Biochemistry

Unit 1 · Lesson 2 · Sugars: classes, rings and links

The notes for Lesson 2 of Unit 1: chapters 1.3 to 1.5 of the unit book, with their figures, worked examples, exam traps and quizzes, in one file. The full unit book, with every chapter, the exam question bank and the glossary, is linked at the end.

Lesson 2 of 4 | 3 chapters | Chapters 1.3 to 1.5

About these notes

These are the notes for **Lesson 2 · Sugars: classes, rings and links** of the University free n easy video lessons on Biochemistry Unit 1, Foundations: Water, pH and Carbohydrates. They are chapters 1.3 to 1.5 of the unit book, unchanged, so a page here is the same page in the full book.

1.3 Carbohydrates: classification and functions

Carbohydrates are polyhydroxy aldehydes or ketones, or substances that give these on hydrolysis. They are the most abundant biomolecules on Earth: every year photosynthesis turns more than 100 billion tonnes of CO_2 and water into cellulose and other plant products. In living things they are fuel, fuel stores, building materials and identity tags on cell surfaces. Every university's syllabus opens carbohydrates with this classification, and it is one of the most common long-answer questions.

You need: functional groups and the glycosidic bond as a condensation (Chapter 1.1).

What counts as a carbohydrate

Many simple carbohydrates have the empirical formula $(CH_2O)_n$, which is where the old name "hydrates of carbon" comes from. The formula is a poor definition. Deoxyribose ($C_5H_{10}O_4$) is a carbohydrate that does not fit it, while formaldehyde (CH_2O), acetic acid ($C_2H_4O_2$) and lactic acid ($C_3H_6O_3$) fit it but are not carbohydrates. Some carbohydrates also contain nitrogen (amino sugars), phosphorus (sugar phosphates) or sulfur (sulfated glycosaminoglycans). Define carbohydrates by structure instead: several –OH groups plus an aldehyde or ketone group, or a polymer built from such units.

Classification by size

The main classification counts sugar units (Figure 1.3.1).

- **Monosaccharides** are simple sugars that cannot be hydrolysed into smaller carbohydrates. Each gets two descriptions: by its carbonyl group (an **aldose** has an aldehyde at C1; a **ketose** has a ketone, usually at C2) and by its number of carbons (triose 3, tetrose 4, pentose 5, hexose 6, heptose 7). Combined, glucose is an aldohexose, fructose a ketohexose, ribose an aldopentose, glyceraldehyde an aldotriose and dihydroxyacetone a ketotriose. Their structures and isomers are Chapter 1.4.
- **Oligosaccharides** contain 2 to about 10 units joined by glycosidic bonds. Disaccharides (maltose, lactose, sucrose) are the most important (Chapter 1.5). Raffinose, a trisaccharide of galactose, glucose and fructose, is found in rajma, chana and soybean; our small intestine cannot digest it, so gut bacteria ferment it, and the gas they make is the familiar side effect of a pulse-rich meal. Many oligosaccharides in cells are attached to proteins and lipids (Chapter 1.7).
- **Polysaccharides** (glycans) contain many units, often hundreds to thousands. A **homopolysaccharide** has one kind of unit (starch, glycogen, cellulose, chitin, inulin); a **heteropolysaccharide** has two or more kinds (hyaluronic acid, heparin, chondroitin sulfate, the peptidoglycan of bacterial cell walls). Unlike a protein, a polysaccharide is made without a template, so its chain length varies from molecule to molecule and it has no single molecular mass (Chapter 1.6).

