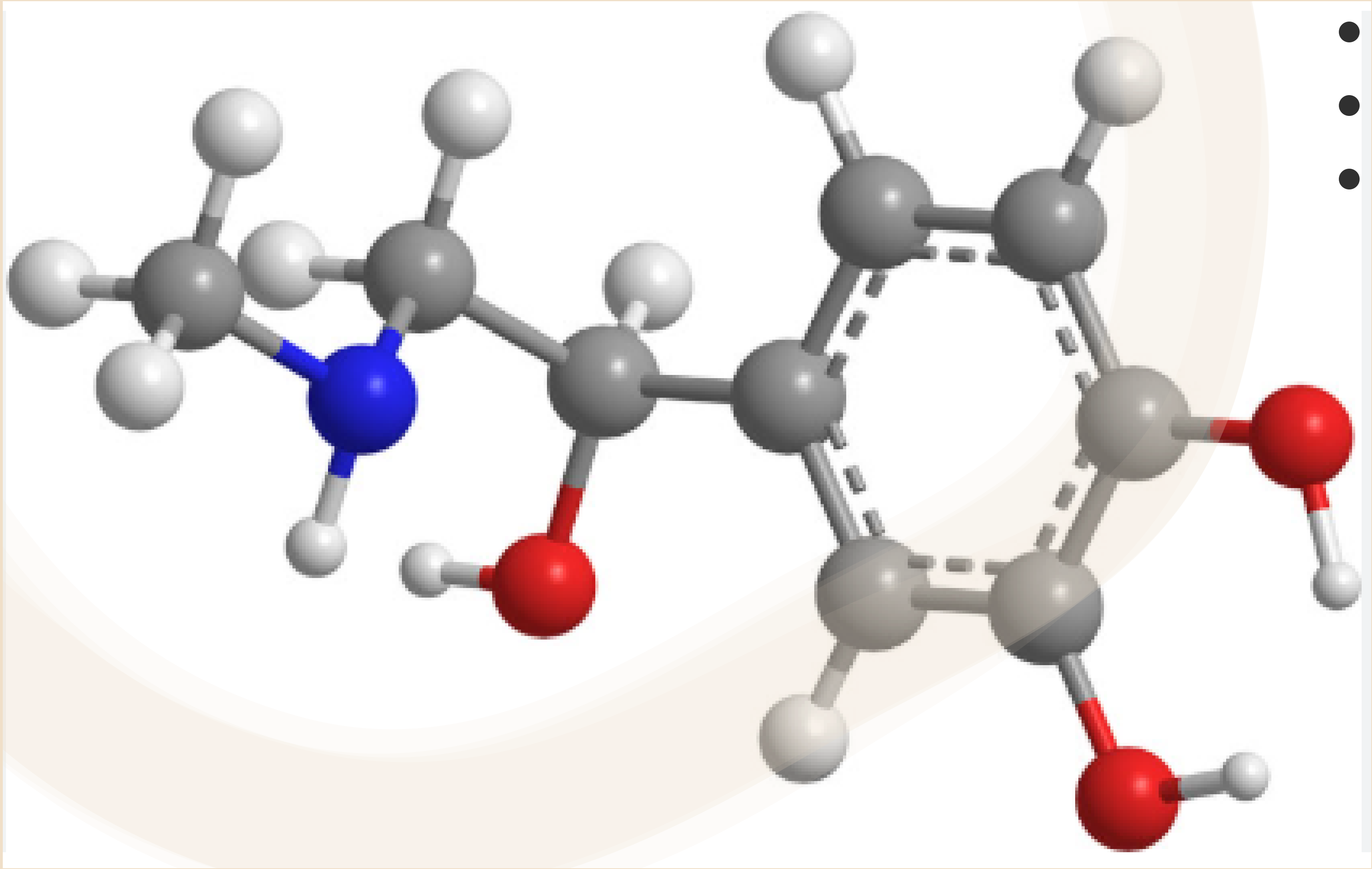
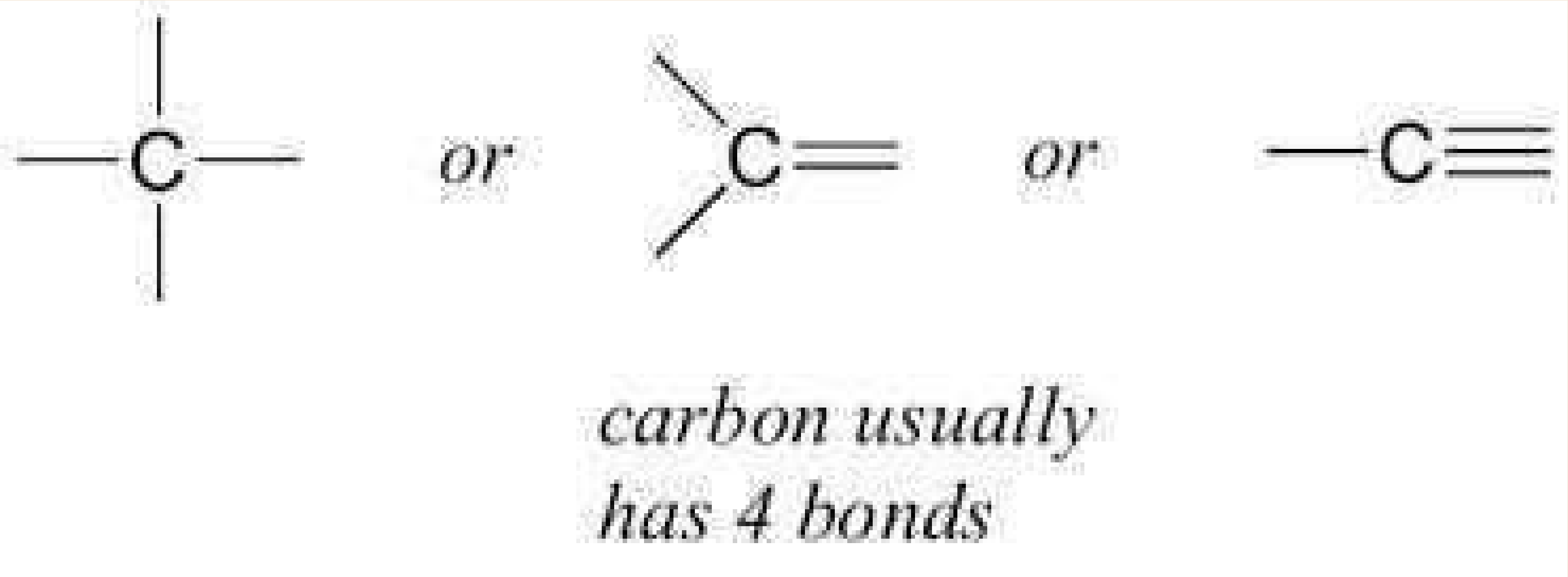
Organic Compounds and Biological Molecules



