DP IB Biology: HL

Your notes

2.2 Carbohydrates & Lipids

Contents

2.2.1 Carbohydrates

Your notes

Complex Carbohydrates

- **Monosaccharides** can join together via **condensation reactions** to form **disaccharides**
  - A condensation reaction is one in which two molecules join together via the formation of a new chemical bond, with a **molecule of water** being **released** in the process
  - The new chemical bond that forms between two monosaccharides is known as a **glycosidic bond**
  - To calculate the chemical formula of a disaccharide, you add all the carbons, hydrogens and oxygens in both monomers then subtract 2 H and 1 O (for the water molecule lost)

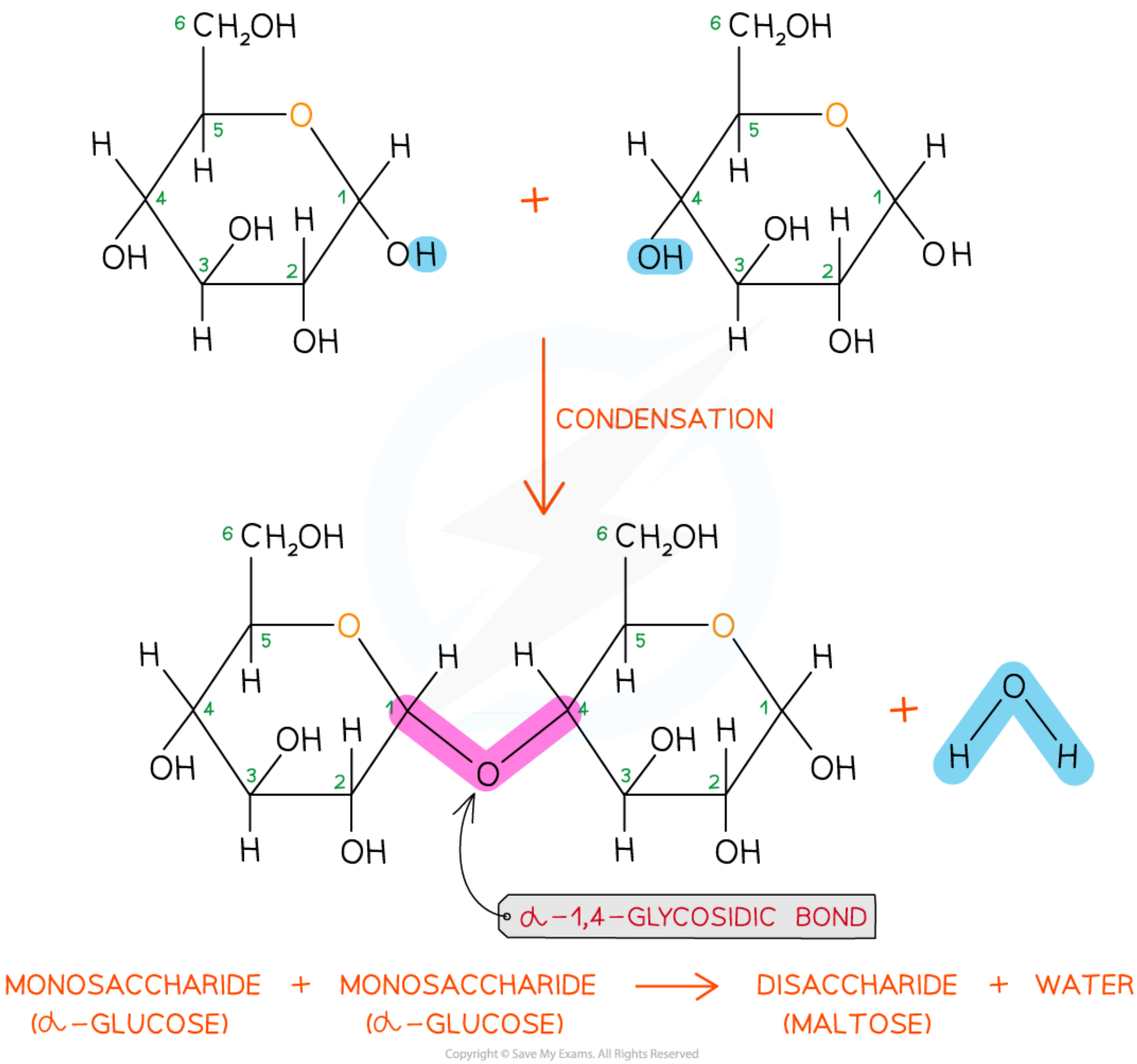
- Common examples of disaccharides include:
  - **Maltose** (the sugar formed in the production and breakdown of starch)
  - **Sucrose** (the main sugar produced in plants)
  - **Lactose** (a sugar found only in milk)

- All three of the common examples above have the formula $C_{12}H_{22}O_{11}$

Common Disaccharides and their Monosaccharide Monomers Table

Name of disaccharide	Names of monosaccharide components	
Maltose	α-glucose	α-glucose
Sucrose	α-glucose	fructose
Lactose	α-glucose	galactose

Your notes


CONDENSATION
α–1,4–GLYCOSIDIC BOND
MONOSACCHARIDE (α–GLUCOSE) + MONOSACCHARIDE (α–GLUCOSE) → DISACCHARIDE (MALTOSE) + WATER
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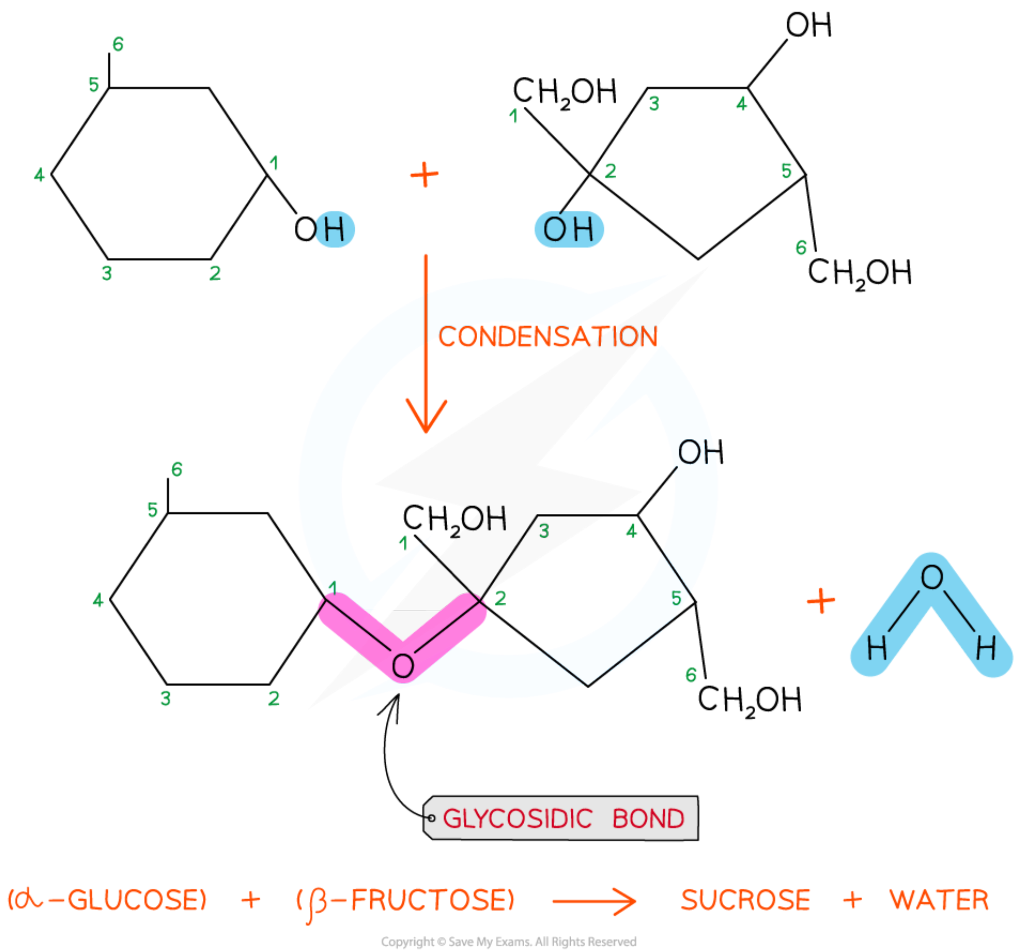


Examiner Tip

Galactose and fructose are monosaccharides and actually have the same molecular formula as glucose. However, the atoms that make up these three monosaccharides are arranged in different ways, meaning they each have slightly different molecular structures, giving them slightly different properties. For example, fructose is sweeter in taste than glucose. The three sugars are **isomers**.

