Natural selection: operates on the phenotypes of individuals, produced by their particular combinations of alleles. In natural populations, the allele combinations of some individuals are perpetuated at the expense of other genotypes. This differential survival of some genotypes over others is called natural selection. The effect of natural selection can vary; it can act to maintain the genotype of a species or to change it. Stabilizing selection maintains the established favorable characteristics and is associated with stable environments. In contrast, directional selection favors phenotypes at one extreme of the phenotypic range and is associated with gradually changing environments. Disruptive selection is a much rarer form of selection favoring two phenotypic extremes, and is a feature of fluctuating environments.

Stabilizing Selection
Extreme variations are culled from the population (there is selection against them). Those with the established (middle range) adaptive phenotype are retained in greater numbers. This reduces the variation for the phenotypic character. In the example right, light and dark snails are eliminated, leaving medium colored snails. Stabilizing selection can be seen in the selection pressures on human birth weights.

Directional Selection
Directional selection is associated with gradually changing conditions, where the adaptive phenotype is shifted in one direction and one aspect of a trait becomes emphasized (e.g. coloration). In the example right, light colored snails are eliminated and the population becomes darker. Directional selection was observed in peppered moths in England during the Industrial Revolution. They responded to the air pollution of industrialization by increasing the frequency of darker, melanic forms.

Disruptive or Diversifying Selection
Disruptive selection favors two extremes of a trait at the expense of intermediate forms. It is associated with a fluctuating environment and gives rise to balanced polymorphism in the population. In the example right, there is selection against medium colored snails, which are eliminated. There is considerable evidence that predators, such as insectivorous birds, are more likely to find and eat common morphs and ignore rare morphs. This enables the rarer forms to persist in the population.

1. (a) Distinguish between directional selection and disruptive selection, identifying when each is likely to operate:

(b) Identify which of the three types of selection described above will lead to evolution, and explain why:

2. Explain how a change in environment may result in selection becoming directional rather than stabilizing:

3. Explain how, in a population of snails, through natural selection, shell color could change from light to dark over time:
Adaptations for Absorption

In most animal phyla, the small products of enzymic digestion are absorbed through a gut lining. Absorption of the simple components of food (e.g., simple sugars, amino acids, fatty acids, and glycerol) must take place before the nutrients can be assimilated (taken up by all the body's cells). In animals with a tubular gut, it is an advantage to maximize the uptake of nutrients from the intestine as the digested food passes through. There is great diversity amongst the invertebrate phyla in the way in which absorption is facilitated. In cnidarians, specialized cells lining the gut ingest food particles directly by phagocytosis. In other phyla, the inner surface area of the gut is increased by infoldings so that the area over which nutrient uptake can occur is very large. This is the case in vertebrates also, as shown for mammals in the activity Stomach and Small Intestine.

Cnidarian gastrovascular cavity
EXAMPLE: Hydra

In Hydra, specialized cells line the gastrovascular cavity. Some of these secrete enzymes into the cavity to begin digestion. Special nutritive cells (illustrated) take in the partly digested fragments by phagocytosis, to form food vacuoles where digestion is completed. These cells have beating hair-like flagella that create currents and improve the delivery of food to the cells.

Insect gastric ceca
EXAMPLE: Grasshopper or locust

In insects of the grasshopper family (and others), the gastric ceca (sing. cecum) are midgut pouches just behind the proventriculus. The ceca improve absorption by transferring nutrients into the blood. Secretion of enzymes and absorption of nutrients occurs in the midgut. Unlike the fore- and hindgut (which are lined with chitin), the midgut is lined with a permeable peritrophic membrane which allows nutrient absorption.

Annelid typhlosole
EXAMPLE: Lumbricus (earthworm)

In earthworms, the entire length of the small intestine is folded into a structure called the typhlosole. Secretion of enzymes, digestion, and absorption all occur in the intestine and the typhlosole increases the amount of surface area for absorption of nutrients. Not all annelids have a typhlosole, although many have similar foldings to increase surface area.

1. Discuss adaptations for increasing the surface area of the inner gut, identifying the advantages of this:

2. Refer to the activity Stomach and Small Intestine and answer the following:
   (a) Identify the features and structures in the mammalian gut that increase surface area:

   (b) Explain how the transport of nutrients from the gut is facilitated:

   (c) Compare the degree of infoldings with that generally found in invertebrates and suggest a reason for the difference:
The Human Digestive Tract

It is estimated that an adult consumes about 20,000 kg of food between the ages of 18 and 38 years, about a metric tonne a year. Although babies grow rapidly from birth, growth is not the most significant reason for our ongoing eating. Our bodies require a constant source of energy for the vast number of biochemical reactions that constitute metabolism. Food provides the source of this energy. Tube-like digestive tracts (guts) run through the body from the mouth to the anus. The digestive tract prepares the food we eat for use by the body's cells through five basic activities: eating (ingestion), movement (of food through the gut), digestion (physical and chemical breakdown), absorption, and elimination. However, different specializations that occur in each region will depend both on the diet and the method of ingestion (prechewed, liquid, unchewed).

Structures of the Human Gut

Word list: Liver, small intestine, gall bladder, stomach, salivary glands, colon (large intestine), esophagus, pancreas, mouth and teeth, anus, rectum, appendix.

A  B  C  D  E  F  G  H  I  J  K  L

The Functions of Gut Structures

In the boxes provided, write the letter (A-L) that represents the part of the gut responsible for each of the functions summarized below:

(a) Main region for enzymatic digestion & nutrient absorption
(b) Consolidation of the feces before elimination
(c) Main function (humans) is water and mineral absorption
(d) Secretes acid and peptin, stores and mixes food
(e) A gland which produces an alkaline, enzyme-rich fluid
(f) Produces bile and has many homeostatic functions
(g) Produces saliva which contains the enzyme amylase

Code: RA 2
1. In the spaces provided on the diagram (opposite), identify the parts labeled A L (choose from the word list provided). Match each of the functions described (a)-(g) with the letter representing the corresponding structure on the diagram.

2. On the diagram opposite, mark with lines and labels: anal sphincter (AS), pyloric sphincter (PS), cardiac sphincter (CS).

3. Identify the region of the gut illustrated by the photographs (a)-(f) on the opposite page:
   (a) ____________________________________________ (b) ____________________________________________
   (c) ____________________________________________ (d) ____________________________________________
   (e) ____________________________________________ (f) ____________________________________________

4. Explain how a bolus of food is moved through a tube gut: ____________________________________________

5. Describe an advantage of having a gut where food moves in only one direction: _________________________

6. Identify one factor that would influence the length and specialization in the gut: _________________________

7. Briefly describe how the following processes are involved in processing food:
   (a) Mastication: ____________________________________________

   (b) Absorption: ____________________________________________
Intestinal villi and microvilli
The photograph (left) shows a section through the ileum with the intestinal villi and intestinal glands (crypts of Lieberkuhn) indicated. The intestinal glands secrete mucus and alkaline fluid. Epithelial cells lining the surface of the villi are regularly worn off and replaced by new cells migrating from the base of the intestinal glands. Each epithelial cell has many microvilli (microscopic projections called the brush border) which further increase the intestinal surface area.

Enzymes bound to the microvilli surfaces of the epithelial cells (peptidases, maltase, lactase, and sucrase) break down small peptides and carbohydrate molecules into their constituent parts. The breakdown products (monosaccharides, amino acids) are then absorbed into the underlying blood and lymph vessels. Mucous cells (white spots arrowed) produce mucus to protect the epithelial cells from enzymatic digestion. The blood vessels transport nutrients to the liver. Lymph vessels transport the products of fat digestion.

