S.5 BIOLOGY NOTES

(HETEROTROPHIC NUTRTION)

This is a type of nutrition in which an organism obtains organic food molecules by feeding on other organisms or their bi- products. Heterotrophs are unable to synthesize their own food substances from simple inorganic raw materials, therefore, they obtain their food in form of organic molecules. Such organisms include all animals and fungi, most bacteria, protists, and a few flowering plants.

TYPES OF HETEROTROPHIC NUTRITION

(a) Holozoic nutrition

(b) Saprotrophic nutrition (Saprophytic nutrition)

(c) Symbiosis: (i) Parasitism (ii) Mutualism (iii) Commensalism

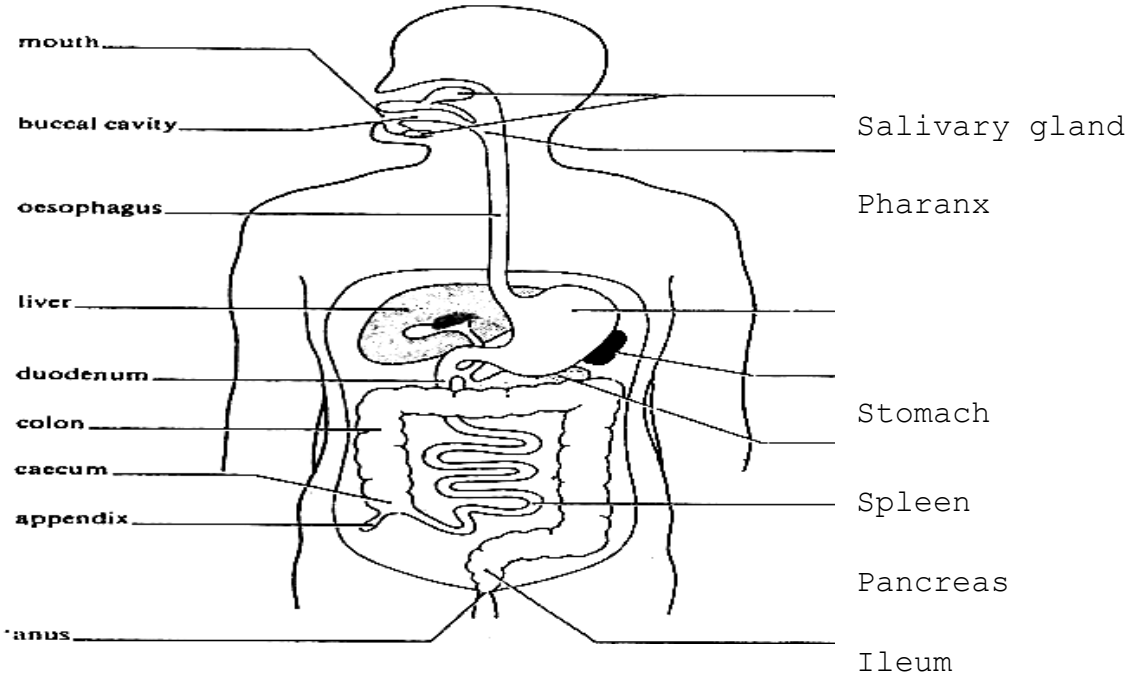
HOLOZOIC NUTRITION

This is the type of nutrition in which complex organic food is taken in and broken down inside the body of an organism into simple soluble molecules which are then absorbed and assimilated.

BASIC PROCESSES INVOLVED IN HOLOZOIC NUTRITION

1. Obtaining food: May involve movements to capture or find new food sources from the environment.
2. Ingestion: The intake of food into the body (feeding mechanisms).
3. Digestion: Chemical breakdown (by enzymes) and physical breakdown (by teeth, gizzard, mandibles, radula) of large insoluble molecules of food into small soluble molecules.
4. Absorption: The uptake of nutrient molecules into the cells of the digestive tract and, from there, into the bloodstream
5. Defecation (Egestion): elimination of undigested residue.
6. Assimilation: The utilization of the absorbed soluble food substances to form energy or materials which are incorporated into the body tissues.

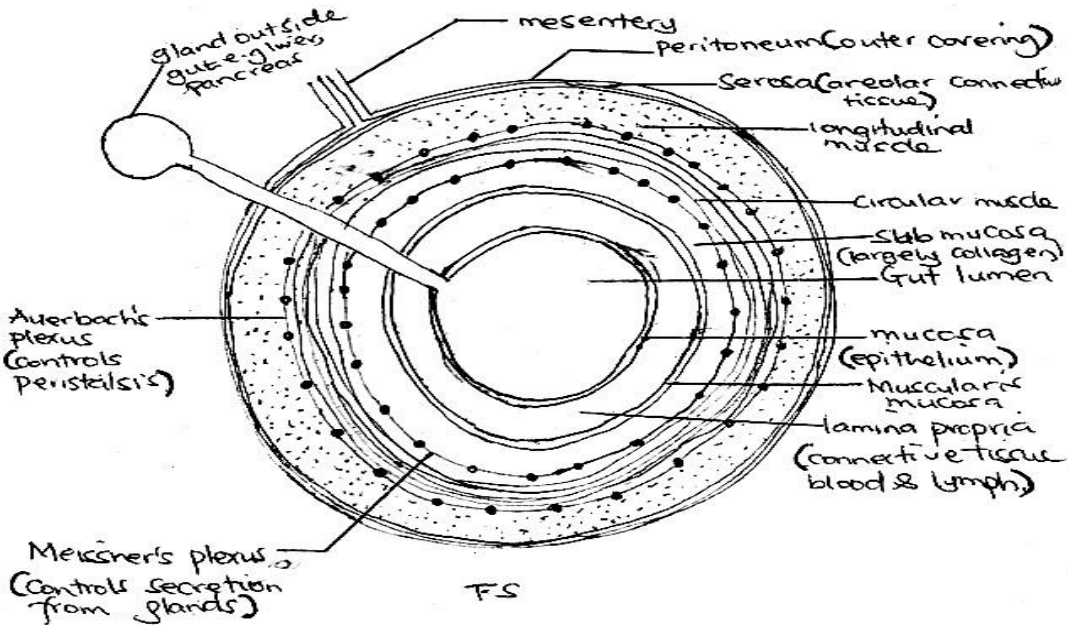
THE HUMAN ALIMENTARY CANAL



Rectum

GENERAL PLAN OF THE GUT STRUCTURE

While each portion of the digestive tract possesses its own special characteristics, all conform to a basic common structure, as shown below;



This consists of four distinct layers; namely; the mucosa, submucosa, muscularis external and serosa.

1. **Mucosa;**

   This is the inner most layer of the gut and is composed of glandular **epithelium** which secretes **mucus** and possesses enzymes embedded in the brush border. The mucus lubricates the food and facilitates its easy passage along the digestive tract and prevents autolysis. The epithelial cells rest on a basement membrane beneath which is the **lamina propria**, containing connective tissue, blood and lymph vessels. Outside this is a thin layer of smooth muscle, the **muscularis mucosa**.

2. **Submucosa**

   This is the layer of connective tissue containing nerves, **blood, lymph,** collagen and elastic fibres. It may contain some mucus secreting glands which deposit their contents onto the surface via ducts e.g the Brunner's glands in the duodenum.

3. **Muscularis externa**

   This layer is composed of an inner circular and an outer longitudinal layer of smooth muscle coordinated. Movements of the two layers provide the wavelike **peristaltic** activity of the gut wall which propels food along.

   At a number of points along the gut, the circular muscles thickens into structures called **sphincters** which when they relax or contract control the movement of food from one part of the alimentary canal to another. They are found in the junction of the oesophagus and stomach(cardiac sphincter), stomach and duodenum (pyloric sphincter), ileum and caecum (ileo- caeco sphincter) and at the anus.

Between the circular and longitudinal muscle layers is **Auerbach's plexus**. This consists of nerves from the autonomous nervous system which controls **peristalsis**.

Between the circular muscles and the submucosa, is another nerve plexus the **Meissner's plexus**. This controls **secretions from glands** in the gut wall.

4. **Serosa;** this is the outermost layer of the gut wall. It is composed of loose fibrous connective tissue. It protects the rest of the gut from friction with other organs in the abdomen. It is surrounded by an epithelium; the **peritoneum**.

DIGESTION IN THE MOUTH

1. **Physical/ mechanical digestion**

This involves the chewing action of the teeth (mastication).

This aids to break down food to small pieces increasing the surface area for enzyme activity. Hence physical digestion does not involve action of enzyme.

2. **Chemical digestion**

While chewing the food, the tongue manipulates it, mixing it with saliva from salivary glands.

Saliva contains the following

- 99% **water**: moistens food and binding it together for swallowing.
- **Salivary amylase** (**ptyalin**) which is a digestive enzyme and catalyses the hydrolysis of **amylose** of cooked **starch** to **maltose.**
- **Chloride ions** activate salivary amylase.
- **Mucin:** a sticky material which binds food materials together and lubricates it to enable swallowing.
- **Lysozymes** kill bacteria in the buccal cavity.

NB: Amount of amylase secreted in saliva depends on amount of starch the animal regularly feeds on in diet.

1. Amylase is usually absent in the saliva of carnivores because of absence of cooked starch in the diet.

2. In separate human groups, the relative amounts of amylase (in arbitrary units) produced in saliva were as follows:

Tswana: 248, Bushmen 22, European: 101. Which human group's diet is largely made of flesh?

SWALLOWING

This is a reflex action, which lasts less than 10 seconds.

Stages of swallowing

1. Tongue contracts to push the bolus towards the throat, forcing the soft palate upwards to close the nasopharynx
2. Larynx and hyoid bone move anteriorly and upwards.
3. Epiglottis bends downwards to close larynx (trachea entrance) to prevent food from entering the trachea.

   NB: Any food that enters into trachea is expelled out by coughing reflex.
4. Breathing briefly stops due to closure of glottis.
5. Pharynx shortens.

6. Upper oesophageal sphincter (Cricopharyngeal sphincter) relaxes, to allow the bolus enter into oesophagus
7. In oesophagus the food bolus moves by peristalsis, a sequence of wave-like contractions that squeeze food down the oesophagus. The centre responsible for controlling peristalsis is located in the medulla of the brain.
8. Lower oesophageal sphincter (cardiac sphincter) relaxes to allow food into stomach.

DIGESTION IN THE STOMACH

The stomach is a J-shaped distensible bag situated below the diaphragm, which acts as a temporary storage organ for food and a digestive organ. Food is allowed in from the esophagus by the cardiac sphincter and allowed out by the pyloric sphincter. Physical digestion is by churning of the food, following rhythmic wavelike contractions which pass along the stomach.

Arrival of food in the stomach stimulates secretion of gastrin hormone from G-cells from the pyloric antrum of the stomach into the blood stream, which stimulates the gastric glands to secrete gastric juice, whose components include: mucus, pepsinogen, hydrochloric acid and intrinsic factor.

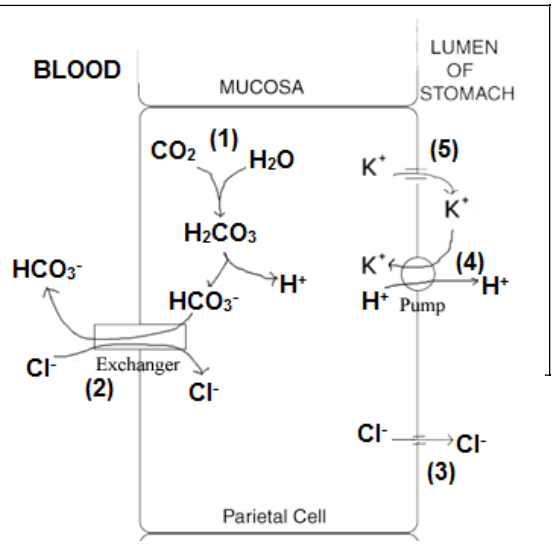
Chemical digestion is by components of gastric juice which is secreted by gastric gland (in the gastric mucosa) found as a folded inner layer in the muscular stomach. The mucosa layer has gastric pits with cells that secrete gastric juice.

