DP IB Biology: SL

Your notes

6.1 Digestion & Absorption

Contents

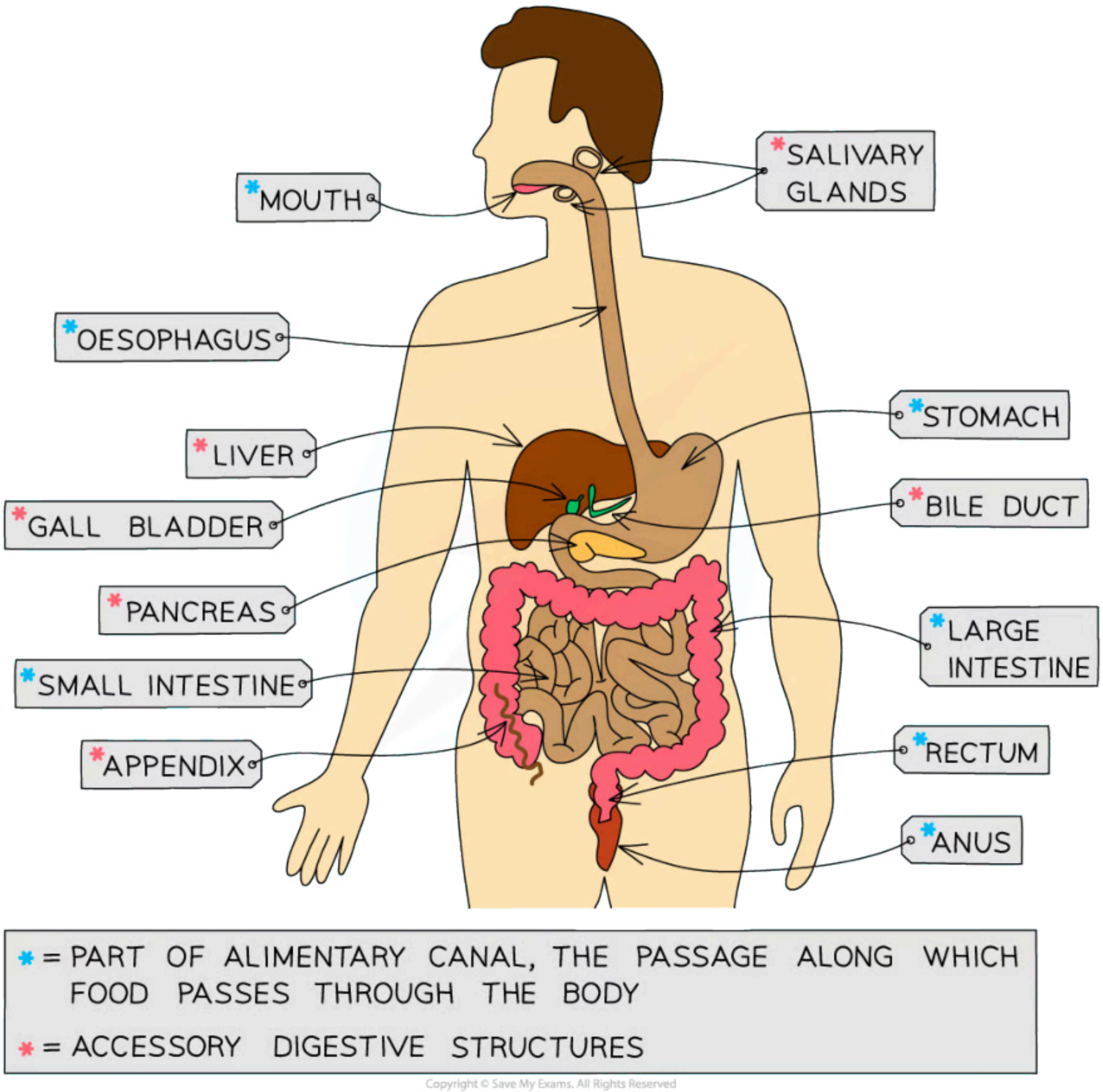
6.1.1 Digestion

Your notes

Introduction to Digestion

- The digestive system is an example of an **organ system** in which several organs work together to digest and absorb food
- Digestion is a process in which relatively **large, insoluble molecules** in food (such as **starch** and **proteins**) are broken down into **smaller, soluble molecules** that can be absorbed into the bloodstream and delivered to cells in the body
- These small, soluble molecules (such as **glucose** and **amino acids**) are used either to release **energy** (via respiration) to the cells, or to provide cells with materials with which they can **build other molecules** to **grow, repair and function**
- The human digestive system is made up of the organs that form the alimentary canal, and accessory organs
  - The alimentary canal is the channel or passage through which food flows through the body, starting at the **mouth** and ending at the **anus**
  - Digestion occurs within the alimentary canal
  - Accessory organs produce substances that are needed for digestion to occur (such as **enzymes** and **bile**) but food does not pass directly through these organs

Your notes

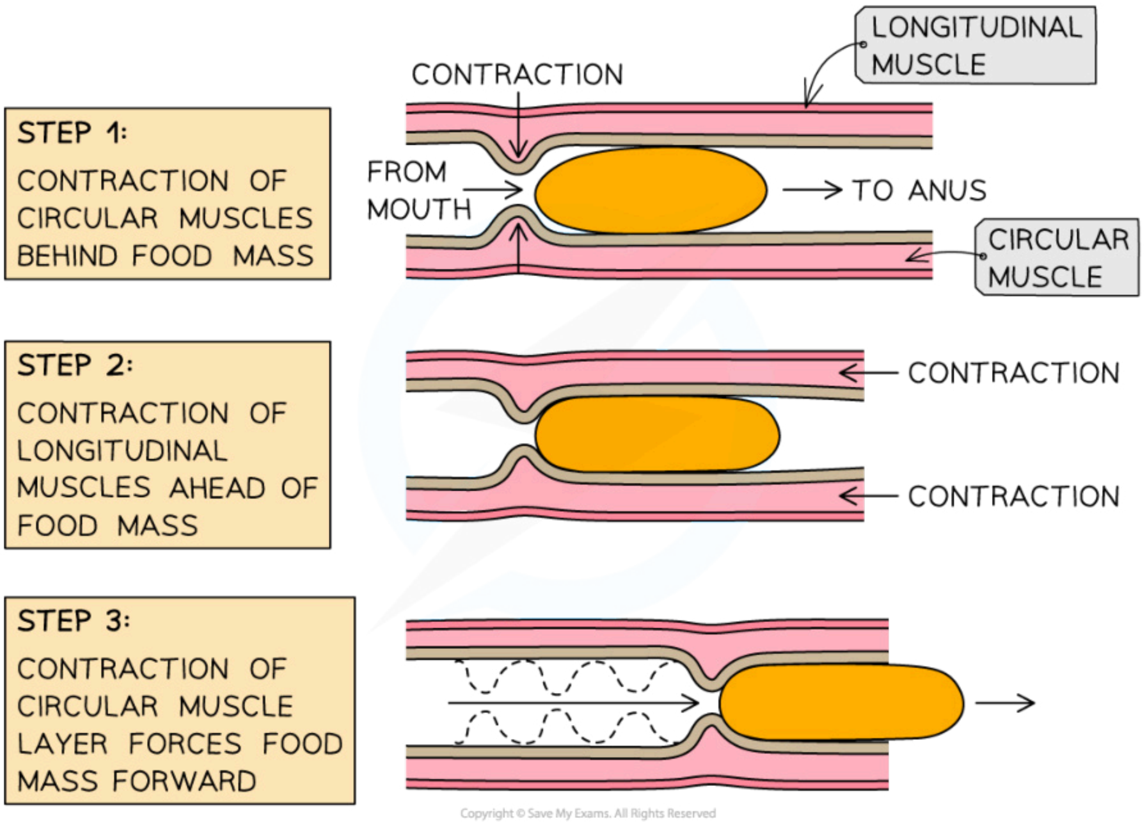


The human digestive system includes the organs of the alimentary canal and accessory organs that work together to break large insoluble molecules into small soluble molecules