<table>
<thead>
<tr>
<th>Secretion and source</th>
<th>Site of action</th>
<th>Active enzyme</th>
<th>Substrate and products</th>
<th>Control of secretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric juice: stomach</td>
<td>Stomach</td>
<td>Pepsin</td>
<td>Protein → peptides</td>
<td>Reflex stimulation, stretching of the stomach wall, and the hormone gastrin.</td>
</tr>
<tr>
<td>Pancreatic juice: pancreas (exocrine region only)</td>
<td>Duodenum</td>
<td>Pancreatic amylase, Trypsin, Chymotrypsin, Pancreatic lipase</td>
<td>Starch → maltose, Protein → peptides, Protein → peptides, Fats → fatty acids + glycerol</td>
<td>Control of pancreatic secretions is via release of the hormones secretin and cholecystokinin.</td>
</tr>
<tr>
<td>Intestinal juice and enzymes: small intestine</td>
<td>Small intestine</td>
<td>Maltase, Peptidases</td>
<td>Maltose → glucose, Polypeptides → amino acids</td>
<td>Reflex action and contact with intestinal wall.</td>
</tr>
</tbody>
</table>

2. Discuss the digestive and storage role of the stomach in humans, identifying important structures and secretions:

3. Identify two sites for enzyme secretion in the gut, give an example of an enzyme produced there, and state its role:
   (a) Site: ____________________________________________ Enzyme: ____________________________________________
       Enzyme's role: ____________________________________________
   (b) Site: ____________________________________________ Enzyme: ____________________________________________
       Enzyme's role: ____________________________________________

4. (a) Suggest why the pH of the gut secretions varies at different regions in the gut:

(b) Explain why it is necessary for protein-digesting enzymes (e.g. trypsin, chymotrypsin, and pepsin) to be secreted in an inactive form and then activated after release:

5. Explain why alcohol exerts its effects more rapidly when the stomach is empty (rather than full):

6. Explain the role of sphincter muscles in the digestive tract:
The Large Intestine

After most of the nutrients have been absorbed in the small intestine, the remaining fluid contents pass into the large intestine (appendix, cecum, and colon). The fluid comprises undigested or undigestible food, bacteria, dead cells sloughed off from the gut wall, mucus, bile, ions, and a large amount of water. In humans and other omnivores, the large intestine is concerned mainly with the reabsorption of water and electrolytes. Infection or disease can cause an increase in gut movements, resulting in insufficient reabsorption of water and diarrhea. Sluggish gut movements cause the reabsorption of too much water and the feces become hard and difficult to pass, a condition known as constipation. The semi-solid waste material (feces) passes from the colon to the rectum, where it is stored and consolidated before being expelled (egested). Egestion of feces is controlled by the activity of two sphincters in the anus, one being under involuntary reflex control.

A single crypt from the intestinal wall

The lining of the large intestine consists of a simple columnar epithelium. The epithelium is not folded into villi, but instead contains tubular glands called crypts containing numerous goblet cells. The goblet cells produce mucus, which lubricates the colon wall and aids formation of the feces.

Appendicitis

Obstruction of the appendix by fecal matter or some other cause can lead to an inflammation called appendicitis. Appendicitis usually develops rapidly with little warning over a period of 6-12 hours. The usual symptom is abdominal pain, accompanied by nausea, vomiting and a slight fever. When severe, it can be life threatening. Acute appendicitis is treated by surgical removal of the appendix (appendectomy). The entire procedure usually takes about one hour and is performed in one of two ways: through what is called an open operation or through the laparoscopic technique.

1. Outline the main function of the large intestine:

2. Suggest why the lining of the large intestine consists of crypts as opposed to villi like projections:

3. The photograph below shows a cross section through the colon wall. Using the diagram of the single crypt (above right) label the features indicated using the following word list: circular muscle, submucosa, lymph nodule, epithelial cells

   (a) __________
   (b) __________
   (c) __________
   (d) __________
The Control of Digestion

The majority of digestive juices are secreted only when there is food in the gut and both nervous and hormonal mechanisms are involved in coordinating and regulating this activity appropriately. The digestive system is innervated by branches of the autonomic nervous system (sympathetic and parasympathetic stimulation).

Hormonal regulation is achieved through the activity of several hormones: gastrin, secretin, and cholecystokinin (formerly called pancreozymin). These are released into the bloodstream in response to nervous or chemical stimuli and influence the activity of gut and associated organs.

Hormonal and Nervous Control of Digestion

Salivation is entirely under nervous control. Some saliva is secreted continuously in response to parasympathetic stimulation via the vagus nerve. The presence of food in the mouth stimulates the salivary glands (and stomach) to increase their secretions. This response operates through a simple cranial reflex via the vagus nerve. The smell, sight, and thought of food also stimulates salivary (and gastric) secretion. These stimuli involve higher brain activity and learning (a conditioned reflex).

The entry of food into the small intestine, especially fat and gastric acid, stimulates the cells of the intestinal mucosa to secrete the hormones cholecystokinin (CCK) and secretin.

Cholecystokinin circulates in the blood and stimulates the pancreas to increase its secretion of enzyme-rich fluid. CCK also stimulates the release of bile into the intestine from the gall bladder. Secretin stimulates the pancreas to increase its secretion of alkaline fluid. This fluid neutralizes the acid entering the intestine. Secretin also stimulates the production of bile from the liver cells. Both secretin and CCK stimulate the secretion of intestinal juice but inhibit gastric secretion and general motility of the gastrointestinal tract.

The feeding center of the brain

The feeding center in the hypothalamus is constantly active. It monitors metabolites in the blood and stimulates hunger when these metabolites reach low levels. After a meal, a neighboring region of the hypothalamus, the satiety center, suppresses the activity of the feeding center for a period of time. Impulses from these two centers travel via the vagus nerve to stimulate the secretion of particular digestive hormones.

The secretions and muscular activity of the gut are regulated by both nervous and hormonal mechanisms. Parasympathetic stimulation of the stomach and pancreas via the vagus nerve increases their secretion. Sympathetic stimulation has the opposite effect.

The presence of food in the stomach causes it to stretch. This mechanical stimulus results in secretion of the hormone gastrin from cells in the mucosa of the stomach. This activity is mediated through a simple reflex.

Gastrin is secreted in response to eating food (particularly protein). Gastrin is released into the bloodstream where it acts back on the stomach to increase gastric secretion and motility. Gastrin also increases the motility of the gastrointestinal tract in general, and this helps to propel food through the gut.

1. Describe the role of each of the following stimuli in the control of digestion, identifying both the response and its effect:
   (a) Presence of food in the mouth: 
      
   (b) Presence of fat and acid in the small intestine: 
      
   (c) Stretching of the stomach by the presence of food: 
      
2. Outline the role of the vagus nerve in regulating digestive activity:
The Role of the Liver

The liver is a large organ, weighing about 1.4 kg, and is well supplied with blood. It carries out several hundred different functions and has a pivotal role in the maintenance of homeostasis. Its role in the digestion of food centers around the production of the alkaline fluid, bile, which is secreted at a rate of 0.8–1.0 liter per day. It is also responsible for processing absorbed nutrients, which arrive at the liver via the hepatic portal system. These functions are summarized below.

**Digestive Functions of the Liver**

The digestive role of the liver is in the production of bile. Bile is a yellow, brown, or olive-green alkaline fluid (pH 7.6–8.6), consisting of water and bile salts, cholesterol, lecithin, bile pigments, and several ions. The bile salts are used in the small intestine to break up (emulsify) fatty molecules for easier digestion and absorption. The high pH neutralizes the acid entering the small intestine from the stomach. Bile is also partly an excretory product; the breakdown of red blood cells in the liver produces the principal bile pigment, bilirubin. Bacteria act on the bile pigments, giving the brownish color to feces. The production and secretion of bile is regulated through nervous and hormonal mechanisms. The hormones (secretin and cholecystokinin) are released into the blood from the intestinal mucosa in response to the presence of food (especially fat) in the small intestine.

**Liver Tissue**

The liver tissue is made up of many lobules, each one comprising cords of liver cells (hepatocytes), radiating from a central vein (CV), and surrounded by branches of the hepatic artery, hepatic portal vein, and bile ductule. Bile is produced by the individual liver cells, which secrete into canaliculi that empty into small bile ducts. The hepatocytes also process the nutrients entering the liver via the hepatic portal system.

**Internal Gross Structure of the Human Liver**

- **Vagus nerve** stimulates bile production
- **Secretin** stimulates bile production
- **Common bile duct** transports bile from the gallbladder to the small intestine
- **Gallbladder** stores bile, releasing it into the small intestine when required
- **Cholecystokinin (CCK)** stimulates release of bile into the gut
- **Sphincter of Oddi** relaxes to release bile into the small intestine. Sphincter relaxation is stimulated by the hormone CCK.