Components of Gastric juice

- ***Water*** in which other materials are dissolved.
- ***Pepsinogen*****;** this is secreted by ***chief cells / zymogen cells*** in an inactive form to prevent it from autolysis (hydrolysis of the proteins of the cells secreting it)**.** Once in the stomach, it is activated to pepsin by HCl. Pepsin is an **endopeptidase** which hydrolyses proteins to polypeptides.
- ***Prorenin*****;** this is also secreted by ***zymogen/ chief cells.*** It is the inactive form of rennin, an enzyme which coagulates milk by converting the soluble caseinogen into insoluble casein. It is important in young mammals. Prorenin is activated dry HCl to renin.
- ***Mucin/ mucus*****;** produced by ***goblet cells*** and forms a protective layer on the stomach wall thus preventing pepsin and HCl from break down the stomach walls.
  It also lubricates and helps in the movement of food within the stomach
- ***Hydrochloric acid (HCl);*** secreted by ***oxyntic (parietal cells).***

MECHANISM OF HYDROCHLORIC ACID SECRETION IN PARIETAL CELLS

- Hydrochloric acid is produced by **parietal** cells through a complex series of reactions.
- Catalysed by the enzyme **carbonic anhydrase**, **carbon dioxide** (which diffused from capillaries) reacts with **water** to form **carbonic acid**, which dissociates into **bicarbonate ion** and **hydrogen ion**.
- **Bicarbonate ion** is transported into the blood stream by an **ion exchange molecule** in plasma membrane which exchanges **bicarbonate ions** exiting parietal cells for **chloride ions** entering.
- **Hydrogen ions** are **actively pumped** into the



duct of **gastric gland** and the **negatively charged chloride ions diffuse** with the **positively charged hydrogen ions**. ● **Potassium ions** are **counter pumped** into the parietal cell in exchange for **hydrogen ions**. ● The net result is production of hydrochloric acid in the **parietal cells** and its secretion into the **duct** of **gastric gland**.	

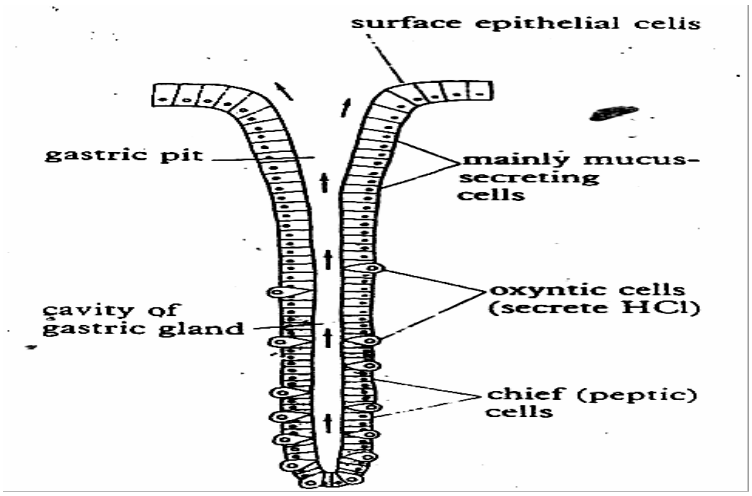
Functions of HCl

- provides a suitable pH for enzyme action.
- Kills bacteria in the food preventing fermentation which result into poisonous products.
- Stops the action of salivary amylase thereby ensuring that only digestion of proteins occurs in the stomach (since acidic medium does not favour activity of ptyalin/salivary amylase).
- Denaturation of proteins breaking down of connective tissues hence exposing more bonds to action of pepsin, easing digestion.
- It also initiates hydrolysis of substances like sucrose and nucleoproteins.

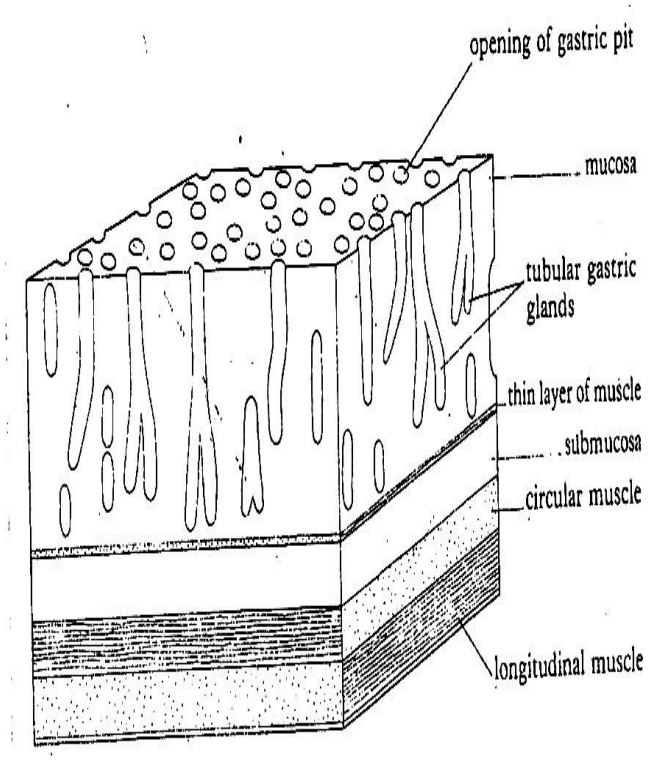
Periodic contractions of the stomach wall mix the churned food with gastric juice forming a creamy fluid known as chyme.

Relaxation of pyrolic sphincter and contraction of the stomach allows the chyme to enter the duodenum.

Structure of the gastric gland.



PART OF THE STOMACH WALL



DIGESTION IN THE SMALL INTESTINES

Small intestines consist of the duodenum where most digestion occurs and the ileum which is mainly for absorption.

DIGESTION IN THE DUODENUM

Arrival of partially digested, acid food mixture in the duodenum stimulates endocrine cells in duodenal walls to secrete the hormones: Secretin, Enterogastrone, Cholecystokinin (CCK) formerly Cholecystokinin-Pancreozymin (CCK-PZ), Villikinin and Enterocrinin. These hormones coordinate activities of the stomach, pancreas, gall bladder and ileum as follows:

Hormone	**Stimulus for secretion**	**Effect**
Secretin hormone	Acid chyme in duodenum	● Stimulates the **liver** to secrete **bile** into the **gall bladder**. ● Stimulates pancreatic secretion of **non-enzymatic** substances (**hydrogen carbonate ions)** from **acinar cells.** HCO_3^- neutralise the acid from the stomach to provide an alkaline pH optimum for pancreatic enzymes. ● Inhibits secretion of **HCl** by **oxyntic cells** as chyme leaves the stomach.
Enterogastrone hormone	Acid and fat in the duodenum	● Reduces stomach motility ● Inhibits oxyntic cells from secreting hydrochloric acid in order to provide an optimum pH for pancreatic enzymes. ● Signals the stomach to empty slowly when fat is present, allowing much time for digestion of fat already emptied. **NOTE**: High fat diets stimulate enterogastrone production, which prolongs food stay in the stomach, and is therefore useful in treating duodenal ulcer.

Cholecystokin in hormone (CCK) formerly called **Cholecystokin in**	Partially digested **fat** and **protein** in the duodenum	●Stimulates contraction of **gall bladder** to release **bile** into **duodenum**. **(i)** Bile salts (sodium glycocholate) emulsify fats i.e. fats physically break into droplets due to reduced surface tension, which increases their surface area ●Stimulates the pancreas to secrete **pancreatic enzymes**: **(i) Pancreatic amylase** which catalyses the hydrolysis of **starch** into **maltose** (ii) **Enterokinase**, a non-digestive enzyme which activates **Trypsinogen** to **Trypsin.** **(iii) Trypsinogen**, which is activated by **enterokinase** to **Trypsin. Trypsin:** **(1)** Catalyses hydrolysis of **polypeptides** to **peptides.** **(2)** Activates **chymotrypsinogen** to **chymotrypsin**. (iii) **Chymotrypsinogen,** which is activated to **chymotrypsin** by **Trypsin. Chymotrypsin** catalyses hydrolysis of **casein** / **polypeptides** into **peptides**.
Villikinin (Motilin)	**Alkaline pH** in the duodenum	●Increases peristalsis in the small intestine and ileum villi movements, in preparation for incoming food.

Digestive juices which operate in the duodenum come from the liver and pancreas.

The liver produces bile which is stored in the gall bladder from which it flows to the duodenum along the bile duct.

Bile is a complex green fluid produced by the liver. It contains no enzymes but possesses the following, important in digestion.

- **Mineral salts**; for example sodium hydrogen carbonate ($NaHCO_3$), which neutralizes the acid chyme from the stomach hence creating a neutral PH for the enzymes of the small intestines.
- **Bile salts;** these contain sodium and potassium glycocholate and taurocholate. They emulsify lipids, breaking them down into smaller droplets to provide a larger surface area for pancreatic lipase to work. They are also important for absorption of breakdown- products- of fatty acids and other fat soluble compounds/ substances eg vitamin K and cholesterol.

The pancreas produces pancreatic juice containing a variety of enzymes. In addition to water, pancreatic juice contains.

Mineral salts; $NaHCO_3$ that neutralize acid chyme from the stomach and provide a suitable PH for the operation of intestinal enzymes.

Enzymes which include

- **proteases**; these include typsinogen activated by enzyme enterokinase from intestinal wall to form an endopeptidase called **typsin** (an active form of trypsinogen). Trypsin hydrolyses protein to polypeptides. Trypsin also activates another pretease in secretion, chymotrypsinogen into chymotrypsin which converts proteins to peptides.

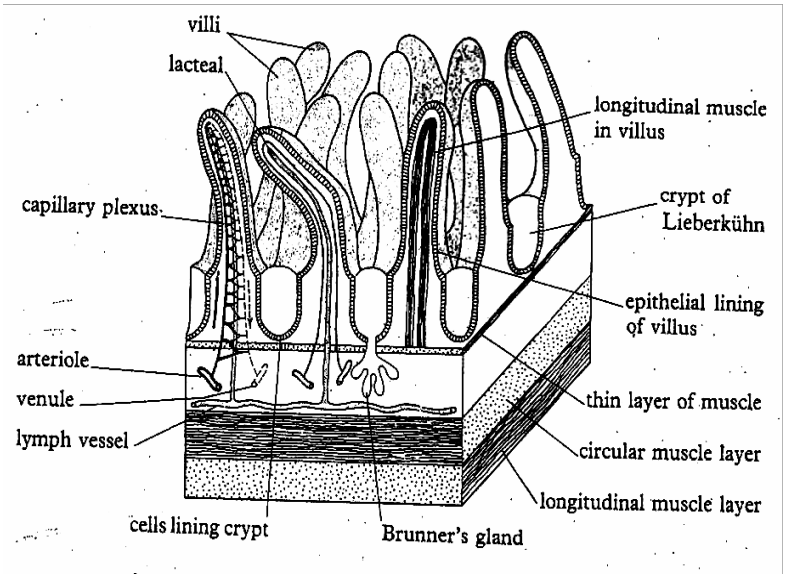
Proteases also include **exopeptidases** and **endopeptidases**. **Aminopeptidase** is an exopeptidase that acts on the terminal peptide bonds of the amino end of a polypeptide chain, where as **carboxypeptidase** hydrolyses the peptide bond at the carboxyl end of a polypeptide chain.

NB. Trypsin is an endopeptidase;

- pancreatic amylase; complete the hydrolysis of starch to maltose.

- Pancreatic lipase which breaks down fat into fatty acids and glycerol.
- Nucleases; break down nucleic acids into nucleotides.

NB. The wall of the duodenum is deeply folded to form crypts of Lieberkuhn beneath which are Brunner's glands which secrete a viscus alkaline fluid and mucus, but no enzymes. It protects the walls of the duodenum from pepsin and HCl in the acidic chime.



Ileum

It is largely concerned with absorption. Its walls are highly folded to form villi, which are further folded into microvilli. The villi contain fibres of smooth muscles and regularly contact and relax to mix food with the intestinal juice, also called succus intericus, containing the following enzymes.