Peristalsis

Your notes

- Peristalsis is **series of muscle contractions** in the **walls of the oesophagus** or **small intestine** that pass like a **wave** along the alimentary canal
  - This wave forces the bolus of food along the alimentary canal
  - These contractions are controlled unconsciously by the autonomic nervous system
- Peristalsis is controlled by **circular** and **longitudinal** muscles
- These muscles are smooth muscle (not striated)
  - **Circular muscles** contract to reduce the **diameter** of the lumen of the oesophagus or small intestine
    - This **prevents the food moving backwards** towards the mouth
  - **Longitudinal muscles** contract to reduce the **length** of that section the oesophagus or the small intestine
    - This **forces the food forwards** through the alimentary canal
- Once the bolus has reached the stomach, it is churned into a less solid form, called chyme, which continues on to the **small intestine**
- **Mucus** is produced to continually **lubricate** the food mass and reduce friction
- In the **small intestine** peristalsis is **slow** compared to the peristalsis that occurs in the oesophagus. It also aids digestion by **churning** up the food with enzymes as it pushes it along the gut



Circular and longitudinal muscles in the alimentary canal contract rhythmically to move the bolus along in a wave-like action

Pancreatic Juices

Your notes

- The pancreas is a gland made up of two types of tissue
  - The first type of tissue secretes the hormones insulin and glucagon into the **blood**
  - The second type of tissue **synthesises** and **secretes digestive enzymes** into the lumen of the small intestine
    - Enzymes are synthesised on the **ribosomes** of the rough endoplasmic reticulum. They are then processed within the Golgi apparatus before being secreted by exocytosis into the lumen of the **small intestine**

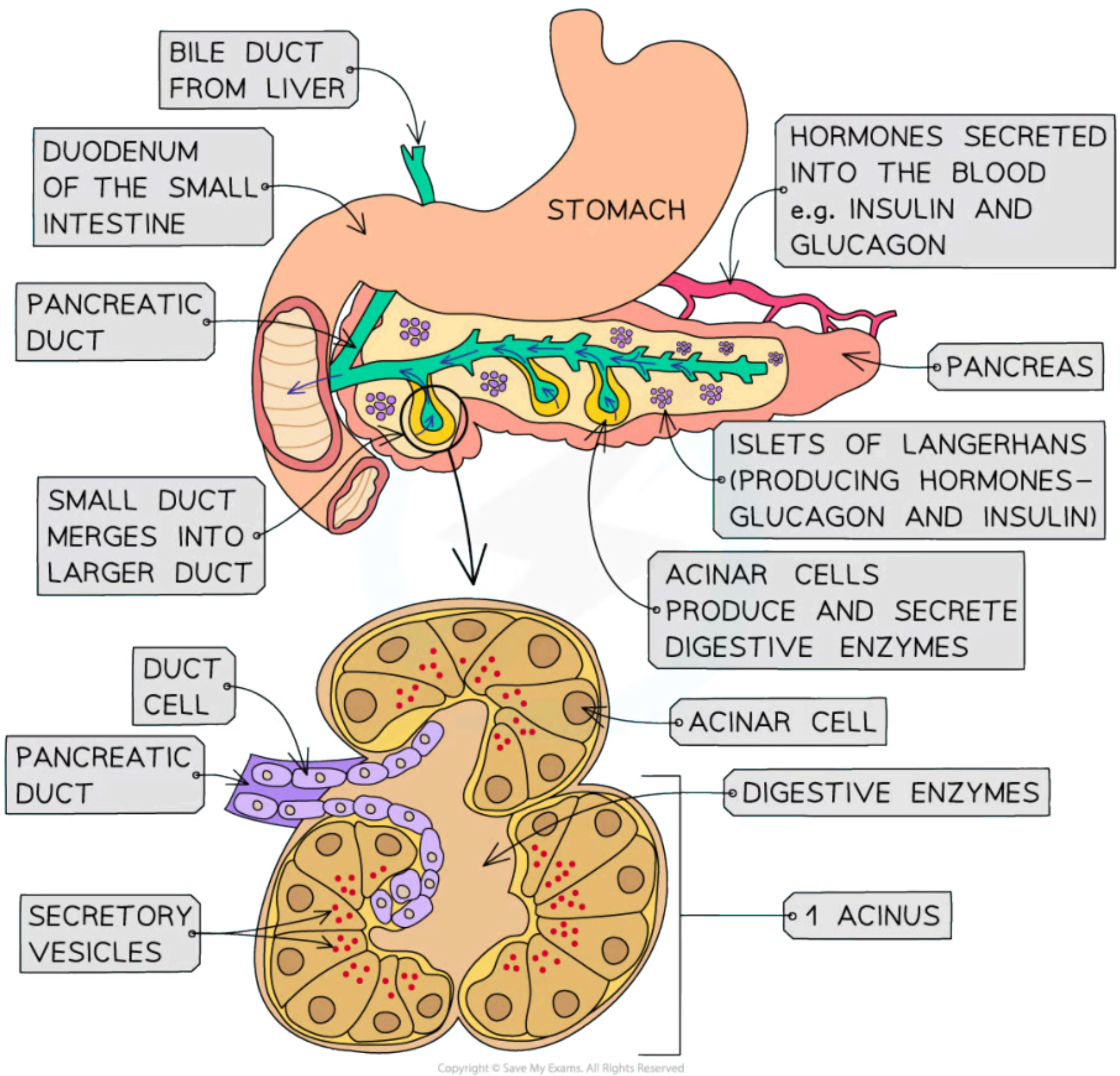
- Secretion of pancreatic enzymes is stimulated by the release of **hormones** into the stomach and intestines in response to ingestion of food
  - This is an automatic response of the **autonomic nervous system**

- The **enzymes found in pancreatic juice** include amylase, lipase, phospholipase, and protease enzymes.

The structure of the pancreas

- Digestive enzymes are produced in specialised gland cells which are known as **acinar** cells
- These cells are located in clusters around the ends of tubes called **ducts**
- Ducts join together to form larger ducts and eventually, one **pancreatic duct**
  - This is where the pancreatic juices, containing enzymes, are secreted into the duodenum of the small intestine

Your notes



Acinar cells synthesise and secrete pancreatic enzymes into the ducts and the pancreatic duct secretes the pancreatic juice into the small intestine

Enzymes in Small Intestine Digestion

Your notes

- Enzymes are required to carry out the **hydrolysis** reactions required to digest large insoluble macromolecules into small, soluble, monomers
- The **enzymes found in pancreatic juice** include:
  - **Amylase** - for the partial digestion of starch into maltose
  - **Lipase** - for digestion of triglycerides into fatty acids and glycerol/monoglycerides
  - **Phospholipase** - for digestion of phospholipids into fatty acids, glycerol and phosphate
  - **Protease** - for the partial digestion of proteins and polypeptides into shorter peptides

- As well as those enzymes found in **pancreatic juices**, enzymes are also produced in the walls of the **small intestine**
  - These enzymes break the products of pancreatic enzyme digestion down into **monomers,** e.g.
    - Nucleases break down nucleic acids
    - Lactase digests lactose
    - Sucrase digests sucrose
    - Maltase digests maltose
    - Dipeptidase digests dipeptides

  - Some enzymes are **secreted** from the **epithelial cells** into the intestinal lumen with partially digested food
  - Other enzymes e.g. maltase, are **immobilised and are attached to the membrane** of the epithelial cells where they digest substrate molecules as the food is forced through the small intestine
    - These enzymes are examples of **integral proteins**

- Some substances that we consume, such as **cellulose**, may remain **undigested** as humans are unable to produce the enzymes required