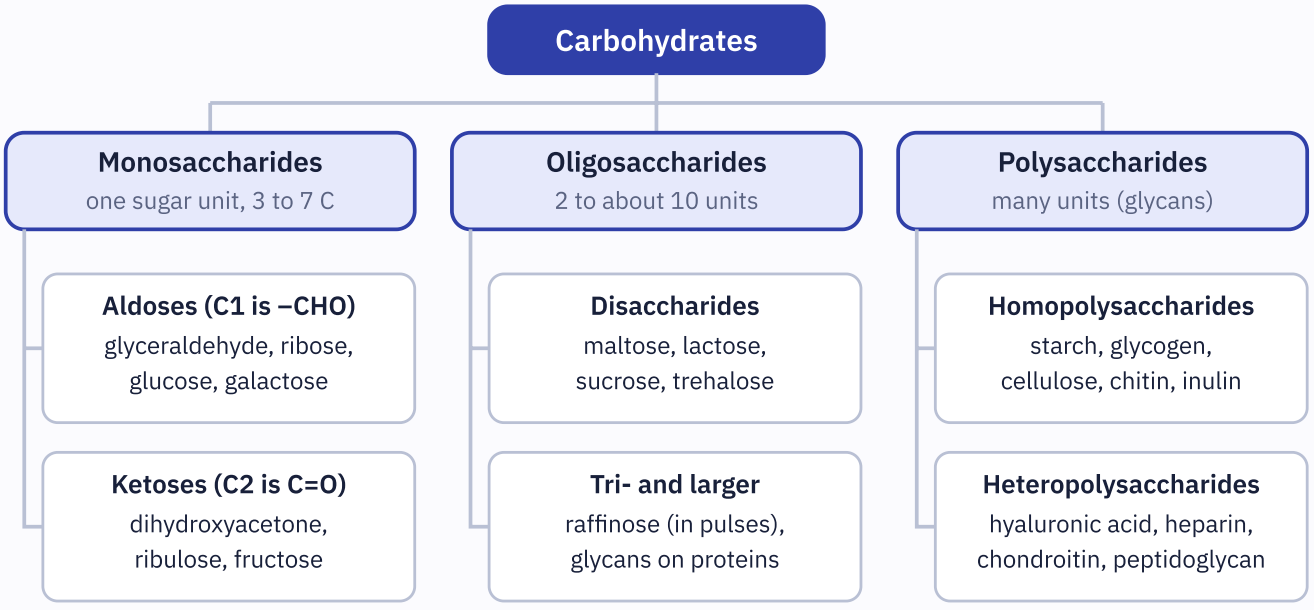


Figure 1.3.1 Classification of carbohydrates by the number of sugar units, with the second level each class is split into. Notice that "homo" and "hetero" refer to the kinds of unit, not to branching: branched glycogen is still a homopolysaccharide.

Chemically modified monosaccharides are called **derived sugars**: deoxy sugars (2-deoxyribose in DNA), amino sugars (glucosamine and galactosamine, often N-acetylated), sugar acids (gluconic acid, glucuronic acid, sialic acids), sugar alcohols (sorbitol, mannitol, xylitol) and sugar phosphates (glucose 6-phosphate). The reactions that make them are in Chapter 1.8.

Functions of carbohydrates

1. **Fuel.** Digestible carbohydrate supplies about 17 kJ (4 kcal) per gram. Glucose is the main fuel of the brain and the only fuel of red blood cells, which have no mitochondria.
2. **Fuel storage.** Plants store starch, animals and fungi store glycogen, and some plants such as chicory store inulin, a fructose polymer.
3. **Structure.** Cellulose builds plant cell walls and cotton; chitin builds the shells of insects and crabs and the walls of fungi; peptidoglycan builds bacterial cell walls (the target of penicillin); glycosaminoglycans give cartilage its spring.
4. **Parts of other biomolecules.** Ribose is part of RNA, ATP, NAD^+, FAD and coenzyme A; deoxyribose is part of DNA (Unit 4).
5. **Recognition and signalling.** Sugar chains on proteins and lipids act as tags read by other proteins: the ABO blood groups, influenza virus attaching to sialic acid on our cells, and white blood cells rolling to a site of infection all depend on them (Chapters 1.7 and 1.9).

6. **Protection and lubrication.** Hyaluronic acid lubricates joints; mucins in mucus protect the gut and airways.

WORKED EXAMPLE

Question (8 marks). Classify each of the following, with a reason and one source or role: glyceraldehyde, dihydroxyacetone, ribose, fructose, sucrose, raffinose, glycogen, hyaluronic acid. Then find the energy in a meal with 60 g of digestible carbohydrate.

CARBOHYDRATE	CLASS	REASON	SOURCE OR ROLE
Glyceraldehyde	Aldotriose	3 C, aldehyde at C1	its phosphate is a glycolysis intermediate
Dihydroxyacetone	Ketotriose	3 C, ketone at C2, no chiral carbon	its phosphate is a glycolysis intermediate
Ribose	Aldopentose	5 C, aldehyde	RNA, ATP
Fructose	Ketohexose	6 C, ketone at C2	fruits, honey
Sucrose	Disaccharide	glucose + fructose	sugarcane, table sugar
Raffinose	Trisaccharide	galactose + glucose + fructose	pulses
Glycogen	Homopolysaccharide	only glucose, branched	energy store in liver and muscle
Hyaluronic acid	Heteropolysaccharide	two kinds of unit (glucuronic acid, N-acetylglucosamine)	lubricates joints

1. Energy = mass × energy per gram = 60 g × 17 kJ/g = **1020 kJ**, about 1.0 MJ.
2. In kilocalories: 60 g × 4 kcal/g = **240 kcal**.

Examiners give marks for the reason column: the class alone earns half.

EXAM TRAPS

- "Carbohydrate = $(CH_2O)_n$" is not a definition: deoxyribose breaks it, and lactic acid fits it without being a carbohydrate.
- Not every carbohydrate is sweet. "Sugar" usually means mono- and disaccharides; starch and cellulose are tasteless.
- Dihydroxyacetone has no chiral carbon, so it has no D and L forms; glyceraldehyde is the smallest chiral sugar.
- Homo- and heteropolysaccharide refer to the kinds of unit, not to branching or bond type.
- Glycogen is often called "animal starch", but it is more branched than amylopectin (Chapter 1.6).

CHECK YOURSELF

– REMEMBER **Define a monosaccharide and give one aldotriose and one ketotriose.** 2 marks

A monosaccharide is a simple sugar that cannot be hydrolysed into smaller carbohydrates. Aldotriose: glyceraldehyde. Ketotriose: dihydroxyacetone.