1. The liver produces bile. Describe the two main functions of bile in digestion:
   (a) 
   (b) 

2. Describe the two primary functions of the liver related to the processing of digestion products arriving from the gut:
   (a) 
   (b) 

3. Explain the role of the gall bladder in digestion:

4. Describe in what way bile is an excretory product as well as a digestive secretion:

5. Name the two principal hormones controlling the production (secretion) and release of bile, and state the effect of each:
   (a) Hormone 1: __________ Effect: 
   (b) Hormone 2: __________ Effect: 

6. State the stimulus for hormonal stimulation of bile secretion:
Absorption and Transport

All the chemical and physical processes of digestion from the mouth to the small intestine are aimed at the breakdown of food molecules into forms that can pass through intestinal lining into the underlying blood and lymph vessels. These breakdown products include monosaccharides, amino acids, fatty acids, glycerol, and glycerides. Passage of these molecules from the gut into the blood or lymph is called absorption. After absorption, nutrients are transported directly or indirectly to the liver for storage or processing. Some of the features of nutrient absorption and transport are shown below. For simplicity, all nutrients are shown in the lumen of the intestine, even though some nutrients are digested on the epithelial cell surfaces.

The Hepatic Portal System

The liver obtains oxygenated blood from the hepatic artery, but it also receives deoxygenated blood containing newly absorbed nutrients via the hepatic portal vein. The hepatic portal system refers to all the blood flow from the digestive organs that passes through the liver before returning to the heart. Hepatic portal blood is rich in nutrients: the liver monitors and processes this load before the blood passes into general circulation.

Absorption: Most of the simple molecules that are the final products of food breakdown are absorbed by the epithelial cells of the villi into the blood vessels and are transported directly to the liver where they are processed.

Lumen of gut
Glucose and galactose
Fructose
Amino acids
Dipeptides
Tripeptides
Short chain fatty acids
Long chain fatty acids
Monoglycerides
Fat soluble vitamins (A, D, E, K)

Brush border of microvilli
Active transport
Facilitated diffusion
Active transport
Active transport
Diffusion
Diffusion
Diffusion (+ micelles)

Intestinal epithelial cell
Diffusion
Amino acids

Capillary of villus
Transport of lipids: Most lipids are long chain fatty acids. These and the monoglycerides reach the liver by a more indirect route than other molecules. Once within the epithelial cells (aided by micelles), long chain fatty acids and glycerol are recombined in the smooth endoplasmic reticulum to form triglycerides. The triglycerides aggregate into chylomicrons, which leave the epithelial cell and enter the lymphatic circulation. Eventually they enter the general circulation near the heart and arrive at the liver via the hepatic artery.

Chylomicrons are formed in the endoplasmic reticulum of the intestinal epithelial cells. Triglycerides aggregate with phospholipids and cholesterol and become coated with protein. The protein coat keeps the fat in suspension during transport.

1. State the function of the following in fat digestion:
   (a) Micelles:
   (b) Chylomicrons:

2. Explain why it is important that venous blood from the gut is transported first to the liver via the hepatic portal circulation:
Nutrients are required for metabolism, tissue growth and repair, and as an energy source. Good nutrition (provided by a balanced diet) is recognized as a key factor in good health. Conversely, poor nutrition (malnutrition) may cause ill-health or deficiency diseases. A diet refers to the quantity and nature of the food eaten. While not all foods contain all the representative nutrients, we can obtain the required balance of different nutrients by eating a wide variety of foods. In a recent overhaul of previous dietary recommendations, the health benefits of monounsaturated fats (such as olive and canola oils), fish oils, and whole grains have been recognized, and people are being urged to reduce their consumption of highly processed foods and saturated (rather than total) fat. Those on diets that restrict certain food groups (e.g. vegans) must take care to balance their intake of foods to ensure an adequate supply of protein and other nutrients (e.g. iron and B vitamins). Dietary information, including Recommended Daily Amounts (RDAs) for energy and nutrients, is provided to consumers through the food labelling. Such information helps individuals to assess their nutrient and energy intake and adjust their diet accordingly.

**The OLD Food Pyramid**

The dietary recommendations of the 1990s emphasized a reduced fat intake, the natural consequence of which was that a high carbohydrate intake was desirable. These guidelines led to increased marketing of low fat, high sugar foods, despite the fact that there are no studies clearly demonstrating a link between low (total) fat diets and long term health benefits.

<table>
<thead>
<tr>
<th>Key to symbols in both figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Fat (including added)</td>
</tr>
<tr>
<td>▼ Sugar (added)</td>
</tr>
<tr>
<td>AB Use in abundance</td>
</tr>
<tr>
<td>S Include at most meals</td>
</tr>
<tr>
<td>Use these foods sparingly</td>
</tr>
<tr>
<td>Number of servings per day</td>
</tr>
</tbody>
</table>

**The NEW Food Pyramid**

New dietary recommendations distinguish between healthy and unhealthy types of carbohydrates and fats. Daily intake of dairy products should be limited, but alcohol in moderation is allowable. A high intake of plant oils (particularly monounsaturated oils such as olive and canola oils) is correlated with reduced rates of heart disease.

1. Identify two major roles of nutrients in the diet:
   (a) 
   (b) 

2. (a) Compare the two food pyramids (above) and discuss how they differ in their recommendations for good nutrition:
Lungs are internal sac-like organs found in most amphibians, and all reptiles, birds, and mammals. The paired lungs of mammals are connected to the outside air by way of a system of tubular passageways: the trachea, bronchi, and bronchioles. Ciliated, mucus-secreting epithelium lines this system of tubules, trapping and removing dust and pathogens before they reach the gas exchange surfaces. Each lung is divided into a number of lobes, each receiving its own bronchus. Each bronchus divides many times, terminating in the respiratory bronchioles from which arise 2-11 alveolar ducts and numerous alveoli (air sacs). These provide a very large surface area (70 m²) for the exchange of respiratory gases by diffusion between the alveoli and the blood in the capillaries. The details of this exchange across the respiratory membrane are described opposite.

**Morphology of the Respiratory System**

Nasal passages warm and moisten the air entering through the nostrils. Each nostril has a border of hairs to trap particles and filter them out of the system.

Air entering the body through the mouth enters the pharynx and mixes with air from the nasal passages.

The trachea lies in front of the esophagus and extends into the thorax. It is strengthened with C-shaped bands of cartilage and lined with ciliated epithelium.

The trachea splits into two bronchi. These are also supported by cartilage bands.

Bronchioles branch off the bronchi and divide into progressively smaller branches. The cartilage is gradually lost as the bronchioles decrease in diameter.

The smallest respiratory bronchioles subdivide into the alveolar ducts from which arise the alveoli. The walls of the smallest bronchioles lack cartilage but have a large amount of smooth muscle.

The alveolar ducts lead to the alveoli. The alveoli tend to recoil inward (deflate) after each breath out. A phospholipid surfactant helps to prevent this by decreasing surface tension in the lung.
An Alveolus

The diagram above illustrates the physical arrangement of the alveoli to the capillaries through which the blood moves. Phagocytic monocytes and macrophages are also present to protect the lung tissue. Elastic connective tissue gives the alveoli their ability to expand and recoil.

The Respiratory Membrane

The respiratory membrane is the term for the layered junction between the alveolar epithelial cells, the endothelial cells of the capillary, and their associated basement membranes (thin, collagenous layers that underlie the epithelial tissues). Gases move freely across this membrane.

1. (a) Explain how the basic structure of the human respiratory system provides such a large area for gas exchange:

(b) Identify the general region of the lung where exchange of gases takes place:

2. Describe the structure and purpose of the respiratory membrane:

3. Describe the role of the surfactant in the alveoli:

4. Using the information above and opposite, complete the table below summarizing the histology of the respiratory pathway. Name each numbered region and use a tick or cross to indicate the presence or absence of particular tissues.

<table>
<thead>
<tr>
<th>Region</th>
<th>Cartilage</th>
<th>Ciliated epithelium</th>
<th>Goblet cells (mucus)</th>
<th>Smooth muscle</th>
<th>Connective tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>gradually lost</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Alveolar duct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Babies born prematurely are often deficient in surfactant. This causes respiratory distress syndrome; a condition where breathing is very difficult. From what you know about the role of surfactant, explain the symptoms of this syndrome:
Breathing in Humans

In mammals, the mechanism of breathing (ventilation) provides a continual supply of fresh air to the lungs and helps to maintain a large diffusion gradient for respiratory gases across the gas exchange surface. Oxygen must be delivered regularly to supply the needs of respiring cells. Similarly, carbon dioxide, which is produced as a result of cellular metabolism, must be quickly eliminated from the body. Adequate lung ventilation is essential to these exchanges. The cardiovascular system participates by transporting respiratory gases to and from the cells of the body. The volume of gases exchanged during breathing varies according to the physiological demands placed on the body (e.g. by exercise). These changes can be measured using spirometry.