Polysaccharides: Structure & Function

Your notes

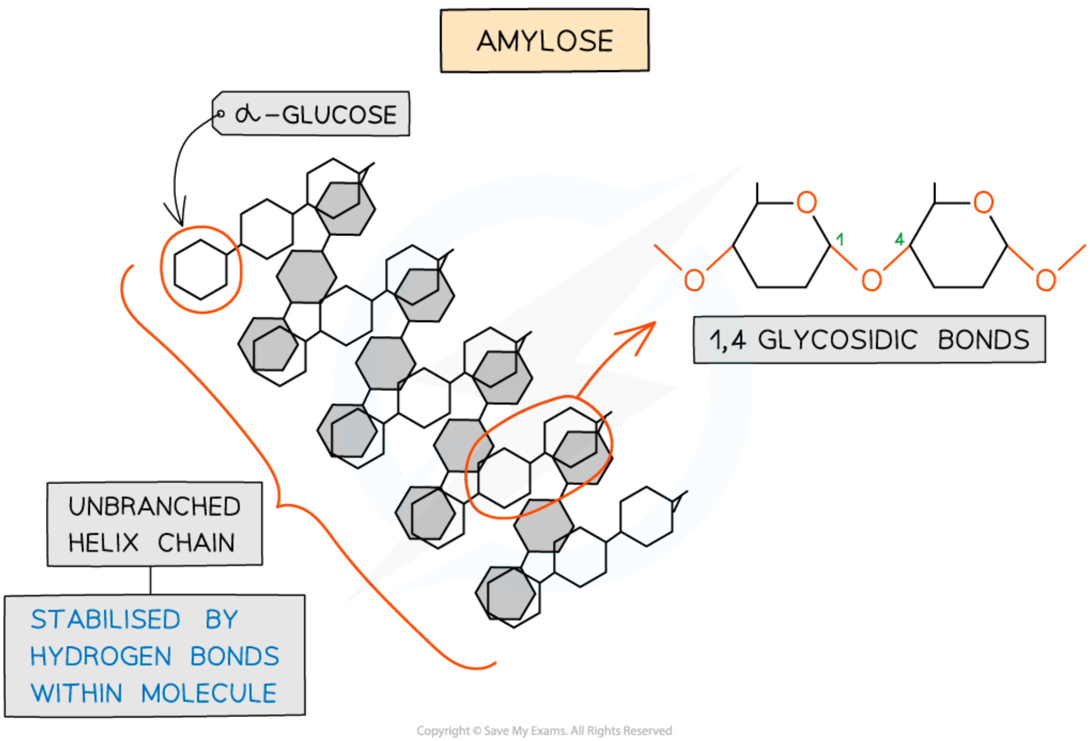
- **Starch, cellulose** and **glycogen** are **polysaccharides**
- Polysaccharides are macromolecules that are **polymers** formed by **many** monosaccharides joined together by **glycosidic** bonds
- The bonds form from **condensation** reactions, resulting in polysaccharide chains
- These chains may be:
  - Branched or unbranched
  - Folded (making the molecule compact which is ideal for storage eg. starch and glycogen)
  - Straight (making the molecules suitable to construct cellular structures e.g. cellulose) or coiled

- **Starch** and **glycogen** are storage polysaccharides because they are:
  - **Compact** (so large quantities can be stored)
  - **Insoluble** (so will have **no osmotic effect)**
    - The monosaccharide glucose lowers the osmolarity of a cell causing water to move into cells
    - If too much water enters an animal cell it will burst
    - Plant cells have developed thicker cell walls to prevent this

- **Cellulose** is a structural polysaccharide because it is:
  - **Strong** and **durable**
  - **Insoluble** and slightly **elastic**
  - Chemically **inert** (hardly any organisms possess enzymes that can hydrolyse it)
  - Is an ideal material for plant cell walls
  - The main constituent of **dietary fibre** for animals that eat plants

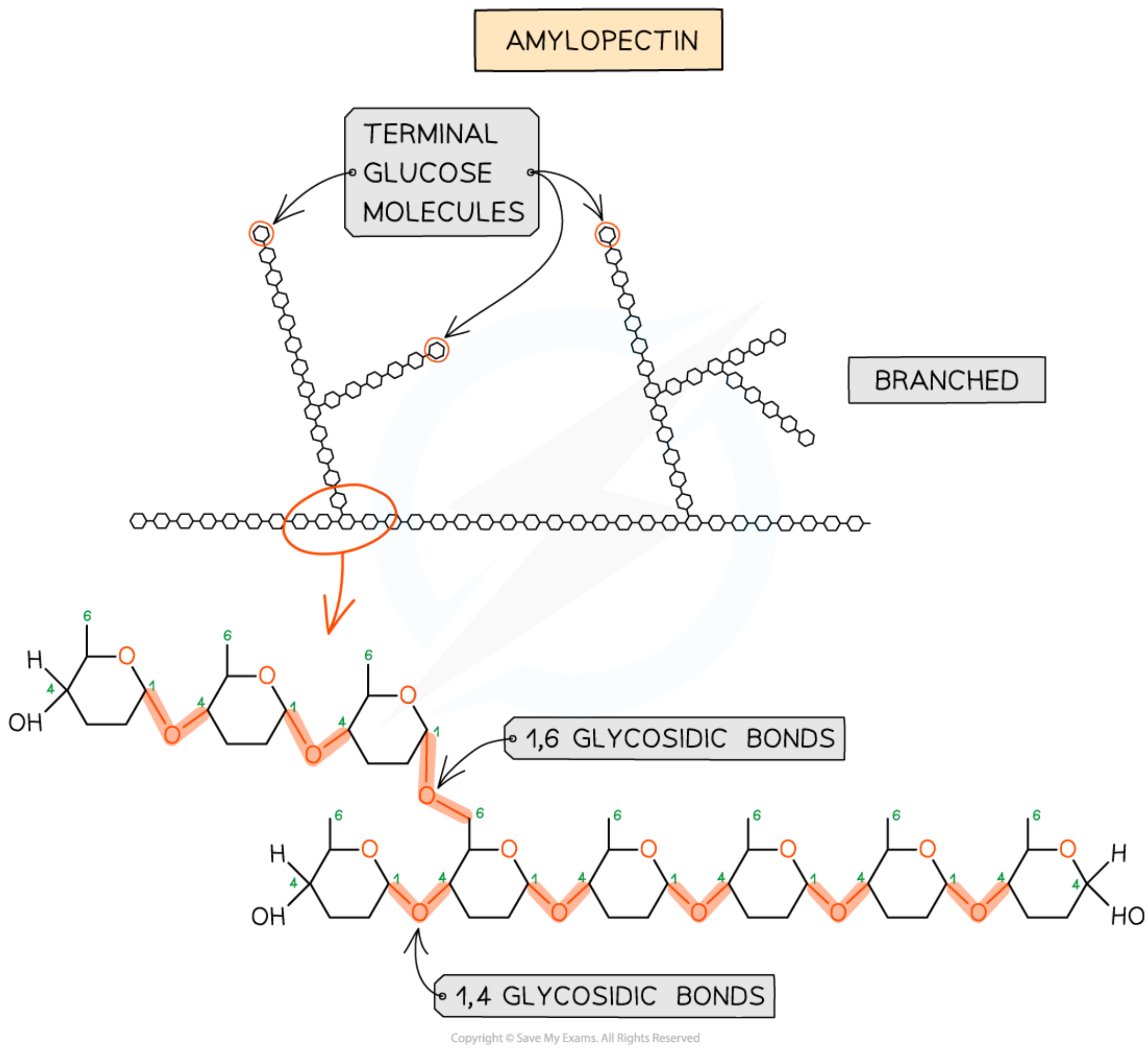
Starch

- Starch is the **storage** polysaccharide of **plants**
- It is stored as granules in plastids (e.g. chloroplasts)
- Due to the many monomers in a starch molecule, it takes longer to digest than glucose
- Starch is constructed from **two different** polysaccharides:
  - Amylose (10 - 30% of starch)
    - **Unbranched** helix-shaped chain with 1,4 glycosidic bonds between **α-glucose molecules**
    - The helix shape enables it to be more **compact** and thus it is more resistant to digestion



Amylose – one of the two polysaccharides that is used to form starch (the storage polysaccharide in plants)

- Amylopectin (70 - 90% of starch)
  - 1,4 glycosidic bonds between α-glucose molecules **as well as 1,6 glycosidic bonds** creating a **branched** molecule
  - The branches result in **many terminal glucose molecules** that can be easily hydrolysed, for use during cellular respiration or added to for storage