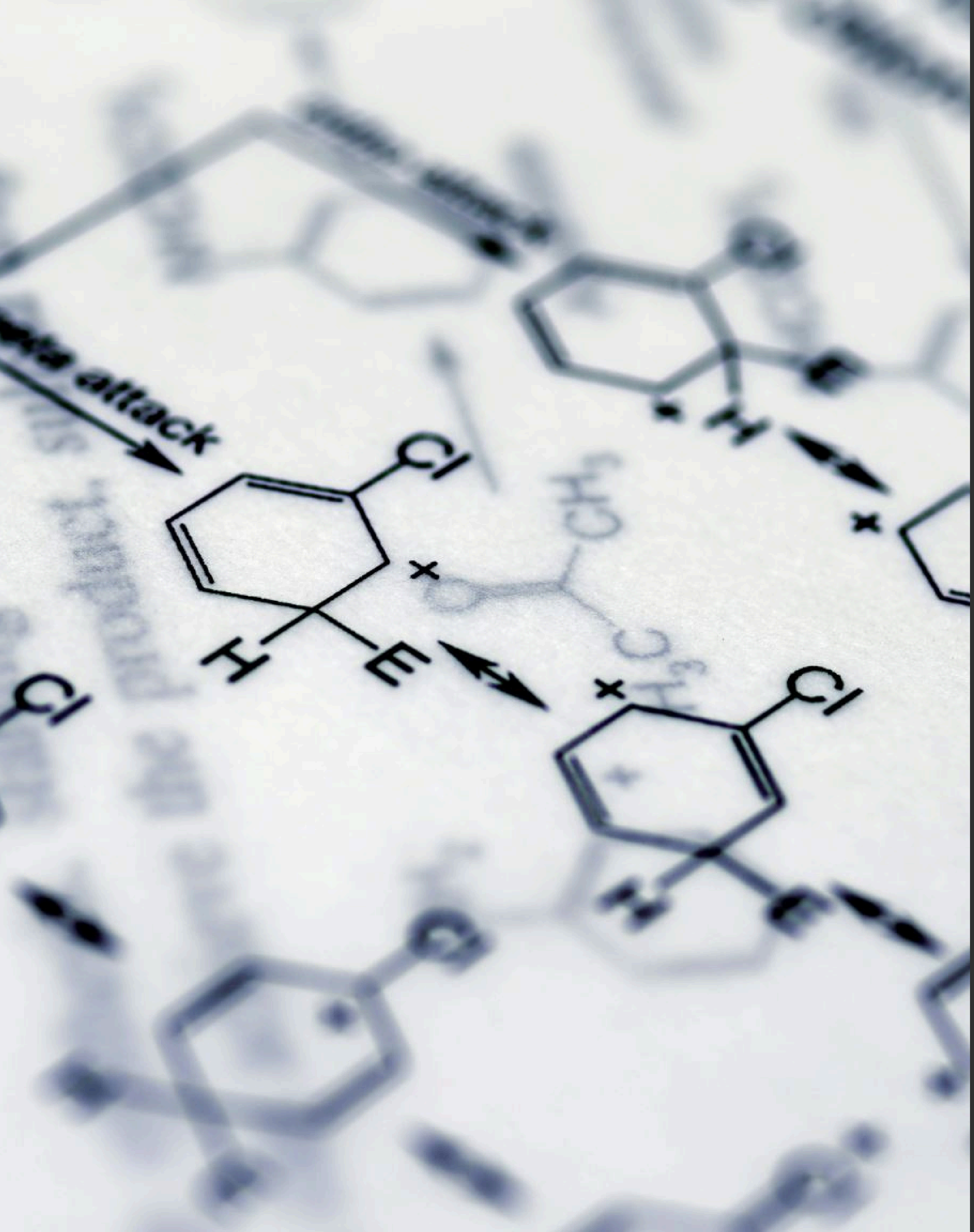
- Biological molecules are essential for the structure and function of all living organisms. Most of these molecules are **organic compounds**, meaning they contain **carbon atoms**.

- ## What Are Organic Compounds?

- Organic compounds are molecules that:
- **Always contain carbon**.
- Often contain **hydrogen** and **oxygen**.
- Sometimes contain **nitrogen**, **sulphur**, or **phosphorus**.
- These elements combine in various ways to form the complex molecules that make up cells and tissues.



- **Carbon atoms can form four covalent bonds**, allowing them to bond with many other atoms, including other carbon atoms.
- This makes it possible to build **long chains**, **branched structures**, and **ring-shaped molecules**.
- Carbon's versatility allows the formation of large molecules called **macromolecules**.



Monomers and Polymers

- Many biological molecules are **polymers**, made by linking smaller units called **monomers**.
- For example, sugars (monomers) can join together to form complex carbohydrates (polymers).

Carbohydrates

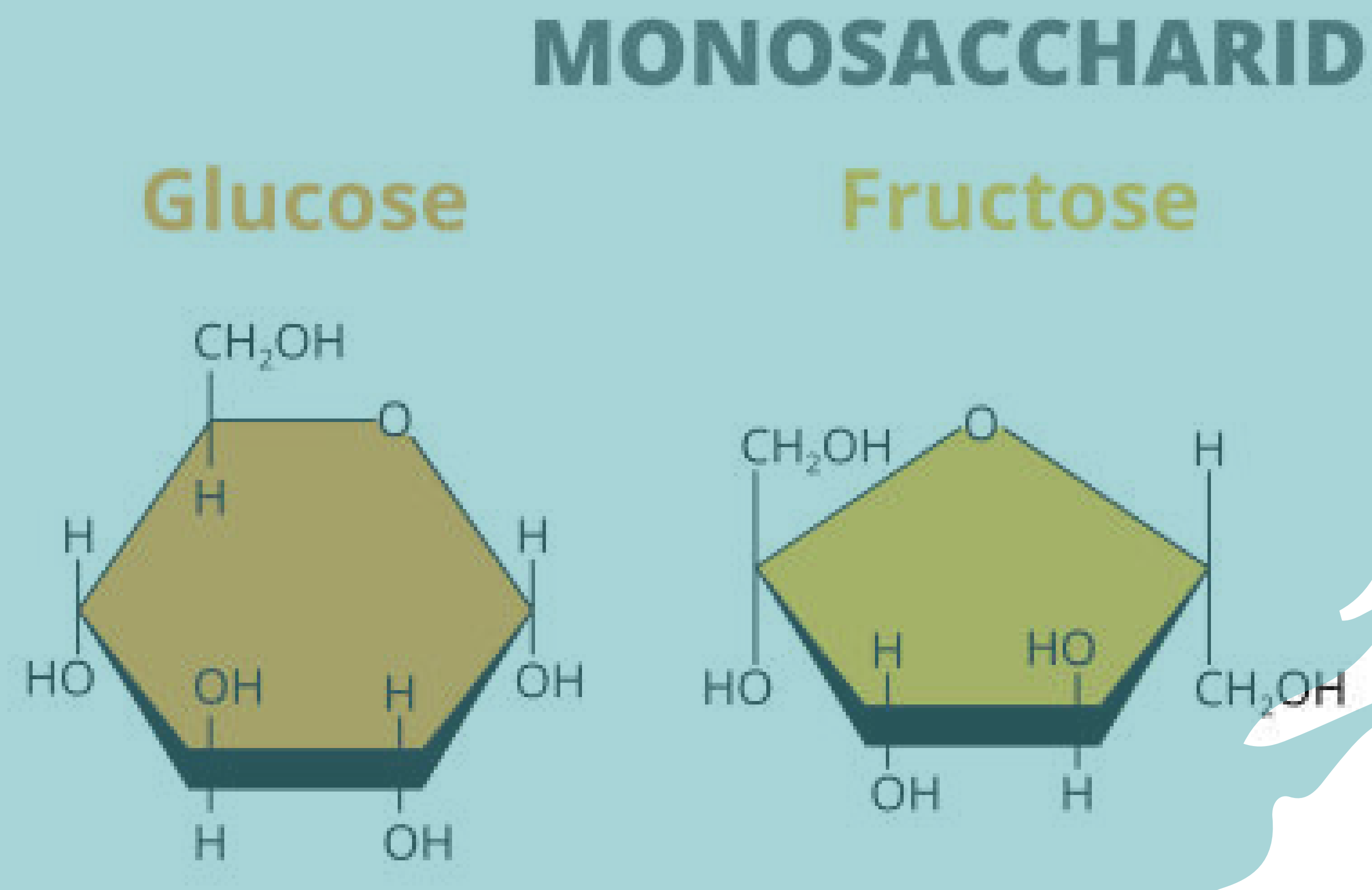
- Carbohydrates are vital for all living organisms.
- In humans and animals, they act as a **primary source of energy**.
- In fact, the glucose you get from carbs fuels cellular respiration, the process that releases energy.
- They're also important in food globally—rice, potatoes, bread, and sugar all contain carbs.
- In **plants**, **fungi**, and **bacteria**, carbohydrates play **structural roles**, such as building cell walls.