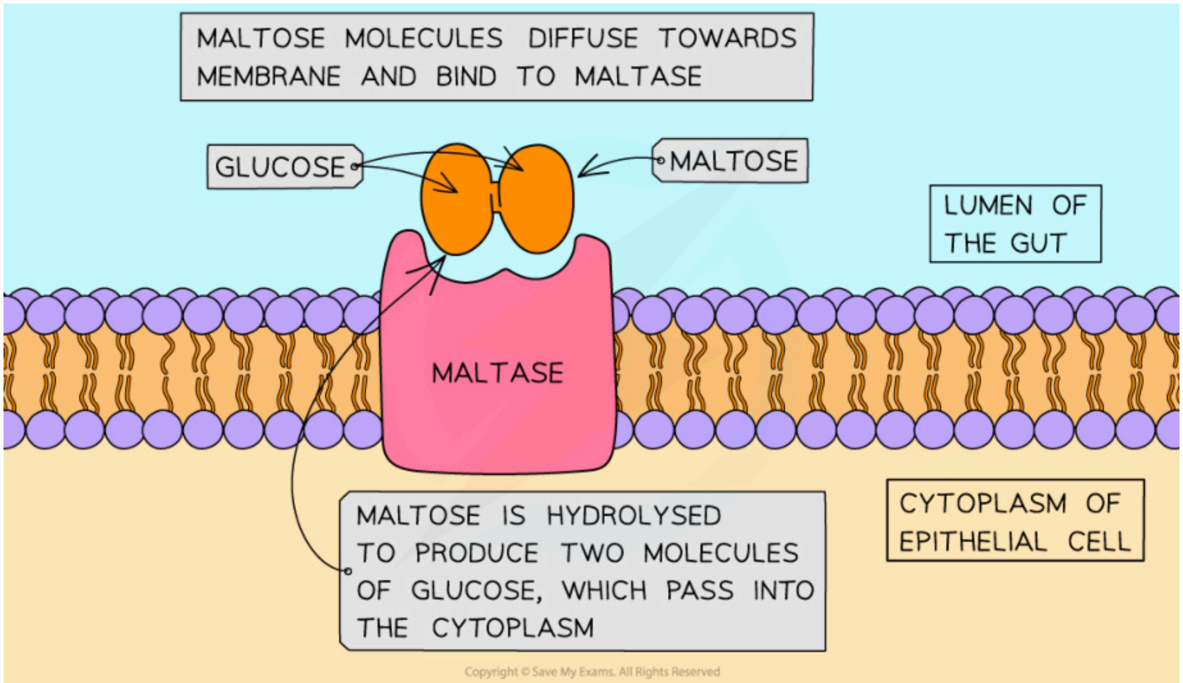


Image showing maltase enzyme attached to the cell-surface membrane of an epithelial cell

Enzymes of the Digestive System Table

Your notes

Substrate	Product	Enzymes involved
Starch	Maltose	Amylase
Triglycerides	Fatty acids & glycerol Or Fatty acids & monoglycerides	Lipase
Phospholipids	Fatty acids, glycerol & phosphate	Phospholipase
Proteins	Shorter polypeptides	Protease
DNA and RNA	Nucleotides	Nucleases
Maltose	Glucose	Maltase
Lactose	Glucose & galactose	Lactase
Sucrose	Glucose & fructose	Sucrase
Peptides	Dipeptide	Exopeptidases
Dipeptides	Amino acids	Endopeptidases

Your notes

Your notes

Small Intestine Digestion

Digestion of proteins

- **Pancreatic juice** contains endopeptidases and exopeptidases
  - **Endo**peptidases hydrolyse peptide bonds **within** polypeptide chains to produce dipeptides
  - **Exo**peptidases hydrolyse peptide bonds at the **ends** of polypeptide chains to produce dipeptides
- Lastly, there are **dipeptidase** enzymes found within the cell surface membrane of the epithelial cells in the small intestine. These enzymes hydrolyse dipeptides into **amino acids** which are released into the cytoplasm of the cell

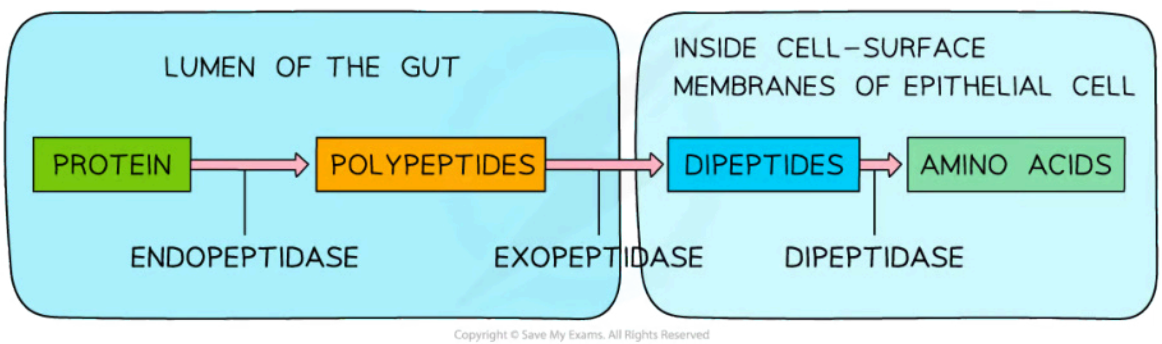


Image showing the digestion of protein by several enzymes

Your notes

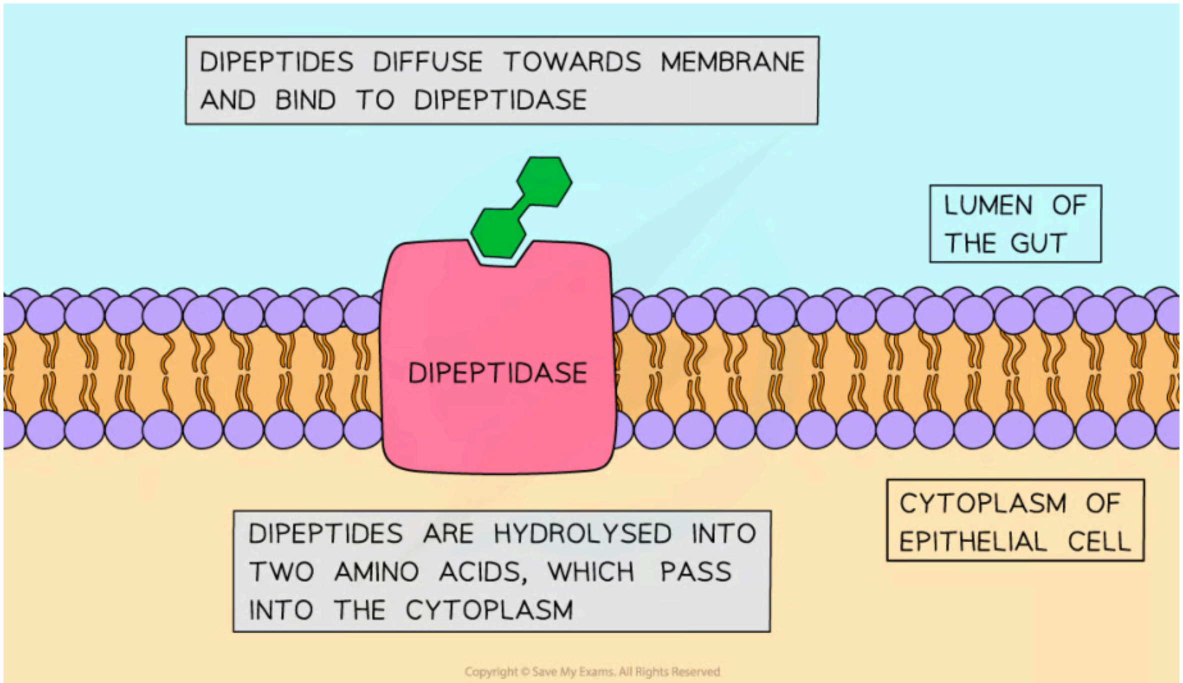


Image showing dipeptidase inside the cell-surface membrane of an epithelial cell

Emulsification of lipids

- When fatty liquid arrives in the small intestine **bile** (containing bile salts), which has been made in the liver and stored in the gallbladder, **is secreted**
- The bile salts bind to the fatty liquid and break the fatty droplets into smaller ones via **emulsification**
  - Emulsification helps to **increase the surface area** of the fatty droplets for action of digestive enzymes

Digestion of lipids

- The digestion of lipids takes place solely in the **lumen of the small intestine**
- Lipase enzymes break down lipids to **glycerol and fatty acids**
  - Lipids can also be broken down into **monoglycerides and fatty acids**
- Lipase enzymes are produced in the **pancreas** and secreted into the **small intestine**

