Bacterial Cells

Bacterial (prokaryotic) cells are much smaller and simpler than the cells of eukaryotes. They lack many eukaryotic features (e.g. a distinct nucleus and membrane-bound cellular organelles). The bacterial cell wall is an important feature. It is a complex, multi-layered structure and often has a role in virulence. These pages illustrate some features of bacterial structure and diversity.

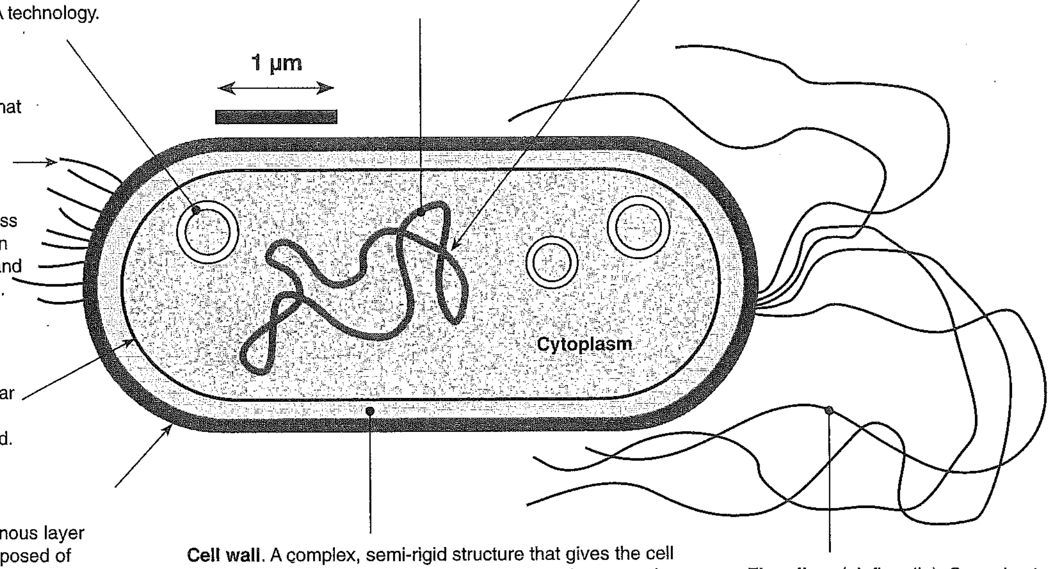
Structure of a Generalized Bacterial Cell

Plasmids: Small, circular DNA molecules (accessory chromosomes) which can reproduce independently of the main chromosome. They can move between cells, and even between species, by **conjugation.** This property accounts for the transmission of antibiotic resistance between bacteria. Plasmids are also used as vectors in recombinant DNA technology.

Single, circular main chromosome: Makes them haploid for most genes. It is possible for some genes to be found on both the plasmid and chromosome and there may be several copies of a gene on a group of plasmids.

The cell lacks a nuclear membrane, so there is no distinct nucleus and the chromosomes are in direct contact with the cytoplasm. It is possible for free ribosomes to attach to mRNA while the mRNA is still in the process of being transcribed from the DNA.

Fimbriae: Hairlike structures that are shorter, straighter, and thinner than flagella. They are used for attachment, not movement. Pili are similar to fimbriae, but are longer and less numerous. They are involved in bacterial conjugation (below) and as phage receptors (opposite).



Cell surface membrane: Similar in composition to eukaryotic membranes, although less rigid.

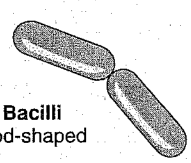
Glycocalyx. A viscous, gelatinous layer outside the cell wall. It is composed of polysaccharide and/or polypeptide. If it is firmly attached to the wall, it is called a **capsule**. If loosely attached, it is called a **slime layer.** Capsules may contribute to virulence in pathogenic species, e.g. by protecting the bacteria from the host's immune attack. In some species, the glycocalyx allows attachment to substrates.