- Maltase; which hydrolyses maltose to glucose, thereby completing digestion of starch.
- Sucrase (invertase); which hydrolyses sucrose to glucose and fructose.
- Lactase; which hydrolyses lactose to glucose and galactose.
- Nucleotidase which split nucleotides into their subunits; pentose sugar, phosphate group and the nitrogen base (look at structure of nucleotide).
- Peptidases ;(both amino – and carboxypeptidases) which break down polypeptides into free amino acids, thereby completing digestion of proteins.
- Intestinal lipase: catalyses hydrolysis of lipids into fatty acids and glycerol.

The juice also contains mucus which lubricates the intestinal walls to prevent autolysis. Mineral salts e.g. $NaHCO_3$ are also present to provide the right PH for enzyme activity.

Questions;

1. Give at least 6 enzymes with the substrates they act upon and the products of their action found in the small intestines (ileum).
2. Describe chemical digestion in the stomach.
3. HCl is important in digestion. Discuss
4. Name six proteolysis enzymes involved in digestion of proteins.

CONTROL OF DIGESTION IN HUMANS

A combination of hormonal and nervous stimulations and inhibitions of the gut that regulate the secretion of digestive juices in the gut.

Importance of control of digestion

(i) Secretion of digestive juices depends on respiratory energy, therefore unnecessary secretion must be prevented to avoid wastage of respiratory substrates.

(ii) Secretion of proteolytic enzymes in inactive form prevents autolysis (self-digestion of tissues).

Mechanisms of controlling digestion in humans

- Involves a combination of hormonal and nervous; stimulations and inhibitions of the gut; that regulate the secretion of digestive juices in the gut;
- The digestive juices secreted include saliva in the buccal cavity; gastric juice in the stomach; pancreatic juice and bile in the duodenum; intestinal juice in the ileum;

Control in the mouth

- Sight / smell / thought of food stimulate conditioned reflexes involving the cerebral cortex, hypothalamus and medulla oblongata; which stimulate salivary glands to secrete saliva.
- Contact of food with tongue taste receptors stimulates nerve impulses via sensory neurons to the hypothalamus and medulla oblongata; relayed along motor neurons to stimulate salivary glands to secrete saliva.

  -Salivary amylase in saliva causes hydrolysis of starch to maltose.
- Loss of appetite / depression inhibit cerebral cortex; parasympathetic centre is not stimulated, no secretion of saliva.

Control in the stomach

Occurs in 3 phases: cephalic; gastric; and intestinal phases;

1. **Cephalic phase / Nervous phase**:

   It occurs before food enters the stomach;

- Sight / smell / thought of food stimulate conditioned and unconditioned reflexes; involving the cerebral cortex, hypothalamus and medulla oblongata; which stimulate the vagus nerve causing the release of acetylcholine; which stimulates the secretion of the hormone gastrin; whose effects are:

  (i) Stimulates secretion of gastric juice.

  (ii) Increases contractions of gastro-intestinal tract

  (iii) Relaxes the pyloric sphincter to let in bolus of food from the gullet;
- Loss of appetite / depression inhibit cerebral cortex; parasympathetic centre is not stimulated, no gastric secretion;

NOTE: Secretion of nervous phase lasts for about one hour during which gastric juice secretion reaches a maximum, after which there is a rapid decrease from 1 hour to 1.5 hours.

Therefore, nervous secretion is: (i) short lasting and (ii) rapid as compared to the hormonal phase.

2. **Gastric phase:**

- Arrival of food bolus distends / stretches the stomach wall which activates stretch receptors to fire impulses to the Meissner's plexus in the stomach wall to cause the following effects:
  - (i) Stimulate local secretory reflexes in the stomach wall to activate gastric glands secrete pepsinogen and HCl;
  - (ii) Stimulate reflexes in the medulla, via the vagus nerve to activate gastric glands wall to secrete pepsinogen and HCl;
  - (iii) Stimulate enteroendocrine cells / G-cells to secrete gastrin hormone; which stimulates secretion of gastric juice;
  - (iv) Stimulate enteroendocrine /enterochromaffin cells to secrete histamine; which activates secretion of gastric juice;
- Partially digested proteins especially peptides / decrease in pH activates chemoreceptors, which stimulate G-cells to secrete gastrin hormone; which stimulates secretion of gastric juice;
- Excessive acidity (PH of less than 2) inhibits G-cells hence gastric juice secretion reduces;
- Emotional upset activates sympathetic nervous system whose effects override the parasympathetic nervous system;

NOTE: The gastric glands are stimulated by hormones to secrete gastric juice for about four hours. Therefore, **hormonal secretion** is: (i) longer lasting and (ii) gradual as compared to the cephalic phase.

3. **Intestinal phase:**

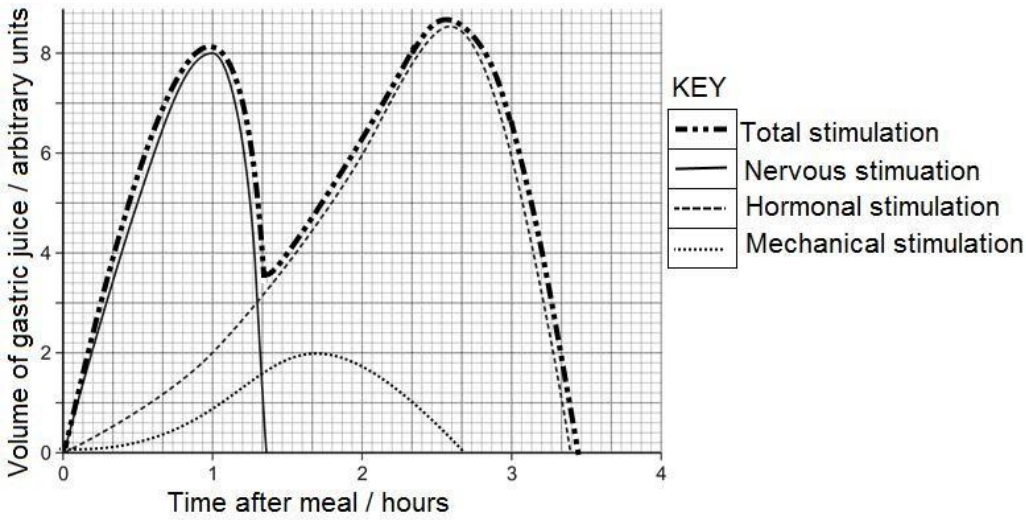
- Distension of duodenum / presence of acid chyme / partially digested food stimulates the secretion of intestinal (enteric) gastrin hormone; which stimulates secretion of gastric juice in the stomach;
- Distension of duodenum / presence of acid chyme / fatty acids / irritants / in the duodenum stimulates the secretion of Intestinal hormones:
  - (i) Secretin; which stimulates the release of bile from the liver and hydrogen bicarbonate ions in pancreatic juice;
  - (ii) Cholecystokinin; which stimulates the pancreas to secrete its enzymes;
  - (iii) Enterogasterone; which inhibits/suppresses gastric activity (any further secretion of acid by the stomach);
  - (iv) Vasoactive intestinal peptide inhibits gastric acid secretion.
- Distension of duodenum / presence of acid chyme / fatty acids / irritants / in the duodenum initiates gastric-inhibitory impulses in the enterogastric reflex causing suppression of gastric activity; and emptying of stomach.

Control in the ileum

Contact of food with intestinal lining stimulates the intestinal glands; to secrete intestinal juice composed of enzymes responsible for completion of digestion of food substrates;

QUESTION

1. Variations in volume of gastric juice produced by nervous, hormonal and mechanical stimulations with time after eating food



NOTE: The maximum volume of gastric juice produced as a result of the different stimulations varies in different mammals.

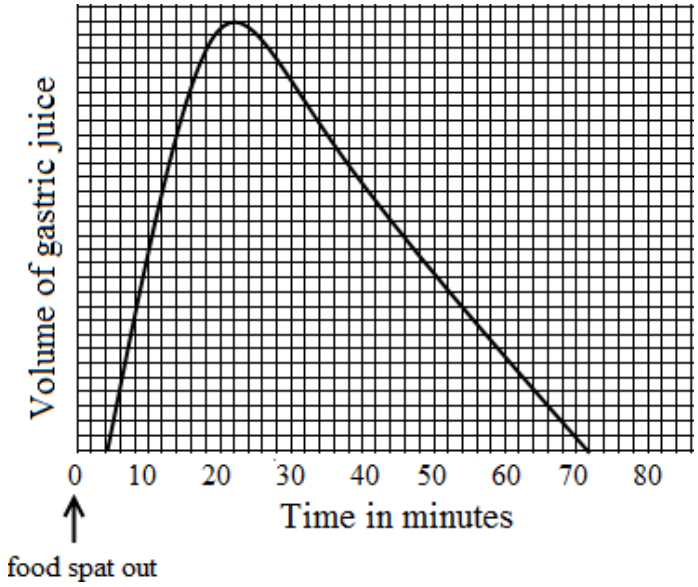
OBSERVATIONS / DESCRIPTION

1. Volume of gastric juice produced during nervous stimulation increases rapidly from 0 hour to a maximum at 1 hour, then decreases rapidly and ceases at 1.5 hours. Nervous secretion is: (i) shorter lasting (ii) instantly rapid as compared to hormonal and mechanical phases.

2. Volume of gastric juice produced during hormonal stimulation increases gradually from 0 hour to 1 hour, then increases rapidly to a maximum at about 2.5 hours, then decreases rapidly and ceases at about 3.3 hours. Therefore, hormonal secretion is: (i) longer lasting and (ii) initially gradual as compared to the cephalic phase.

3. Volume of gastric juice produced during mechanical stimulation (food stretching stomach and duodenal wall) increases gradually from 0 hour to 0.7 hour, then increases rapidly to a maximum at about 1.6 hours, then decreases rapidly and ceases at about 2.6 hours

2. The graph below shows the amount of gastric juice produced by the stomach of an individual who had just chewed some food. The food was spat out after being chewed, and none was swallowed.



(a) Name two constituents of gastric juice

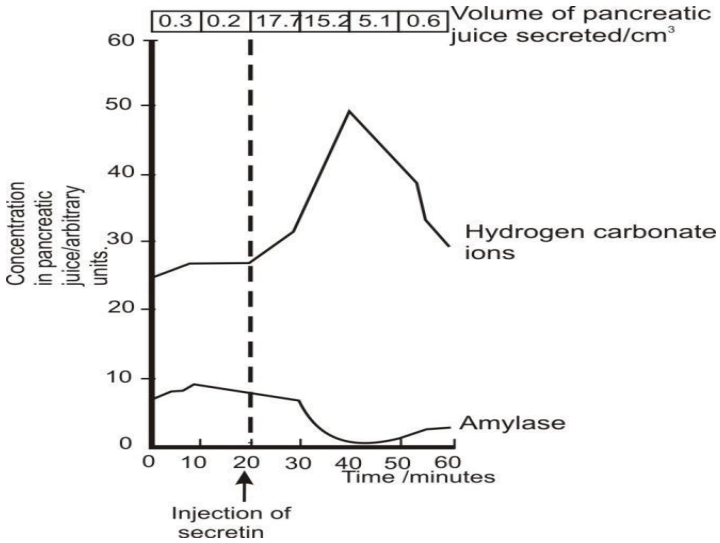
(b) Assuming that no traces of food got down into the stomach, explain how the secretion of gastric juice was brought about.

(c) (i) How much time elapsed between the moment the food was spat out and the moment gastric juice started to be produced?

(ii) Account for the delay in (c) (i) above.

(d) If the stomach of an adult person is surgically removed through an operation, suggest with reasons, the more suitable diet for such a person after recovery from the operation.