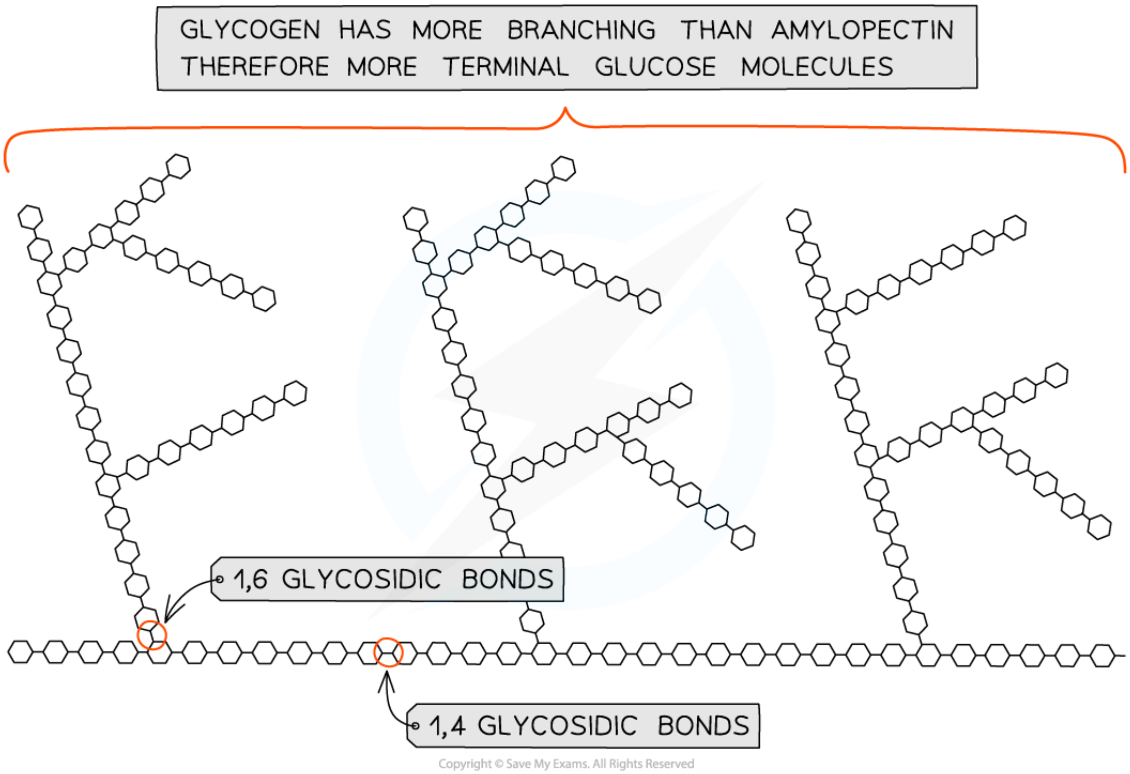


Amylopectin – one of the two polysaccharides that is used to form starch (the storage polysaccharide in plants)

Glycogen

- Glycogen is the **storage** polysaccharide of **animals** and **fungi,** it is highly branched and not coiled
- **Liver** and **muscles** cells have a high concentration of glycogen present as visible granules as the cellular respiration rate is high in these cells (due to animals being mobile)
- Glycogen is **more branched** than amylopectin making it **more compact** which helps animals **store the molecule more efficiently**
- The branching enables **more free ends** where glucose molecules can either be added or removed allowing for condensation and hydrolysis reactions to occur more rapidly – thus the storage or release of glucose can suit the demands of the cell

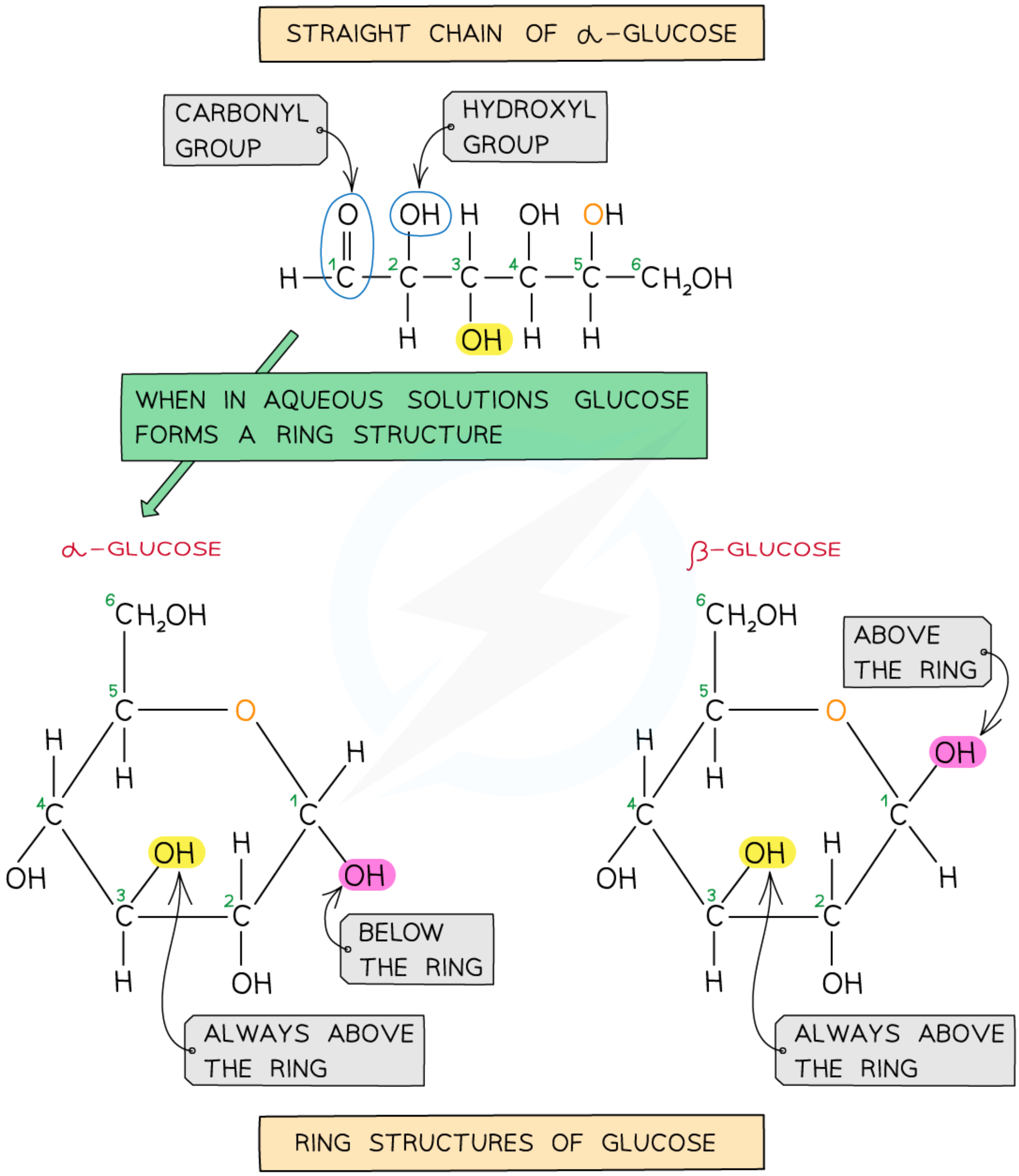
Your notes



Glycogen, the highly branched molecule used as a storage polysaccharide in animals and fungi

Cellulose

- Cellulose is a polymer of **β-glucose** monomers
- β-glucose differs very slightly in structure to α-glucose
- The hydroxyl group on the C1 atom **sits above the carbon ring** in β-glucose, whereas it sits below the ring in α-glucose

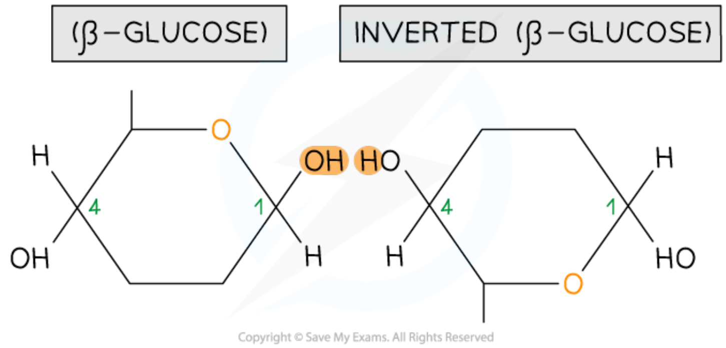


A comparison of the structure of alpha-glucose and beta-glucose

- Alpha-glucose and beta-glucose are isomers
- This **seemingly minor example of isomerism** has **far-reaching consequences** on the functions of the polymers