Cell wall. A complex, semi-rigid structure that gives the cell shape, prevents rupture, and serves as an anchorage point for flagella. The cell wall is composed of a macromolecule called **peptidoglycan**; repeating disaccharides attached by polypeptides to form a lattice. The wall also contains varying amounts of lipopolysaccharides and lipoproteins. The amount of peptidoglycan present in the wall forms the basis of the diagnostic **gram stain**. In many species, the cell wall contributes to their virulence (disease-causing ability).

Flagellum (pl. flagella). Some bacteria have long, filamentous appendages, called flagella, that are used for locomotion. There may be a single polar flagellum (monotrichous), one or more flagella at each end of the cell, or the flagella may be distributed over the entire cell (peritrichous).

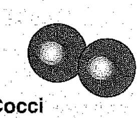
Bacterial cell shapes

Most bacterial cells range between 0.20-2.0 µm in diameter and 2-10 µm length. Although they are a very diverse group, much of this diversity is in their metabolism. In terms of gross morphology, there are only a few basic shapes found (illustrated below). The way in which members of each group aggregate after division is often characteristic and is helpful in identifying certain species.



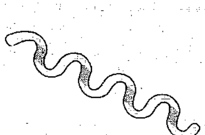
Bacilli
Rod-shaped

Bacilli: Rod-shaped bacteria that divide only across their short axis. Most occur as single rods, although pairs and chains are also found. The term bacillus can refer (as here) to shape. It may also denote a genus.



Cocci
Ball-shaped

Cocci: usually round, but sometimes oval or elongated. When they divide, the cells stay attached to each other and remain in aggregates e.g. pairs (diplococci) or clusters (staphylococci), that are usually a feature of the genus.

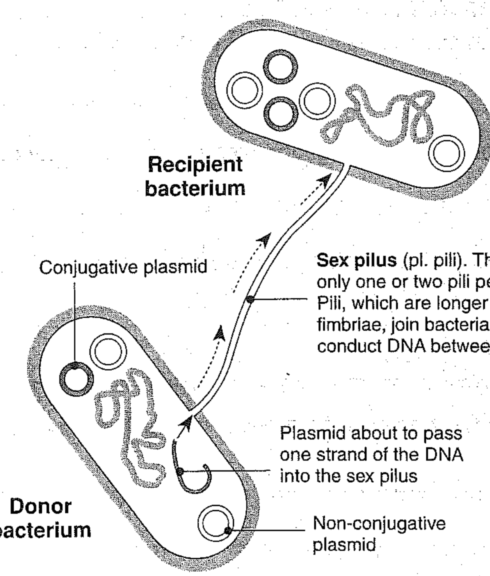


Spirilla
Spiral-shaped

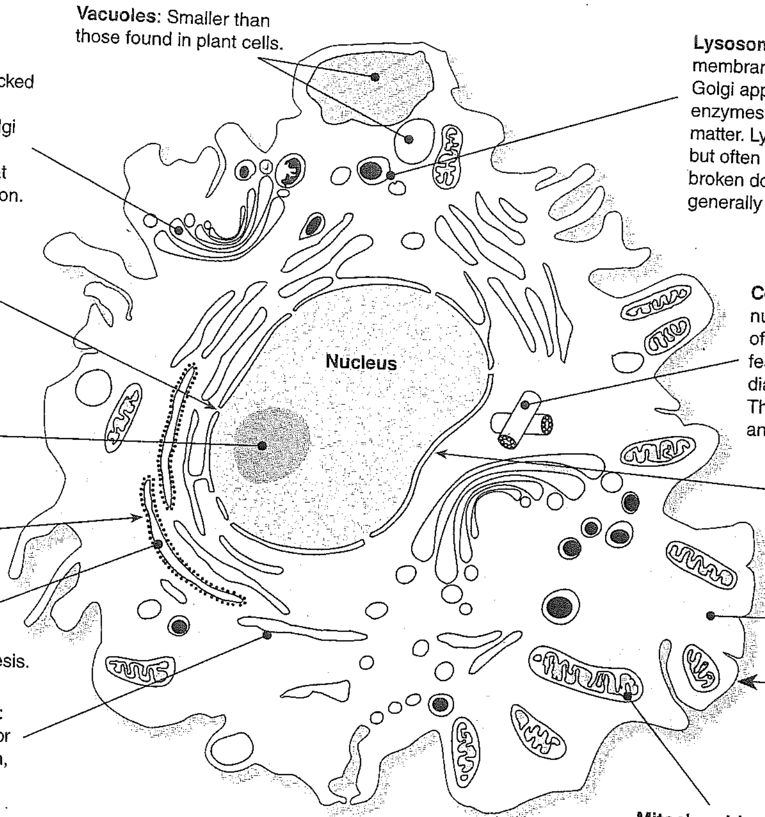
Spirilla and vibrio: Bacteria with one or more twists. Spirilla bacteria have a helical (corkscrew) shape which may be rigid or flexible (as in spirochetes). Bacteria that look like curved rods (comma shaped) are called vibrios.