What Are Carbohydrates?

- Carbohydrates are made up of **carbon, hydrogen**, and **oxygen**, often in a ratio of 1:2:1.
- There are **three main types**, depending on the number of sugar units:
  - **Monosaccharides** – single sugar units (e.g., glucose)
  - **Disaccharides** – two sugar units linked (e.g., sucrose)
  - **Polysaccharides** – long chains of sugar units (e.g., starch and cellulose)

Monosaccharides – Simple Sugars

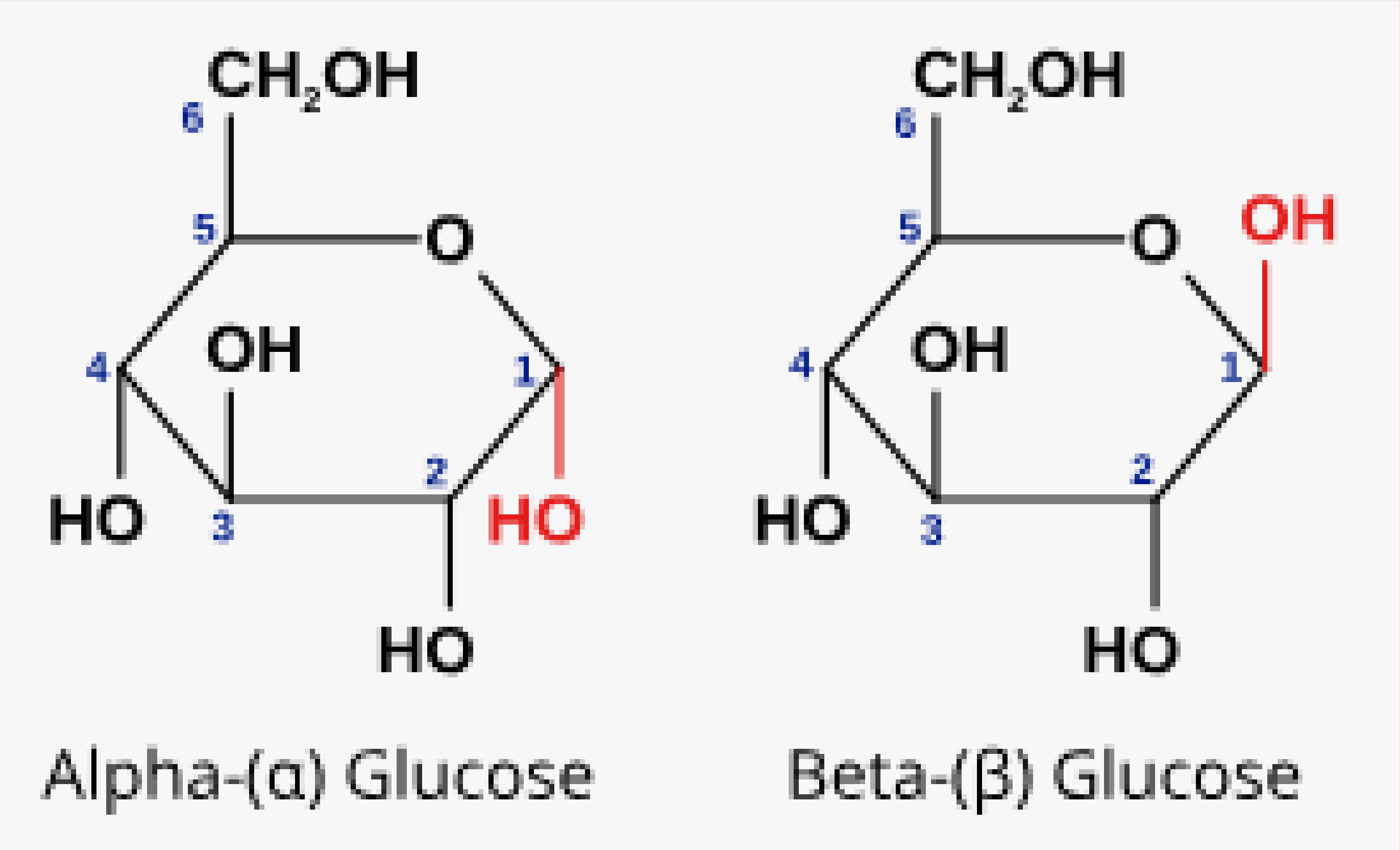
- Monosaccharides are **the most basic units** of carbohydrates.
- General formula is **$(CH_2O)n$,** which means for every carbon atom, there are two hydrogens and one oxygen.
- They're **small**, **soluble in water**, and usually **taste sweet**.



- Monosaccharides are grouped based on how many **carbon atoms** they have.
  - **Triose ($C_3H_6O_3$):**
    - Has 3 carbon atoms.
    - Key in **mitochondria** during respiration (as intermediates).
  - **Pentose ($C_5H_{10}O_5$):**
    - Has 5 carbon atoms.
    - Found in **DNA** and **RNA**.
    - Examples: **Ribose** (RNA) and **Deoxyribose** (DNA)
  - **Hexose ($C_6H_{12}O_6$):**
    - Has 6 carbon atoms.
    - Most common: **glucose**, **fructose**, and **galactose**
    - Involved in energy release and transport in cells