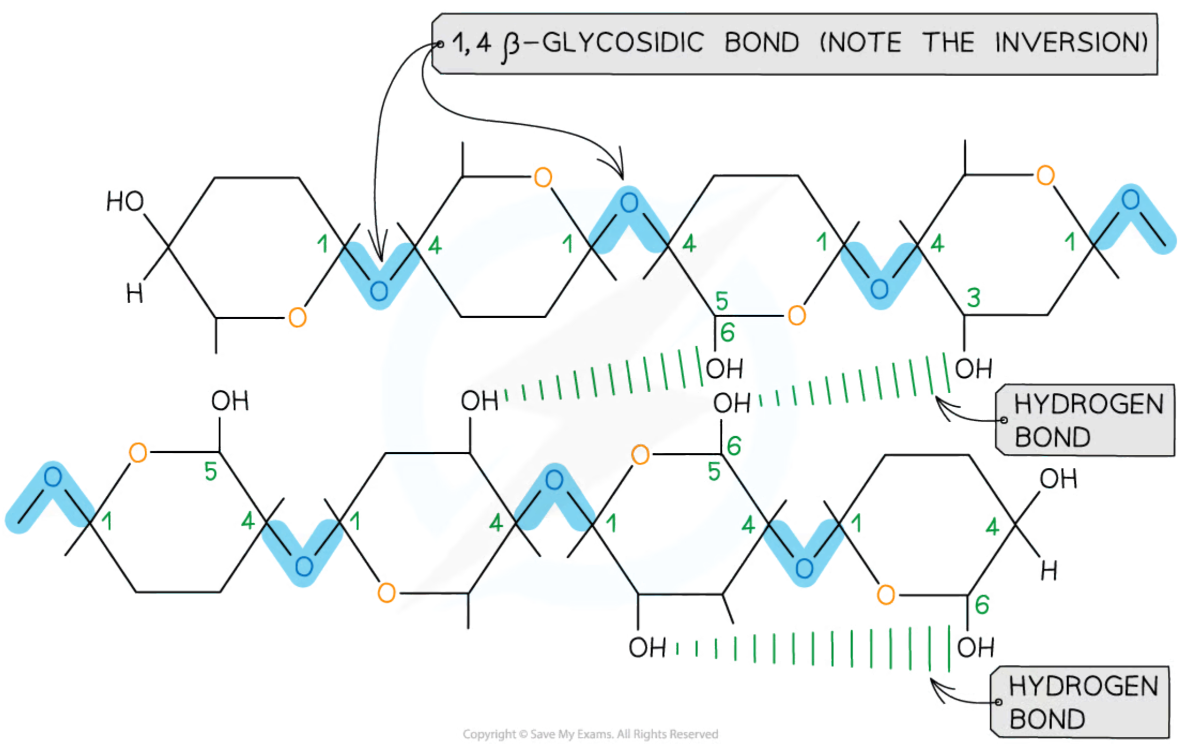
Your notes

- It means that in order to form a glycosidic bond with a molecule of β-glucose, the next molecule of β-glucose in the chain must **invert itself**



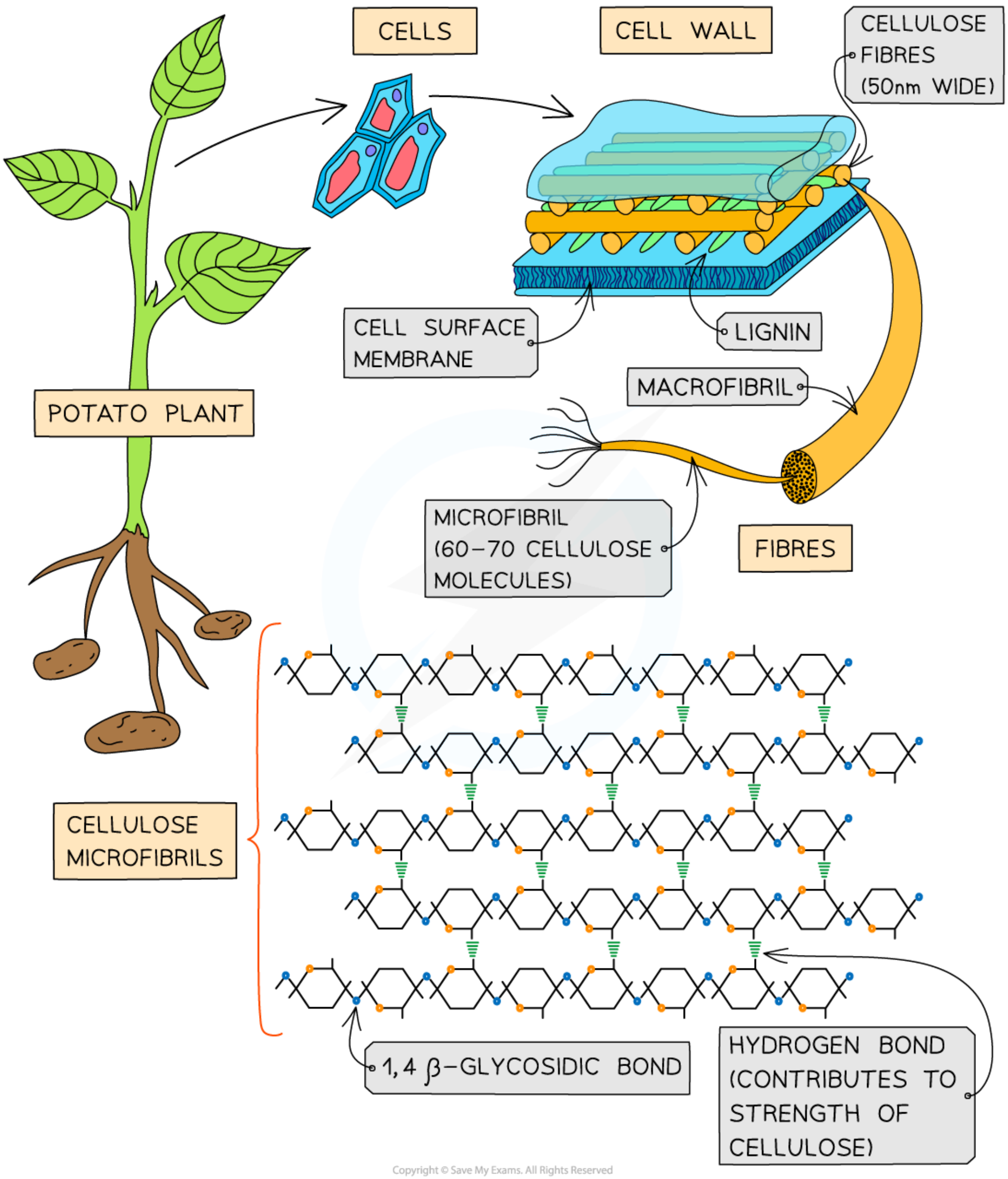
Two beta-glucose molecules orientation in a position where they are able to bond to each other

- This results in a chain of **repeatedly inverted** β-glucose monomers
- The alternating pattern of the monomers allows the chain to grow in **long, straight lengths** which gives **great fibrous strength**
- **Hydrogen bonding** occurs between strands of β-glucose monomers, adding strength to the polymer



The alternating pattern of glycosidic bonds in cellulose

Your notes



How cellulose fibres band together to provide plant strength

Summary of Polysaccharides Table

Your notes

Feature	Starch		Glycogen	Cellulose
	Amylose	Amylopectin		
Monomer	α-glucose	α-glucose	α-glucose	β-glucose
Branched	No	Yes (~every 20 monomers)	Yes (~every 10 monomers)	No
Helix (coiled) shape	Yes	No	No	No
Glycosidic bonds present	1,4	1,4 and 1,6	1,4 and 1,6	1,4
Source	plant	plant	animal	plant

Examiner Tip

Be clear about the differences between starch (amylose and amylopectin), cellulose and glycogen.