Inspiration (inhalation or breathing in)
During quiet breathing, inspiration is achieved by increasing the space (therefore decreasing the pressure) inside the lungs. Air then flows into the lungs to fill the space. Inspiration is always an active process involving muscle contraction.

1a External intercostal muscles contract causing the ribcage to expand and move up
1b Diaphragm contracts and drops downwards
2 Thoracic volume increases, lungs expand, and the pressure inside the lungs decreases
3 Air flows into the lungs in response to the pressure gradient

Expiration (exhalation or breathing out)
During quiet breathing, expiration is achieved passively by decreasing the space (thus increasing the pressure) inside the lungs. Air then flows passively out of the lungs to equalize with the air pressure. In active breathing, muscle contraction is involved in bringing about both inspiration and expiration.

1 In quiet breathing, external intercostal muscles and diaphragm relax. Elasticity of the lung tissue causes recoil.
In forced breathing, the internal intercostals and abdominal muscles also contract to increase the force of the expiration
2 Thoracic volume decreases and the pressure inside the lungs increases
3 Air flows passively out of the lungs in response to the pressure gradient

Using spirometry to determine changes in lung volume
The apparatus used to measure the amount of air exchanged during breathing and the rate of breathing is a spirometer (also called a respirometer). A simple spirometer consists of a weighted drum, containing oxygen or air, inverted over a chamber of water. A tube connects the air-filled chamber with the subject's mouth, and soda lime in the system absorbs the carbon dioxide breathed out. Breathing results in a trace called a spirogram, from which lung volumes can be measured directly.

During inspiration
Air is removed from the chamber, the drum sinks, and an upward deflection is recorded on the paper on the rotating drum.

During expiration
Air is added to the chamber, the drum rises, and a downward deflection is recorded.

Lung Volumes and Capacities
The air in the lungs can be divided into volumes. Lung capacities are combinations of volumes.

<table>
<thead>
<tr>
<th>Description of volume</th>
<th>Vol (liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume (TV)</td>
<td>0.5</td>
</tr>
<tr>
<td>Inspiratory reserve volume (IRV)</td>
<td>3.3</td>
</tr>
<tr>
<td>Expiratory reserve volume (ERV)</td>
<td>1.0</td>
</tr>
<tr>
<td>Residual volume (RV)</td>
<td>1.2</td>
</tr>
<tr>
<td>Inspiratory capacity (IC) = TV + IRV</td>
<td>3.8</td>
</tr>
<tr>
<td>Vital capacity (VC) = IRV + TV + ERV</td>
<td>4.8</td>
</tr>
<tr>
<td>Total lung capacity (TLC) = VC + RV</td>
<td>6.0</td>
</tr>
</tbody>
</table>

The total volume of the lungs. Only a fraction of TLC is used in normal breathing.

Only about 70% of the air that is inhaled reaches the alveoli. The rest remains in the air spaces of the nose, throat, larynx, trachea, and bronchi. This air is unavailable for gas exchange and is called the dead air volume (dead space air).
Measuring Changes in Lung Volume

Changes in lung volume can be measured using spirometry (see opposite). Total adult lung volume varies between 4 and 6 liters (L or dm³) (it is greater in males). The vital capacity is somewhat less than this because of the residual volume of air remaining in the lungs even after expiration. The exchange between fresh air and the residual volume is a slow process and the composition of gases in the lungs remains relatively constant (table, right).

Once measured, the tidal volume can be used to calculate the pulmonary ventilation rate or PV; the amount of air exchanged with the environment per minute. During exercise, breathing rate, tidal volume, and PV increase up to a maximum (indicated below).

<table>
<thead>
<tr>
<th>Respiratory gas</th>
<th>Approximate percentages of O₂ and CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inhaled air</td>
</tr>
<tr>
<td>O₂</td>
<td>21.0</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Above: The percentages of respiratory gases in air (by volume) during normal breathing. The percentage volume of oxygen in the alveolar air (in the lung) is lower than that in the exhaled air because of the influence of the dead air volume in the airways (air unavailable for gas exchange).

---

1. (a) Briefly outline the sequence of events involved in quiet breathing:

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

(b) Explain the essential difference between this and the situation during heavy exercise or forced breathing:

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

2. Using the definitions given opposite, identify the volumes and capacities indicated by the letters A-F on the diagram of a spirogram above. For each, indicate the volume (vol) in liters. The inspiratory reserve volume has been identified for you:

   (a) A: _______________ Vol: _______________

   (b) B: _______________ Vol: _______________

   (c) C: _______________ Vol: _______________

   (d) D: _______________ Vol: _______________

   (e) E: _______________ Vol: _______________

   (f) F: _______________ Vol: _______________

3. Explain what is happening in the sequence indicated by the letter G:

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

4. Calculate PV when breathing rate is 15 breaths per minute and tidal volume is 4.0 L:

   ________________________________________________________________

5. The table above gives approximate percentages for respiratory gases during breathing. Study the data and then:

   (a) Calculate the difference in CO₂ between inhaled and exhaled air:

   ________________________________________________________________

   (b) Explain where this ‘extra’ CO₂ comes from:

   ________________________________________________________________

   (c) Explain why the dead air volume raises the oxygen content of exhaled air above that in the lungs:

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________
The basic rhythm of breathing is controlled by the respiratory center, a cluster of neurons located in the medulla oblongata. This rhythm is adjusted in response to the physical and chemical changes that occur when we carry out different activities. Although the control of breathing is involuntary, we can exert some degree of conscious control over it. The diagram below illustrates these controls.

**The Control of Breathing**

The **respiratory center** (position indicated by white oval) has connections with the cerebral cortex. This allows voluntary control over breathing e.g., when talking, singing, sneezing, and coughing.

The **vagus nerve** carries impulses from stretch receptors to the respiratory center to inhibit inspiration (the inflation reflex).

Internal intercostal muscles (expiration)

**Intercostal nerves** from the respiratory center stimulate inspiration.

Stretch receptors in the bronchioles and bronchi monitor the amount of lung inflation.

**Phrenic nerve** sends impulses to the diaphragm to stimulate contraction.

External intercostal muscles (inspiration)

**Chemoreceptors** in the aorta and carotid arteries monitor the blood's pH. Low pH (caused by high CO₂ in the blood) stimulates the respiratory center to increase the rate and depth of breathing.

1. Explain how the basic rhythm of breathing is controlled:

2. Describe the role of each of the following in the regulation of breathing:
   
   (a) Phrenic nerve: ______________________

   (b) Intercostal nerves: ______________________

   (c) Vagus nerve: ______________________

   (d) Inflation reflex: ______________________

3. (a) Describe the effect of low blood pH on the rate and depth of breathing:

   ______________________

   (b) Explain how this effect is mediated:

   ______________________

   (c) Suggest why blood pH is a good mechanism by which to regulate breathing rate:

   ______________________
Review of Lung Function

The respiratory system in humans and other air breathing vertebrates includes the lungs and the system of tubes through which the air reaches them. Breathing (ventilation) provides a continual supply of fresh air to the lungs and helps to maintain a large diffusion gradient for respiratory gases across the gas exchange surface. The basic rhythm of breathing is controlled by the respiratory center in the medulla of the hindbrain. The volume of gases exchanged during breathing varies according to the physiological demands placed on the body. These changes can be measured using spirometry. The following activity summarizes the key features of respiratory system structure and function. The stimulus material can be found in earlier exercises in this topic.

Components of the respiratory system

(a) 
(b) 
(c) 
(d) 
(e) 
(f) 
(g) 

The control of breathing

(i) controls the rate and depth of breathing. It also has connections with the cerebral cortex that allow voluntary control over breathing (e.g. when talking, singing, sneezing, and coughing).

(ii) carries impulses from stretch receptors to the respiratory center to inhibit inspiration (the inflation reflex).

(iii) from the respiratory center, stimulate inspiration.

(iv) in the aorta and carotid arteries, monitor blood pH. Low pH (caused by high CO₂) in the blood stimulates an increase in the rate and depth of breathing.

(v) in the bronchioles and bronchi, monitor the amount of lung inflation.