Isomers of Glucose – Alpha and Beta

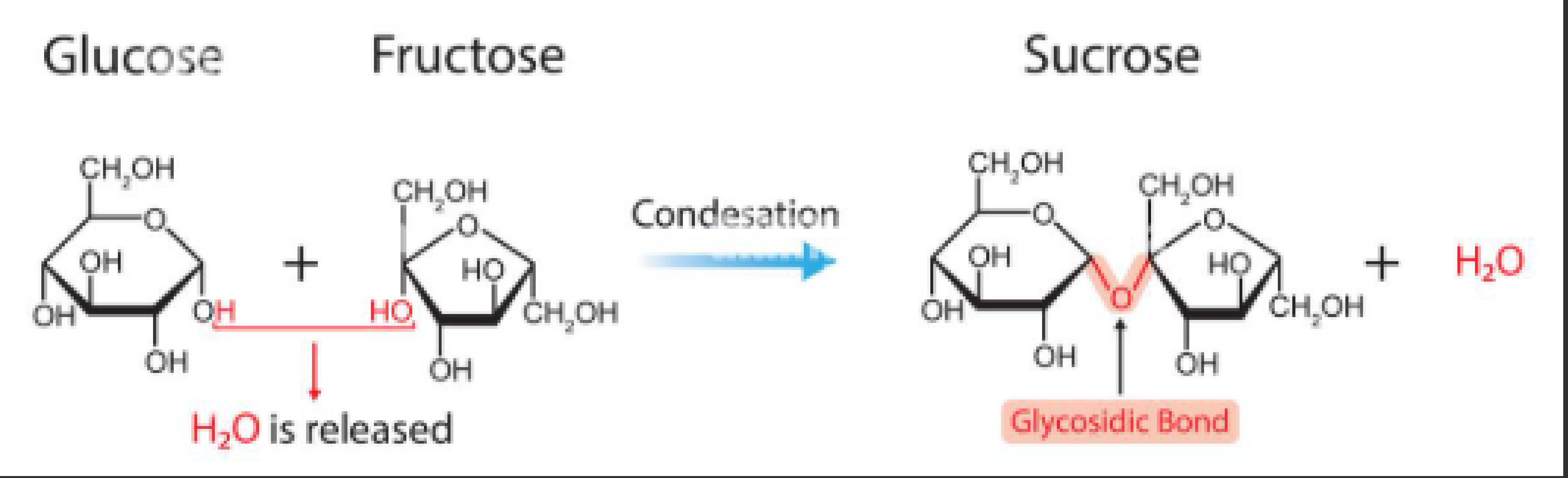
- Glucose exists in **two isomeric forms**—called **alpha-glucose (α-glucose)** and **beta-glucose (β-glucose)**.
- These are both **hexose sugars** ($C_6H_{12}O_6$), meaning they have the same chemical formula and the same atoms, but the **arrangement of atoms differs** slightly.
- In **α-glucose**, the **–OH group on carbon 1** is **below** the ring.
    - In **β-glucose**, the **–OH group on carbon 1** is **above** the ring.



- Even though this is a small difference, it has a **big effect** on how glucose molecules **link together** to form polymers.

- **Why does it matter?**
- **Alpha-glucose** molecules join via **1,4 glycosidic bonds** to form **starch (amylose)** or **glycogen**—these are used for **energy storage**.
- **Beta-glucose** molecules link differently, forming **cellulose**, a polymer with straight, strong chains used for **structural support** in plant cell walls.

- So, even though both are glucose molecules, their isomeric forms lead to the creation of **very different biological molecules** with different functions.



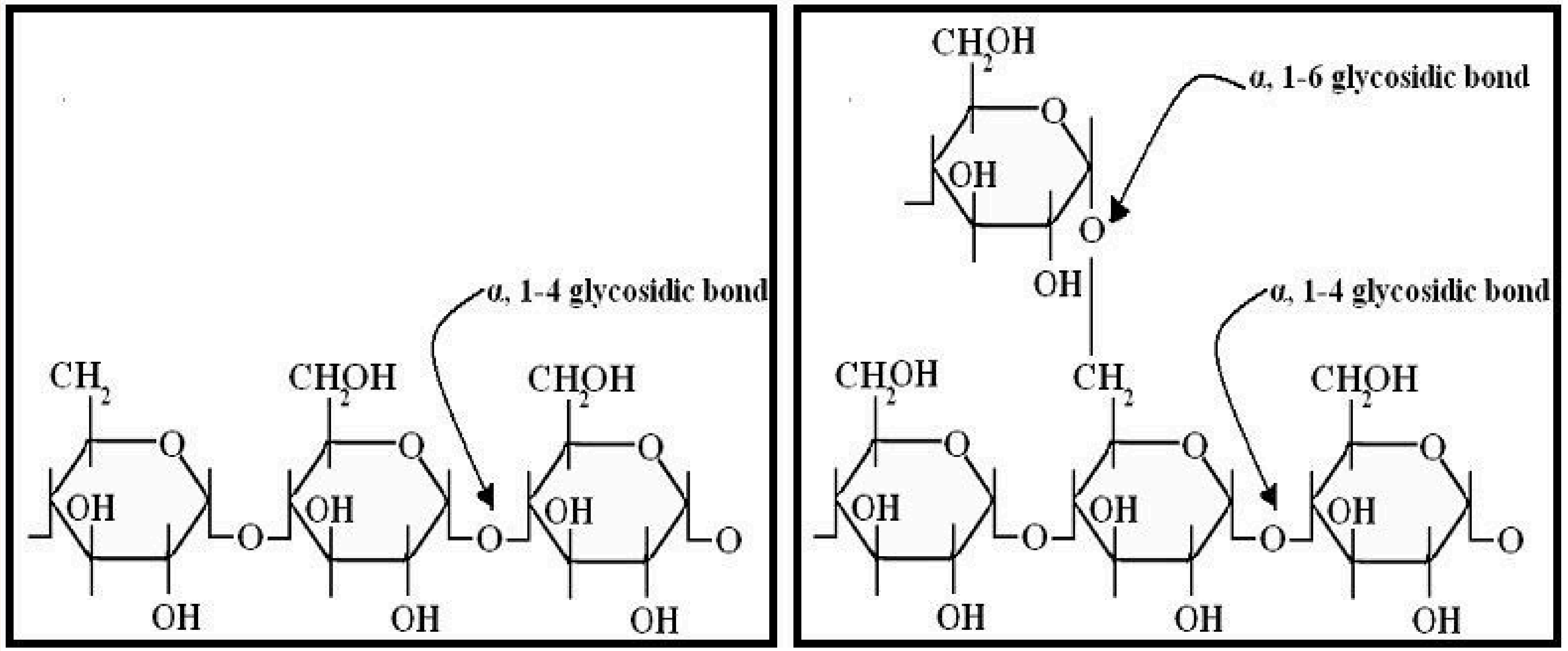
Glycosidic Bond

- The bond formed between the two monosaccharides is called a **glycosidic bond**—a type of **covalent bond**.

  How Is a Glycosidic Bond Formed?
  It forms through a **condensation reaction**:
- One monosaccharide provides a **–OH group** from **carbon 1**.
- The other monosaccharide provides a **hydrogen (H)** from one of its –OH groups (commonly carbon 4 or carbon 6).
- **A molecule of water (H_2O)** is removed.
- The oxygen atom left behind links the two sugar rings together.