– REMEMBER **Name two storage and two structural polysaccharides.** 2 marks

Storage: starch, glycogen (also inulin). Structural: cellulose, chitin (also peptidoglycan).

– UNDERSTAND **Why do pulses such as rajma cause gas when rice does not?** 2 marks

Pulses contain raffinose and related oligosaccharides that our small intestine cannot digest. They reach the colon, where bacteria ferment them and release gases. Rice starch is digested and absorbed before it gets there.

– APPLY **Classify sedoheptulose (7 carbons, ketone at C2) and 2-deoxyribose.** 2 marks

Sedoheptulose is a ketoheptose. 2-Deoxyribose is a derived sugar: an aldopentose lacking the –OH at C2.

– APPLY **A glass of sweet lassi has 30 g of sugar. How much energy is that in kJ and kcal?** 2 marks

30 × 17 = **510 kJ**; 30 × 4 = **120 kcal**.

– ANALYZE **Why do red blood cells depend entirely on glucose, while muscle can also burn fat?** 3 marks

Red blood cells have no mitochondria, so they cannot oxidise fatty acids or run the citric acid cycle. Glycolysis, which needs glucose, is their only source of ATP. Muscle has mitochondria and can oxidise fatty acids.

BEYOND THE SYLLABUS

Glycobiology studies the full set of sugars a cell makes, its "glycome", using mass spectrometry and glycan arrays. The CAZy database classifies the enzymes that make and break carbohydrates, and biorefineries use such enzymes to turn crop waste into fuels and chemicals (see the Environmental Biotechnology and Bioenergy subject). Dietary fibre research now focuses on how gut bacteria ferment polysaccharides into short-chain fatty acids. Search next for "glycome", "CAZy" and "dietary fibre gut microbiome". None of this is for the exam.

1.4 Monosaccharides: structure, isomerism and mutarotation

A monosaccharide is a chain of 3 to 7 carbons carrying one aldehyde or ketone group and several –OH groups. Most of its carbons are chiral, so each sugar has many stereoisomers, and in water the chain closes into a ring. Ring closure creates one more chiral centre, the anomeric carbon, whose two forms (α and β) slowly interconvert. This chapter teaches you to draw a sugar three ways (Fischer, Haworth, chair) and to name every kind of isomer an examiner asks about.

You need: chirality, configuration and conformation (Chapter 1.1); aldoses and ketoses (Chapter 1.3).

Fischer projections and the D/L system

In a Fischer projection the carbon chain is drawn vertically with C1, the most oxidised end, at the top. Horizontal bonds point towards you and vertical bonds away. The reference is glyceraldehyde, the simplest chiral sugar: in D-glyceraldehyde the –OH on the chiral carbon is on the right; in L-glyceraldehyde it is on the left.

For longer sugars, D or L is set by the chiral carbon farthest from the carbonyl group (C5 in glucose and fructose, C4 in ribose): –OH on the right means D. Almost all natural sugars are D.

The label says nothing about the direction of optical rotation, which is measured and written (+) for dextrorotatory or (–) for levorotatory. D-glucose is (+), but D-fructose is (–).

Kinds of isomers

Glucose, fructose, galactose and mannose all have the formula $C_6H_{12}O_6$, so they are isomers. The relationships to know are:.

TYPE	MEANING	EXAMPLE
Structural (functional) isomers	same formula, different carbonyl group	glucose (aldose) and fructose (ketose)
Enantiomers	mirror images; every chiral centre inverted	D-glucose and L-glucose
Diastereomers	stereoisomers that are not mirror images	D-glucose and D-galactose
Epimers	diastereomers differing at only one chiral centre	glucose and mannose (C2); glucose and galactose (C4)
Anomers	epimers at the new centre made by ring closure	α- and β-D-glucopyranose

A molecule with n chiral centres has at most 2^n stereoisomers. An open-chain aldohexose has four (C2 to C5), so there are $2^4 = 16$ aldohexoses, 8 D and 8 L. A ketohexose has three (C3 to C5), giving $2^3 = 8$. Mannose and galactose differ at two centres (C2 and C4), so they are diastereomers but not epimers.

Ring formation: pyranoses, furanoses and anomers

An aldehyde reacts with an alcohol to give a hemiacetal; a ketone gives a hemiketal. Inside a sugar the alcohol is the molecule's own –OH. In glucose the C5–OH attacks the C1 aldehyde, closing a six-membered ring of five carbons and one oxygen. Six-membered sugar rings are **pyranoses** (after pyran) and five-membered ones are **furanoses** (after furan). Fructose forms a furanose when its C5–OH attacks the C2 ketone, the form found in sucrose (Chapter 1.5).

Ring closure turns the carbonyl carbon (C1 of glucose) into a new chiral centre, the **anomeric carbon**. In the Haworth projection, a flat hexagon seen edge-on with the ring oxygen at the back right, every group on the right in the Fischer projection points down, and the CH_2OH (C6) of a D-sugar points up. The anomer with the C1–OH down, opposite the CH_2OH, is **α**; with C1–OH up, on the same side, it is **β** (Figure 1.4.1).