Your notes

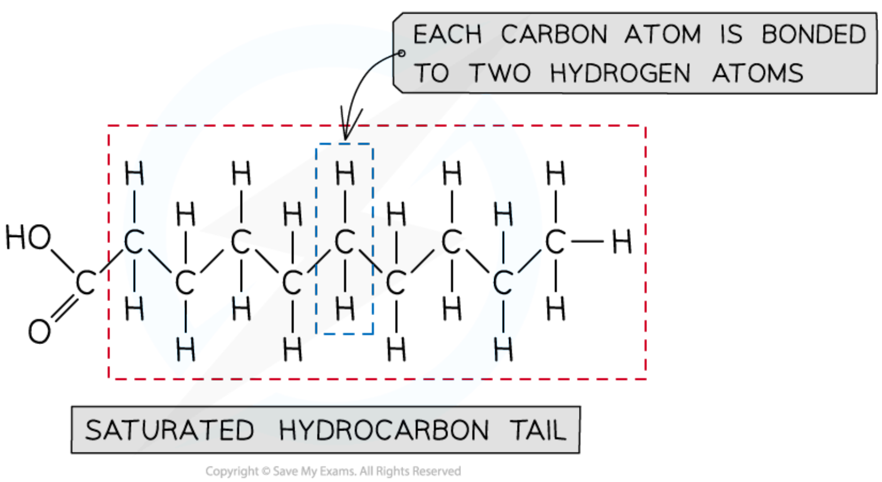
2.2.2 Fatty Acids

Fatty Acids: Types

- Triglycerides are a form of lipid, made up of one molecule of **glycerol** with three **fatty acids** attached to it
- These fatty acids have **long hydrocarbon 'tails'**
- Fatty acids occur in **two** forms:
  - **Saturated** fatty acids
  - **Unsaturated** fatty acids
    - Unsaturated fatty acids can be **monounsaturated** or **polyunsaturated**
- The difference between these fatty acid types is found in their hydrocarbon tails

Saturated fatty acids

- In saturated fatty acids, the bonds between the carbon atoms in the hydrocarbon tail are **all single bonds**
- The fatty acid is said to be **'saturated' with hydrogen**
  - This means that each carbon atom in the hydrocarbon tail (except for the final carbon atom) is bonded to **two hydrogen atoms**
- Saturated fatty acids can be **synthesised industrially** by **hydrogenation** (reaction with hydrogen gas) of unsaturated fatty acids
- All the carbon-to-carbon bonds are **single bonds** in saturated fatty acids

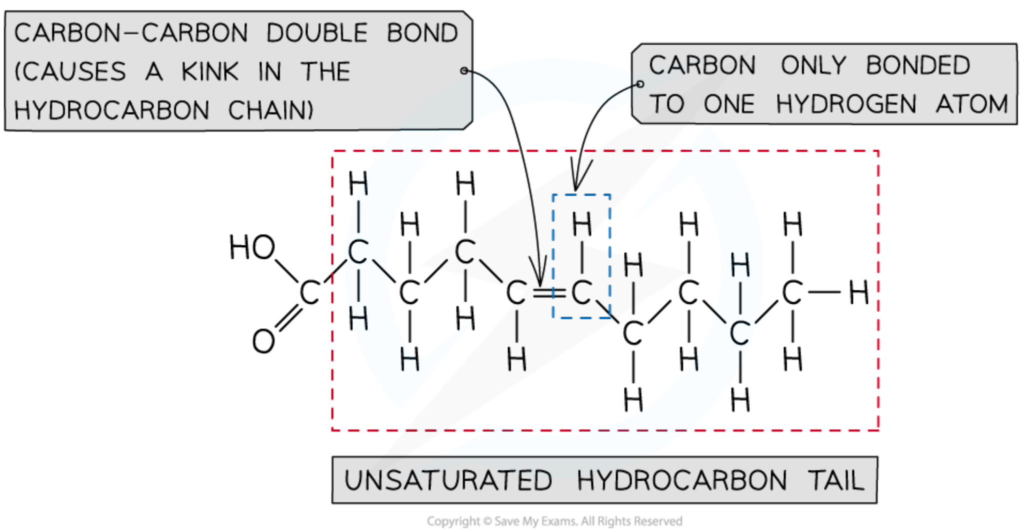


An example of a saturated fatty acid

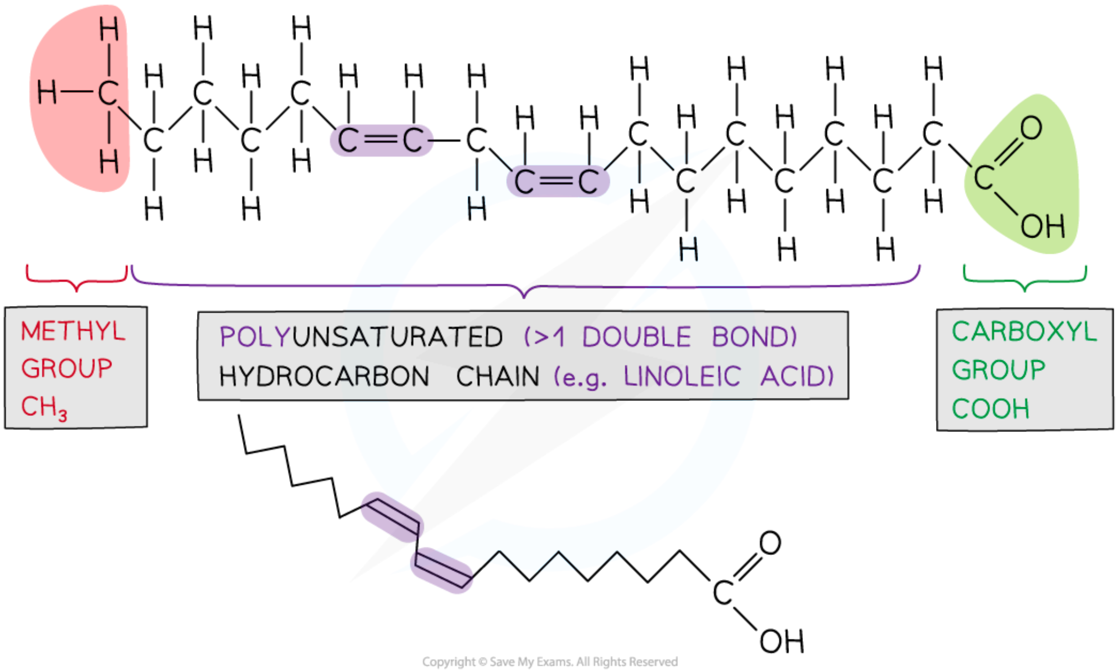
Unsaturated fatty acids

Your notes

- In unsaturated fatty acids, the bonds between the carbon atoms in the hydrocarbon tail are **not all single bonds**
  - There is **at least one carbon-carbon double bond**; a fatty acid with one C=C double bond is known as **monounsaturated** fatty acid
  - In some unsaturated fatty acids, there are **many** carbon-carbon double bonds; these are known as **polyunsaturated** fatty acids
  - These double bonds can cause the hydrocarbon tail of unsaturated fatty acids to **kink** (**bend slightly**), meaning they are **not as straight as saturated fatty acids**
- The fatty acid is said to be **'unsaturated'** because the hydrocarbon tail **does not contain the maximum number of hydrogen atoms** possible
  - This is because each carbon atom in a carbon-carbon double bond **can only bond to one hydrogen atom** (instead of two)



An example of a monounsaturated fatty acid



An example of a polyunsaturated fatty acid

Your notes

Examiner Tip

You don't need to know the names of various fatty acids, but you should be able to recognise from a diagram whether a fatty acid is saturated, monounsaturated or polyunsaturated (look for any carbon-carbon double bonds)!

Your notes

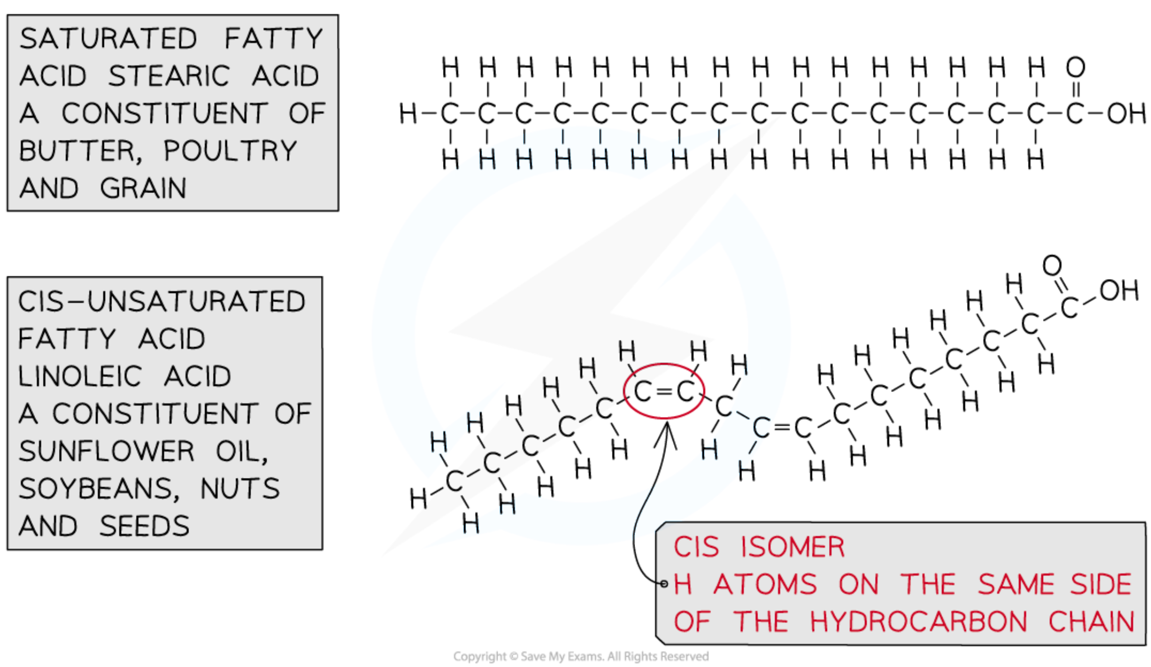
Unsaturated Fatty Acids

The different isomers of unsaturated fatty acids

- A single C-C bond in a hydrocarbon chain is able to **rotate along its axis so** that rotation of one part of the molecule in relation to others is possible
- The rotation may cause conformational changes in molecules but they all remain **identical**
- However, when there is a **C=C double bond** in a hydrocarbon chain, **no rotation** is possible
- This causes **isomers** of fatty acids to be formed, each with different properties
- The isomers are labelled **cis** and **trans** isomers