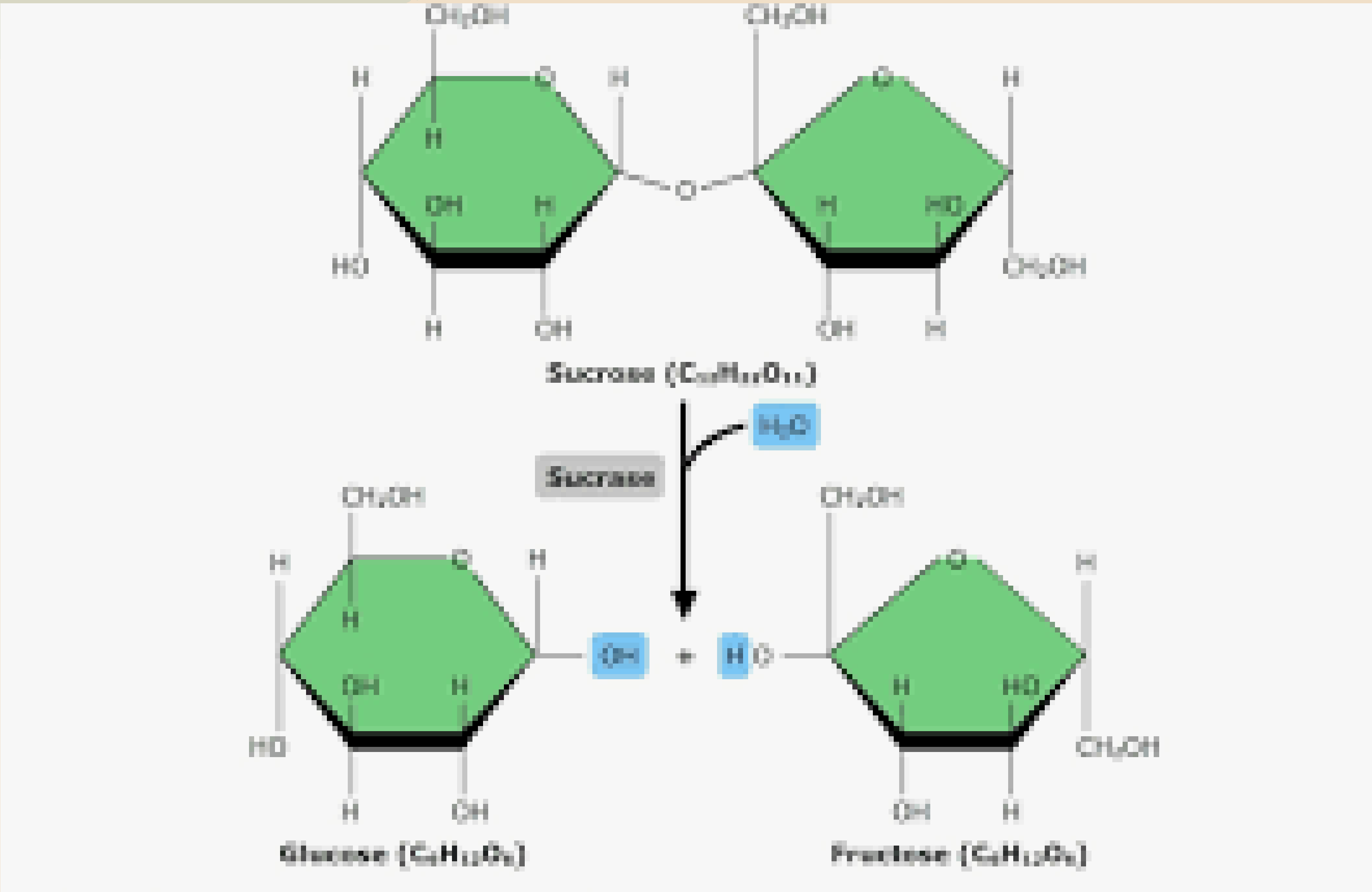
Naming Glycosidic Bonds

- We use **numbers** to show which carbon atoms are involved:
- **1,4-glycosidic bond**:
  - Carbon 1 of the first sugar bonds with carbon 4 of the second.
  - Common in **maltose** and **amylose** (part of starch).
- **1,6-glycosidic bond**:
  - Carbon 1 of the first sugar bonds with carbon 6 of the second.
  - Found in **branched polysaccharides** like **amylopectin** and **glycogen**.



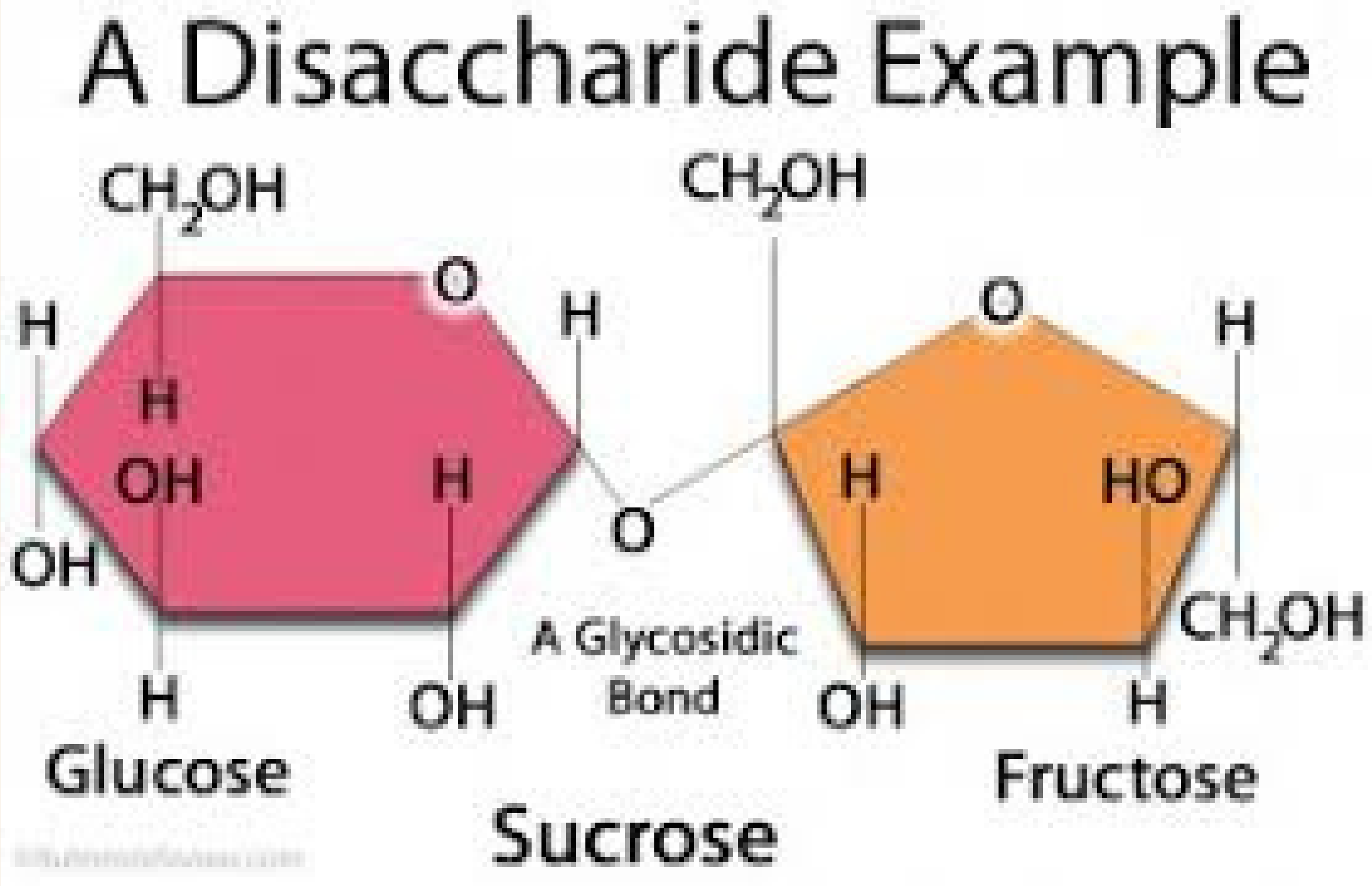
(a) amylose (b) amylopectin

- Glycosidic bonds can be broken by **hydrolysis**, the reverse of condensation:
- A **water molecule is added**.
    - An enzyme (e.g., maltase, sucrase, or lactase) catalyzes the reaction.
    - The bond breaks, releasing **two monosaccharide units**.