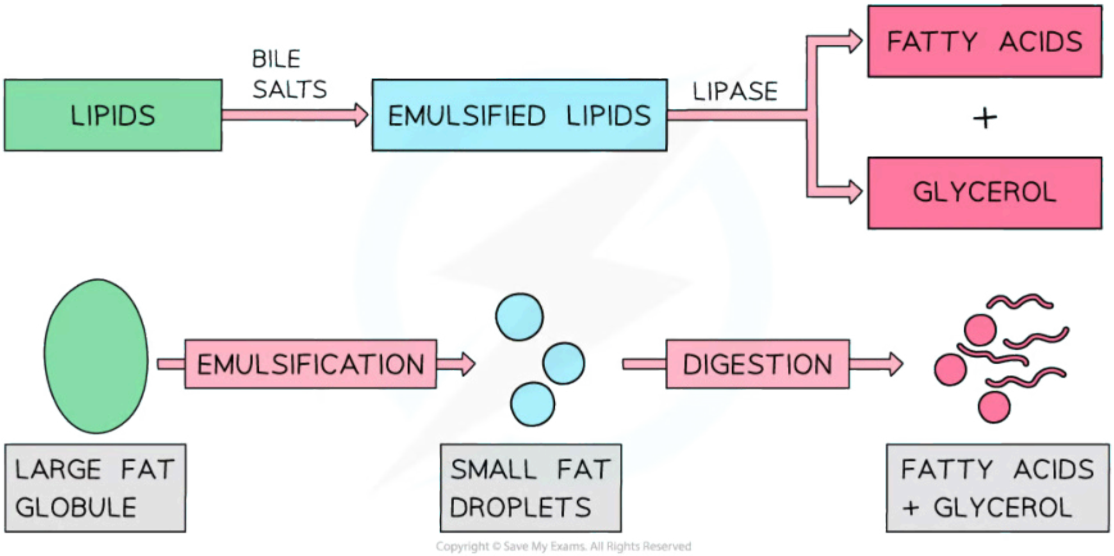


Image showing the digestion of lipids by lipase enzymes in the lumen of the gut.

Digestion of starch

- Starch is a macromolecule made up of many **α-glucose** molecules bonded together in **condensation** reactions
- There are two main types of starch
  - **Amylose** - an unbranched molecule containing [popover id="tpMGiuKDIISd8vkG" label="1,4 glycosidic bonds" only]
  - **Amylopectin** - a branched molecule with 1,4 and 1,6 glycosidic bonds

- The digestion of starch begins in the **mouth** and the **small intestine** with the enzyme **amylase**
  - **Amylase** is a carbohydrase that is made in the salivary glands, the pancreas and the small intestine
  - It **hydrolyses** the **1,4 glycosidic bonds** found in both amylose and amylopectin
  - Amylase action breaks starch down into **maltose**
  - Amylase is **unable** to digest the **1,6 bonds** found in amylopectin; as a result, short strands of amylopectin (containing these bonds) are produced. These short strands are called **dextrins**.

- The next stage of starch digestion involves enzymes **immobilised** in the **membranes of the microvilli** e.g.
  - **Maltase** - a disaccharidase which hydrolyses maltose into **glucose**
  - **Dextrinase** - digests the 1,6 glycosidic bonds found in dextrins

- After digestion, the monosaccharides can be absorbed into epithelial cells of the small intestine which pass them into the blood stream
  - Glucose is absorbed by **co-transport** with **sodium ions** into the **epithelium cells**
  - It then moves by **facilitated diffusion** into the spaces between villus cells, before entering the villus **capillaries**

Your notes

- Note that the lining of the small intestine is folded and there are **microvilli** present. This increases the surface area for proteins such as membrane-bound disaccharidases and co-transporters

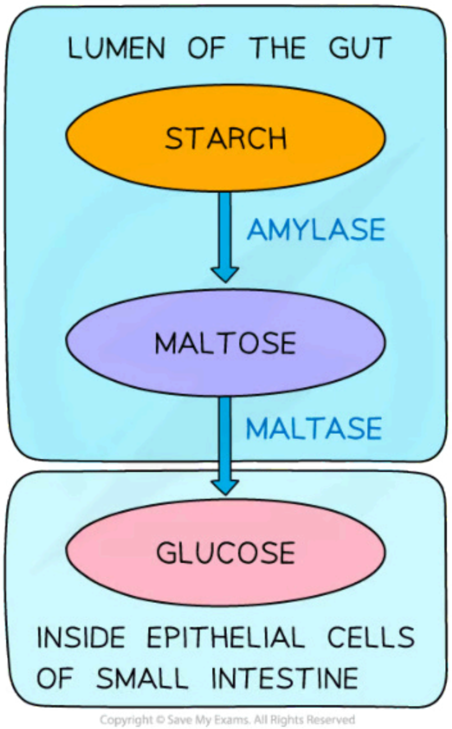


Image showing the digestion of starch by enzymes. Amylase is a carbohydrase enzyme and maltase is a disaccharidase enzyme.

Digestion of nucleic acids

- **Nucleases** are enzymes which break down **DNA and RNA** into **nucleotides**
- They break the **phosphodiester bonds** between the nucleotide bases
- These can then be **absorbed** into the blood

The products of digestion

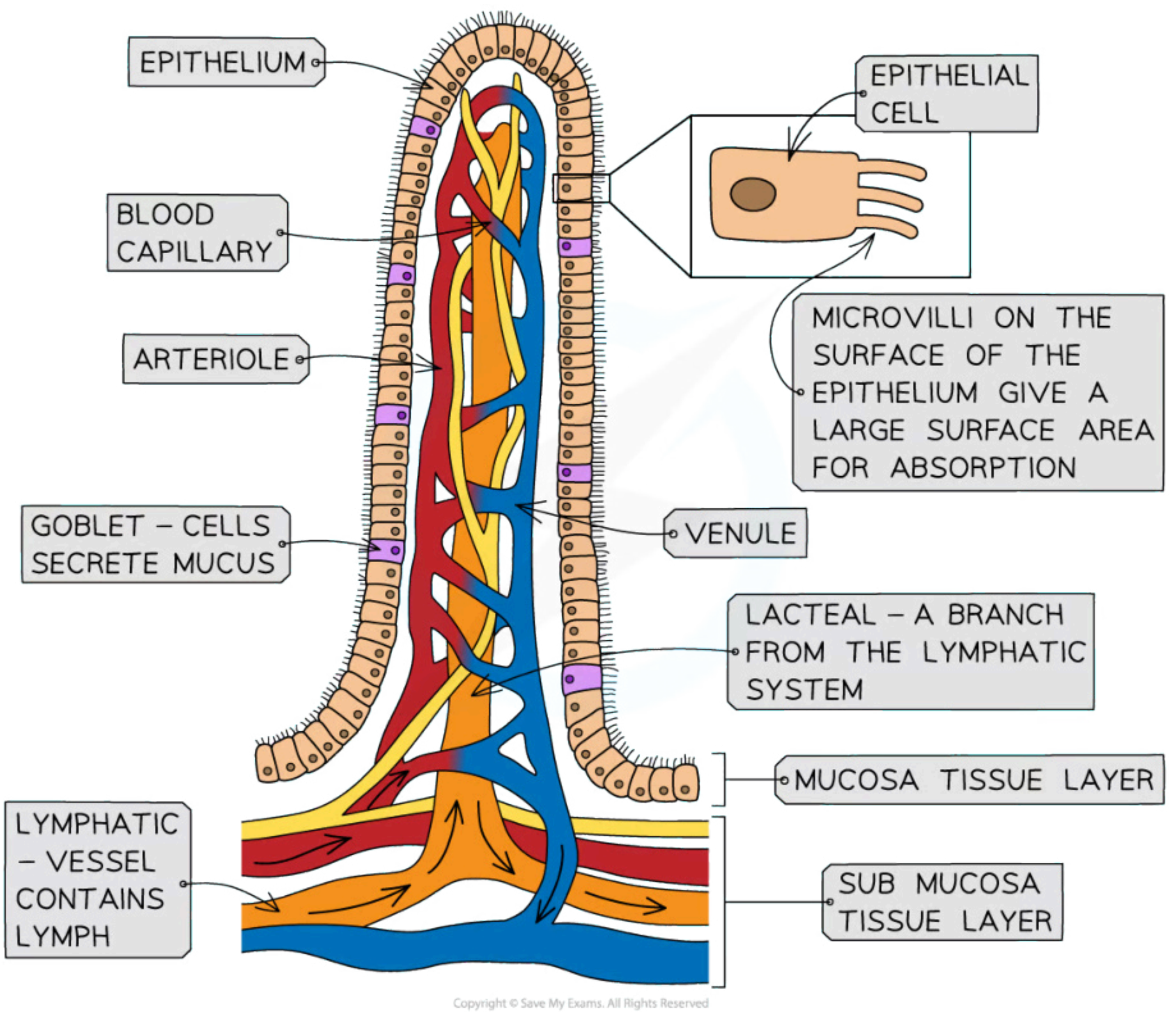
- The products of digestion travel via the **hepatic portal vein** into the **liver**
- The liver absorbs **excess glucose** and stores it as **glycogen**
  - Glycogen has a similar branched structure to amylopectin but is **more branched** due to having a higher proportion of 1,6 glycosidic bonds