(vi) sends impulses to the diaphragm to stimulate contraction.

1. On the diagram above, label the components of the respiratory system (a-g) and the components that control the rate of breathing (i - vi).

2. Identify the volumes and capacities indicated by the letters A - E on the diagram of a spirogram below.

---

Spirogram for a male during quiet and forced breathing

A = 
B = 
C = 
D = 
E = 

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Diseases Caused by Smoking

Tobacco smoking has only recently been accepted as a major health hazard, despite its practice in Western countries for more than 400 years, and much longer elsewhere. Cigarettes became popular at the end of World War I because they were cheap, convenient, and easier to smoke than pipes and cigars. They remain popular for the further reason that they are more addictive than other forms of tobacco. The milder smoke can be more readily inhaled, allowing nicotine (a powerful addictive poison) to be quickly absorbed into the bloodstream. Lung cancer is the most widely known and most harmful effect of smoking; 98% of cases are associated with cigarette smoking. Symptoms include chest pain, breathlessness, and coughing up blood. Tobacco smoking is also directly associated with coronary artery disease, emphysema, chronic bronchitis, peripheral vascular disease, and stroke. The damaging components of cigarette smoke include tar, carbon monoxide, nitrogen dioxide, and nitric oxide. Many of these harmful chemicals occur in greater concentrations in sidestream smoke (passive smoking) than in mainstream smoke (inhaled) due to the presence of a filter in the cigarette.

The Effects of Tobacco Smoking

Long term effects

Smoking damages the arteries of the brain and may result in a stroke.

All forms of tobacco-smoking increase the risk of mouth cancer, lip cancer, and cancer of the throat (pharynx).

Lung cancer is the best known harmful effect of smoking.

In a young man who smokes 20 cigarettes a day, the risk of coronary artery disease is increased by about three times over that of a nonsmoker.

Short term effects

- Reduction in capacity of the lungs.
- Increase in muscle tension and a decrease in steadiness of the hands.
- Raised blood pressure (10-30 points).
- Very sharp rise in carbon monoxide levels in the lungs contributing to breathlessness.
- Increase in pulse rate by up to 20 beats per minute.
- Surface blood vessel constriction drops skin temperature by up to 5°C.
- Dulling of appetite as well as the sense of smell and taste.

Smoking leads to severe constriction of the arteries supplying the extremities and leads to peripheral vascular disease.

How Smoking Damages Lung Tissue

Non-smoker

- Normal arrangement of alveoli
- Cells lining alveoli

Smoker

- Coalesced alveoli
- Extra mucus produced
- Cancerous cell

Smoke particles indirectly destroy the walls of the lung's alveoli.

Gross pathology of lung tissue from a patient with emphysema. Tobacco tar deposits can be seen. Tar contains at least 17 known carcinogens.

1. Describe the effect of the following constituents of tobacco smoke when inhaled:

(a) Tar:

(b) Nicotine:

(c) Carbon monoxide:

2. Describe two physical changes to the lung that result from long-term smoking:

3. List the symptoms of the following diseases associated with long-term smoking:

(a) Emphysema:

(b) Coronary artery disease:

(c) Lung cancer:
The blood vessels of the circulatory system form a vast network of tubes that carry blood away from the heart, transport it to the tissues of the body, and then return it to the heart. The arteries, arterioles, capillaries, venules, and veins are organized into specific routes to circulate the blood throughout the body. The figure below shows a number of the basic circulatory routes through which the blood travels. Mammals have a double circulatory system: a pulmonary system (or circulation), which carries blood between the heart and lungs, and a systemic system (circulation), which carries blood between the heart and the rest of the body. The systemic circulation has many subdivisions. Two important subdivisions are the coronary (cardiac) circulation, which supplies the heart muscle, and the hepatic portal circulation, which runs from the gut to the liver.

**Schematic Overview of the Human Circulatory System**

Deoxygenated blood (colored gray below) travels to the right side of the heart via the vena cavae. The heart pumps the deoxygenated blood to the lungs where it releases carbon dioxide and receives oxygen. The oxygenated blood (colored white below) travels via the pulmonary vein back to the heart from where it is pumped to all parts of the body. The venous system (figure, left) returns blood from the capillaries to the heart. The arterial system (figure right) carries blood from the heart to the capillaries. Portal systems carry blood between two capillary beds.

1. Complete the diagram above by labeling the boxes with the organs or structures they represent.
The Human Heart

The heart is the center of the human cardiovascular system. It is a hollow, muscular organ, weighing on average 342 grams. Each day it beats over 100,000 times to pump 3780 liters of blood through 100,000 kilometers of blood vessels. It comprises a system of four muscular chambers (two atria and two ventricles) that alternately fill and empty of blood, acting as a double pump.

The left side pumps blood to the body tissues and the right side pumps blood to the lungs. The heart lies between the lungs, to the left of the body's midline, and it is surrounded by a double layered pericardium of tough fibrous connective tissue. The pericardium prevents overdistension of the heart and anchors the heart within the mediastinum.

Human Heart Structure
(sectioned, anterior view)

- Aorta carries oxygenated blood to the head and body
- Vena cava receives deoxygenated blood from the head and body
- Pulmonary artery carries deoxygenated blood to the lungs
- Tricuspid valve prevents backflow of blood into right atrium
- Chordae tendineae non-elastic strands supporting the valve flaps
- Semi-lunar valve prevents the blood flow back into ventricle.
- Septum separates the ventricles

The heart is not a symmetrical organ. Although the quantity of blood pumped by each side is the same, the walls of the left ventricle are thicker and more muscular than those of the right ventricle. This difference affects the shape of the ventricular cavities, so the right ventricle is twisted over the left.

Key to abbreviations

- RA Right atrium; receives deoxygenated blood via anterior and posterior vena cava
- RV Right ventricle; pumps deoxygenated blood to the lungs via the pulmonary artery
- LA Left atrium; receives blood returning to the heart from the lungs via the pulmonary veins
- LV Left ventricle; pumps oxygenated blood to the head and body via the aorta

Coronary arteries: The high oxygen demands of the heart muscle are met by a dense capillary network. Coronary arteries arise from the aorta and spread over the surface of the heart supplying the cardiac muscle with oxygenated blood. Deoxygenated blood is collected by cardiac veins and returned to the right atrium via a large coronary sinus.

1. In the schematic diagram of the heart, below, label the four chambers and the main vessels entering and leaving them. The arrows indicate the direction of blood flow. Use large colored circles to mark the position of each of the four valves.
Pressure Changes and the Asymmetry of the Heart

The heart is not a symmetrical organ. The left ventricle and its associated arteries are thicker and more muscular than the corresponding structures on the right side. This asymmetry is related to the necessary pressure differences between the pulmonary (lung) and systemic (body) circulations (not to the distance over which the blood is pumped per se). The graph below shows changes blood pressure in each of the major blood vessel types in the systemic and pulmonary circuits (the horizontal distance not to scale). The pulmonary circuit must operate at a much lower pressure than the systemic circuit to prevent fluid from accumulating in the alveoli of the lungs. The left side of the heart must develop enough "spare" pressure to enable increased blood flow to the muscles of the body and maintain kidney filtration rates without decreasing the blood supply to the brain.

![Blood pressure graph with labels]

2. Explain the purpose of the valves in the heart:

3. The heart is full of blood. Suggest why, despite this, it needs its own blood supply:

4. (a) Explain why the pulmonary circuit must operate at a lower pressure than the systemic circuit:

(b) Relate this to differences in the thickness of the wall of the left and right ventricles of the heart:

5. Identify the vessels corresponding to the letters A-D on the graph above:
   A:  
   B:  
   C:  
   D:  

6. (a) Find out what is meant by the pulse pressure and explain how it is calculated:

(b) Predict what happens to the pulse pressure between the aorta and the capillaries:

7. Explain what you are recording when you take a pulse:
Large, complex organisms require a circulatory system to transport materials because diffusion is too inefficient and slow to supply all the cells of the body adequately. The circulatory system in humans transports nutrients, respiratory gases, wastes, and hormones, aids in regulating body temperature and maintaining fluid balance, and has a role in internal defence. All circulatory systems comprise a network of vessels, a circulatory fluid (blood), and a heart. This activity summarizes key features of the structure and function of the human heart. The necessary information can be found in earlier activities in this topic.

1. On the diagram above, label the identified components of heart structure and intrinsic control (1-8), and the components involved in extrinsic control of heart rate (A-D).