Bacterial conjugation

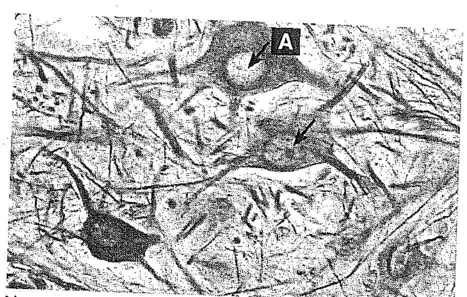
The two bacteria illustrated below are involved in 'pseudo sex'. This involves a one-way exchange of genetic information from a donor cell to a recipient cell. The plasmid, which must be of the 'conjugative' type, passes through a tube called a **sex pilus** to the other cell. Which is donor and which is recipient appears to be genetically determined.



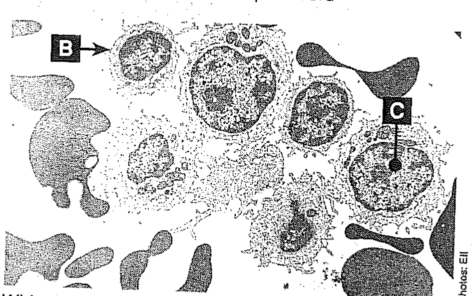
Animal cells, unlike plant cells, do not have a regular shape. In fact, some animal cells (such as phagocytes) are able to alter their shape for various purposes (e.g. engulfment of foreign material). The diagram below shows the structure and function of a typical animal cell and its organelles. Note the differences between this cell and the generalized plant cell. Also see the previous page and following two pages, where further information is provided on the organelles listed here but not described.



Generalized Animal Cell



Neurons (nerve cells) in the spinal cord



White blood cells and red blood cells (blood smear)

1. The two photomicrographs (left) show several types of animal cells. Identify the features indicated by the letters A-C:

   A: ______________________________

   B: ______________________________

   C: ______________________________

2. White blood cells are mobile, phagocytic cells, whereas red blood cells are smaller than white blood cells and, in humans, lack a nucleus.

   (a) In the photomicrograph (below, left), circle a white blood cell and a red blood cell:

   (b) With respect to the features that you can see, explain how you made your decision.