3. The graph shows how an injection of secretin affects the secretion of pancreatic juice by the pancreas.



a) i) Use the graph to describe the effect of secretin on the pancreas.

ii) Explain why the concentration of amylase in the pancreatic juice decreased shortly after the injection of secretin.

b) What other digestive secretion is stimulated by secretin.

c) Certain types of ulcer are thought of to be made worse by the production of too much acid from the stomach. Doctors have used a number of different methods ot treat these ulcers. Suggest how the following treatments might reduce the amount of acid secreted by the stomach.

i) Cutting the vagus nerve to the stomach.

ii) Giving the patient atropine, a drug which blocks the action of acetylcholine.

d) Giving examples, explain how organisms are able to utilize cellulose available in their diet.

e) In what ways are saprophytes important to man?

PROBABLE SOLUTIONS

(a) Secretin injection causes a rapid increase in the volume of pancreatic juice from 20 minutes to 30 minutes; followed by gradual decrease to 40 minutes; then a rapid decrease to 60 minutes;

- Secretin injection causes gradual increase in the concentration of bicarbonate ions from 20 minutes to 30 minutes; followed by rapid increase to a peak at 40 minutes; then rapid decrease until 60 minutes;
- Secretin injection causes gradual decrease in concentration of amylase from 20 minutes to 30 minutes; followed by rapid decrease to a minimum at 40 minutes; then gradual increase until 55 minutes and thereafter remains constant until 60 minutes;
- Upon injection into blood, secretin hormone circulates to reach the pancreas and liver, first in low concentration from 20 minutes to 30 minutes; gradually stimulating pancreatic secretion of watery hydrogen carbonate ions from acinar cells and gradually stimulating secretion of somatostatin hormone which gradually inhibits secretion of pancreatic amylase enzyme.
- From 30 minutes to 40 minutes, there is now much secretin concentration in blood circulation; which rapidly stimulates pancreatic acinar cells to rapidly secrete hydrogen carbonate ions and also greatly stimulates secretion of somatostatin hormone which rapidly inhibits secretion of pancreatic amylase enzyme;
- From 40 minutes to 60 minutes, high PH (alkalinity) due to hydrogen carbonate ions inhibits the working of secretin hormone; causing less stimulation of acinar cells hence rapid decrease in secretion of hydrogen carbonate ions. Somatostatin hormone secretion decreases hence decreasing the inhibition of pancreatic exocrine cells causing increased amylase enzyme secretion;

(b) (i) Pancreatic juice is mainly composed of substances (like water), hydrogen carbonate ions, and small amounts of enzymes like amylase.

(ii) Secretion of bile in liver cells, stored in the gall bladder which when released in the duodenum emulsifies fats into droplets, which is physical digestion.

(c) (i) Conditioned reflexes from vagal centre in the brain fail to stimulate secretion of acetylcholine, no secretion of gastrin hormone, no secretion of gastric juice (HCl) during the cephalic phase (before food reaches the stomach) hence the stomach wall will be less irritated.

(ii) Blocking the action of acetylcholine using atrophine inhibits the secretion of gastrin hormone; hence secretion of gastric juice (HCl) is inhibited.

ABSORPTION OF DIGESTED FOOD AND ASSIMILATION

It is the process by which soluble food substances are absorbed across the gut epithelium into blood circulatory system or lymphatic system to be carried to all body cells. A part from alcohol that is absorbed in the stomach, most absorption of digested food occurs in the ileum.

During absorption, substances move as follows:

(i) From intestinal lumen across the free end / apical end / mucosal end of the absorbing cell.

(ii) Across the base / basilar end / serosal end of absorbing cell into the subcellular space, and finally into blood circulatory system or lymphatic system.

The ileum is adapted for absorption by having a large surface area which is achieved in the following ways;-

Question;

The main purpose of the ileum in feeding is absorption of food. Discuss the different ways in which it is adapted for this function.

Adaptations of the ileum to absorption of food

(i) Ileum is long and highly folded for increased surface area in absorption of soluble food substances.

(ii) Ileum has numerous finger-like projections called villi which increase the surface area for absorption of soluble food.

(iii) Ileum epithelial cells have microvilli which further increase the surface area for efficient food absorption.

(iv) Ileum epithelium is thin to reduce diffusion distance for soluble food substances to allow fast rate of diffusion.

(v) Ileum epithelium is permeable to allow movement of soluble food substances across with minimum resistance.

(vi) Ileum villi have dense network of blood capillaries to rapidly carry away digested food from the absorption area which maintains a steep diffusion gradient.

(vii) Ileum villi have permeable lacteal, a branch of the lymphatic system for carrying away fats

(viii) Ileum epithelial cells have numerous mitochondria to generate ATP energy for active transport of some ions.

(ix) Ileum inner surface is lined with a lot of mucus to prevent autolysis (self-digestion) by proteolytic enzymes.

For absorption, the following are necessary;

Absorption of glucose and amino acids is made by active transport and vitamin D.

Absorption of Calcium Ions is enhanced by presence of Vitamin D

Absorption of ions is enhanced by the presence of vitamin C.

Sugars, amino acids and other water soluble materials enter the blood capillaries in the villi from where they enter the vessels- (venules) which later merge to form the hepatic portal vein which carries blood to the liver for homeostatic regulation.

The liver also breaks down any harmful substances absorbed, by a process of detoxification.

QUESTION

1. (a) Explain how the structure of villi in the small intestine is related to absorption of digested food.
   - Large surface area by microvilli / protrusion of exposed parts for fast uptake of soluble substances.
   - Epithelium only one layer thick to reduce diffusion distance.
   - Protein channels allow facilitated diffusion and active transport.
   - Numerous mitochondria provide much ATP for active uptake of some nutrients like glucose and salts.
   - Blood capillaries close to epithelium/ surface to reduce diffusion distance during absorption of glucose/ amino acids
   - Lacteal / lymphatic vessel is permeable/has large surface area at centre to absorb fatty acids and glycerol.
   - Tight junctions between adjacent villi enable controlling absorption of substances

(b) The table below shows experimental results of the rate of absorption of hexose sugars (Glucose, galactose and fructose), and pentose sugars (xylose and arabinose) by pieces of living intestine and by pieces of intestine poisoned with cyanide. The results are shown as relative to the rate for glucose.

	Rate of absorption	
	By living intestine	By poisoned intestine
Glucose	1.00	0.33
Galactose	1.10	0.53
Fructose	0.43	0.37
Xylose	0.31	0.31
Arabinose	0.29	0.29

(i) Explain the observed rates of sugar absorption shown by the two tissues.

- The rate of absorption of glucose and galactose is faster in living intestine; but much slower in poisoned intestine; because absorption of these sugars is active transport requiring ATP whose formation depends on enzymes; which are inhibited by respiratory inhibitor cyanide; To a small extent, the two sugars are absorbed passively;
- Rate of absorption of fructose, xylose and arabinose is the same or relatively the same in living intestine and in poisoned intestine; because absorption of these sugars is facilitated diffusion which does not require ATP; therefore not inhibited by respiratory poison cyanide;

COLON

Most water drunk by humans is absorbed by the stomach. In the colon, there is mainly absorption of:

(i) Water into the blood capillaries by osmosis.

(ii) Vitamins Biotin (B7) and K, which is synthesised by Escherichia coli bacteria that live in the colon.

(iii) Na^+, Cl^- and K^+

NOTE: The colon wall contains mucus secreting cells for lubricating the movement of undigested food through the colon.

APPENDIX AND CAECUM

In ruminants like cattle and in non-ruminants like rabbits, mutualistic bacteria secrete cellulase enzyme which digests cellulose to glucose, which is lost along with faeces.

In the process described as coprophagy (caecopathy), rabbits eat own faecal pellets while dung beetles feed on cow dung to enable absorption of glucose at the ileum.

In humans, appendix and caecum have no obvious role.

RECTUM

In the rectum, food is stored temporarily to enable osmotic absorption of water into blood capillaries. After 24 - 36 hours in the large intestines, the faeces pass to the rectum for temporary store before they are removed through the anus by a process known as defecation. Control of this removal is by two sphincters around the anus, the opening of the rectum to the outside.

The fatty acids and glycerol from lipid digestion enter the epithelial cells lining the villi, where they recombine into lipids. These enter the lacteals rather than the blood capillaries. From here they are transported in the lymph vessels before later joining the venous system of the blood near the heart.

ASSIMLIATION OF FOOD

Assimilation: The process by which simple soluble food substances that have been absorbed are used by body cells in the various ways.

The products of digestion are brought directly through the hepatic portal vein to liver, which controls the amount of nutrients released into the mainstream blood circulatory system.

Assimilation supports growth, development, body renewal, and storing up of reserves used as a source of energy.

Metabolism: Chemical processes within cells of an organism.

It involves:

(i) Catabolism: Break down of complex molecules into simpler molecules, with release of energy**.**

(ii) Anabolism: Assembly / building up of complex molecules from simple molecules using energy.

FOOD	HOW ABSORBED FOOD IS USED IN THE BODY	HOW BODY DEALS WITH EXCESS
Glucose	● ATP synthesis in respiration ● Formation of glycoproteins involved in cell to cell recognition mechanisms. ● For production of mucus ● Excess carbohydrates are stored in the form of glycogen in the liver and muscles.	● Stored in the liver as glycogen. ● Excess carbohydrates may be converted into fats for storage.
Amino acids	● Formation of protoplasm of cells during growth ● Production of enzymes and antibodies ● Formation of body structures such as hairs, nails, hooves, cell membranes ● Oxidised to release ATP energy during severe starvation i.e. in the absence of glucose and fats. ● Formation of hormones e.g. insulin ● Formation of plasma membrane components e.g. glycoproteins, channel proteins	● Deaminated in the liver to form urea, which is expelled by kidneys. ● Some amino acids are **transaminated** to produce a different amino acid
Fatty acids and glycerol	● The long chain fatty acids are desaturated in the liver and are then broken down to carbon dioxide and water by successive oxidations.	● Stored as fat under the skin

	●Some of it can be converted into glucose ●Some used to form various structures which are components of cells e.g. phospholipids	

EXAMINATION QUESTION
(a) What roles do the liver and pancreas play in: (i) food digestion (ii) metabolism of absorbed products
(b) How can the diet of raw liver prevent the disease pernicious anaemia?

	Digestion	**Metabolism of absorbed products**
Pancreas	On stimulation by **cholecystokinin hormone**, the pancreas secretes enzymes whose effects are as follows: (i) Amylase catalyses hydrolysis of starch into maltose (ii) Enterokinase enzyme which activates Trypsinogen to Trypsin. (iii) Trypsin: (1) Catalyses hydrolysis of polypeptides to peptides. (2) Activates chymotrypsinogen to chymotrypsin. (iii) Chymotrypsin catalyses hydrolysis of casein / polypeptides into peptides. (iv) Lipase hydrolyses fats to fatty acids and glycerol (v) Nuclease hydrolyses nucleic acids to nucleotides (vi) Polypeptidase hydrolyses polypeptides to amino acids. On stimulation by secretin hormone, the pancreas secretes hydrogen carbonate ions from acinar cells, which neutralise the acid chyme from the stomach to provide an alkaline pH optimum for pancreatic enzymes.	(i) If in excess (above 90mg/100cm^3), the pancreas is stimulated to secrete insulin hormone which causes conversion of glucose to glycogen for storage, fat or metabolizing it to energy and CO_2. (ii) If little (below 90mg/100cm^3), the pancreas is stimulated to secrete glucagon hormone which causes conversion of glucagon to glucose hence increasing the blood glucose level.
Liver	On stimulation by secretin hormone, the liver secretes **bile** into the **gall bladder**. On stimulation by CCK hormone, **gall bladder** contracts to release bile salts which emulsify fats i.e. fats physically break into droplets due to reduced surface tension, which increases their surface area	**1. The Liver regulates blood glucose:** (i) If in excess (above 90mg/100cm^3), glucose is converted into glycogen for storage. (ii) If little (below 90mg/100cm^3), glycogen is converted into glucose for use. **2. The liver regulates amino acids in the body:** Excess amino acids are not stored in the body, but undergo deamination process. i.e. the amino group ($-NH_2$) from the amino acid is removed to form ammonia, which later forms urea that is carried in blood to kidneys for excretion. **3. The liver regulates lipids (fats) in the body:** It synthesizes and degrades phospholipids and cholesterol. **4.** The liver forms red blood cells in foetus and breaks down worn out red blood cells in adults. **5.** The liver forms plasma proteins from amino acids **6.** The liver stores fat soluble vitamins A, D, E, K and water soluble vitamins B_{12} and C **7.** The liver stores minerals like Iron, potassium, copper, zinc and trace elements. **8.** The liver detoxifies poisonous substances i.e. toxic substances are turned harmless by the liver cells e.g. alcohol, cholesterol and hydrogen peroxide.