Disaccharides – Double Sugars

- Disaccharides are known as **"double sugars"**.
  They are made when **two monosaccharides** (single sugar units) **join together**.
- This reaction is called a **condensation reaction**—it forms a new bond and **releases a molecule of water**.
- Disaccharides are also soluble in water and have a sweet taste.



- Here are three well-known disaccharides and the monosaccharides that form them:

Disaccharide	Source	Monosaccharides
Sucrose	Sugarcane, sugar beet	Glucose + Fructose
Lactose	Milk (main sugar)	Glucose + Galactose
Maltose	Germinating barley	Glucose + Glucose

Hydrolysis of Disaccharides

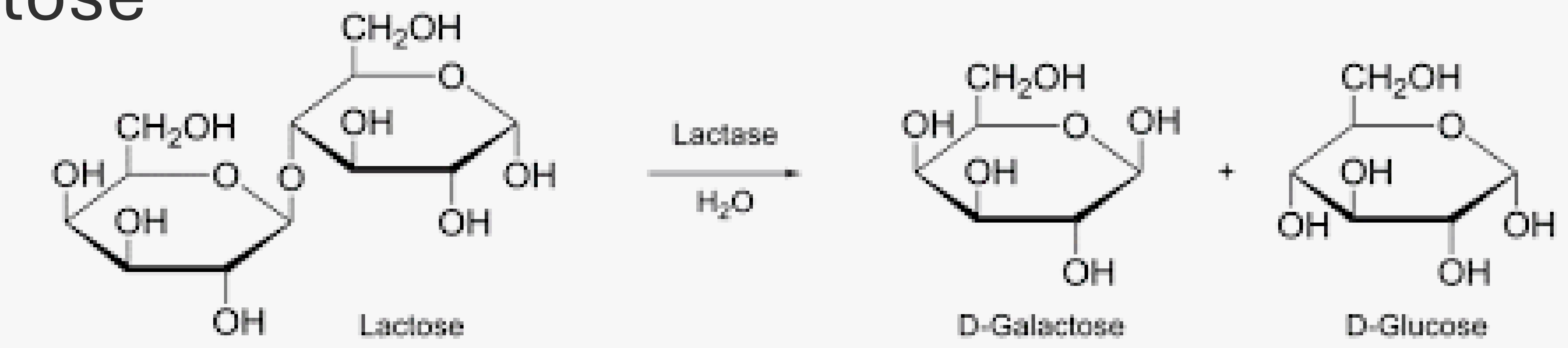
- Our bodies break disaccharides down into monosaccharides using **enzymes** like:
- **Sucrase** (for sucrose)
- **Lactase** (for lactose)
- **Maltase** (for maltose)

- These enzymes catalyze **hydrolysis reactions**, which **add water** to break the glycosidic bond.

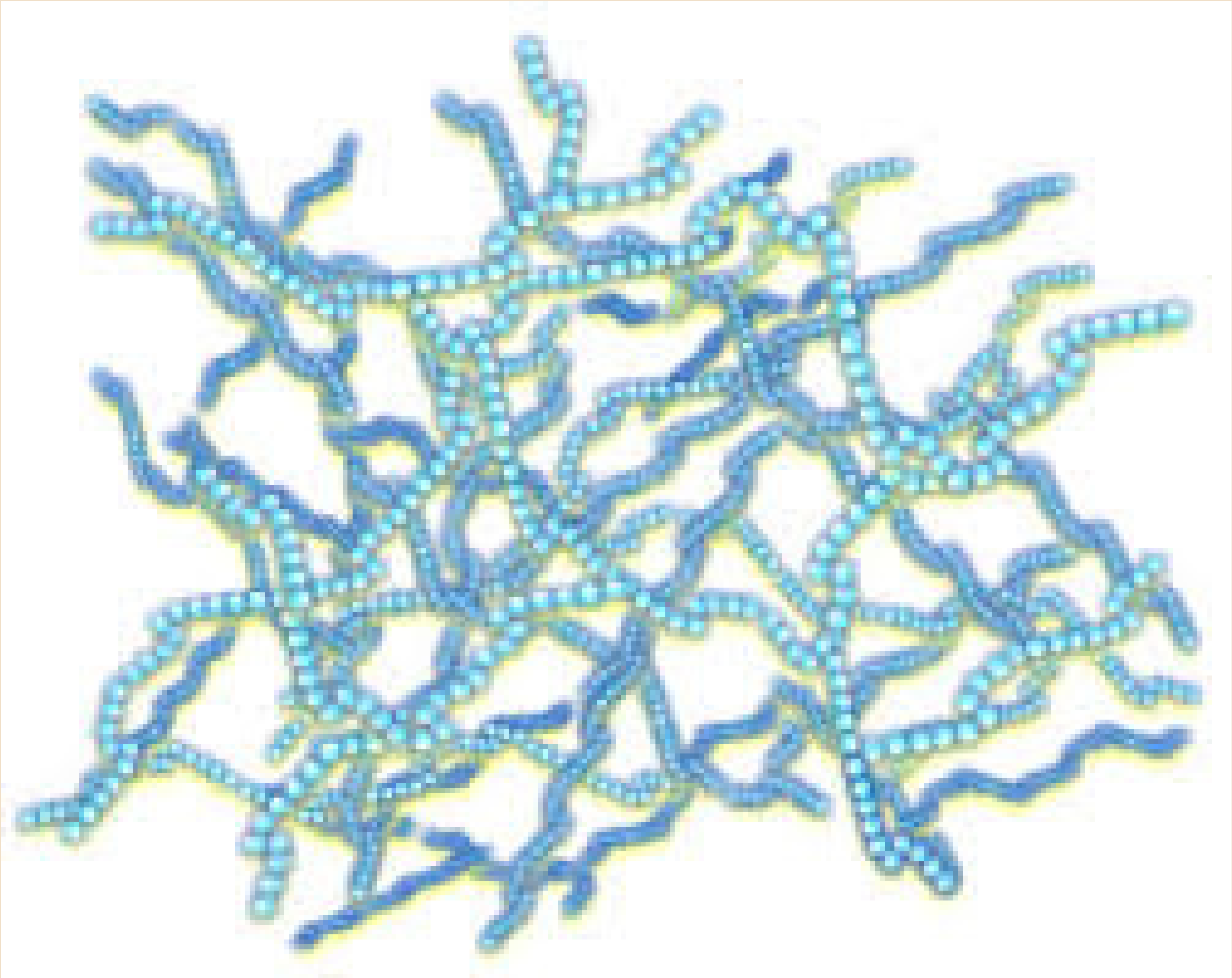
- Maltose + Water → Glucose + Glucose

- Sucrose + Water → Glucose + Fructose

- Lactose + Water → Glucose + Galactose



Polysaccharides – The Complex Carbohydrates



- Polysaccharides are the **largest and most complex carbohydrates**.
- They're made when **many monosaccharide units** (usually glucose) are joined together by **condensation reactions**.
- Each of these reactions forms a **glycosidic bond** and releases a **water molecule**.
    - When have **3–10 sugar units**, we call the molecule an **oligosaccharide**.
    - When have **11 or more**, it's a **polysaccharide**.
    - Polysaccharides **do not taste sweet**, unlike simple sugars, but they serve **vital biological functions**.