   ____

   ____

   ____

   ____

3. Name and describe one structure or organelle present in generalized animal cells but absent from plant cells:

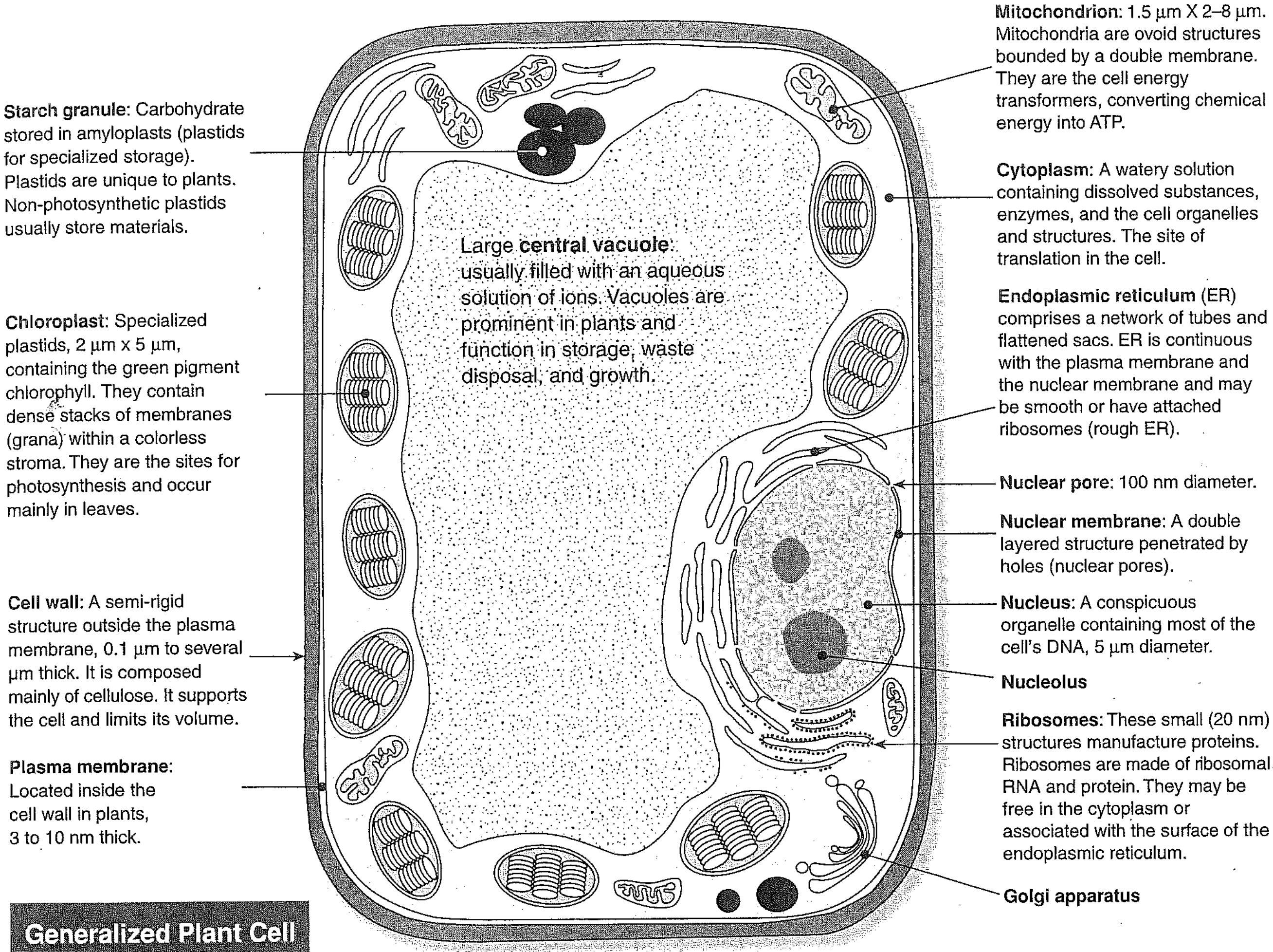
   ____

   ____

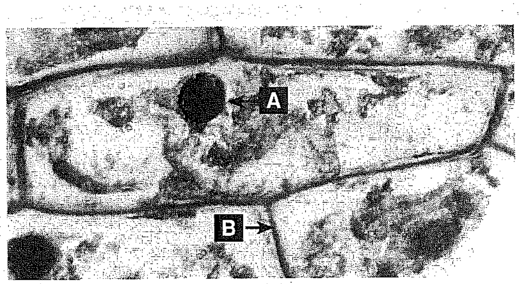
Related activities: Plant Cells, Cell Structures and Organelles
Web links: Review of Eukaryotic Cells