(b) Raw liver is rich in vitamin B_{12} which is essential for formation of red blood cells (erythrocytes), whose absence causes pernicious anaemia characterised by paleness, slowness and death.

BALANCED DIET

- Balanced diet is one which contains the correct proportions and quantity of protein, carbohydrate, lipids, vitamins, mineral salts, water and dietary fibre/roughage required to maintain health.
- Mainly, carbohydrates and lipids are for energy production, proteins are for growth and repair, vitamins and mineral salts are for protection of good health, water is a solvent while roughage stimulates peristalsis to prevent constipation.
- An unbalanced diet can lead to deficiency diseases.

EFFECTS OF UNDERFEEDING AND OVERFEEDING

- If energy output exceeds energy input, carbohydrate reserves (glycogen) and fat reserves (adipose tissue) are respired and the person's body mass decreases. When carbohydrate and fat reserves exhaust, tissue protein is respired and the body wastes away.
- If energy intake exceeds energy usage over a period of time, carbohydrate is turned into fat and the person's body mass increases leading to obesity (overweight).

  Disadvantages of obesity:

  (1) the extra mass causes a person to get tired quickly (2) increases chances of stroke/heart attack.

  How an obese person can lose weight:

  (1) Eating less energy food (2) Taking more exercises to increase energy output

BODY MASS INDEX (BMI)

This is one of the ways of determining whether a person is underweight or overweight. BMI can be calculated using the formula:

BMI = **Mass in kg /(Height in m)^2**

Qn. Calculate the BMI of a female of mass 69 kg and height of 1.67m

Another way of determining whether a person is underweight or overweight is to use a graph showing the relationship between height and body mass.

CHANGES IN BODY ENERGY RESERVES DURING STARVATION

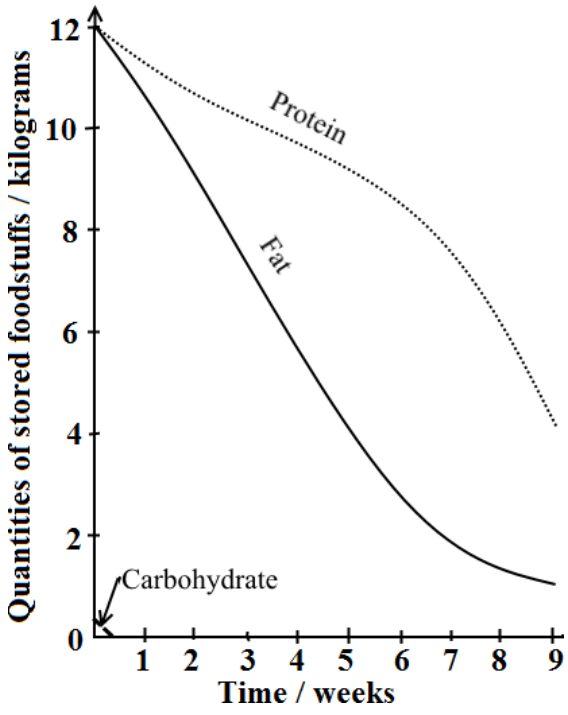
- **Starvation** results from the inadequate intake of nutrients or the inability to metabolize or absorb nutrients.

CAUSES OF STARVATION
Prolonged fasting, anorexia, deprivation, or disease
SYMPTOMS OF STARVATION
Weight loss, dehydration, apathy, listlessness, withdrawal, increased susceptibility to infectious disease, discoloured hair color, flaky skin, and massive edema in abdomen and lower limbs causing the abdomen to appear bloated.

ADVERSE EFFECTS OF STARVATION
(i) Marasmus: occurs on account of extreme energy deficiency, typically from inadequate amounts of protein and calories.
(ii) Kwashiorkor: is related to marasmus, affects children who are protein-energy deficient, and can result in edema (fluidic inflammation) and an enlarged fatty liver — resulting in the counterintuitive distending of bellies, giving the illusory impression that starving children are well fed.

INTERVENTIONS AGAINST STARVATION
- Rehydration and feeding the starving person low-bulk food with much proteins, much energy and fortified with vitamins and minerals. Avoid foods high in bulk but low in protein content

DESCRIPTION OF CHANGES IN ENERGY RESERVES
- Glycogen, proteins, and fats are all metabolized during starvation.
- Exhaustion of blood glucose stimulates **glucagon** secretion and **insulin** secretion is inhibited.
- Within the first 24 hours, the very low glycogen amount stored in the liver and muscles decreases rapidly to depletion **because** glycogen is broken down into glucose for oxidation to release energy, while the amounts of fats and protein remain high. Anaerobic breakdown of glycogen in skeletal muscle is also stimulated.



Within week 1, a few hours after depletion of carbohydrate/glycogen, the amount of fats decreases rapidly while the amount of protein decreases gradually until about 6 weeks of starvation.

- This is because fats are hydrolysed rapidly into fatty acids and glycerol while oxidation of amino acids releases energy.
- The liver metabolizes fatty acids into **ketone bodies** that are degraded to release energy. Accumulation of ketones causes **ketosis,** by condition characterised by blood becoming **acidic**
- Fatty acids in skeletal muscles are broken down to release energy, thus decreasing the use of glucose by tissues other than the brain.
- Glycerol is converted into small amount of glucose, but most of the glucose is formed from the amino acids of proteins.
- The brain begins to use ketone bodies, as wells as glucose, for energy.
- Dependency on fats for energy release decreases the demand for glucose, protein breakdown reduces but does not stop.
- The liver degrades **non-essential proteins** into glucose for the brain in a process called **gluconeogenesis,** which involves converting carbon skeletons into pyruvate or Krebs' cycle intermediates and excreting amino groups from the body as urea.

From 6 weeks to 8 weeks, amount of fat decreases slowly to very low levels, while amount of protein decreases rapidly.

- This is because as fat reserves / stores are getting depleted, metabolism of fats to release energy occurs gradually and the body begins to rapidly break down **essential proteins**, leading to loss of liver and heart function as these organs are broken down for fuel metabolizing proteins as the major energy source.
- Muscles, the largest source of protein in the body, are rapidly depleted.

EXAMINATION QUESTIONS

A group of rats were encouraged to over eat by feeding them with unlimited supplies of processed foods such as chocolate and cakes over a three week period. These rats were called **cafetarian rats**. Over the same period, another group of control rats fed on unlimited supplies

	AVERAGE OVER 21 DAYS	
	Cafetarian rats	**Control rats**
Energy content of food eaten (kj)	11670	6480
Gain in the body mass (g)	131	103
Gain in body fat (g)	66	40
Energy used (kj)	9440	4690

(i) What was the effect of feeding the rats on food other than their natural food? (1½ marks)
They gained more body mass, fat and energy

(ii) Determine the average gain in mass of the cafetarian rats over the control rats during the 21 days
Average gain in mass = gain in body mass of cafeterian – gain in body mass of control rats = 131 – 103 = 28g

(iii) State three features of the two groups of rats which should be kept the same: Age, sex, species **(1½ marks)**

(iv) Which chemical of life in the rats would have been responsible for most of the gain in mass? Body fat **(½ marks)**

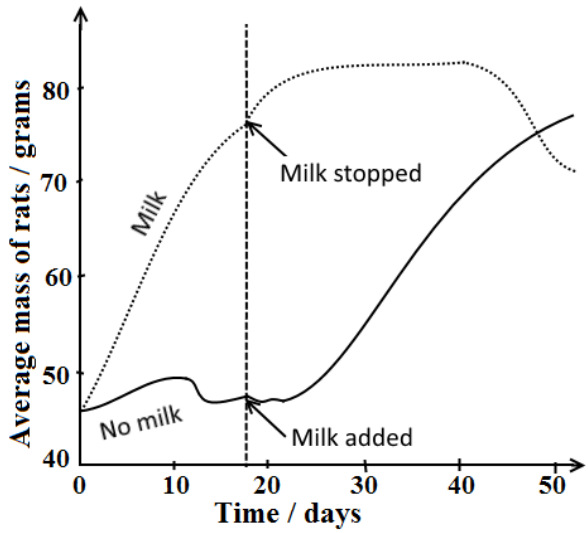
(c) **Explain the observation that some people eat enormous amounts of foods without putting on weight where as others become over-weight on quite small food intake:** Weight gain does not only depend on food intake, but on other factors like genetic makeup.

(d) Using evidence from the data, explain why cafetarian rats were able to gain more weight than control rats. (2 marks)
The difference between the energy content of food and energy used is higher in cafetarian rats; so unused food had to be converted to fat

(e) **Why were control rats necessary in this experiment?** For comparison of results **(1 mark)**

FEEDING EXPERIMENTS ILLUSTRATING THE IMPORTANCE OF VITAMINS IN NORMAL

In his investigations exploring the relationship between diet and growth in rats, **Frederick Gowland Hopkins** found that a diet consisting of protein, salts, fats, and carbohydrates **could not alone** support growth.



EXPERIMENT

Two groups of young rats were used.
Group A were fed on a diet of purified casein, starch, glucose, lard, minerals and water only for the first 18 days.
Group B were fed on a diet of purified casein, starch, glucose, lard, minerals and water **plus** an extra of $3cm^3$ of milk daily for the first 18 days.
After 18 days milk was given to group A rats and removed from group B's diet.

OBSERVATIONS

Group A rats increased in mass gradually from 0 day to 10 days, mass decreased gradually until about 12 days, mass remained relatively constant up to 22 days, then mass increased rapidly from about 22 days to 50 days

weight thereafter.

CONCLUSION: Hopkins's experiments revealed that, to grow, animals needed small amounts of other substances he called **"accessory food factors"**- now known as **vitamins**.

EXPLANATION
Group A rats resumed growth and increased in weight after 18 days while **group B** rats stopped growing and lost weight after 18 days. While the $3cm^3$ of milk had an insignificant food value in terms of carbohydrate, fat, protein and minerals, the milk contains an extra nutrient which the rats needed to be able to grow and develop.

Why it was necessary to transfer milk from group B to group A half way through the experiment?
To ensure that all groups of rats are subjected to identical conditions e.g. feeding them on identical food so as to establish the effect of milk on growth while eliminating the possibility of other factors being responsible the observed differences in results e.g. choice of rats in one group (group A) may have been more sickly than those in group B etc.

Why feeding rats on one type of protein (casein), not a variety is ruled out as a possible cause of growth stoppage and weight loss?
Although proteins are essential for growth and there are different types, proteins are hydrolysed in the body into different amino acids, and the body is able to make some amino acids for itself. Therefore even though the rats were only getting casein this was enough to not have an effect on growth.

Why while a diet of protein alone is sufficient for young animals, it is inadequate for adults?
Much as milk contains all the nutritional requirements like protein, carbohydrates (lactose), lipids, mineral salts, vitamins and water, some amounts may be nutritionally insufficient to meet the metabolic demands of adults.
Some people who are lactose intolerant can't digest the main sugar (lactose) in milk. In normal humans, production of lactase enzyme that digests lactose stops between ages of two and five years, which would result in insufficient ATP production.