Your notes

6.1.2 Villi & Absorption

Villi: Increasing the Surface Area

- The **ileum** is adapted for **absorption**
  - It is **very long**
  - It has a **highly folded surface**
  - It has **millions of villi** (singular villus)
    - Finger like projections on the internal intestinal walls
  - The epithelium of each villus is covered in **microvilli**
    - Foldings of the cell surface membrane of the epithelial cells
- All of these features significantly **increase the surface area** of the ileum, allowing absorption to take place faster



A villus is covered in microvilli which provide a huge surface area to maximise absorption in the small intestine

Your notes

Villi: Absorption

- **Absorption** takes place in the **ileum**
- Absorption is the **movement of digested food molecules, vitamins and mineral ions from the digestive system into the blood and lymph**
- This includes the following **products of digestion:**
  - **Simple monosaccharides** e.g. glucose, fructose, galactose
  - **Amino acids**
  - **Fatty acids, monoglycerides and glycerol**
  - **Nucleotide bases**
- And the following **additional substances**:
  - **Mineral ions** e.g. calcium, potassium, sodium
  - **Vitamins** e.g. vitamin C
- **Water** is absorbed in both the **small intestine** and the **colon**, but **most absorption of water** occurs in the **small intestine**

Absorption of unwanted substances

- The epithelium provides a **barrier** to prevent absorption of some harmful substances
- However, some **unwanted substances** can still pass into the blood. This includes:
  - Some **harmless chemicals** found in food colourings and flavours; these are removed by the **kidney** and lost in the urine
  - Small numbers of **bacteria –** these are **engulfed** and digested by **phagocytes** in the blood
  - Some other **harmful substances –** these are removed from the blood and broken down by the **liver**

Examiner Tip

There are three key parts to the small intestine, and whilst your syllabus does not specify you know any of the terms it is a good idea to be familiar with them.

Most often referred to in exam questions are the duodenum and the ileum.

- The duodenum is the first part of the small intestine and connects to the stomach.
- The ileum is the last part of the small intestine and connects to the colon (the large intestine).

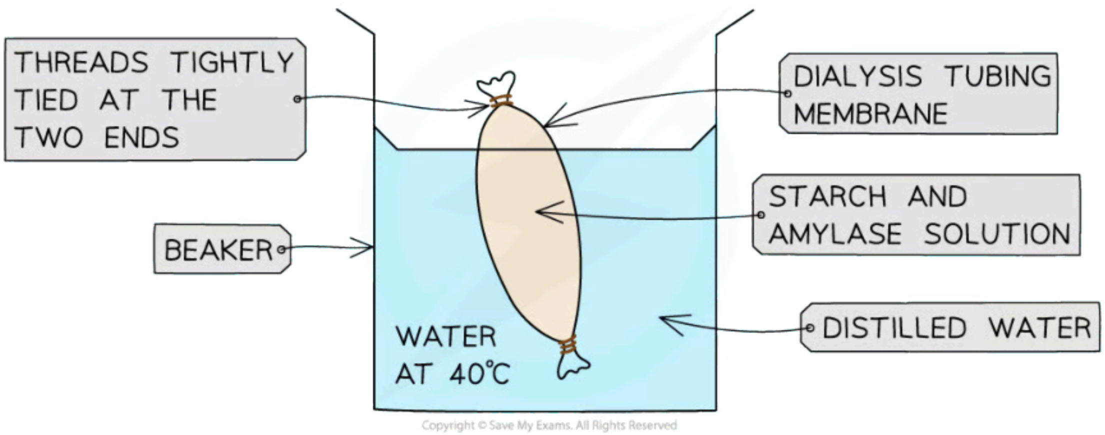
Not often referred to is the middle section of the small intestine, known as the jejunum. All three parts are involved in the digestion and absorption of nutrients.

Your notes

Dialysis Tubing Experiment

Investigating the absorption of the products of digestion using dialysis tubing

- **Dialysis tubing** (sometimes referred to as Visking tubing) is a non-living, **partially permeable** membrane made from cellulose
- It is sometimes used to model the process of **digestion** and **absorption** that occurs in the small intestine
- Pores in the membrane are small enough to **prevent the passage of large molecules** (such as **starch** and **sucrose**) but allow **smaller molecules** (such as **glucose**) to pass through by **diffusion**



Dialysis tubing can be used to model the epithelium of the small intestine

Method

- Fill a section of **dialysis tubing** (tube 1) with a mixture of:
  - 1 ml 1% amylase solution
  - 10 ml 1% starch solution
- Tie up the tubing tightly with a piece of thread
- Suspend the tubing in a beaker of water for a set period of time at 40°C
- Take samples from the liquid outside the dialysis tubing at regular intervals and **test for the presence of starch** and **glucose**
  - **Iodine** is used to test for the presence of starch. A **blue-black colour** is produced in the presence of starch
  - **Benedict's reagent** is used to test for the presence of glucose. An **orange-red precipitate** is formed in the presence of glucose when Benedict's solution is added and the solution is heated to 90°C or above
- **Repeat** the same method in a second dialysis tube (tube 2) with a mixture of:

- 1 ml distilled water
- 10 ml 1% starch solution

Your notes

Results

- **Tube 1**:
  - The **amylase** present inside the dialysis tube **breaks down** starch into **glucose**
  - Over time the **concentration of glucose** in the liquid outside the dialysis tube should **increase** as more starch is digested
    - Glucose is **small enough to diffuse across** the partially permeable membrane
    - The amount of precipitate produced from the Benedict's reagent test will **increase over time**
  - **No starch** should be found in the liquid outside the dialysis tubing
    - Starch molecules are **too large to diffuse across** the partially permeable membrane
    - The iodine test will be negative
- **Tube 2:**
  - Without amylase present, the starch is **not broken down** into glucose
  - The glucose tests done on the water outside the dialysis tube show no glucose is present as **no precipitate** is formed
  - Starch molecules are **too large to diffuse across** the partially permeable membrane, so the iodine test will be negative

Limitations

- This test is **qualitative**, so does not show the rate of enzyme activity
  - The rate of digestion can be investigated **quantitatively** by using the semi-quantitative Benedict's test
    - Comparisons can be made at time intervals using a set of colour standards (known glucose concentrations) or a **colorimeter** to give a quantitative set of results
    - A graph could be drawn showing how the rate of diffusion changes with the concentration gradient between the inside and outside of the tubing

Other investigations using dialysis tubing

- Dialysis tubing can also be used to investigate other features of digestion such as
  - The effects of different **factors** on the rate of digestive enzyme activity
    - Investigating the effect of **pH**
      - Eg. multiple dialysis tubings are set up containing solutions of starch and amylase kept at different pH levels using buffer solutions
    - Investigating the effect of **temperature**
      - Eg. multiple dialysis tubings are set up in water baths of different temperatures
  - The effect of **membrane permeability** on absorption

Your notes

- E.g. using cola to show how some smaller particles (glucose) can diffuse through the partially permeable membrane whilst larger molecules (food colouring) cannot

Using Models to Represent Real Life

NOS: Use models as representations of the real world; dialysis tubing can be used to model absorption in the intestine