Cis-isomers

- At a C=C double bond, the attached hydrogen atoms are on the **same side** of the hydrocarbon chain as each other
  - This causes a **kink in the fatty acid chain** which means the fatty acid chains are less tightly packed together, **lowering their melting point** (less kinetic energy is needed to break them apart)
  - Triglycerides that contain cis-unsaturated fatty acids are **liquid** (oils) at room temperature



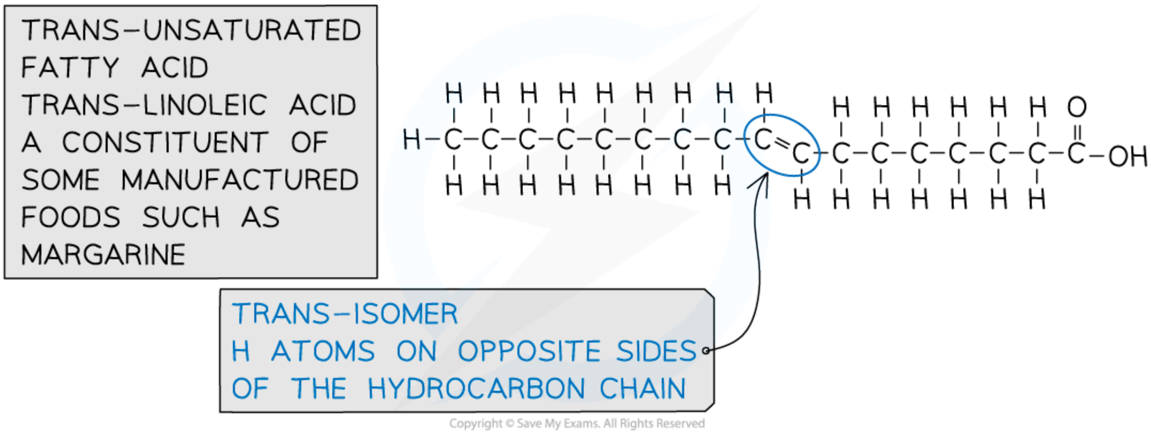
The Structural Differences Between a Saturated and a Cis-Unsaturated Fatty Acid

Trans-isomers

- At a C=C double bond, the attached hydrogen atoms are on the **opposite sides** of the hydrocarbon chain to each other
  - The lack of bend in the hydrocarbon chain allows them to pack more closely together meaning they have a **higher melting point** (this property makes them more attractive to food

manufacturers)

- Triglycerides that contain trans-saturated fatty acids are **solid** are room temperature



The Structure of a Trans-Unsaturated Fatty Acid

Your notes

Fatty Acids: Health Risks

Your notes

The use of trans-fatty acids in the food industry

- Trans-fatty acids occur in small quantities in natural products such as **dairy** and **red meat**
- Artificial trans-fats (which contain trans-fatty acids) are made industrially by the **hydrogenation** of liquid vegetable oils
- Trans-fats are **favoured by food manufacturers** for commercial reasons
  - They are more **solid at room temperature**
  - They create **more stable emulsions** in shortening agents
  - Food products with trans-fats appear (in their retail packaging) **drier** and **less 'greasy'** to consumers
  - Alleged **taste** benefits (though this is subjective)
  - They can be **reused** more times eg. in large-scale deep-fat fryers
  - Many countries have **legislated to restrict the use of trans-fats** in the foodservice industry

- Many foods that contains trans-fats (often labelled as '**partially hydrogenated vegetable oils**') are sold as processed products in supermarkets
  - Biscuits/cookies
  - Cakes
  - Doughnuts
  - Pie crusts
  - Crisps
  - Pizza bases
  - Certain kinds of margarine and spreads

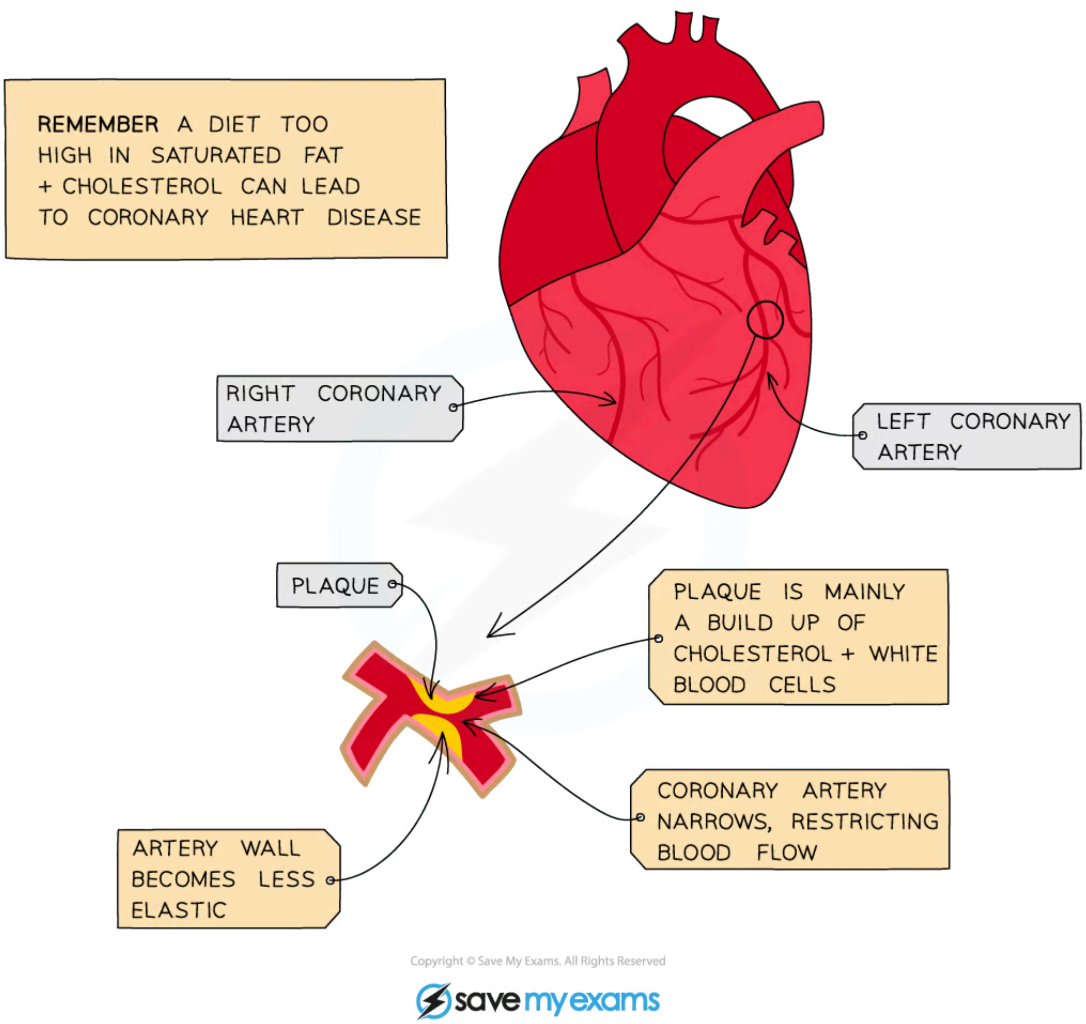
Trans-fatty acids have associated health risks

- The two types of fat that lead to health problems are namely **saturated fats** and **trans-fats**
  - Doctors recommend limiting your intake of these types of fats

- Trans-fats alter the balance of various types of cholesterol
  - They **increase low-density lipoprotein (LDL)** levels in circulation (so-called 'bad' cholesterol)
  - They **decrease high-density lipoprotein (HDL)** levels in circulation (so-called 'good' cholesterol)