NUTRITION IN CARNIVORES AND HERBIVORES
(a) Carnivorous animals: are either **predators** or **scavengers** whose diet consists of mainly flesh obtained from **preys**.
(i) Predator: An animal that hunts and kills animals for food.
(ii) Prey: An animal that is hunted and killed for food.
(iii) Scavenger: An animal that eats dead animals, but doesn't kill them.
(b) Herbivore: An animal whose diet is mainly vegetation
(i) Grazers: Mainly feed on grass
(ii) Browsers: Mainly feed on leaves of shrubs and trees

	Carnivore	**Herbivore**
Adaptations for finding and capturing prey (**carnivores**) or grazing / browsing (**herbivores**)	● Well-developed sense of smell for locating prey ● Fast moving to outpace and capture prey ● Well-built body to manipulate and capture prey. ● Very sharp claws for gripping and killing prey. ● Keen eye sight for locating prey from a distance ● Foot pads enable stealth movement to ambush prey. ● Long, sticky tongue for reaching distant prey e.g. toads. ● Elongated canines for digging up prey e.g. walrus	● Upper jaw lacks incisors to provide a hard pad against which lower incisors press and cut grass. ● Tongue is highly muscular for manipulating food during chewing.
Adaptations for ingesting the food	● Sharp pointed canines for tearing the fresh of prey ● Flat molars to crush prey ● Incisors pointed for nipping and biting. ● Carnassial teeth present for shearing	● Molars and premolars are ridged for maximum grinding of hard cellulose materials. ● Molars and premolars have large surface area for maximum grinding of the

	flesh. ● Upper jaw wider than lower jaw to facilitate shearing. ● Up-and-down jaw action only prevents lateral movement hence reducing the danger of dislocation ● Powerful jaw muscles provide much force for chewing	hard cellulose materials. ● Articulation of lower jaw permits lateral movement to enable maximum grinding of food. ● Well-developed jaw muscles provide much grinding power for crushing cellulose materials. ● Between the front and cheek teeth, there's a gap called diastema for separating crushed grass from uncrushed grass for effective chewing.
Adaptations for digesting the food	● No cellulose in diet hence less developed caecum and appendix to reduce on body weight to enable fast running. ● Relatively short alimentary canal reduces weight, since diet is entirely protein.	● Ruminant stomachs are four chambered to derive maximum nourishment from grass. ● Mutualistic bacteria in caecum and appendix enable chemical digestion of cellulose into glucose. ● Relatively long alimentary canal to digest vegetation

DIFFERENCES BETWEEN CARNIVORES AND HERBIVORES RELATED TO NUTRITION

Carnivores	Herbivores
● Closed pulp cavity in teeth ● Upper jaw incisors present ● Canines present and well developed ● Carnassial teeth present ● Cheek teeth pointed ● Articulation of lower jaw prevents lateral movement ● Relatively short alimentary canal ● No cellulose digestion	● Open pulp cavity in teeth ● Upper jaw incisors absent in most herbivores ● Canines small or absent to create a diastema ● Carnassial teeth absent ● Cheek teeth flattened with enamel ridges and dentine grooves ● Articulation of lower jaw permits lateral movement ● Relatively long alimentary canal ● Cellulose digestion occurs in caecum

EXAMPLES OF SYMBIOTIC ASSOCIATIONS IN ANIMALS

● **Symbiosis:** Ecological relationship between two or more organisms living together with some form of feeding relationship.

● **Mutualism:** Close relationship where two organisms of different species depend on each other for reciprocal benefit, without any harm e.g. pollination flowers by insects, **(protozoa)** and **termites,** cellulase producing bacteria and herbivores, etc. other e.g

-Termites with protozoa ***(Trichonympha)***; termites feed on wood which contains cellulose which when in the gut, the protozoa release enzyme e.g cellulose that digest the cellulose to produce soluble products e.g glucose. The termite utilizes the glucose but the protozoa also use some of the glucose and obtain shelter from the host.

-Lichens; this is an association between an alga and a fungus. The fungus produces a mycelium high provides a later for the alga to absorb water which its uses during photosynthesis. The mycelium also produces nitrogenous wastes which are used by alga to synthesize food. The aigae produces food which it shares with the fungus.

-Hydra- chlorella symbiosis; chlorella are unicellular green algae found in the endoderm of the cnidarian hydra. They are able to photosynthesize and supply hydra with maltose (food nutrients). Chlorella obtains shelter. Where one organism lives symbiotically inside the cells of another, the relationship is referred to as **endo symbiosis.**

-Mycorrhiza: this is a symbiotic association between fungi and the roots of plants. In this association, the fungus gains from the use of the sugar being translocated to the roots of the plant. The plant gains in many ways:-Protection from bacteria and other parasites attacking it by antibiotics produced by the fungus, increased mineral absorption from the soil by utilizing some of the minerals absorbed by the fungus.

Other mutualistic associations include Nitrogen fixing bacteria in plant root nodules, ruminants and bacteria, Sea anemone and shells of hermite crab etc.

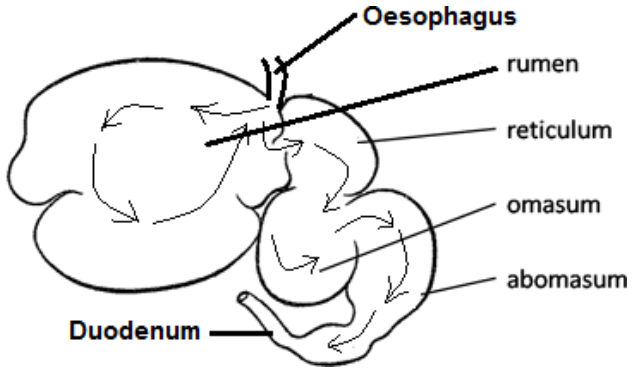
● **Commensalism:** Loose relationship in which two organisms of different species live together, only one organism benefits while the other remains unharmed e.g. sea anemone and clown fish, Hydractinia

echinata, is a small marine animal living in colonies on shells occupied by hermit crabs. The hydractinia is transported to new sources of food, but the hermit crab does not gain not is it harmed in any way. Commensalisms literally mean eating at the same table.

- **Parasitism:** Close relationship between organisms of different species in which one organism called **parasite** obtains nutrients from and harms a larger living organism called host.

DIGESTION IN RUMINANT MAMMALS

Ruminants: are the mammals, which have a 4-chambered stomach for the digestion of plant based food.
Rumination involves regurgitation of fermented grass known as cud, chewing and re-chewing it again to further break down plant matter and stimulate digestion.
Ruminating mammals include cattle, goats, sheep, giraffes, deer, camels, antelope, etc.
Four-chambered stomach showing food movement during feeding



1. Rumen (Paunch): Bacteria and protozoa in the rumen secrete **cellulase enzyme** which breaks down cellulose into glucose which undergoes fermentation to form **organic acids**, **carbon dioxide** and **ethane**. The fermentation process produces heat that keeps ruminants warm.

2. Reticulum (Honeycomb bag): Here any foreign objects that may have been accidentally swallowed with food settle out in the **honeycomb** structure of the reticulum's walls. Reticulum is sometimes called **"hardware stomach".**

3. Omasum (Psalterium / Manyplies): Absorbs water from food and also absorbs more nutrients called volatile fatty acids that supply ruminants with energy.

4. Abomasum (Reed / True stomach): Here, the food particles are digested by hydrochloric acid in the same way it occurs in human stomachs. The remaining particles are then passed on to the small intestine where most of the nutrients are absorbed by the body and made available to the ruminant.

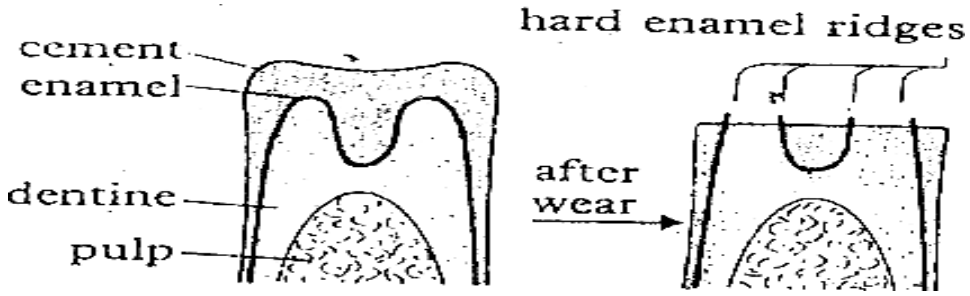
CELLULOSE DIGESTION IN TERMITES

Guts of wood-eating termites contain a micro-organism called **Trichonympha,** which secretes **cellulase enzyme** to digest cellulose in wood. The termite absorbs some of the products of digestion (**glucose**), while **Trichonympha** gets sheltered.

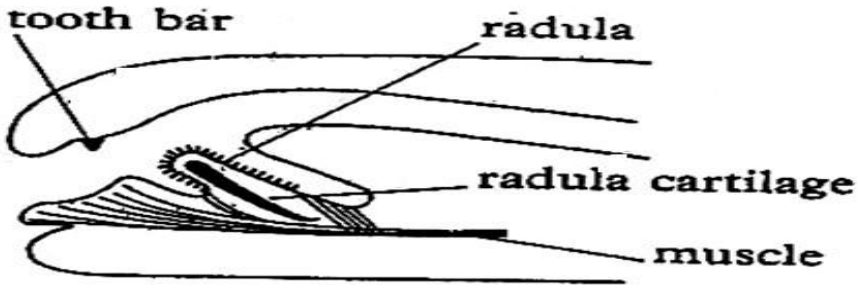
CELLULOSE DIGESTION IN RABBITS (NON RUMINANTS)

The caecum and appendix of a rabbit contain bacteria that secrete **cellulase enzyme** for digesting **cellulose** into **glucose**. The herbivore gains **glucose** while the bacteria get **shelter**.
In the process described as **coprophagy (caecopathy)**, rabbits eat own faecal pellets while dung beetles feed on cow dung to enable absorption of glucose at the ileum.
Herbivores mammals e.g. horse or elephant use their molar teeth. As the teeth are worn down in the course of life, the different materials of the crown are exposed. These wear away at different rates resulting in a flat serrated surface ideally suited to grinding up tough plant material.

Vertical section through molar tooth of herbivorous mammals e.g horse.



Herbivorous molluscs such as the snails possess a rasping organ, the radula, located in a sac opening into the lower side of the buccal cavity. The radula is like a conveyor belt which, by rubbing backwards and forwards against the hardened roof of the mouth, can tear plant food.



Vertical section through head of snail to show radula.

Herbivorous insects like the locusts have a pair of mandibles with a jagged edge for cutting through leaves and blades of grass. There, together with a set of manipulating devices, make up the mouth parts.

PARASITISM

Close relationship between organisms of different species in which one organism called **parasite** obtains nutrients from and harms a larger living organism called host.

Challenges / Dangers faced by ectoparasites	Challenges / Dangers faced by endoparasites
●Failure to cling on the host to avoid being dislodged. ●Failure to obtain nutritive molecules from the host. ●Failure to find the right host for dispersal to their final host	●Failure to penetrate the host ●Failure to obtain nutritive molecules from the host. ●Destruction by the digestive enzymes and immune responses of the hosts. ●Complete elimination or extinction. ●Fluctuating environment e.g. low oxygen tensions, excess heat, solute concentration, darkness etc. ●Failure to find the right host for dispersal to their final host

GENERAL ADAPTATIONS OF PARASITES

Structural adaptations	Physiological adaptations	Reproductive adaptations
●Possession of penetrative devices for host entry e.g. fungal haustoria, cutting teeth in hook worms *Ancylostoma duodenale*) ●Possession of nutrient suckers e.g. leech ●Development of digestive-resistant outer covering to avoid host's enzyme attack e.g. *Ascaris* and *Taenia* etc. ●Camouflaging morphology to increase survival chances e.g. brown ticks on brown cattle. ●Possession of specialised mouth parts in some ecto-parasites to suck hosts e.g. sharp stylets in aphids and tsetse flies.	●Production of enzymes to digest the host's tissues during penetration into the host e.g. fungi and plasmodium ●Production of anticoagulants by blood feeding parasitic animals such as mosquitoes and ticks to avoid blood clotting during feeding. ●Highly tolerant to fluctuating environment e.g. anaerobic respiration in areas of low oxygen tensions, high temperatures, darkness and pH changes in places where they live e.g. most endoparasites. ●Rapid means of escape which	●Some are hermaphrodites with the ability to carry out self fertilisation to increase the rate of reproduction e.g. *Fasciola*, *Taenia*. ●Some asexually reproduce for high rate of reproduction to avoid extinction. ●Release of sexually mature forms of the parasites as free living organisms e.g. in some parasitic animals such as the horse hair worms ●Production of large number of infective agents such as eggs, cysts, and spores which increase survival chances to avoid

●Possession of specialised haustorial structures in Cuscuta (Dodder plants) for obtaining nutrients from the host ●Degeneration of non-essential organs e.g. no feeding organs, no locomotory organs, no alimentary canal to reduce body size and fit in intestines /blood vessels and for reducing energy expenditure on such organs for example *Fasciola hepatica* (liver fluke), tape worm, hook worm etc.	increases their chances of survival e.g. fleas and mosquitoes. ●Production of much mucus for resisting digestion by host's enzymes. ●Some endoparasites produce chemicals to protect themselves against the immune response of the host.	extinction e.g. tape worms. ●Development of reproductive bodies that are highly resistant when out of the host to survive adverse conditions e.g. cysts in amoeba, fungal spores, etc. ●Use of intermediate host (vector) for their transfer to primary host e.g. plasmodium in female anopheles mosquito to man. ●Some parasites localise the strategic points for propagation to the next host e.g. HIV which causes AIDS is localised in the sex organs. ●Some use hereditary transmission for increased spreading i.e. some parasites infect the ovary of primary host which lays parasite infected eggs.

