the C–O bonds of carbohydrates are held tightly because of oxygen's high electronegativity. Thus, they have relatively low potential energy.
2. The electrons involved in the C–H bonds of carbohydrates are shared equally because the electronegativity of carbon and hydrogen is about the same. Thus, these electrons have relatively high potential energy.
3. Electrons are also shared equally in the carbon–carbon C–C bonds of carbohydrates—meaning that they, too, have relatively high potential energy.

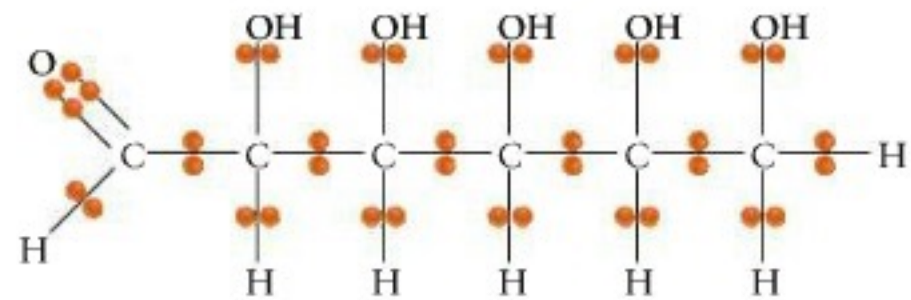
How does photosynthesis yield sugar?



(a) Carbon dioxide



(b) A carbohydrate



(c) A fatty acid (a component of fat molecules)

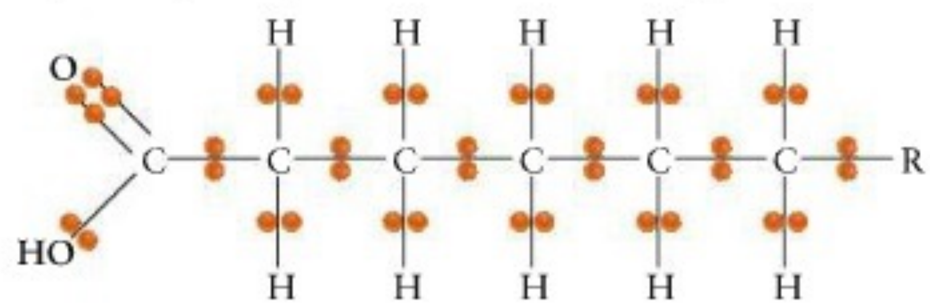


FIGURE 5.7 In Organisms, Potential Energy Is Stored in C–H and C–C Bonds. (a) In carbon dioxide, the electrons involved in covalent bonds are held tightly by oxygen atoms. **(b)** In carbohydrates such as the sugar shown here, many of the covalently bonded electrons are held equally between C and H atoms. **(c)** The fatty acids found in fat molecules have more C–H bonds and fewer C–O bonds than carbohydrates do. ("R" stands for the rest of the molecule.)

✔ **EXERCISE** Circle the bonds in this diagram that have high potential energy.

Because fats and other lipids contain more C–H bonds than do carbohydrates such as starch and sugars, fats provide over twice the energy per gram. Specifically, carbohydrates and proteins provide about 4 kcal/g, and fats provide about 9 kcal/g.

Starch and Glycogen Are Hydrolyzed to Release Glucose

- The hydrolysis of α-glycosidic linkages in *glycogen* is catalyzed by the enzyme **phosphorylase**
  - Most animal cells contain phosphorylase
  - They can readily break down glycogen to provide glucose
- The α-glycosidic linkages in *starch* are hydrolyzed by **amylase** enzymes
  - Amylases play a key role in carbohydrate digestion

Energy Stored in Glucose Is Transferred to ATP

- When a cell needs energy, carbohydrates participate in
  - Exergonic reactions that synthesize **adenosine triphosphate** (**ATP**):

$$CH_2O + O_2 + ADP + P_i \rightarrow CO_2 + H_2O + ATP$$

- The free energy in ATP is used to drive endergonic reactions and perform cell work
- Carbohydrates contain a large number of C–H bonds
  - These bonds have high free energy
- Fatty acids have even more C–H bonds
  - They have more free energy than carbohydrates

How Do Carbohydrates Store Energy?

- Starch and glycogen are efficient energy-storage molecules
  - The α-linkages are readily hydrolyzed
- The β-linkages of structural carbohydrates resist enzymatic degradation
- The enzyme amylase catalyzes hydrolysis of α-glycosidic linkages in glycogen

How Do Carbohydrates Store Energy?

- The enzyme phosphorylase catalyzes hydrolysis of α-glycosidic linkages in starch
  - α-glycosidic linkages in glycogen and starch, respectively
- The released glucose subunits can then be used in the production of ATP

Energy Stored in Glucose Is Used to Make ATP

- When a cell needs energy
  – Reactions lead to the breakdown of the glucose
  – They also capture released energy through synthesis of the nucleotide adenosine triphosphate (ATP)
- The chemical energy stored in the C–H and C–C bonds of carbohydrate is transferred to a new bond linking a third phosphate group to ADP to form ATP
- Carbohydrates store chemical energy
- ATP makes chemical energy useful to the cell

check your understanding

C Y U

If you understand that . . .

- Carbohydrates provide building blocks for the synthesis of more complex compounds.
- Polysaccharides such as cellulose, chitin, and peptidoglycan form cell walls, which give cells structural strength.
- Glycoproteins project from the surface of cells. They provide a molecular badge that identifies the cell's type or species.
- Starch and glycogen store sugars for later use in reactions that produce ATP. Sugars contain large amounts of chemical energy because they contain carbon atoms that are bonded to hydrogen atoms or other carbon atoms. The C–H and C–C bonds have high potential energy because the electrons are shared equally by atoms with low electronegativity.

✔ You should be able to . . .

1. Identify two aspects of the structures of cellulose, chitin, and peptidoglycan that correlate with their function as structural molecules.
2. Describe how the carbohydrates you ate during breakfast today are functioning in your body right now.

Answers are available in Appendix A.