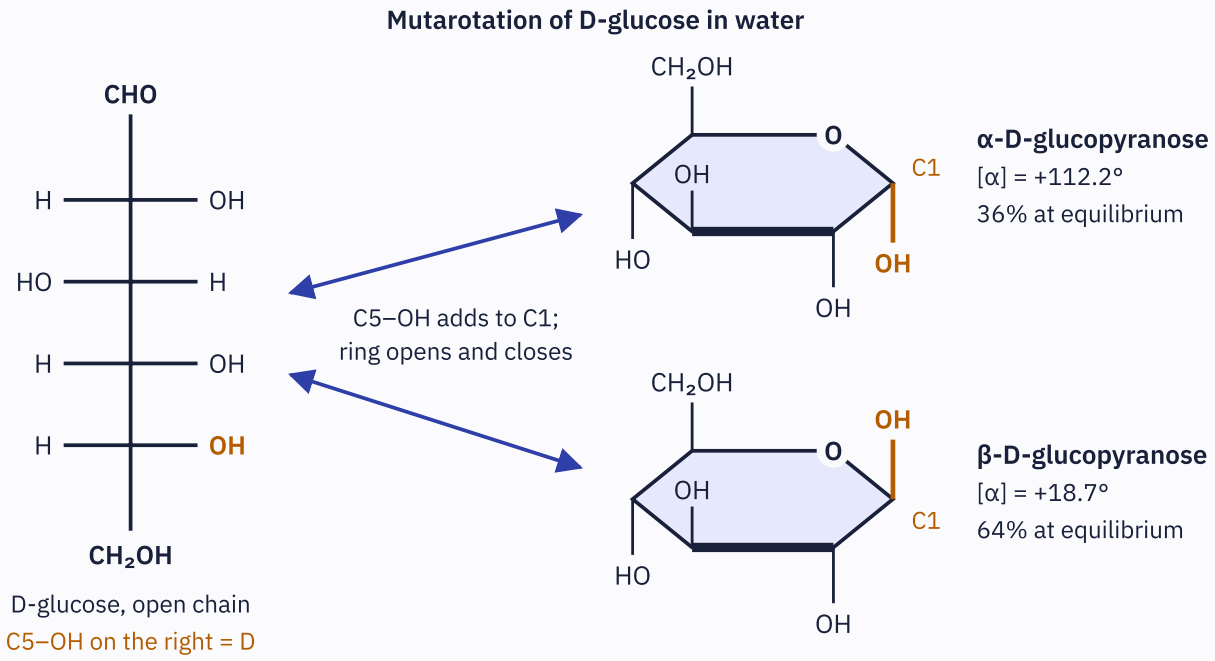


Figure 1.4.1 The open chain of D-glucose closes into two rings that differ only at C1, the anomeric carbon (highlighted). Groups on the right in the Fischer projection point down in the Haworth ring; ring hydrogens are left out for clarity. Notice that α has the C1–OH on the opposite side to CH_2OH and β on the same side; in water they interconvert through the open chain until the mixture reaches +52.7°.

Mutarotation and conformation

Crystals of pure α-D-glucose dissolved in water have a specific rotation of +112.2°; pure β-D-glucose gives +18.7°. With time both solutions drift to the same value, +52.7°. This change in optical rotation is **mutarotation**. It happens because the ring opens to the open-chain aldehyde and closes again, either way, until the anomers reach equilibrium. The open chain is only a tiny fraction (well under 1%). Acid and base speed mutarotation up, and cells have an enzyme for it, mutarotase. Only sugars with a free anomeric carbon mutarotate; in a glycoside or in sucrose the anomeric carbon is locked (Chapter 1.5).

Haworth rings are flat for convenience, but a real pyranose ring is puckered into a **chair**. In the chair each ring carbon has one axial bond (parallel to the ring axis) and one equatorial bond (pointing outwards), and bulky groups are more stable equatorial. In β-D-glucopyranose every bulky group (four –OH and the CH_2OH) is equatorial, one reason β is the main form at equilibrium. In α the C1–OH is axial; a stereo-electronic effect called the anomeric effect partly stabilises an axial group at C1, which is why α still makes up about a third. Flipping between chairs changes conformation, not configuration.

WORKED EXAMPLE

Question (5 marks). Fresh solutions of α-D-glucose ([α] = +112.2°) and β-D-glucose ([α] = +18.7°) both change to +52.7°. (a) Name and explain the change. (b) Calculate the percentage of each anomer at equilibrium, ignoring the open chain. (c) What does the answer say about stability?

1. (a) Mutarotation: each anomer opens to the aldehyde form and recloses as either anomer until equilibrium.
2. (b) Let x be the fraction of α. The observed rotation is the weighted average: 112.2x + 18.7(1 − x) = 52.7.
3. Rearrange: 112.2x − 18.7x = 52.7 − 18.7, so 93.5x = 34.0 and x = 0.364.
4. So α = **36.4%** and β = **63.6%**. In general, fraction α = ([α]eq − [α]β) / ([α]α − [α]β).
5. (c) β is favoured, because in its chair all bulky groups are equatorial.