2. An ECG is the result of different impulses produced at each phase of the cardiac cycle (the sequence of events in a heartbeat). For each electrical event indicated in the ECG below, describe the corresponding event in the cardiac cycle:

A. The spread of the impulse from the pacemaker (sinoatrial node) through the atria.
B. The spread of the impulse through the ventricles.
C. Recovery of the electrical activity of the ventricles.

3. Describe one treatment that may be indicated when heart rhythm is erratic or too slow:
The Structure of Flowers

Flowering plants (angiosperms) are highly successful organisms. The egg cell is retained within the flower of the parent plant and the male gametes (contained in the pollen) must be transferred to it by pollination in order for fertilization to occur. Most angiosperms are monoecious, with male and female parts on the same plant. Some of these plants will self-pollinate, but most have mechanisms that make this difficult or impossible. The female and male parts may be physically separated in the flower, or they may mature at different times (in protandrous plants the male matures first, whereas in protogynous plants the female matures first). Dioecious plants avoid this problem by carrying the male and female flowers on separate plants. Different methods of pollination (animal, wind, and water pollination) also help to ensure that cross-pollination occurs. Common animal pollinators include insects, bats, birds, and small reptiles. Animals are able to transfer pollen between plants very effectively and often over large distances, so much so that many plants have come to depend on only one or two animal pollinators.

Insect Pollinated Flowers

In most angiosperms the flower has both male and female parts. The flowers are temporary structures, often produced in large numbers. Those that are pollinated by insects typically offer an attraction such as nectar or edible flower parts and their pollen is relatively large and heavy. In general, each flower consists of a stem, bearing sepals, petals, stamens, and carpels. Such flowers may be able to self-pollinate although there are often mechanisms to prevent this. In dioecious plants, the male and female flowers occur on separate plants and cross pollination is assured.

Wind Pollinated Flowers

Wind pollinated flowers typically have many tiny flowers grouped on a stalk or spikelets. Most grasses are wind pollinatied. The feathery appearance of their flowers is typical of wind pollinated plants.
1. Using the diagram opposite to help you, identify the parts of the flower labeled (a) to (g) on the cross section below.

(a) (b) (c) (d) (e) (f) (g)

2. (a) Name the male structures on a flower: 

(b) Name the female structures on a flower: 

3. Distinguish between monoecious and dioecious plants and explain how each type of plant avoids self-pollination: 

4. Describe two adaptations of insect-pollinated flowers:

(a) 

(b) 

5. Describe two adaptations of wind-pollinated flowers:

(a) 

(b) 

6. Describe one advantage and one cost to the plant of insect pollination:

(a) Advantage: 

(b) Cost: 

7. Describe two ways in which plants manage to attract animal pollinators:

(a) 

(b) 

8. Contrast the efficiency of wind and animals as pollinating agents, giving a reason for your answer:

9. Describe the main advantage of cross-pollination and discuss the ways in which plants can ensure this occurs:

[Diagram of a flower cross-section with labels (a) to (g)]
Pollination and Fertilization

Before the egg and sperm can fuse in fertilization, the pollen (which contains the male gametes) must be transferred from the male anthers to the female stigma in pollination. Plants rarely self-pollinate, although they can be made to do so. Most often the stigma of one plant receives pollen from other plants in cross-pollination. After pollination, the sperm nuclei can enter the ovule and fertilization can occur. In angiosperms, there is a double fertilization: one to produce the embryo and the other to produce the endosperm nucleus. The endosperm nucleus gives rise to the endosperm: the food store for the embryonic plant.

Growth of the pollen tube and double fertilization

Pollen grains are immature male gametophytes, formed by meiosis in the microspore mother cells within the pollen sac. Pollination is the actual transfer of the pollen from the stamens to the stigma. Pollen grains cannot move independently. They are usually carried by wind (anemophily) or animals (entomophily). After landing on the sticky stigma, the pollen grain is able to complete development, germinating and growing a pollen tube that extends down to the ovary. Directed by chemicals (usually calcium), the pollen tube enters the ovule through the micropyle, a small gap in the ovule. A double fertilization takes place. One sperm nucleus fuses with the egg to form the zygote. A second sperm nucleus fuses with the two polar nuclei within the embryo sac to produce the endosperm tissue (3N). There are usually many ovules in an ovary, therefore many pollen grains (and fertilizations) are needed before the entire ovary can develop.

Different pollens are variable in shape and pattern, and genera can be easily distinguished on the basis of their distinctive pollen. This feature is exploited in the relatively new field of forensic botany; the tracing of a crime through botanical evidence. The species specific nature of pollen ensures that only genetically compatible plants will be fertilized. Some species, such as Primula, produce two pollen types, and this assists in cross pollination between different flower types.

1. Distinguish clearly between pollination and fertilization:

2. Describe the role of the double fertilization in angiosperm reproduction:

3. Name the main chemical responsible for pollen tube growth:

4. Suggest a reason for the great variability seen in the structure of pollen grains:

5. Pollen can be used as an indicator of past climates and vegetation. Give two reasons why pollen is well suited to this use:
   (a) 
   (b) 

Code: RA 2
A fruit is a mature, ripened ovary, although other plant parts, in addition to the ovary, may contribute to the fleshy parts of what we call the fruit. As a seed develops, the ovary wall around it enlarges to become the fruit wall or pericarp. The pericarp has three regions: the outer exocarp, central mesocarp, and inner endocarp. Fruits may open to release the seeds or they may retain the seeds and be dispersed whole. They are classified according to the number of ovaries involved in their formation and the nature of the fruit wall (dry or fleshy). Succulent fruits are usually dispersed by animals and dry fruits by wind, water, or mechanical means. Fruits occur only in angiosperms. Their development has been a central feature of angiosperm evolution.

<table>
<thead>
<tr>
<th>Type of fruit</th>
<th>Description</th>
<th>Type of fruit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berry</td>
<td>A fleshy fruit with soft tissues throughout. The single seed or seeds are scattered through flesh.</td>
<td>Aggregate fruit</td>
<td>Formed from a single flower that has many carpels (ovaries) fused to form a single fruit.</td>
</tr>
<tr>
<td>Drupe</td>
<td>The fruit wall is fleshy but the endocarp surrounding the single seed forms a hard stone.</td>
<td>Multiple fruit</td>
<td>Formed from the ovaries of many flowers, fused together at maturity (e.g. fig, pineapple).</td>
</tr>
<tr>
<td>Legume</td>
<td>A simple fruit. Fruit wall is dry when mature and splits open along two seams to release the seeds.</td>
<td>False fruit</td>
<td>The fleshy part is formed from tissues other than the ovary, often the flower base.</td>
</tr>
<tr>
<td>Grain</td>
<td>A simple dry, one seeded fruit. The fruit wall and seed coat are joined and cannot be separated.</td>
<td>Nut</td>
<td>A simple, one-seeded dry fruit with a hard fruit wall (the nut shell). The nut is the seed.</td>
</tr>
</tbody>
</table>

1. Describe the two main purposes of fruits in the life cycle of flowering plants:
   (a) 
   (b) 

2. Using the table and the examples above to help you, classify the following fruits:
   (a) Plum: 
   (b) Pea: 
   (c) Raspberry: 
   (d) Watermelon: 

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After fertilization has occurred, the ovary develops into the fruit and the ovules within the ovary become the seeds. Recall that in plants there is double fertilization. One sperm fertilizes the egg to form the embryo, but another sperm combines with the diploid endosperm nucleus to form a large triploid cell which gives rise to the endosperm. The development of the endosperm is important and begins before embryonic development in order to produce a nutrient store for the young plant. A seed is an entire reproductive unit, housing the embryonic plant in a state of dormancy. During the last stages of maturing, the seed dehydrates until its water content is only 5-15% of its weight. The embryo stops growing and remains dormant until the seed germinates. At germination, the food store is mobilized to provide the nutrients for plant growth and development. An activity, Events in Germination, which covers the metabolic events of germination in more detail, is available on the Teacher Resource CD-ROM.

**Seed Structure and Formation**

![Diagram of seed structure](image)

**Dicot seeds: soy (above) cashew (below)**
There are two fleshy cotyledons. These store food that was absorbed from the endosperm.