Plant Cells

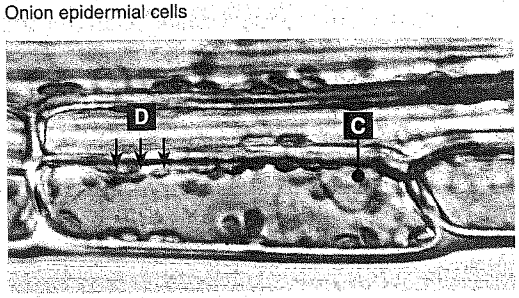
Plant cells are enclosed in a cellulose cell wall. The cell wall protects the cell, maintains its shape, and prevents excessive water uptake. It does not interfere with the passage of materials into and out of the cell. The diagram below shows the structure and function of a typical plant cell and its organelles. Also see the following pages where further information is provided on the organelles listed here but not described.



Generalized Plant Cell



Onion epidermial cells



Elodea cells

Photos: RCN

1. The two photographs (left) show plant cells as seen by a light microscope. Identify the basic features labelled A-D:

   A: ______________________

   B: ______________________

   C: ______________________

   D: ______________________

2. Cytoplasmic streaming is a feature of eukaryotic cells, often clearly visible with a light microscope in plant (and algal) cells.

   (a) Explain what is meant by cytoplasmic streaming:

   ____

   ____

   (b) For the *Elodea* cell (lower, left), draw arrows to indicate cytoplasmic streaming movements.

3. Describe three structures/organelles present in generalized plant cells but absent from animal cells (also see page 92):