- LDLs are known **to increase the risk of coronary heart disease**, blood clotting and strokes
- Doctors recommend that the bulk of fats intake should come from **monounsaturated fats**, which **reduce** LDL levels
  - Omega-3 fats and oils are a well-publicised source of monounsaturated fats; these are found in fish, pulses and certain nuts

Your notes



Excess consumption of trans-fatty acids and saturated fats can lead to the buildup of cholesterol and the blockage of coronary arteries, causing Coronary Heart Disease (CHD)

Evaluating claims

- Evidence for the claims surrounding the health risks associated with trans-fats often comes from '**cohort studies**'
  - Eg. Greenland Eskimos, whose diet is rich in oily fish and meat, have a very low incidence of heart disease
- Other **epidemiological studies** can establish correlations between diet and incidence of disease
- Whilst **it is rare to find a direct causal link** between fat intake and heart disease, the many claims about fats **suggest strongly** that trans-fats have an overall **detrimental effect** on health when consumed in high quantities
- Other conditions linked to trans-fats include

- Allergy
- Breast cancer
- Colonic cancer
- Cardiovascular diseases
- Premature birth
- Preeclampsia (a condition associated with pregnancy)
- Disorders of the nervous system
- Vision defects in infants
- Diabetes
- Obesity

Your notes

Examiner Tip

- It is important to remember that correlation does not always mean causation
  - **Correlation** is an association or relationship between variables
  - **Causation** occurs when one variable has an influence or is influenced by, another
  - There is a clear distinction between correlation and causation: a correlation does not necessarily imply a causative relationship

2.2.3 Lipids

Your notes

Long Term Storage

Lipids are excellent storage compounds

- Lipid macromolecules, like carbohydrates, contain **carbon, hydrogen** and **oxygen** atoms
- However, unlike carbohydrates, lipids contain **a low proportion of oxygen**
- More of the oxygen required for their respiration has to come from **the air**
- This allows lipids to be **energy-dense**, maximising the energy content per gram versus carbohydrates
  - They contain **2× more energy per gram** than most carbohydrates
  - **Less body mass** is required to store a given amount of energy

- Lipids are **insoluble** so do not affect osmosis, so do not risk upsetting the water balance of the organism
- When lipids are respired, **a lot of water is produced** compared to the respiration of carbohydrates
  - This is called **metabolic water** and can be used as a **dietary water source** when drinking water is unavailable
    - A **camel's hump** is not a water sac, it is a lipid-rich storage organ that yields metabolic water for the camel in its dry desert habitat
    - A **bird's egg** also makes use of lipid-rich yolk to provide energy and metabolic water to the growing chick

- All these features make lipids **ideal for long term energy storage**

Forms of lipid storage

- In **animals**, lipids are stored in various areas
  - **Subcutaneous** fats are stored below the skin
  - **Visceral** fats are stored around the major internal organs

- There are **genetic** and **gender differences** between how individuals store fat
- Fat is stored in **adipose cells**, which are specialised to contain large globules of fat
- **Adipose cells shrink** when the fat is respired to generate metabolic energy
- In many plants, **seeds** have evolved to store fats to provide energy for a growing seedling plant
- **Olives**, **sunflowers**, **nuts**, **coconuts** and **oilseed rape** are good examples of crops whose oils are harvested for edible oil production by humans

Other roles of lipids

- As well as energy storage molecules, lipids have a **number of other roles**
  - Physical **protection of soft organs** eg. visceral fat around the heart
  - **Thermal insulation** from subcutaneous fat eg. whale blubber
  - Subcutaneous fat as a **buoyancy aid** eg. in seals (fat is less dense than water so assists flotation)
  - **Waterproofing secretions** eg. birds' preening glands or waxy cuticles on leaf surfaces
  - **Electrical insulation** eg. the myelin sheath around certain nerve axons

- Certain **photosynthetic pigments** eg. carotenoids
- **Glycolipids**, typically as cell-surface recognition molecules/receptors

Your notes

Examiner Tip

Ensure that you are familiar with the structure of a triglyceride and that you can recognise whether the fatty acids are saturated or unsaturated.

Lipids: Health Claims

Your notes

- Lipids have been **associated with poor health** for a long time, even though they perform vital functions in tissues and organs
- High-fat diets tend to supply **more chemical energy** than an individual needs
  - Consuming excess fat can cause an individual to become **overweight** or **obese** due to the **storage of fat** in adipose tissue

- **Body Mass Index** (BMI) is a rough and ready measure of a person's mass in relation to their height
- The calculation of BMI is as follows

$$\text{Body Mass Index} = \frac{\text{Body mass (kg)}}{\text{Height}^2\ \text{(metres)}}$$

  - A BMI below 18.5 is considered **underweight**
  - A BMI 18.5–24.9 is considered **normal**
  - A BMI of 25.0–29.9 is considered **overweight**
  - A BMI of 30.0–39.9 is considered **obese**
  - A BMI of 40.0 or more is considered **morbidly obese**

- BMI is a **crude measurement** as it works against individuals who are heavily muscular but who are also extremely lean
- Overweight and obese people have a higher risk of developing **type II diabetes** and **high blood pressure** and **coronary heart disease**
- Because many risk factors combine in the prevalence of these conditions, **lipids are by no means the only cause**

NOS: Evaluating claims; health claims made about lipids in diets need to be assessed

- Popular literature, TV and social media make **claims about various foods** and their health benefits
- A food product labelled, 'Low Sugar' may in fact contain a lot of trans-fats but **hides that information**, or doesn't label it at all!
- Many health claims are based on **pseudoscience**, or backed up with only very small trials or small samples sizes
- Only **scientifically controlled studies** are able to prove **causal links** between food choices and health risks
- Techniques such as **randomised clinical trials** provide data to **inform government policy** and consumers about their food choices
- There remain **complex challenges** for consumers, food producers and governments to ensure a food supply that puts people **at least risk of disease** whilst ensuring that enough food is produced

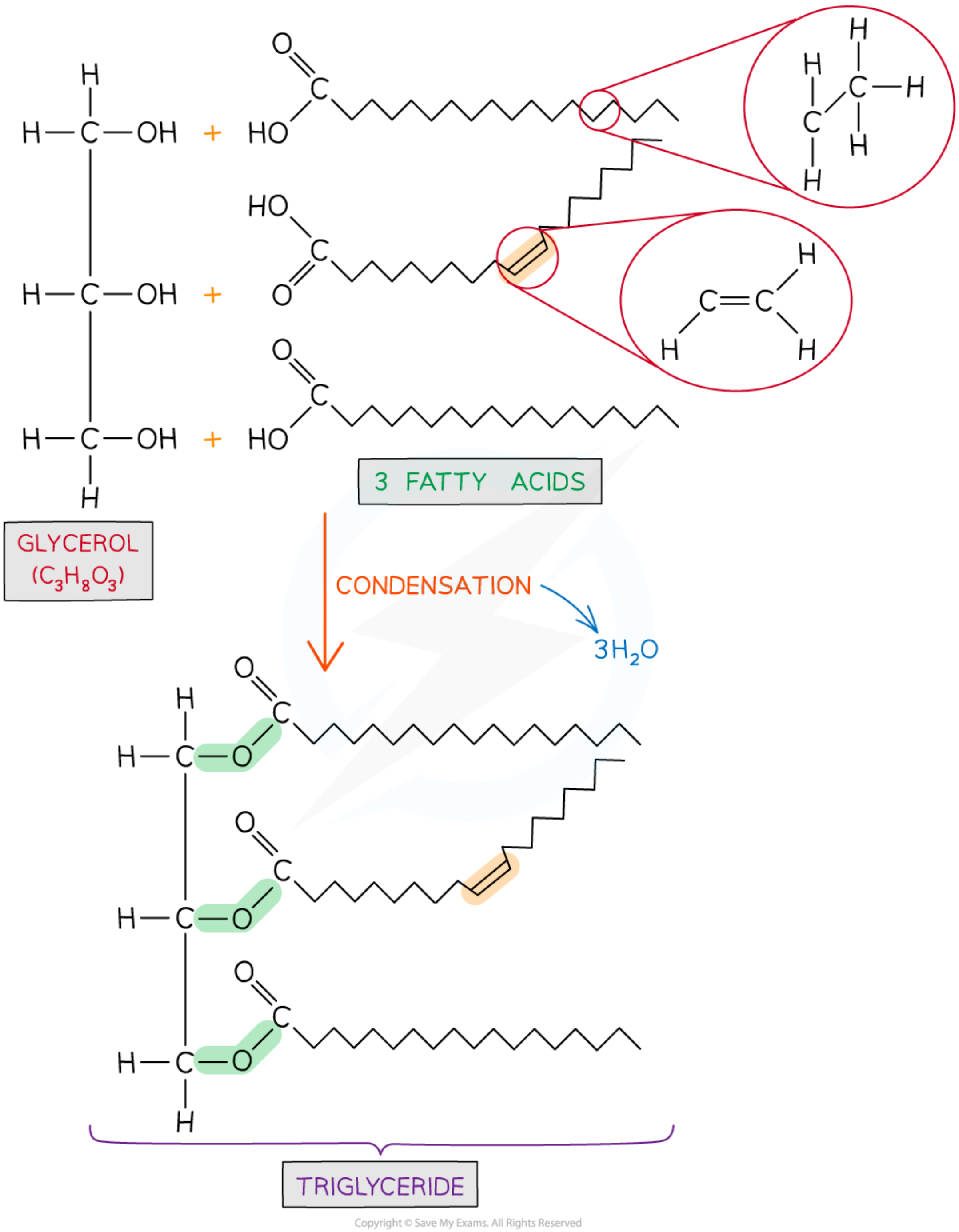
Formation of Lipids

- Triglycerides are formed by esterification
- An **ester bond** forms when the hydroxyl (-OH) group of the glycerol bonds with the carboxyl group (-COOH) of the fatty acid
  - The formation of an ester bond is a **condensation reaction**
    - For each ester bond formed a water molecule is released