EXAM TRAPS

- D does not mean dextrorotatory: D-fructose is levorotatory. D/L is read from the highest-numbered chiral carbon (C5 in hexoses), not from C2.
- Mannose and galactose are not epimers: they differ at two centres.
- Mutarotation is not racemisation. D-glucose stays D-glucose; only C1 changes.
- Ring closure adds a chiral centre: the open-chain aldohexose has 4, the pyranose has 5 (2^5 = 32 stereoisomers).
- For D-sugars in Haworth, α means the anomeric –OH is down, trans to the CH_2OH; β means up.

CHECK YOURSELF

– REMEMBER **Define epimers and anomers, with one example each.** 2 marks

Epimers differ in configuration at only one chiral carbon (D-glucose and D-galactose at C4). Anomers are epimers at the anomeric carbon created by ring closure (α- and β-D-glucopyranose).

– UNDERSTAND **In which direction do the –OH groups at C2, C3 and C4 of D-glucose point in the Haworth ring?** 2 marks

Right in Fischer becomes down in Haworth: C2–OH down, C3–OH up (it was on the left), C4–OH down; the CH_2OH at C5 points up.

– UNDERSTAND **Why does the rotation of a fresh β-D-glucose solution rise from +18.7° to +52.7°?** 2 marks

Some β opens to the aldehyde and recloses as α, which rotates light far more (+112.2°). The rotation rises until the α:β ratio reaches equilibrium (about 36:64).

– APPLY **How many stereoisomers are possible for (a) an aldopentose, (b) a ketopentose, (c) a glucopyranose?** 3 marks

(a) 3 chiral centres: 2^3 = **8**. (b) 2 chiral centres: 2^2 = **4**. (c) 5 chiral centres: 2^5 = **32**.

– APPLY **A hexose has [α] = +150.7° for its α anomer and +52.8° for β; its equilibrium value is +80.2°. Find the percentage of α.** 3 marks

Fraction α = (80.2 − 52.8)/(150.7 − 52.8) = 27.4/97.9 = 0.28, so **28% α** and 72% β.

– ANALYZE **Why is the anomeric carbon C1 in glucose but C2 in fructose?** 2 marks

The anomeric carbon is the former carbonyl carbon, which becomes the hemiacetal or hemiketal carbon on ring closure. Glucose's aldehyde is at C1; fructose's ketone is at C2.

– ANALYZE **β-D-glucopyranose is the most abundant form of glucose in water. Explain with conformation.** 3 marks

In the $^4C_1$ chair of β-D-glucopyranose all five bulky substituents are equatorial, so there are no crowded axial groups. In α the C1–OH is axial, which costs some stability, only partly offset by the anomeric effect.

BEYOND THE SYLLABUS

Chemists assign α and β by NMR: the coupling between H1 and H2 is larger in β, where both are axial, than in α. Rare sugars are now made by enzymes that change one centre at a time; D-allulose, the C3 epimer of D-fructose, is produced this way as a low-calorie sweetener. The anomeric effect remains a lively topic in physical organic chemistry. Search next for "anomeric effect", "rare sugars Izumoring" and "carbohydrate NMR". None of this is for the exam.

1.5 Disaccharides and the glycosidic bond

Two monosaccharides join when the anomeric –OH of one condenses with an –OH of the other, releasing water. The new link, the glycosidic bond, is an acetal. Which carbons it joins, and whether it is α or β, decide everything else about the disaccharide: its name, whether our enzymes can cut it, and whether it is a reducing sugar.

You need: the anomeric carbon, α and β (Chapter 1.4).

Making and naming the glycosidic bond

A sugar ring is a hemiacetal: its anomeric carbon carries both the ring oxygen and an –OH. When that anomeric –OH reacts with an –OH of another molecule, water is lost and the anomeric carbon now carries two –OR groups. It has become an acetal, and the new link is an **O-glycosidic bond**; the product is a **glycoside**. When the partner is another sugar, the product is a disaccharide. When the nitrogen of a base takes the place of the –OH, the bond is an N-glycosidic bond, as in nucleosides (Unit 4). How cells and chemists actually make the bond is Chapter 1.9.

Two consequences follow. The anomeric carbon in the bond is locked: it can no longer open to the aldehyde, so that unit cannot mutarotate or reduce Cu^{2+}. And its configuration is fixed as α or β, which enzymes recognise exactly. To name a disaccharide:

1. Start with the unit whose anomeric carbon is in the bond (the non-reducing end), written on the left.
2. Give its configuration at the anomeric carbon (α or β) and, in full names, its ring size (pyranose or furanose).
3. Give the two carbons joined, the arrow pointing from the anomeric carbon: (1→4).
4. Name the second unit. If both anomeric carbons are in the bond, use a double arrow (↔) and give both configurations.

Maltose is therefore Glc(α1→4)Glc, in full α-D-glucopyranosyl-(1→4)-D-glucopyranose. Sucrose is Glc(α1↔2β)Fru, or β-D-fructofuranosyl α-D-glucopyranoside.