Key properties

- **Insoluble in water**: won’t dissolve easily
- **Compact**: fit large energy stores into small spaces
- **Chemically inactive**: do not interfere with other cell reactions
- **No osmotic effect**: do not affect water potential, so they won’t draw in water
- This makes them **ideal for energy storage**.
- When energy is needed, **hydrolysis** (the **reverse of condensation**) breaks the glycosidic bonds by **adding water**, releasing **glucose**. This process happens:
- In the **gut**, during digestion
- In **liver and muscle cells**, when stored carbs are broken down for **cellular respiration**

Starch – Energy Storage in Plants

- Starch is the **main storage carbohydrate in plants**. After photosynthesis, the glucose produced is **quickly converted into starch** because:
- It's **insoluble** (won't affect water potential)
- It's **compact** (good for storage)
- It's **easily broken down** when needed

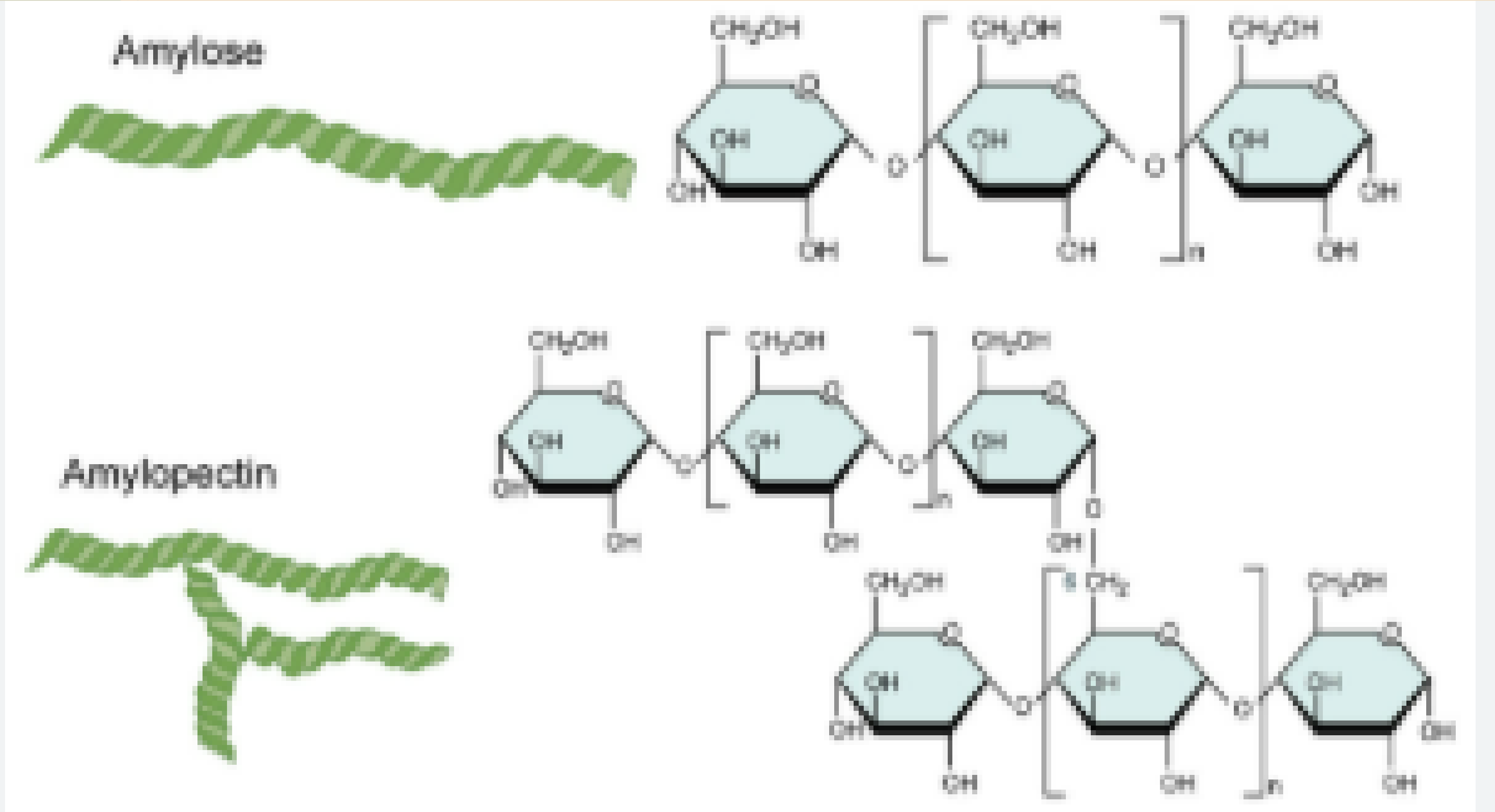
- Starch is made of **two polymers of α-glucose**:

Amylose:

- A **long, unbranched chain** of α-glucose
- Joined by **α-1,4 glycosidic bonds**
- As the chain grows, it **spirals into a helix** → this makes it **very compact**
- Releases glucose **slowly and steadily**

Amylopectin:

- A **branched chain** of α-glucose
- Mostly **α-1,4 bonds**, but with **α-1,6 glycosidic bonds** at branch points
- Has many **terminal ends**, so enzymes can **break it down quickly**
- Glucose is released **rapidly** when needed

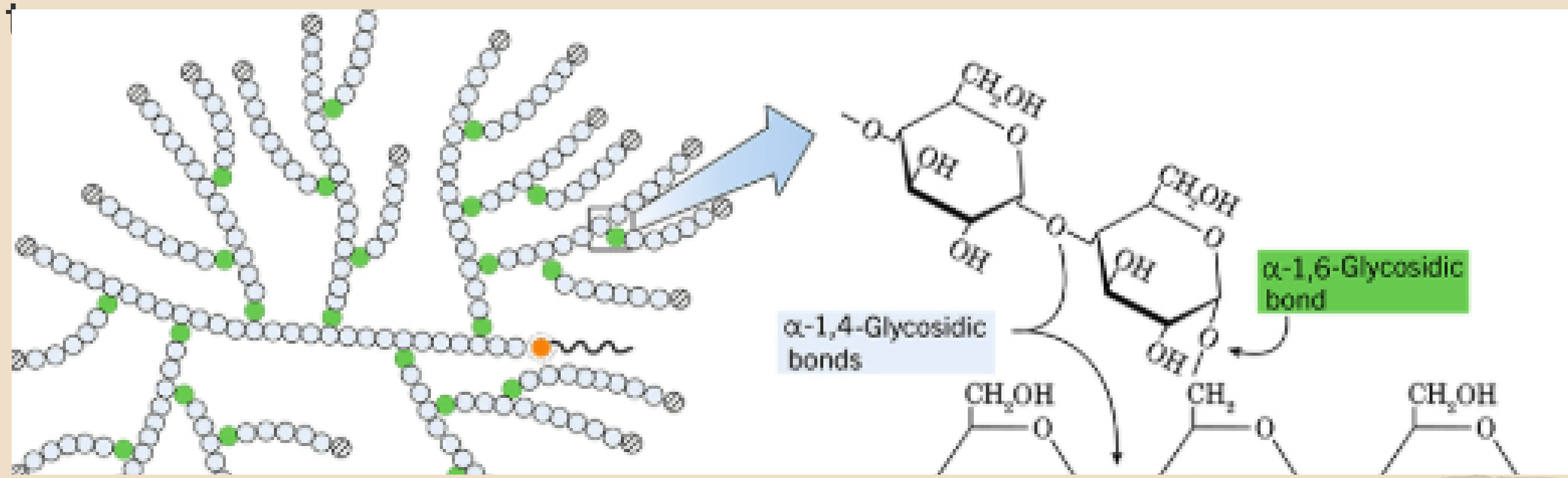


- Amylopectin gives a **quick energy release**
  - Amylospectine is Highly **branched**
  - It Contains **α-1,4 glycosidic bonds** along the chain and **α-1,6 glycosidic bonds** at branch points.
  - These **branches create many "ends"** where enzymes (likeamylase) can attach
    and **start hydrolyzing glucose units**.
  - More ends creates **more access points for enzymes**
  - This allows **multiple glucose molecules** to be released **atthe same time**.
  - So, energy is made available **quickly** — ideal during bursts ofactivity.