  - **Three fatty acids** join to **one glycerol** molecule to form a **tri**glyceride
  - Therefore for one triglyceride to form, **three water molecules** are released

Your notes

Your notes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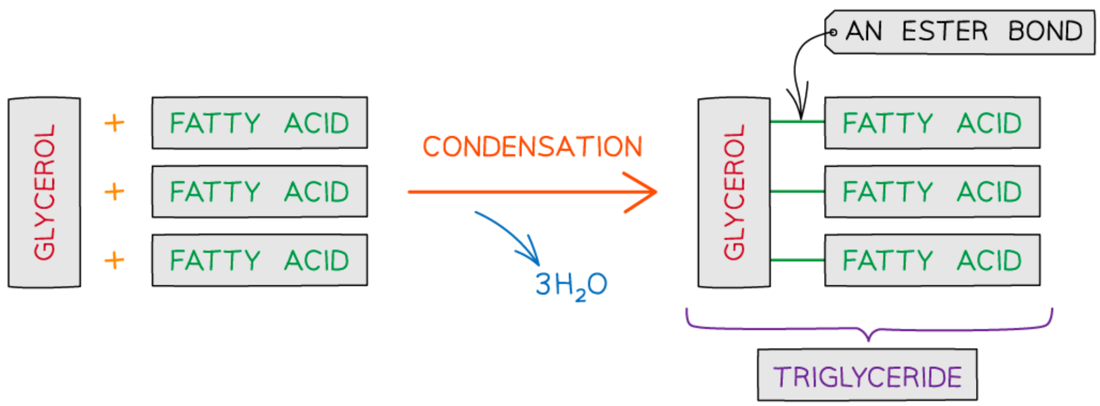


Formation of a triglyceride from a glycerol molecule and three fatty acid molecules by the process of esterification

Your notes

2.2.4 Skills: Visualising Carbohydrates

Molecular Visualisation: Carbohydrates

- **Online learning tools** exist that can provide **visualisations** of large biomolecules
- Mouse functions can **zoom** and **rotate** molecules
- Many of these make use of **JMol** software, a database of large molecules that can be visualised in near-3D
- The differences between **cellulose, starch** and **glycogen** can be observed in close to 3-D quality
- An Internet search for '**molecular visualisation software**' will identify some good options
- Features include
  - Loading multiple molecules to show **independent movement**
  - **Surface topography**; as many biological reactions are on a theme of **3-D shapes fitting together**
  - **Cavity visualisation**; has applications when looking at structures eg. channel proteins in membranes
  - The **appearance of atoms can be adapted** to fill space or **show gaps in molecules** eg. the helical nature of amylose
- Having a visualisation of these molecules helps to understand **how they have evolved to fulfil their specific functions**

Your notes

2.2.5 Skills: Calculating BMI

Body Mass Index Calculations

- Body Mass Index (BMI) is a **rough and ready measure** of a person's mass in relation to their height
- The calculation of BMI is as follows

$$\text{Body Mass Index} = \frac{\text{Body mass (kg)}}{\text{Height}^2 \text{ (metres)}}$$

- A BMI below 18.5 is considered **underweight**
- A BMI 18.5–24.9 is considered **normal**
- A BMI of 25.0–29.9 is considered **overweight**
- A BMI of 30.0–39.9 is considered **obese**
- A BMI of 40.0 or more is considered **morbidly obese**
- BMI is a crude measurement as it works against individuals who are heavily muscular but who are also extremely lean; their BMI might be an overestimate
- BMI may also be misleading in the case of elderly people who have lost a lot of muscle mass; their BMI might be an underestimate

Worked example

Calculate the Body Mass Index (BMI) for an adult male whose mass is 77.3kg and who is 1.73m in height.

Comment on whether his BMI would be regarded as healthy or not.

Step 1: Ensure that mass and height are expressed in the correct units

Mass units are kg - this is correct

Height units are in metres - this is correct

Step 2: Use the formula

$$\text{Body Mass Index} = \frac{\text{Body mass (kg)}}{\text{Height}^2 \text{ (metres)}}$$

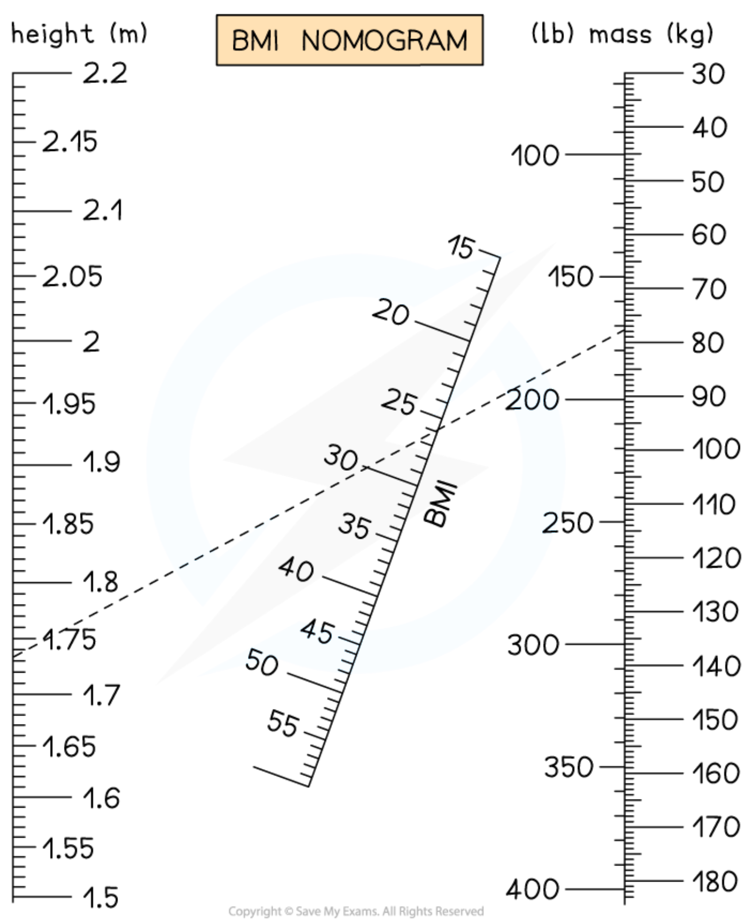
$$\text{BMI} = \frac{77.3}{1.73^2} = 25.8$$

This man's BMI falls just into the 'overweight' category (25.0 - 29.9). It is not possible to judge his health by this measure alone, but if his BMI has been trending upwards over recent time, this might suggest to a doctor that there is an underlying cause of his weight gain.

A nomogram can help to calculate BMI

Your notes

- A nomogram is a **two-dimensional chart** that allows rapid estimation of BMI by reading off two scales, one for mass and one for height
- A line is drawn, between the two scales, that **intersects a third axis** in the middle
  - This reveals the **BMI**
- This **removes the need for a calculation** and requires **no mathematical expertise**
- Because the relationships between mass, height and BMI are **all fixed**, they can be represented on a chart like this
- Nomograms have been **largely superseded** by rapid **online calculators** or **smartphone apps**, but still have a use
  - For example, **doctors** and **health workers** will often have a BMI nomogram on the wall of their office for rapid reference when consulting a patient



A BMI nomogram. A line can be drawn from the height scale to the mass scale. Where the line intersects the BMI scale is the person's BMI (26 in this case)

Examiner Tip

We commonly discuss a person's size as 'weight', though strictly speaking, we should refer to their 'mass'. In your written answers, use the scientifically correct term wherever possible.

Your notes