The disaccharides to know

DISACCHARIDE	UNITS AND LINK	REDUCING?	SOURCE OR USE
Maltose	Glc(α1→4)Glc	yes	starch digestion; malt from germinating barley

DISACCHARIDE	UNITS AND LINK	REDUCING?	SOURCE OR USE
Isomaltose	Glc(α1→6)Glc	yes	branch points of starch and glycogen
Cellobiose	Glc(β1→4)Glc	yes	breakdown of cellulose
Lactose	Gal(β1→4)Glc	yes	milk sugar
Sucrose	Glc(α1↔2β)Fru	no	sugarcane and beet; table sugar
Trehalose	Glc(α1↔1α)Glc	no	insects and fungi; protects cells from drying
Lactulose	Gal(β1→4)Fru	yes	forms when milk is heated; a laxative

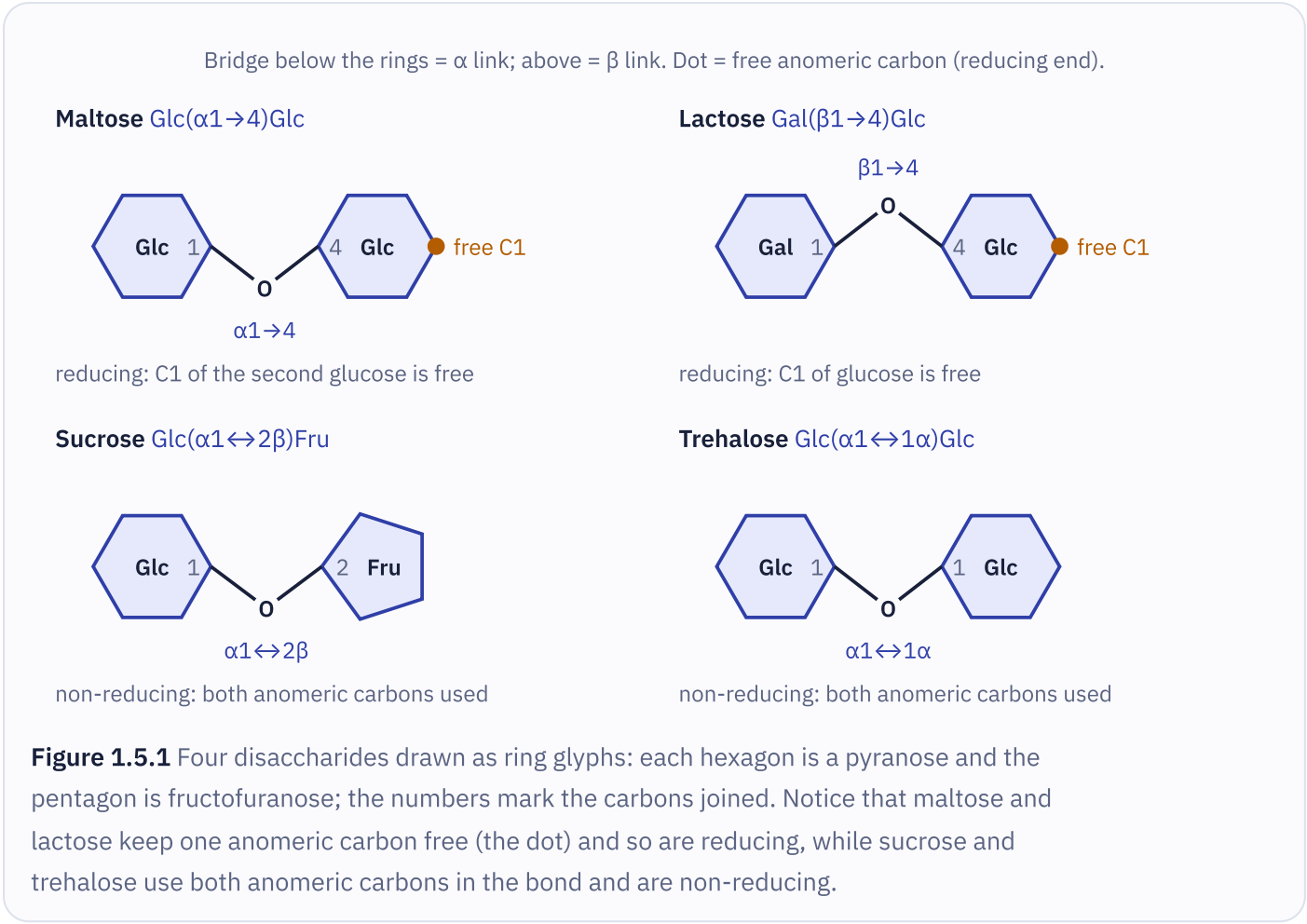


Figure 1.5.1 Four disaccharides drawn as ring glyphs: each hexagon is a pyranose and the pentagon is fructofuranose; the numbers mark the carbons joined. Notice that maltose and lactose keep one anomeric carbon free (the dot) and so are reducing, while sucrose and trehalose use both anomeric carbons in the bond and are non-reducing.