**Monocot seed** *(maize: Zea mays)*

**Dicot seed** *(garden bean: Phaseolus vulgaris)*

Every seed contains an embryo comprising a rudimentary shoot (plumule), root (radicle), and one or two cotyledons (seed leaves). The embryo and its food supply are encased in a tough, protective seed coat or testa. In monocots, the endosperm provides the food supply, whereas in most dicots, the nutrients from the endosperm are transferred to the large, fleshy cotyledons.

**Germination in a Dicot Seed** *(garden bean: Phaseolus vulgaris)*

1. Explain the purpose of a seed: ____________________________

2. (a) State the function of the endosperm in angiosperms: ____________________________

   (b) State how the endosperm is derived: ____________________________

3. Explain the role of the testa in seeds: ____________________________

4. Explain why the seed requires a food store: ____________________________

5. Explain why stored seeds must be kept dry: ____________________________
Exercise and Blood Flow

Exercise promotes health by improving the rate of blood flow back to the heart (venous return). This is achieved by strengthening all types of muscle and by increasing the efficiency of the heart.

During exercise blood flow to different parts of the body changes in order to cope with the extra demands of the muscles, the heart and the lungs.

1. The following table gives data for the rate of blood flow to various parts of the body at rest and during strenuous exercise. Calculate the percentage of the total blood flow that each organ or tissue receives under each regime of activity.

<table>
<thead>
<tr>
<th>Organ or tissue</th>
<th>At rest</th>
<th>% of total</th>
<th>Strrenuous exercise</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm³ min⁻¹</td>
<td></td>
<td>cm³ min⁻¹</td>
<td></td>
</tr>
<tr>
<td>Brain</td>
<td>700</td>
<td>14</td>
<td>750</td>
<td>4.2</td>
</tr>
<tr>
<td>Heart</td>
<td>200</td>
<td></td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Lung tissue</td>
<td>100</td>
<td></td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Kidneys</td>
<td>1100</td>
<td></td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td>1350</td>
<td></td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Skeletal muscles</td>
<td>750</td>
<td></td>
<td>12 500</td>
<td></td>
</tr>
<tr>
<td>Bone</td>
<td>250</td>
<td></td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td>300</td>
<td></td>
<td>1900</td>
<td></td>
</tr>
<tr>
<td>Thyroid gland</td>
<td>50</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Adrenal glands</td>
<td>25</td>
<td></td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Other tissue</td>
<td>175</td>
<td></td>
<td>175</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5000</strong></td>
<td><strong>100</strong></td>
<td><strong>17 800</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

2. Explain how the body increases the rate of blood flow during exercise:

3. (a) State approximately how many times the total rate of blood flow increases between rest and exercise:

(b) Explain why the increase is necessary:

4. (a) Identify which organs or tissues show no change in the rate of blood flow with exercise:

(b) Explain why this is the case:

5. (a) Identify the organs or tissues that show the most change in the rate of blood flow with exercise:

(b) Explain why this is the case:
The mammalian urinary system consists of the kidneys and bladder, and their associated blood vessels and ducts. The kidneys have a plentiful blood supply from the renal artery. The blood plasma is filtered by the kidneys to form urine. Urine is produced continuously, passing along the ureters to the bladder, a hollow muscular organ lined with smooth muscle and stretchable epithelium. Each day the kidneys filter about 180 liters of plasma.

Most of this is reabsorbed, leaving a daily urine output of about 1 liter. By adjusting the composition of the fluid excreted, the kidneys help to maintain the body’s internal chemical balance. All vertebrates have kidneys, but their efficiency in producing a concentrated urine varies considerably. Mammalian kidneys are very efficient, producing a urine that is concentrated to varying degrees depending on requirements.

The Human Urinary System

**Vena cava** returns blood to the heart.

**Dorsal Aorta** supplies oxygenated blood to the body.

**Adrenal glands** are associated with, but not part of, the urinary system.

**Renal vein** returns the blood from the kidney to the venous circulation.

**Renal artery** carries blood from the aorta into the kidney.

**Kidney** produces urine (blood filtration, the removal of waste products, and the regulation of blood volume).

**Ureter** carries urine to the bladder.

**Bladder** (sectioned) stores the urine before it passes out of the body. It can expand to hold about 80% of the daily urine output.

**Urethra** conducts urine from the bladder to the outside. The urethra is regulated by a voluntary sphincter muscle.

The kidneys of rats (above), humans, and other mammals are distinctive, bean-shaped organs that lie at the back of the abdominal cavity to either side of the spine. The kidneys lie outside the peritoneum of the abdominal cavity and are partly protected by the lower ribs. Each kidney is surrounded by three layers of tissue. The innermost renal capsule is a smooth fibrous membrane that acts as a barrier against trauma and infection. The two outer layers comprise fatty tissue and fibrous connective tissue. These act to protect the kidney and anchor it firmly in place.

The very precise alignment of the nephrons (the filtering elements of the kidney) and their associated blood vessels gives the kidney tissue a striated appearance, as seen in this cross section.

Transitional epithelium lines the bladder. This type of epithelium is layered, or stratified, and can be stretched without the outer cells breaking apart from each other.

1. Identify the components of the urinary system and describe their functions:

2. Calculate the percentage of the plasma reabsorbed by the kidneys:

3. The kidney receives blood at a higher pressure than other organs. Suggest why this is the case:

4. Suggest why the kidneys are surrounded by fatty connective tissue:
The Physiology of the Kidney

The functional unit of the kidney, the **nephron**, is a selective filter element, comprising a renal tubule and its associated blood vessels. Filtration, i.e., forcing fluid and dissolved substances through a membrane by pressure, occurs in the first part of the nephron, across the membranes of the capillaries and the glomerular capsule. The passage of water and solutes into the nephron and the formation of the glomerular filtrate depends on the pressure of the blood entering the afferent arteriole (below). If it increases, filtration rate increases; when it falls, glomerular filtration rate also falls. This process is so precisely regulated that, in spite of fluctuations in arteriolar pressure, glomerular filtration rate per day stays constant. After formation of the initial filtrate, the urine is modified through secretion and tubular reabsorption according to physiological needs at the time.

**Internal Structure of the Human Kidney**

Human kidneys are about 100-120 mm long and 25 mm thick. The functional unit of the kidney is the **nephron**. The other parts of the urinary system are primarily passageways and storage areas. The inner tissue of the kidney appears striated (striped), due to alignment of the nephrons and their surrounding blood vessels. It is the precise alignment of the nephrons in the kidney that makes it possible to fit in all the filtering units required. Each kidney contains more than 1 million nephrons. They are **selective filter elements**, which regulate blood composition and pH, and excrete wastes and toxins. The initial urine is formed by **filtration** in the glomerulus. Plasma is filtered through three layers: the capillary wall, and the basement membrane and epithelium of Bowman's capsule. The epithelium comprises very specialized epithelial cells called **podocytes**. The filtrate is modified as it passes through the tubules of the nephron and the final urine passes out the ureter.

**Nephron Structure**

Bowman's capsule is a double walled cup, lying in the cortex of the kidney. It encloses a capillary network called the **glomerulus**. The capsule and its enclosed glomerulus form a **renal corpuscle**.

The epithelium of Bowman's capsule comprises specialized epithelial cells called **podocytes**. The finger-like cellular processes of the podocytes wrap around the glomerular capillaries and the plasma filtrate passes through the filtration slits between them.
Fluid is forced through the capillaries of the *glomerulus*, forming a filtrate similar to blood but lacking cells and proteins.

### Summary of activities in the kidney nephron

Urine is formed in the kidney nephron by ultrafiltration of the blood and subsequent modification of the filtrate to add or remove substances (e.g. ions). The processes involved in urine formation are summarized below for each region of the nephron: glomerulus, proximal convoluted tubule, loop of Henle, distal convoluted tubule, and collecting duct.

### Proximal convoluted tubule

<table>
<thead>
<tr>
<th>Reabsorption of 90% of filtrate</th>
<th>Passive transport</th>
<th>Osmosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active transport</td>
<td>Glucose, Na⁺, K⁺, Mg²⁺, Ca²⁺</td>
<td>Cl⁻</td>
</tr>
</tbody>
</table>

### Loop of Henle

- **Active transport**: Salt transported from the ascending limb
- **Reabsorption**: H₂O by osmosis from the descending limb
- **Passive transport**: Na⁺ and Cl⁻ from the thin part of the limb

*The loop of Henle* has varying permeability to salt and water. The transport of salts and passive movement of water establish and maintain the salt gradient across the medulla necessary for the concentration of the urine in the collecting duct.