COMMON PARASITES

Definitive host (final host / primary host): a host in which a parasite attains sexual maturity.

Intermediate host (secondary host): a host in which a parasite passes one or more of its asexual stages; usually designated first and second, if there is more than one.

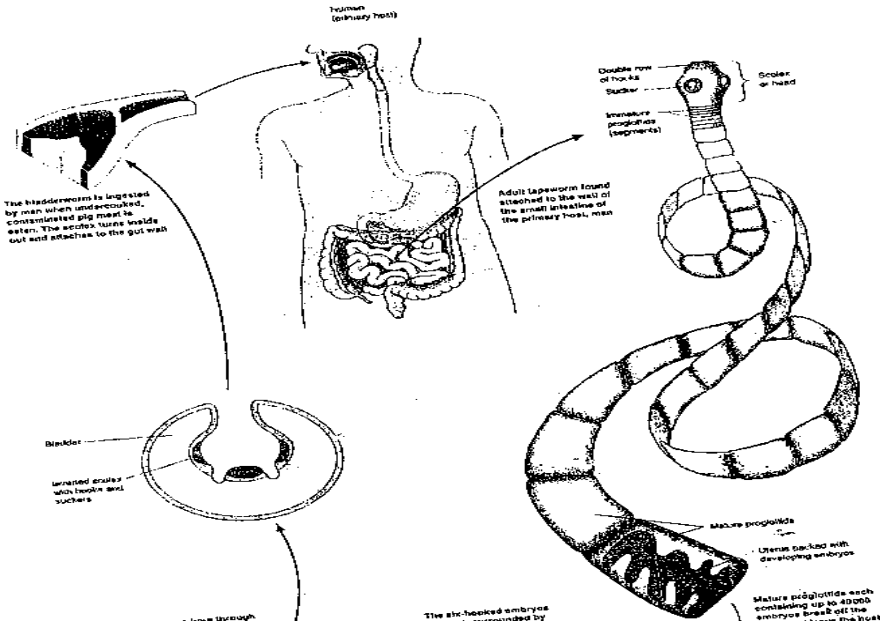
Phylum/division	Parasite	**Host**		**Effect on primary host**
		Primary	**Secondary**	
Platyhelminthes	*Fasciola hepatica* (liver Fluke)	Sheep, cattle	Pond snails	Liver rot
	Schistosoma mansoni (blood fluke)	Humans	Pigs	*Schistosomiasis* (Bilharzia)
	Taenia solium (Pork tape worm)	Humans	Pigs	**Taeniasis;** Anaemia, Weight loss Abdominal (intestinal) pain
	Taenia saginata (Cattle tapeworm)	Humans	Cattle	
Nematoda	*Ascaris lumbricoides (*roundworm*)*	Humans	None	*Ascariasis*, Intestinal obstruction
Spermatophyta (Seed plants)	Dodder plant (Cuscuta)	**Nettle**, clover, tomato, potato	None	Damages tissues causing secondary infections
Spermatophyta (Seed plants)	*Striga* sp. (witch weeds)	Maize, millet, groundnut, etc.	None	Stunted growth, wilting, and chlorosis
Heterokontophyta	*Phytophthora infestans*	Tomato leaves	None	Late blight of potato and tomato (Black leaf spots, tuber rot)
Arthropoda	*Plasmodiun*	Female Anopheles	Humans	Malaria fever

LIFECYCLES OF SELECTED PARASITES

Lifecycle of *Ascaris lumbricoides (*roundworm*)*	**Adaptations of *Ascaris* to parasitic life**
●Adult female in lumen of ileum lays about 200,000 eggs daily, which are passed out in faeces. ●Fertile eggs **embryonate** and become infective after about **three** weeks, (***optimum conditions:*** moist, warm, shaded soil). ●On being swallowed by humans, eggs hatch into larvae, which invade intestinal wall, and are carried via the portal , then systemic circulation to lungs. ●Larvae mature further in lungs (10 to 14 days), penetrate alveolar walls, ascend the bronchi to the throat, and are swallowed into gut. ●Upon reaching the ileum, they develop into adult worms. ●Between 2 and 3 months are required from ingestion of	●Degeneration of structures reduces space occupied. ●Possession of digestive-resistant cuticle resists destruction by the host's enzymes. ●Ability to position itself in a habitat where it gains maximum nourishment. ●Eggs have protective/resistant shell which is their main ineffective and resistant stage. ●Tolerance to oxygen deficient environment ●Ability to copulate within the intestines followed by the laying of very many eggs increases survival chances.

the infective eggs to **oviposition** by the adult female. ● Adult worms can live 1 to 2 years.	

Lifecycle of *Taenia sp.* (Tapeworm)	**Adaptations of *Taenia* to parasitism**
● Humans are the definitive hosts for *T. saginata* and *T. solium*. ● Eggs or **gravid proglottids** are passed out in faeces; ● Cattle (*T. saginata*) and pigs (*T. solium*) become infected by ingesting vegetation contaminated with eggs or gravid proglottids. ● In the animal's intestine, the **oncospheres** hatch, invade the intestinal wall, and migrate to striated muscles, where they develop into **cysticerci**. A cysticercus can survive for several years in the animal. ● Humans become infected by ingesting raw or undercooked infected meat. ● In the human intestine, the cysticercus develops over 2 months into an adult tapeworm, which can survive for years. ● Adult tapeworms attach and stay in small intestine by their scolex. ● The adults produce proglottids which mature, become gravid, detach from the tapeworm, and migrate to the anus or are passed in the stool (approx 6 per day). ● The eggs contained in the gravid proglottids are released after the proglottids are passed with the feces.	● Has hooks and suckers for holding tightly onto ileum wall. ● Flattened body increases surface area for absorbing its host's digested food ● Degeneration of structures reduces on space occupied. ● Lays many eggs to increase survival chances. ● Hooks for boring through the gut of the host ● Eggs have a thick shell for resisting enzyme destruction. ● Being hermaphrodite increases reproductive rate



Hygienic practices for controlling endoparasites

● Avoid eating infected under cooked meat
● Through proper disposal of sewage which prevents these worms from spreading
● Through cooking meat thoroughly for example prolonged heating destroys the tapeworm bladders
● Regular deworming to flush the worm out of the wall of the intestines in faeces.
● Through regular meat inspection before it is consumed by man.
● By prohibition of the discharge of raw sewage into inland waters and seas.

***PLASMODIUM* – THE MALARIA CAUSING PARASITE**

There are approximately 156 named species of *Plasmodium* which infect various species of vertebrates. Four species are considered true parasites of humans, as they utilize humans almost exclusively as a natural intermediate host: *P. falciparum, P. vivax, P. ovale* and *P. malariae*.

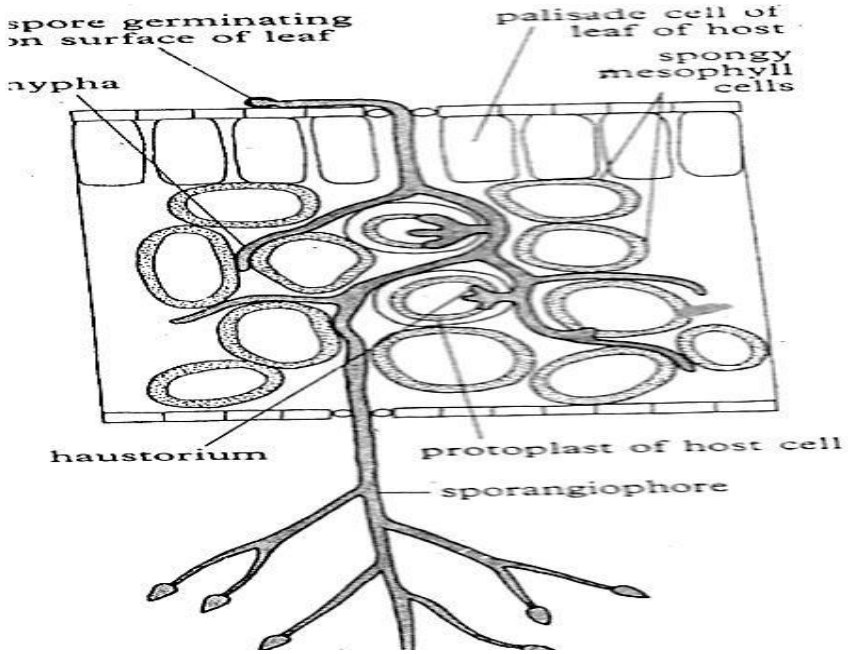
LIFE CYCLE OF *PLASMODIUM*

- Malaria parasite life cycle involves **humans** as **intermediate** host and adult female **anopheles** mosquito as **definitive** host.
- During a blood meal, a malaria-infected female ***Anopheles*** mosquito releases **sporozoites** into human blood.
- On reaching the liver, **sporozoites** infect liver cells and mature into **schizonts**, which rupture and release **merozoites**.
- After this initial replication in the liver (**exo-erythrocytic schizogony**), the parasites undergo asexual multiplication in the erythrocytes (**erythrocytic schizogony**).
- **Merozoites** infect red blood cells, the ring stage **trophozoites** mature into **schizonts**, which rupture releasing **merozoites**.
- Some parasites differentiate into sexual **erythrocytic** stages (**gametocytes**).
- Blood stage parasites are responsible for the clinical manifestations of the disease.
- The gametocytes, male (**microgametocytes**) and female (**macrogametocytes**), are ingested by an *Anopheles* mosquito during a blood meal.
- The parasites' multiplication in the mosquito is known as the **sporogonic cycle**.
- While in the mosquito's stomach, the **microgametes** penetrate the **macrogametes-generating zygotes**.
- **Zygotes** become motile and elongated (ookinetes), invade the midgut wall of the mosquito to develop into **oocysts**.
- **Oocysts** grow, rupture, and release **sporozoites**, which enter the mosquito's salivary glands.
- Inoculation of the **sporozoites** into a new human host perpetuates the malaria life cycle.

LIFECYCLE OF *Phytophthora Infestans*.

This parasite causes potato blight leading to yellowing of leaves. A spore landing on the surface of a moist leaf and sends out Slender filaments (hyphae) which enter the leaf either through the stomata or penetrating the epidermis.

The fungus consists of an intercellular network of mycelium and slender filaments (hyphae) which grow into the cells. The hyphae penetrate the cellulose cell walls by secreting cellulase enzyme at their tips. Once inside the cell, they produce or develop finger like structures called **haustoria** which secrete digestive enzymes. The soluble products are absorbed and sent back to the rest of the fungus.



Effects of Phytophthora infestans.

-This kind of parasite causes destructive effects since it affects the leaves that are supposed to synthesize food for the plant.

-Leads to death of the plant.

-Dissolves the plant cell walls destroying plant tissues
-Haustoria secrete digestive enzymes which digest away the host food
-Cause wounds on plant wounds as they penetrate through the epidermis.