Hydrolysis: cutting the bond

Glycosidic bonds are stable at neutral pH but are hydrolysed by hot dilute acid or by enzymes called glycosidases, each strictly specific for α or β. In the small intestine maltase cuts maltose, sucrase cuts sucrose and lactase (a β-galactosidase) cuts lactose. We have no enzyme for the β1→4 link between glucoses, which is why cellulose passes through us as fibre (Chapter 1.6).

Many adults make much less lactase than they did as children. Undigested lactose then reaches the colon, where bacteria ferment it and cause gas and bloating: this is lactose intolerance. Curd

and yogurt are easier on such people because the bacteria that set them have already used part of the lactose, and lactose-free milk is made by adding the lactase enzyme.

Hydrolysis of sucrose gives an equal mixture of glucose and fructose called **invert sugar**, because the sign of optical rotation inverts from + to −. The enzyme that does it is invertase (sucrase). Honey is largely invert sugar, made by the bees' own invertase; it is sweeter than sucrose and resists crystallising, so confectioners use it.

Artificial sweeteners

Some are sugar derivatives and some are not. **Sucralose** is sucrose with three –OH groups replaced by chlorine atoms; our sucrase cannot cut it, so it passes through with almost no calories. **Steviol glycosides** from the leaves of *Stevia rebaudiana* are glycosides in the strict sense: sugar units attached by glycosidic bonds to a non-sugar part. **Aspartame** is not a sugar but a dipeptide methyl ester (aspartyl-phenylalanine); because it releases phenylalanine, its labels warn people with phenylketonuria. Saccharin and acesulfame K are unrelated synthetic compounds. The US FDA gives their sweetness relative to sucrose as about 200 times for aspartame and acesulfame K, 200 to 400 for steviol glycosides, 200 to 700 for saccharin, and 600 for sucralose.

WORKED EXAMPLE

Question (6 marks). 34.2 g of sucrose (342.3 g/mol) is dissolved to 100 mL and completely hydrolysed by invertase. Specific rotations: sucrose +66.5°, glucose +52.7°, fructose −92.4°. (a) Write the reaction and find the mass of products. (b) Find the observed rotation in a 1 dm tube before and after. (c) Explain the name "invert sugar".

1. Sucrose + H_2O → glucose + fructose. Moles of sucrose = 34.2/342.3 = 0.100 mol, giving 0.100 mol of glucose (18.0 g) and 0.100 mol of fructose (18.0 g). The products weigh 36.0 g; the extra 1.8 g is the water used (0.100 × 18.02).
2. Observed rotation $\alpha = [\alpha] \times l \times c$, where $[\alpha]$ is the specific rotation, l the tube length in dm and c the concentration in g/mL.
3. Before: c = 34.2 g/100 mL = 0.342 g/mL, so $\alpha = +66.5 \times 1 \times 0.342 =$ **+22.7°**.
4. After: glucose at 0.180 g/mL gives +52.7 × 0.180 = +9.49°; fructose at 0.180 g/mL gives −92.4 × 0.180 = −16.63°. Total α = **−7.14°**.
5. The sign changed from + to −, so the mixture is "inverted". Its specific rotation is (52.7 − 92.4)/2 = −19.9°.

EXAM TRAPS

- Sucrose is non-reducing because both anomeric carbons are in the bond. Lactose is reducing even though its link is β1→4: the C1 of its glucose is free.
- Maltose, isomaltose, cellobiose and trehalose are all two glucoses; only the link differs. Learn them by the link.
- A glycoside is any sugar acetal (methyl glucoside, steviol glycosides), not only a disaccharide.
- "Inversion" in invert sugar means the sign of optical rotation changes, not a change of configuration at a carbon.
- Aspartame is a dipeptide, not a carbohydrate.

CHECK YOURSELF

– REMEMBER **Give the units and the linkage of lactose and of sucrose.** 2 marks

Lactose: galactose and glucose, Gal(β1→4)Glc. Sucrose: glucose and fructose, Glc(α1↔2β)Fru.

– UNDERSTAND **Why does maltose show mutarotation but sucrose does not?** 2 marks

Maltose has one free anomeric carbon (on the second glucose) whose ring can open and reclose as α or β. In sucrose both anomeric carbons are locked in the glycosidic bond, so no ring can open.

– APPLY **Name Glc(β1→4)Glc and say whether it is reducing.** 2 marks

Cellobiose, the repeating unit released from cellulose. It is reducing, because the C1 of the second glucose is free.

– APPLY **Which of maltose, sucrose, trehalose, lactose and cellobiose reduce Benedict's reagent?** 2 marks

Maltose, lactose and cellobiose (one free anomeric carbon each). Sucrose and trehalose do not.

– ANALYZE **Starch and cellulose both give glucose on acid hydrolysis, yet we digest only starch. Explain at the level of the bond.** 3 marks

Starch has α1→4 (and α1→6) links, which our amylases and maltase recognise. Cellulose has β1→4 links; enzymes are specific for the anomeric configuration and humans make no β1→4 glucosidase (cellulase). Hot acid is not specific, so it cuts both.