- Models are often used to study **living systems** which may be **too complicated** to observe in reality and achieve meaningful results
  - There may be too many factors influencing a system at any one time
- Scientists may have access to specialist equipment that enables them to carry out **computer based models** e.g. the Dynamic Gastric Model, used to analyse factors influencing digestion
- It is also possible to model some systems using much **simpler equipment**, such as the **dialysis tubing model** from the experiment above
  - The **dialysis tubing membrane** is used to represent the membrane of the small intestine:
    - It is an accurate model because both are **partially permeable** so smaller particles can pass through the membrane whilst larger particles cannot; the membrane therefore allows the passive movement of solutes in **diffusion,** and water molecules in **osmosis**
    - However, the small intestine has a **much larger surface area** due to the presence of villi
    - Additionally, dialysis tubing is limited in the processes it can mirror and cannot show **active transport**
  - **Distilled water** is used to represent **blood**:
    - This is a good model because both have an initially **low solute concentration**
    - However, the distilled water does not **flow** in the same way as blood and so does not maintain the **concentration gradient** as blood does

6.1.3 Absorption

Your notes

Methods of Absorption

- Digestion breaks down food into **smaller, soluble molecules**
- These products of digestion then pass from the **lumen** of the intestine into the **blood**
  - They pass through the microvilli of the cell surface membrane and into the **epithelium cells**
  - Then they move through the cell surface membrane that separates the epithelium cells from the blood; into the **blood capillaries** and **lacteal** (lymph vessels within the villus)

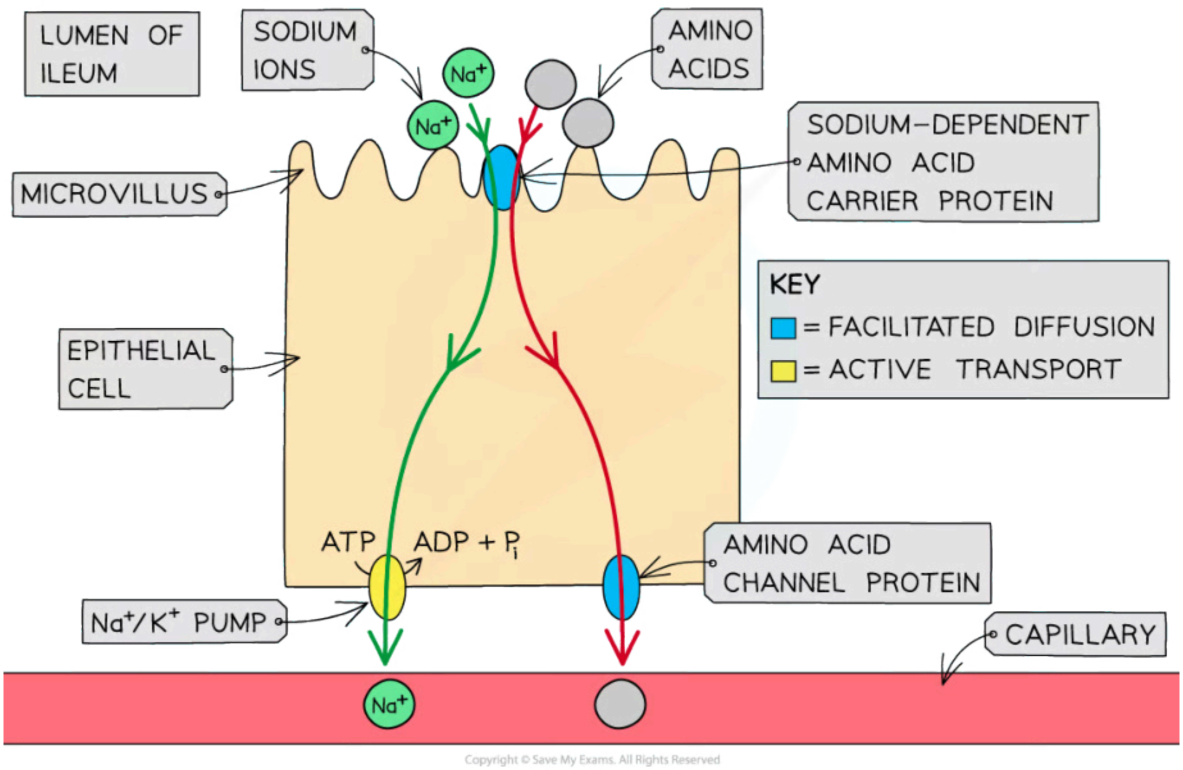
- Different mechanisms are required in the process of absorption including **diffusion, active transport, exocytosis**, and **facilitated diffusion**
  - **Amino acids** and **monosaccharides** both use facilitated diffusion, active transport and **co-transport proteins** in order to move across the epithelial membrane
  - **Lipids** are absorbed in a different way using simple diffusion, facilitated diffusion and exocytosis

Absorption of amino acids

- Specific **amino acid co-transport proteins** (a type of carrier protein) are found within the cell-surface membrane of the **epithelial cells** lining the ileum
- They transport amino acids only when there are **sodium ions** present
- For every sodium ion that is transported into the cell, an **amino acid is also transported in**
  - This occurs via **facilitated diffusion**, which requires the movement of molecules **down their** concentration gradient

- Amino acids diffuse across the epithelial cell and then pass into the capillaries via **facilitated diffusion**
- The concentration gradient of sodium ions from the lumen of the ileum into the epithelial cell is maintained by the **active transport of sodium ions** out of the cell and into the blood via a **sodium-potassium pump** at the capillary end of the cell

Your notes

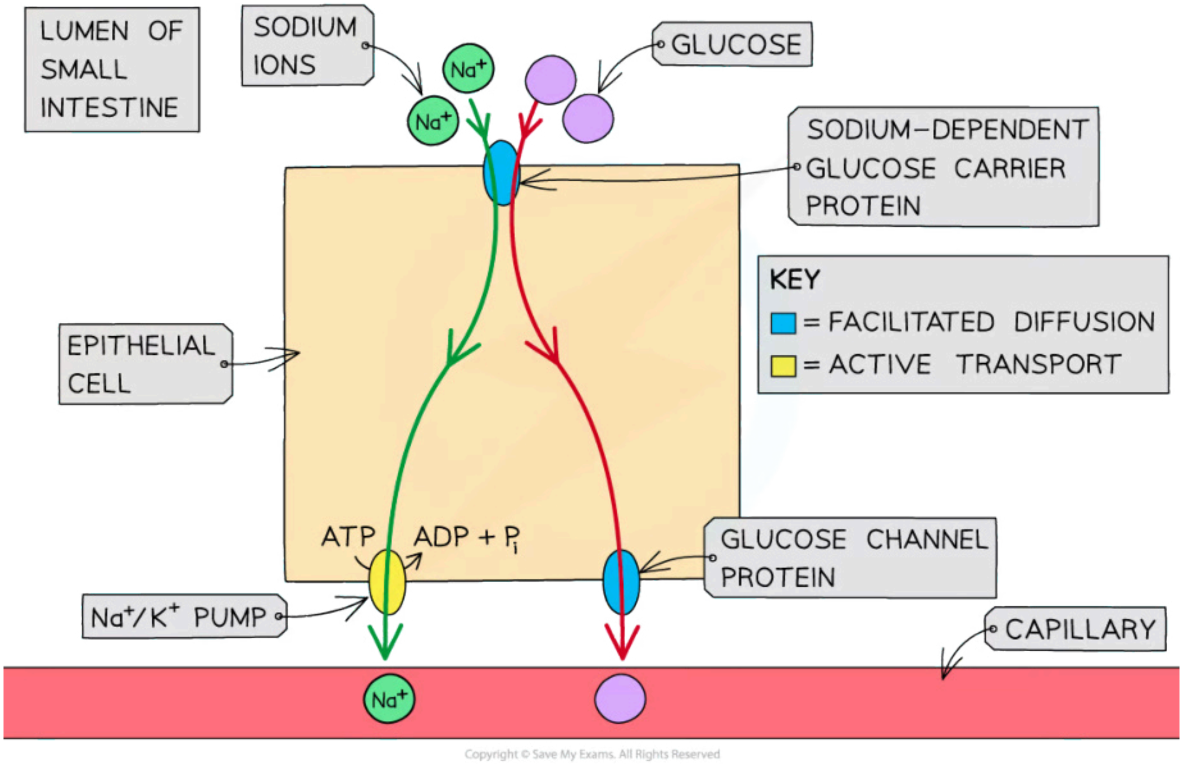


The co-transport of sodium ions and amino acids in the ileum. Both facilitated diffusion and active transport are involved in the process.