Adaptations of phytophthora to its mode of life

-Secretes digestive enzymes which enable it digest food of the host.
-Produces numerous spores which have a persistent stage e.g. zygospore which enables it to survive adverse conditions.
-It has the ability to reproduce both sexually and a sexually.
-It secretes cellulase which helps it to penetrate the host cells.
-The lining of the haustoria is thin ensuring absorption of cellular products of extracellular digestion.

EXAMINATION QUESTION

1. The blood fluke, *Schistosoma mansoni* is an important helminth parasite that resides within the mesenteric veins of its definite host. Experiments were done and the graphs in figures 1, 2 and 3 below show the effect of temperature, light and salinity on the hatching of the eggs of *Schistosoma mansoni.* At hourly intervals, the number of eggs hatching was determined and expressed as a percentage of total hatch.

Figure 1 shows the effect of temperature on hatching. After 4 hours of treatment at the temperatures shown, the samples were incubated for a further two hours at 28^0C at constant light and salinity.

Figure 2 shows the effect of light on hatching. One sample was kept in light for 6 hours while a second sample was first kept in the dark for 3 hours, then transferred to light for 3 hours at constant temperature and salinity.

Figure 3 shows the effect of salinity on hatching after treatment for 6 hours at constant temperature and light (percentage of total hatch is expressed as a % of number of eggs hatching in 0% saline).

Figure 1

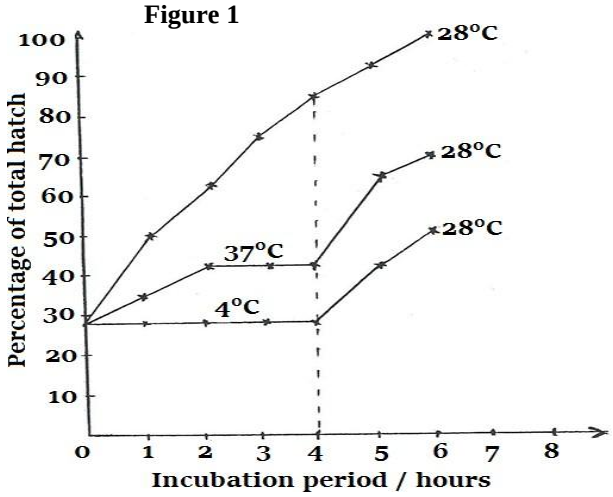
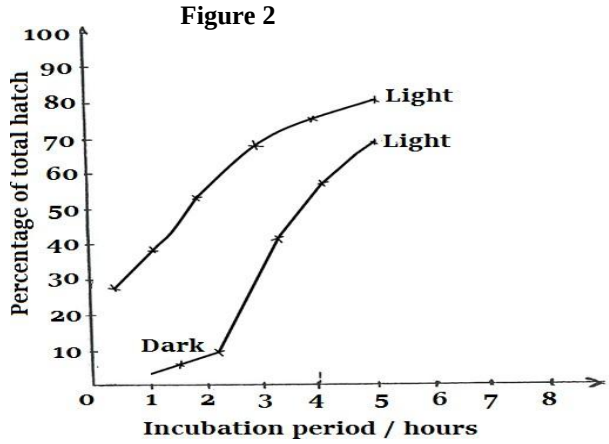


Figure 2



The eggs kept in 0.8% saline for 6 hours as in figure 3 above were removed, divided equally into four lots and placed in a range of saline solutions for a further 6 hours. The results are as shown in **table 1** below

Figure 3

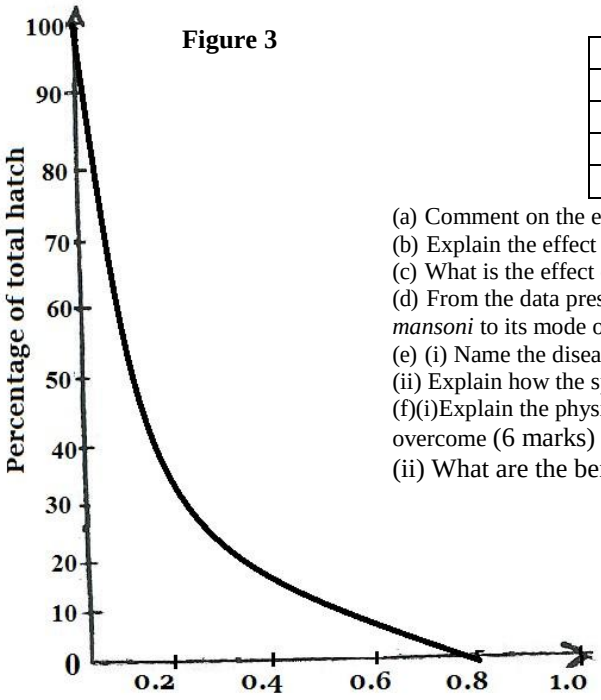


Table 1

Salinity (%)	Total hatch after 6 hours (%)
0.0	100
0.2	40
0.4	20
0.6	8

(a) Comment on the effect of temperature on hatching of *Schistosoma mansoni* eggs. (7 marks)
(b) Explain the effect of light on percentage hatch of eggs. (6 marks)
(c) What is the effect of salinity on percentage hatch of the eggs? (4 marks)
(d) From the data presented and restricting yourself to egg stage only, discuss adaptations of *S. mansoni* to its mode of life. (10 marks)
(e) (i) Name the disease caused by this blood fluke to man (1 mark)
(ii) Explain how the spread of disease can be controlled (4 marks)
(f)(i)Explain the physiological challenges facing human endo-parasites and how they are overcome (6 marks)
(ii) What are the benefits of parasitic nutrition to organisms that exhibit it? (2 marks)

PROBABLE SOLUTIONS

(a) Comment on the effect of temperature on the hatching of the eggs of *Schistosoma mansoni.* (7 marks)

- At constant light, salinity and temperature of 28^0C; ✓ eggs hatched rapidly; ✓ to completion; ✓
- At higher temperature of 37^0C and lower temperature of 4^0C; ✓hatching is just slightly stimulated (greatly inhibited); ✓
- Restoring temperature from 37^0C and 4^0C to 28^0C; ✓stimulates rapid hatching; ✓

(b) Explain the effect of light on the percentage of the total hatch of the eggs. (6 marks)

- The lot of eggs exposed to light hatch rapidly to completion; ✓ because light stimulates / activates a hatching substance/enzyme; ✓ which digests/breaks down the egg membranes to enable emergence of larvae; ✓
- Darkness generally inhibits hatching; ✓ because the hatching substance is inactive; ✓ however in this case a little hatching occurred in the dark probably due to experimental errors which resulted in some illumination of eggs;✓

(c) What is the effect of salinity on the percentage of total hatch of the eggs? (4 marks)

- In fresh water (at 0% salinity) all eggs hatched; ✓ at 0.8% salinity no eggs hatched (hatching was inhibited); ✓ increase in salinity; ✓ causes a rapid decrease in hatching; ✓

(d)* From the data presented and restricting yourself to the egg stage only, discuss the adaptation of *S. mansoni

(For more information, see MBV Roberts; functional approach, pg. 552-553)

- In the mesenteric veins of the main host of *Schistosoma mansoni*; ✓ there is total darkness and temperature is about 37^0C; ✓both of which prevent hatching of eggs into miracidia (larvae) in man; ✓because they would die; ✓
- When faeces with eggs reach fresh water bodies; ✓where there is much illumination (light), lower temperature and very low salinity; ✓ all of which favour rapid hatching of eggs; ✓ many larvae (miracidia) are formed; ✓ which infect water snails; ✓ (intermediate host) and form more larvae (cercariae) that infect man; ✓

(e) (i) Name the disease caused by this blood fluke to man (1 mark)

Bilharzia (Schistosomiasis); ✓

(ii) Explain how the spread of the disease can be controlled (method and its purpose = 01 mark x 4)

- Disposal of faeces in latrines/toilets to avoid their contact with fresh water bodies; ✓
- Deworming to kill adult worms in humans; ✓
- Wearing gear (boots/shoes) that shield/protect feet from larvae (cercaria) infection; ✓
- Use molluscides to kill larvae's (miracidia) intermediate hosts (adult snails) in water; ✓
- Biological control in which some fish and ducks are introduced in water to feed on larvae /snails; ✓

(f)(i) Explain the physiological challenges facing human endo-parasites and how they are overcome (Any 3, @ challenge – 1 mark, how overcome – 1 mark = 06 marks)

Challenge	How it is overcome
• Digestion by the host's enzymes; ✓ • Osmotic changes in the habitat; ✓ • Inhibitory chemical environment; ✓ • Anaerobic conditions; ✓ • Attack by host's immune system; ✓	• Development of thick cuticle/secretion of inhibitory substances /mucus✓ • Increased chemosensitivity in order to equilibrate with host✓ • Secretion of anti-inhibitory substances; ✓ • Ability to respire anaerobically; ✓ • Development of protective structures against the host's immune attack✓

(ii) Importance of parasitic nutrition (2 marks)

- A variety of nutrients required for growth, development and body maintenance may be obtained from one meal

Less development of digestive system since most nutrients obtained are fully /partially digested.

SAPROTROPHISM (SAPROTROPHIC NUTRITION)

The process of obtaining soluble organic substances from extracellular digestion of dead or decayed organic matter.

Saprotroph: An organism that absorbs soluble nutrients from extracellular digestion of dead/decaying organic matter.

EXAMPLES OF SAPROTROPHS

(i) Saprobes: fungi like mushrooms, yeasts and moulds

(ii) Saprophytes: **saprotrophic plants** e.g. sugar stick, gnome plant, Indian-pipe and **putrefying bacteria** which convert complex organic substances into simpler compounds e.g. **Zygomonas** bacterium ferments **glucose** producing **alcohol, lactic acid and carbon dioxide**, **Clostridium aceto-butylicum** forms **butyl alcohol** from **carbohydrates**, **Lactobacillus** converts **sugars** into **lactic acid**.

(iii) **Saprophages**: Animal scavengers, such as dung beetles and vultures

DESCRIPTION OF SAPROTROPHISM IN FUNGAL MOULD LIKE MUCOR/RHIZOPUS

- Under suitable conditions (moisture / water, oxygen, neutral / mildly acidic pH, temperature of about 25 °C) the saprotroph secretes different enzymes into the dead animal/plant body; proteases, lipases, carbohydrases e.g. amylase which break down insoluble complex organic substances into simple soluble substances as follows:

-**Proteases** break down **proteins** into **amino acids**

-**Lipases** break down **lipids** into **fatty acids** and **glycerol**

-**Carbohydrases** e.g. **Amylases** break down **starch** into **maltose**/**simple disaccharides**

- The end products of extra-cellular digestion such as **fatty acids** and **glycerol, glucose, amino acids** plus other nutrients like **vitamins** e.g. **thiamine** and **ions** e.g. **potassium, phosphorus, and magnesium** are re-absorbed into the hypha through the cell wall by **endocytosis / simple diffusion / facilitated diffusion / active transport** and passed on throughout the mycelium complex to enable growth and repair.

COMPARISON OF SAPROPHYTES WITH PARASITES

Similarities

Both: **(1)** are heterotrophs **(2)** absorb soluble food **(3)** have simple digestive systems **(4)** have sexual and asexual phases in their reproduction **(5)** produce large numbers of offspring.

Differences

Parasites	**Saprophytes**
● Energy derived from living organisms ● Many stages in lifecycle ● Very specific to their host ● Nutritionally highly adapted ● Most plant and animal groups have representatives ● Most are aerobic	● Energy derived from dead organisms ● Usually a single adult stage, with spores inclusive ● Use a variety of food sources ● Simple methods of nutrition ● Almost totally fungi and bacteria ● Anaerobic and aerobic

IMPORTANCE OF SAPROPHYTES
● Recycling of materials e.g. carbon, nitrogen, phosphorus ● Brewing and baking e.g. yeast (Saccharomyces) ● Making antibiotics e.g. Penicillin ● Decomposition of wastes e.g. sewage ● Production of yoghurt and cheese ● Food source e.g. mushrooms ● Industrial applications e.g. leather tanning, production of vitamins, etc.