- Amylose gives a **slow, sustained energy supply**
  - **Amylose is Unbranched**, long, helical chain
  - It Contains only **α-1,4 glycosidic bonds**
  - Forms a **spiral** shape, which is **compact** but gives only **two ends** (one at each side of the chain)
  - Fewer ends = **limited enzyme access**
  - Glucose is released **one unit at a time** from the ends
  - This results in **slower, steady energy release** over time

Glycogen – Energy Storage in Animals

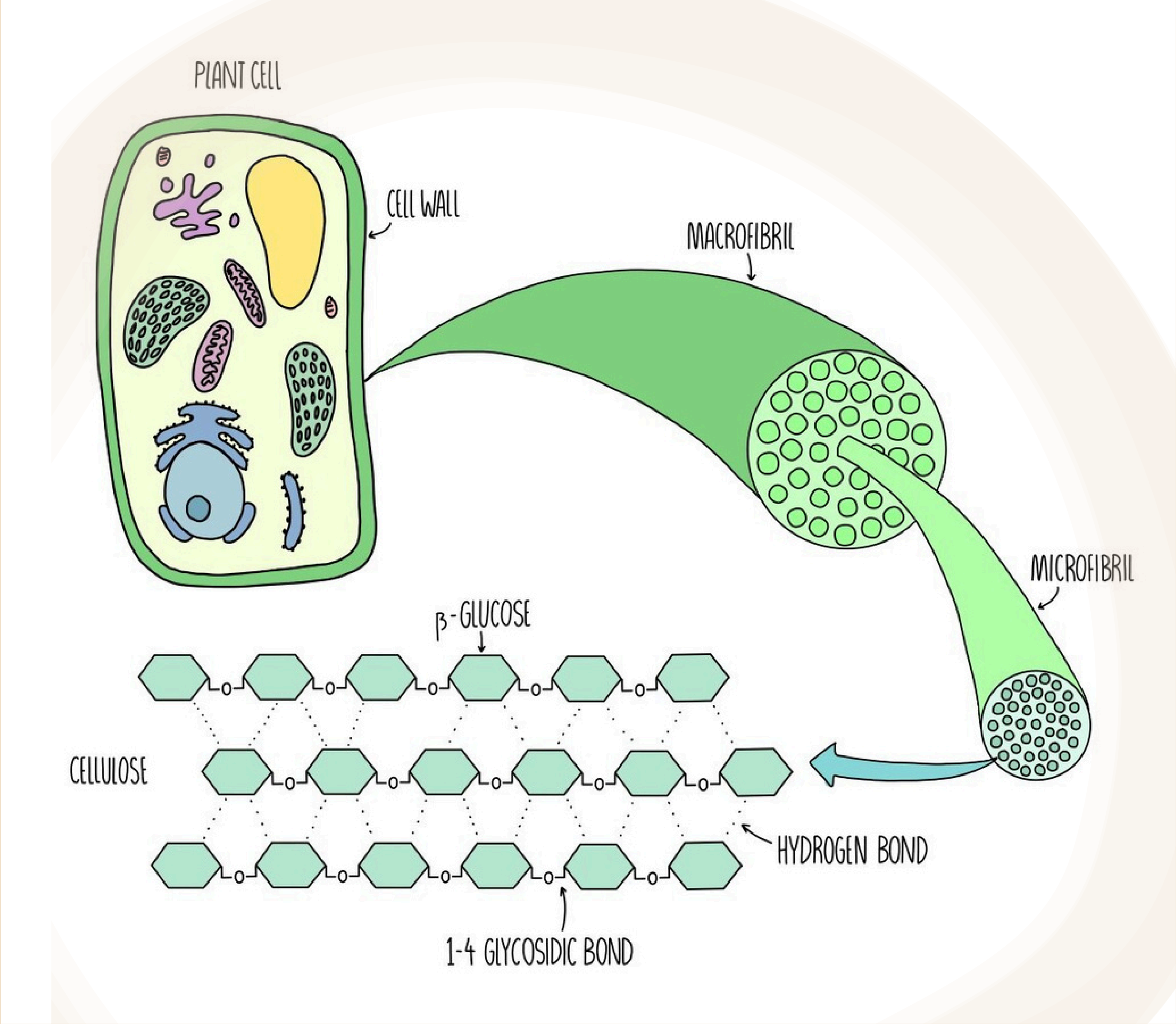
- Glycogen is the **animal equivalent of starch** and is the **main carbohydrate storage molecule in animals and fungi**.
- It is sometimes called **"animal starch"**.
- It is stored in **liver and muscle cells**, where it's **broken down into glucose when needed**.
- Glycogen is **chemically very similar t** amylopectin but with **a more highly branched structure**.



- **Why Glycogen Is Ideal:**
- **Very compact** → stores a lot in a small space
- **Insoluble** → no effect on osmosis
- **Highly branched** → fast energy release
- Found in **tissues that require quick energy**, like **muscles**

- **Structure:**
- Made of **α-glucose units**
- Contains **α-1,4 glycosidic bonds** along the chains
- Has **many α-1,6 glycosidic bonds**, creating **frequent side branches**
- These branches mean:
- **More terminal glucose units**
- **Faster breakdown** by enzymes
- **Rapid glucose release** when animals need energy quickly (e.g., during exercise or fight-or-flight responses)

Structure of Cellulose



- **Monomer unit**:
- **β-glucose** (beta-glucose), not α-glucose like starch/glycogen.
- The chemical formula is the same ($C_6H_{12}O_6$), but the **orientation of the –OH group on carbon 1** is **above** the plane in β-glucose.
- **Bonding**:
- Joined by **β-1,4 glycosidic bonds**.
- To form this bond, **every second β-glucose must rotate 180°**, so the –OH groups align.
- This rotation gives cellulose a **straight, uncoiled structure**.
- **Chains and Fibrils**:
- Individual cellulose chains are **straight and unbranched**.
- Many of these chains lie **parallel to each other** and are held together by **hydrogen bonds**.
- These form **microfibrils** – bundles of cellulose chains.
- Microfibrils group into **fibres** – extremely strong and rigid.

Why is Cellulose So Strong?

- **Hydrogen bonding**: While each bond is weak individually, **thousands together provide incredible tensile strength**.
- **Straight chains**: Unlike coiled starch or branched glycogen, cellulose chains **don’t spiral**—they stack neatly and support each other.
- **Microfibrils**: These provide **high mechanical strength** and **resistance to stretching**, essential for cell wall integrity.