### Distal convoluted tubule

- **Reabsorption**: Na⁺, Cl⁻, Ca²⁺ by active transport
- **H₂O by osmosis**
- **Secretion**: H⁺, K⁺ by active transport
- **NH₃ by diffusion**

Water is carried away by blood capillaries and into the venous circulation so that the high interstitial salt gradient is maintained.

### Collecting duct

- **Concentration of urine**: H₂O leaves tubule by osmosis
- **The role of ADH**: ADH promotes reabsorption of water from the collecting duct. When blood volume is low and more water is required, ADH promotes urine concentration.

1. Give a concise definition of a *nephron* and summarize its role in excretion:

2. Explain the importance of the following in the production of urine in the kidney nephron:
   (a) Filtration of the blood at the glomerulus:

   (b) Active secretion:

   (c) Reabsorption:

   (d) Osmosis:

3. (a) Identify the purpose of the salt gradient in the kidney:

   (b) Explain how this salt gradient is produced:
Male Reproductive System

The reproductive role of the male is to produce the sperm and deliver them to the female. When a sperm combines with an egg, it contributes half the genetic material of the offspring and, in humans and other mammals, determines its sex. The reproductive structures in human males (shown below) are in many ways typical of other mammals.

Cross Section Through Seminiferous Tubule
The photograph (below, left) shows maturing sperm (arrowed) with tails projecting into the tubule. Their heads are embedded in the Sertoli cells in the tubule wall and they are ready to break free and move to the epididymis where they complete their maturation. The same cross-section is illustrated diagrammatically (below, right).

Spermatogenesis
Spermatogenesis is the process by which mature spermatozoa (sperm) are produced in the testes. In humans, they are produced at the rate of about 120 million per day. Spermatogenesis is regulated by the hormones FSH (from the anterior pituitary) and testosterone (secreted from the testes in response to ICSH (LH) from the anterior pituitary). Spermatogonia, in the outer layer of the seminiferous tubules, multiply throughout reproductive life. Some of them divide by meiosis into spermatocytes, which produce spermatids. These are transformed into mature sperm by the process of spermiogenesis in the seminiferous tubules of the testis. Full sperm motility is achieved in the epididymis.
Sperm Structure

Mature spermatozoa (sperm) are produced by a process called spermatogenesis in the testes (see description of the process on the previous page). Meiotic division of spermatocytes produces spermatids which then differentiate into mature sperm. Sperm are quite simple in structure because their sole purpose is to swim to the egg and donate their genetic material. They are composed of three regions: headpiece, midpiece, and tail. Sperm do not live long (only about 48 hours), but they swim quickly and there are so many of them (millions per ejaculation) that some are able to reach the egg to fertilize it.

1. The male human reproductive system and associated structures are shown on the opposite page. Using the following word list identify the labeled parts (write your answers in the spaces provided on the diagram).
   Word list: bladder, scrotal sac, sperm duct (vas deferens), seminal vesicle, testis, urethra, prostate gland

2. In a short sentence, state the function of each of the structures labeled (a)-(g) in the diagram on the opposite page:
   (a)
   (b)
   (c)
   (d)
   (e)
   (f)
   (g)

3. (a) Name the process by which mature sperm are formed:
   (b) Name the hormones regulating this process:
   (c) State where most of this process occurs:
   (d) State where the process is completed:

4. The secretions of the prostate gland (which make up a large proportion of the seminal fluid produced in an ejaculation) are of alkaline pH, while the secretions of the vagina are normally slightly acidic. With this information, explain the role the prostate gland secretions have in maintaining the viability of sperm deposited in the vagina.

5. Each ejaculation of a healthy, fertile male contains 100-400 million sperm. Suggest why so many sperm are needed:

6. Recently, concern has been expressed about the level of synthetic estrogen-like chemicals in the environment. Explain the reason for this concern and discuss evidence in support of the claim that these chemicals lower male fertility:
When an egg cell is released from the ovary, it is arrested in metaphase of meiosis II and is termed a secondary oocyte. Fertilization occurs when a sperm penetrates an egg cell at this stage and the sperm and egg nuclei unite to form the zygote. Fertilization is always regarded as time 0 in a period of gestation (pregnancy) and has five distinct stages (below). After fertilization, the zygote begins its development i.e., its growth and differentiation into a multicellular organism (opposite).

Fertilization (Time 0)
The stages in fertilization are represented below in a numbered sequence (1-5)

1. Capacitation
The surface of the sperm cell undergoes changes that are essential to enabling the acrosome reaction and sperm entry.

2. The Acrosome Reaction
Enzymes from the acrosome (an enzyme-filled bag at the tip of the sperm) are released and digest a pathway through the follicle cells (not shown) and the jelly-like zona pellucida surrounding the egg cell (secondary oocyte).

3. Fusion of Sperm Head
The plasma membranes of the sperm and egg fuse, and the nucleus of the sperm enters the egg cytoplasm. Fusion causes a sudden membrane depolarization that acts as a "fast block" to further sperm entry. The fusion of the two plasma membranes also triggers the completion of meiosis II in the egg cell and induces the cortical reaction (below).

4. The Cortical Reaction
The fusion of the two plasma membranes induces a permanent change in the egg surface that prevents further sperm entry. Cortical granules in the egg cytoplasm release their contents into the space between the plasma membrane and the vitelline layer. Substances released from the granules raise and harden the vitelline layer to form a slow (permanent) block to further sperm entry.

5. Zygote Formation
The haploid nuclei fuse, forming a diploid zygote.

1. Briefly describe the significant events (and their importance) occurring at each of the following stages of fertilization:
   (a) Capacitation: ________________________________
   (b) The acrosome reaction: ________________________________
   (c) Fusion of egg and sperm plasma membranes: ________________________________
   (d) The cortical reaction: ________________________________
   (e) Fusion of egg and sperm nuclei: ________________________________

2. Explain the significance of the blocks that prevent entry of more than one sperm into the egg (polyspermy):
   ________________________________

3. (a) Explain why the egg cell, when released from the ovary, is termed a secondary oocyte: ________________________________
   (b) State at which stage, its meiotic division is completed: ________________________________
The female reproductive system in mammals produces eggs, receives the penis and sperm during sexual intercourse, and houses and nourishes the young. Female reproductive systems in mammals are similar in their basic structure (uterus, ovaries etc.) but the shape of the uterus and the form of the placenta during pregnancy vary. The human system is described below.

1. The female human reproductive system and associated structures are illustrated above. Using the word list, identify the labeled parts. **Word list:** ovary, uterus (womb), vagina, fallopian tube (oviduct), cervix, clitoris.

2. In a few words or a short sentence, state the function of each of the structures labeled (a) - (d) in the above diagram:

(a) 

(b) 

(c) 

(d) 

3. (a) Name the organ labeled (A) in the diagram: 

(b) Name the event associated with this organ that occurs every month: 

(c) Name the process by which mature ova are produced: 

4. (a) Name the stage in meiosis at which the oocyte is released from the ovary: 

(b) State when in the reproductive process meiosis II is completed: 

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The Menstrual Cycle

In non-primate mammals the reproductive cycle is characterized by a breeding season and an estrous cycle (a period of greater sexual receptivity during which ovulation occurs). In contrast, humans and other primates are sexually receptive throughout the year and may mate at any time. Like all placental mammals, their uterine lining thickens in preparation for pregnancy. However, unlike other mammals, primates shed this lining as a discharge through the vagina if fertilization does not occur. This event, called menstruation, characterizes the human reproductive or menstrual cycle. In human females, the menstrual cycle starts from the first day of bleeding and lasts for about 28 days. It involves a predictable series of changes that occur in response to hormones. The cycle is divided into three phases (see below), defined by the events in each phase.

1. Name the hormone responsible for:
   (a) Follicle growth: ____________________________
   (b) Ovulation: ____________________________

2. Each month, several ovarian follicles begin development, but only one (the Graafian follicle) develops fully:
   (a) Name the hormone secreted by the developing follicle: ____________________________
   (b) State the role of this hormone during the follicular phase: ____________________________
   (c) Suggest what happens to the follicles that do not continue developing: ____________________________

3. (a) Identify the principal hormone secreted by the corpus luteum: ____________________________
   (b) State the purpose of this hormone: ____________________________

4. State the hormonal trigger for menstruation: ____________________________