Absorption of monosaccharides

- Glucose is polar so cannot pass into the blood by diffusion
- The **glucose carrier proteins** in the cell-surface membrane of the small intestine work in a similar way to the amino acid carrier proteins
  - **Sodium ions and glucose molecules are co-transported** into the epithelial cells via **facilitated diffusion**
    - This is a **passive process** but depends on the **concentration gradient** of sodium ions from the lumen of the ileum into the epithelial cell
    - The gradient is maintained by the **active transport of sodium ions** out of the cell and into the blood via a **sodium-potassium pump** at the capillary end of the cell
  - The glucose molecules diffuse across the epithelial cell and enter the capillary by **facilitated diffusion** through a glucose channel protein

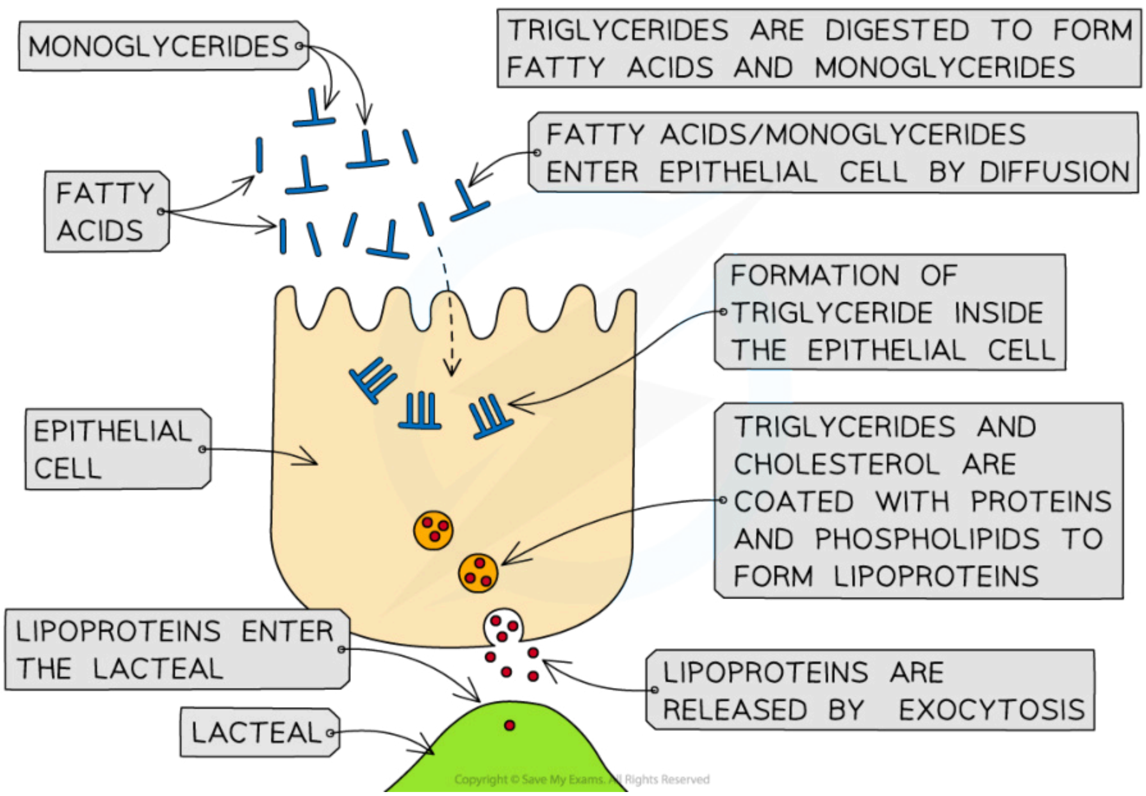
Your notes



The co-transport of sodium ions and glucose in the small intestine. Both facilitated diffusion and active transport are involved in the process.

Absorption of lipids

- The products of lipid digestion are **fatty acids, monoglycerides,** and **glycerol**
- Absorption of these products is **different** from the absorption of monosaccharides and amino acids
- **Fatty acids** and **monoglycerides** can enter the epithelial cell by **simple diffusion**
  - They are non-polar molecules so they can diffuse through the phospholipid bilayer of the cell surface membrane
- Fatty acids also move by **facilitated diffusion** through fatty acid transport proteins
- Inside the epithelial cell, **fatty acid chains** recombine with **monoglycerides** or **glycerol** to form **triglycerides,** which are unable to diffuse back into the lumen
- The **triglycerides** are packaged up with **cholesterol** and encased in phospholipids and proteins to form **lipoproteins**
- These droplets then enter the **lacteal** or **capillaries** via exocytosis



Lipids are absorbed in the small intestine through a combination of simple diffusion, facilitated diffusion and exocytosis

Your notes

6.1.4 Skills: Digestion & Absorption

Your notes

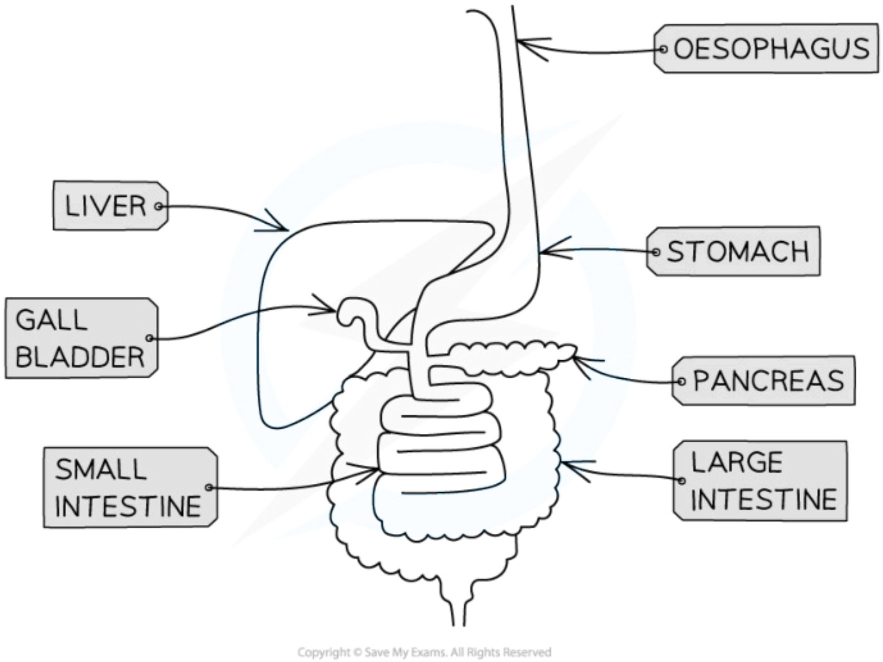
Digestive System Diagram

Human Digestive System

- The human digestive system includes the following:
  - **Glands** - the salivary glands, and glands in the pancreas that produce digestive juices
  - The **stomach** and **small intestine** - the sites of digestion
  - The **liver** - produces bile
  - **Small intestine** - the site of absorption of the products of digestion
  - **Large intestine** - the site of water absorption

Tips for drawing an annotated digestive system diagram

- A simple annotated diagram should include some clear features:
  - The junctions between each section should be **obvious and unobstructed** or covered by other parts of your drawing, this includes the following junctions:
    - Between the stomach and oesophagus
    - Between the stomach and small intestine
    - Between the pancreas, small intestine and gall bladder
  - The shapes of organs should be approximately **true to form** e.g. the stomach should be a j-shaped sac
  - The liver should be the **largest organ** represented and located to the **left of the stomach**
  - The **diameter of the small intestine** needs to be obviously **smaller** than the **diameter of the large intestine**