– ANALYZE **Why can many lactose-intolerant people eat curd without trouble?** 2 marks

The lactic acid bacteria that set curd ferment part of the lactose before it is eaten, so less reaches the colon; the live bacteria also carry β-galactosidase that keeps acting in the gut.

BEYOND THE SYLLABUS

Glycosidases are grouped into families by sequence in the CAZy database, and engineered ones now run in reverse to make new sugars. Food companies use β-galactosidase to turn lactose into galacto-oligosaccharides, prebiotics that feed beneficial gut bacteria, and human milk oligosaccharides such as 2′-fucosyllactose are now made by fermentation for infant formula. Search next for "galacto-oligosaccharides", "human milk oligosaccharides" and "glycoside hydrolase families". None of this is for the exam.

Key terms of this lesson

TERM	MEANING OR FORMULA	CHAPTER
Aldose, ketose	aldehyde at C1; ketone, usually at C2	1.3
Stereoisomers	at most 2^n for n chiral centres (16 aldohexoses)	1.4
Epimer, anomer	differ at one chiral centre; anomers differ at the anomeric carbon (α or β)	1.4
Mutarotation	fraction α = ([α]eq − [α]β)/([α]α − [α]β); glucose about 36% α, 64% β	1.4
Glycosidic bond	acetal made from an anomeric –OH, written for example Glc(α1→4)Glc	1.5
Observed rotation	α = [α] × l × c, with l in dm and c in g/mL	1.5

Glossary (terms used in this lesson)

Anomer Either of the two ring forms, α or β, of a sugar that differ only at the anomeric carbon.

Anomeric carbon	The carbonyl carbon that becomes a new chiral centre when the ring closes: C1 of an aldose, C2 of a ketose.
D and L	The configuration of the chiral carbon farthest from the carbonyl: –OH on the right in a Fischer projection is D.
Enantiomers	Non-superimposable mirror images, with every chiral centre inverted, such as D- and L-glucose.
Epimers	Sugars that differ at only one chiral centre, such as glucose and galactose (C4).
Fischer projection	A drawing of the open chain with carbons in a vertical line, C1 at the top, and groups to the left or right.
Glycosidic bond	The bond from the anomeric carbon of a sugar to an –OH (O-glycosidic) or an –NH (N-glycosidic) of another molecule.
Haworth projection	A flat drawing of a sugar ring, with each group shown above or below the ring.
Hemiacetal	The product of an alcohol adding to an aldehyde; the ring form of an aldose is one, and a ketose ring is a hemiketal.
Invert sugar	The equimolar glucose and fructose mixture from hydrolysis of sucrose; its optical rotation is negative.
Mutarotation	The change in optical rotation of a fresh sugar solution as the α and β anomers interconvert to equilibrium.
Reducing sugar	A sugar with a free anomeric carbon, which reduces Cu^{2+} to red Cu_2O in Benedict's test.

The full unit book

Every chapter of Unit 1, the unit summary, the exam question bank with model answers and the full glossary: Biochemistry · Unit 1 · Foundations: Water, pH and Carbohydrates (one file, works offline).

Sources and further reading

Textbooks

- David L. Nelson and Michael M. Cox, *Lehninger Principles of Biochemistry*, W. H. Freeman; chapters on water and on carbohydrates and glycobiology (from memory; check). Source of the bond energies, the branching frequencies of amylopectin and glycogen and the chain length of cellulose used here.

- Jeremy M. Berg, John L. Tymoczko, Gregory J. Gatto Jr. and Lubert Stryer, *Biochemistry*, W. H. Freeman; chapter on carbohydrates (from memory; check).
- Donald Voet and Judith G. Voet, *Biochemistry*, Wiley (from memory; check).
- U. Satyanarayana and U. Chakrapani, *Biochemistry*, Elsevier India; widely prescribed in Indian universities, with the colour tests for carbohydrates (from memory; check).
- Ajit Varki and others (editors), *Essentials of Glycobiology*, Cold Spring Harbor Laboratory Press, also free on the NCBI Bookshelf; for Chapters 1.7 and 1.9 (from memory; check).

Other standard values in this book, such as the specific rotations of sucrose (+66.5°) and fructose (−92.4°), are textbook values written from memory; check them against your prescribed book.

Open resources opened for this book

- Wikipedia, "Mutarotation": en.wikipedia.org/wiki/Mutarotation. Source of the specific rotations of α- and β-D-glucose (+112.2°, +18.7°), the equilibrium value (+52.7°) and the 36 : 64 ratio of the anomers.
- NPTEL, Module 11 (Carbohydrates), Lecture 30, course 104103071: archive.nptel.ac.in. Confirms the same rotation values and the reducing and non-reducing classes by hemiacetal and acetal form.
- US Food and Drug Administration, "Aspartame and Other Sweeteners in Food": fda.gov. Source of the sweetness of the high-intensity sweeteners relative to sucrose in Chapter 1.5.

Syllabus: the University free n easy universal syllabus, built from top universities' syllabi.

Built for the University free n easy YouTube channel from the universal syllabus of Biochemistry (Oct 2026). Written with top universities' syllabi and standard textbooks; check a formula against your prescribed book before an exam, and report mistakes on the channel.