A diagram of the key components of the human digestive system

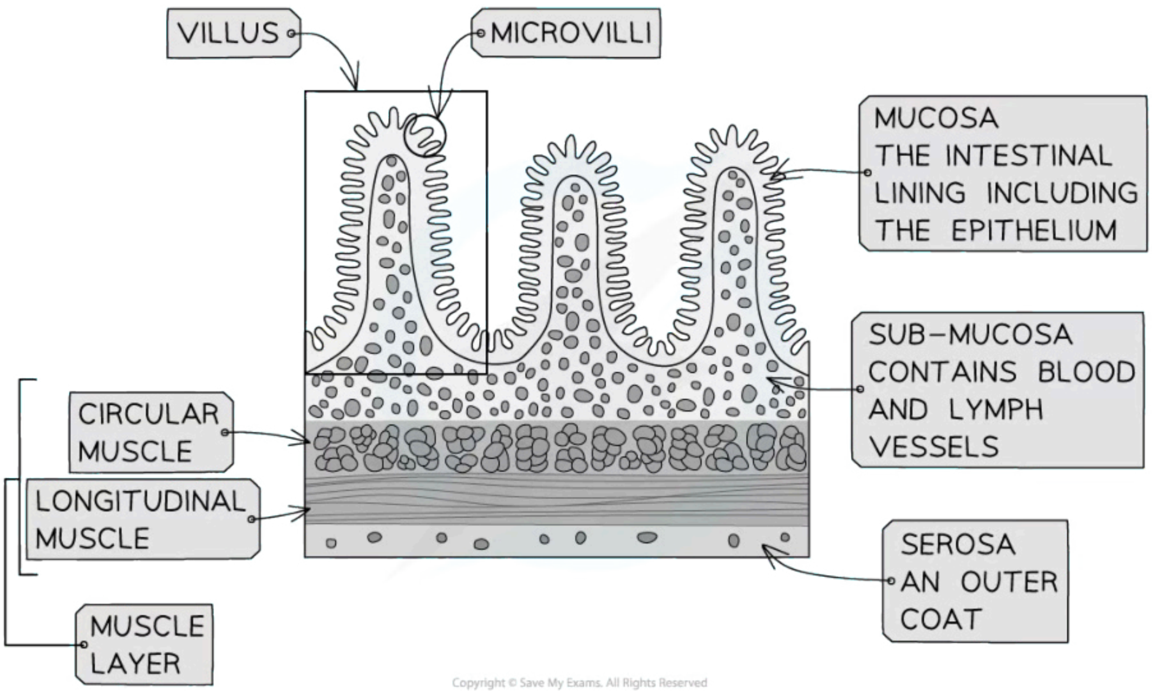
Examiner Tip

Draw your diagrams using a dark pen or pencil to ensure that all components are clear (remember that your paper will be scanned for marking, so your drawing will need to show up clearly after scanning).

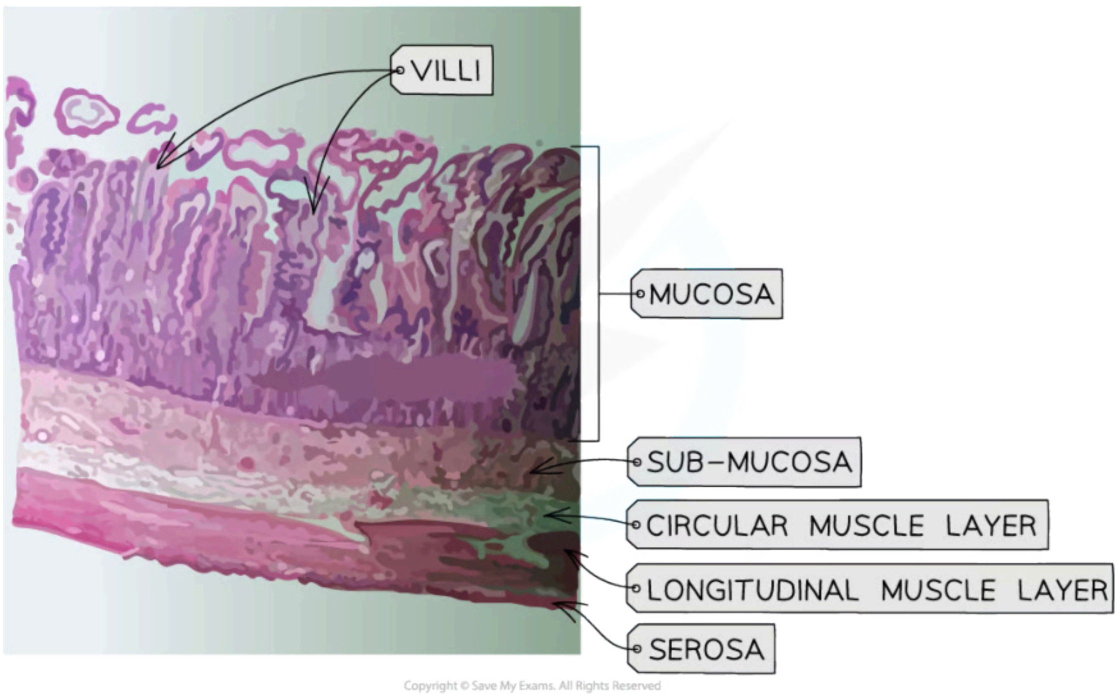
Small Intestine: Identifying Tissue Layers

Your notes

- The wall of the small intestine is made up of several layers including the following:
  - **Serosa** - an outer coat which includes a membrane and connective tissue
  - **Muscle layer** - including longitudinal muscle tissue in the outermost layer with a layer of circular muscle tissue on the inside
  - **Sub-mucosa** - connective tissue containing blood and lymph vessels
  - **Mucosa** - the lining of the small intestine, composed of epithelium which is folded to form the villi



The layers of tissue in the wall of the small intestine


VILLI
MUCOSA
SUB-MUCOSA
CIRCULAR MUSCLE LAYER
LONGITUDINAL MUSCLE LAYER
SEROSA
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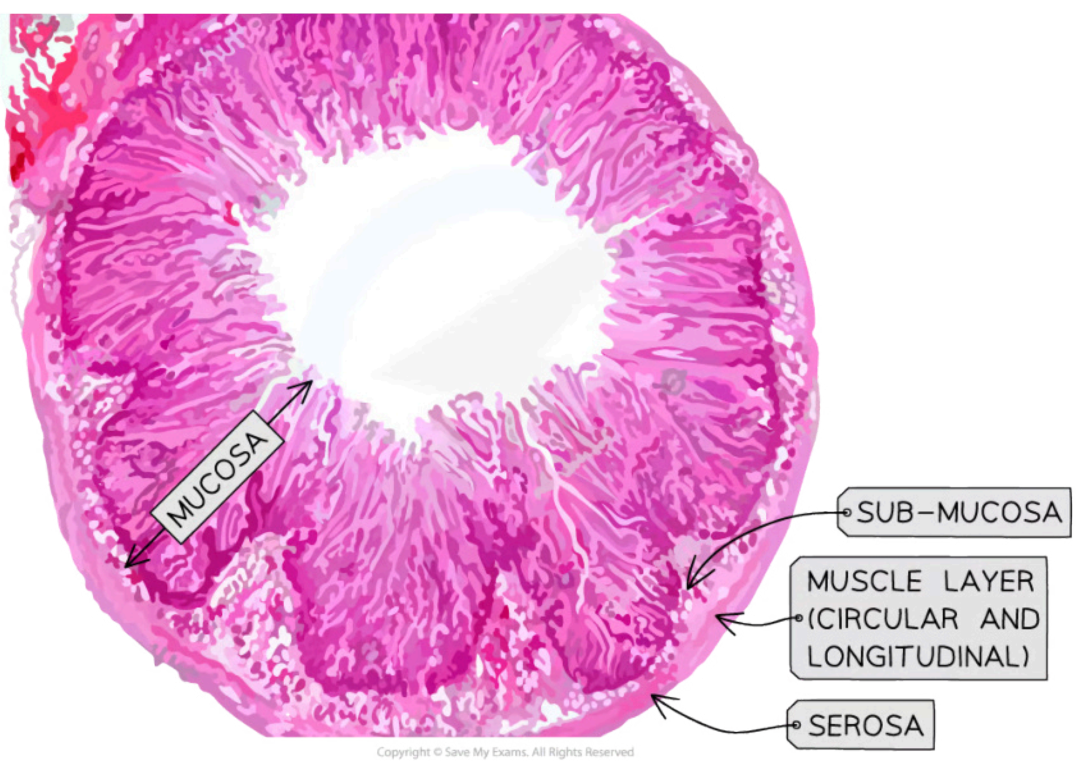
MUCOSA
SUB-MUCOSA
MUSCLE LAYER (CIRCULAR AND LONGITUDINAL)
SEROSA
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The layers of tissue in the wall of the small intestine as viewed under a microscope. Seen in both longitudinal section and cross section