   (a) ______________________

   (b) ______________________

   (c) ______________________

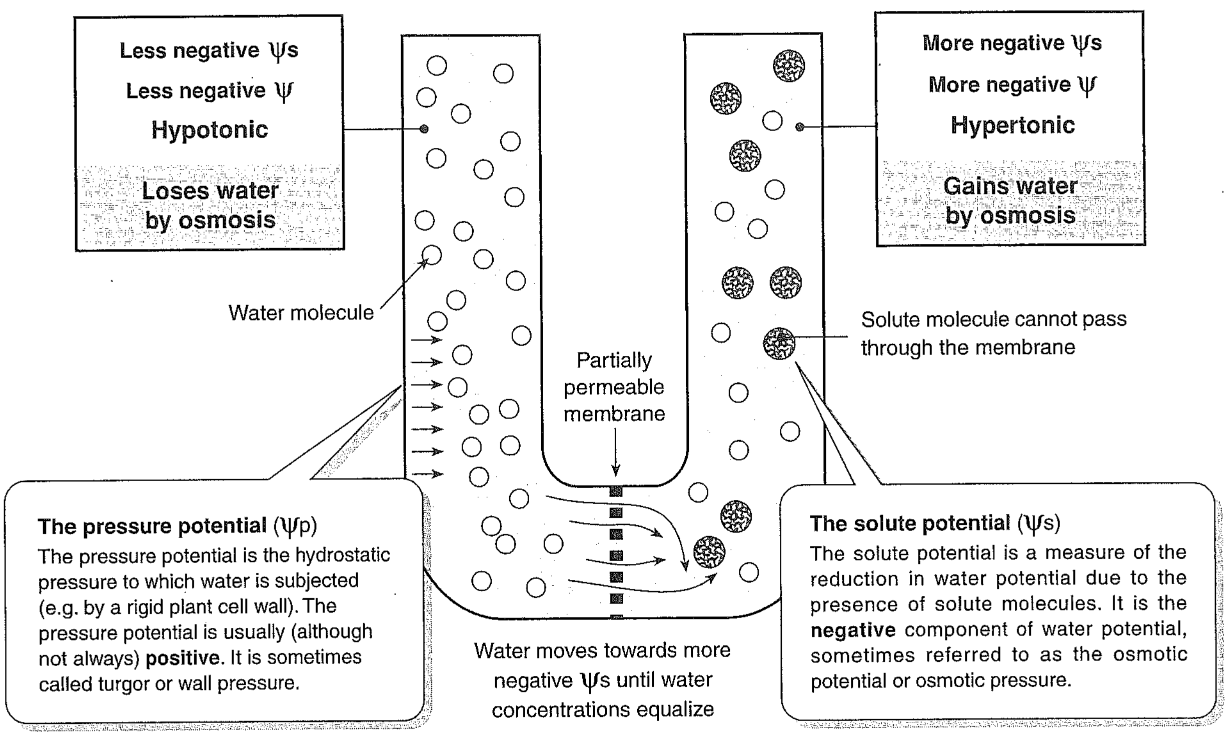
Osmosis and Water Potential

Osmosis is the term describing the diffusion of water along its concentration gradient across a partially permeable membrane. It is the principal mechanism by which water enters and leaves cells in living organisms. As it is a type of diffusion, the rate at which osmosis occurs is affected by the same factors that affect all diffusion rates (see earlier). The tendency for water to move in any particular direction can be calculated on the basis of the **water potential** (ψ) of the cell sap relative to its surrounding environment. The use of water potential to express the water relations of cells has replaced the terms osmotic potential and osmotic pressure although these are still frequently used in areas of animal physiology and medicine. An alternative version which does not use this terminology is available on the *TRC: Osmosis and Diffusion* (or see web links below).

Osmosis and the Water Potential of Cells

Osmosis is simply the diffusion of water molecules from high concentration to lower concentration, across a partially permeable membrane. The direction of this movement can be predicted on the basis of the water potential of the solutions involved. The **water potential** of a solution (denoted with the symbol ψ) is the term given to the tendency for water molecules to enter or leave a solution by osmosis. Pure water has the highest water potential, set at zero. Dissolving any solute into pure water lowers the water potential (makes it more negative). *Water always diffuses from regions of less negative to more negative water potential.* Water potential is determined by two components: the **solute potential**, **ψs** (of the cell sap) and the **pressure potential**, **ψp**. This is expressed as a simple equation:

$$\psi cell = \psi s + \psi p$$



1. State the water potential of pure water at standard temperature and pressure: ______________________

2. The three diagrams below show the solute and pressure potential values for three hypothetical situations where two solutions are separated by a selectively permeable membrane. For each example (a) - (c) calculate ψ for the solutions on each side of the membrane, as indicated:

3. Draw arrows on each diagram to indicate the direction of net flow of water:

	(a) A	(a) B	(b) A	(b) B	(c) A	(c) B
ψs	–400kPa	–500kPa	–500kPa	–600kPa	–500kPa	–600kPa
ψp	300kPa	300kPa	100kPa	200kPa	300kPa	400kPa

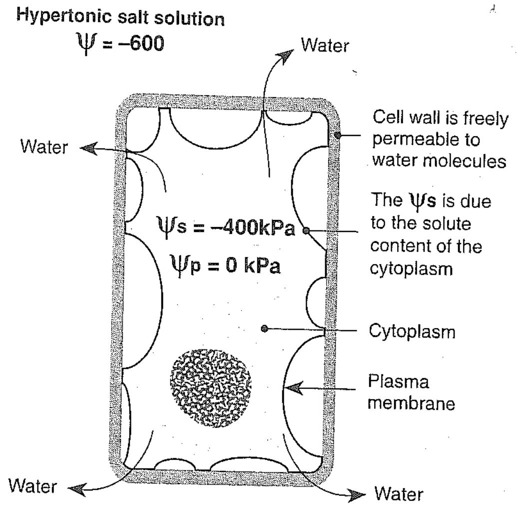
Calculate ψ for side A ______________ ______________ ______________

Calculate ψ for side B ______________ ______________ ______________

Water Relations in Plant Cells

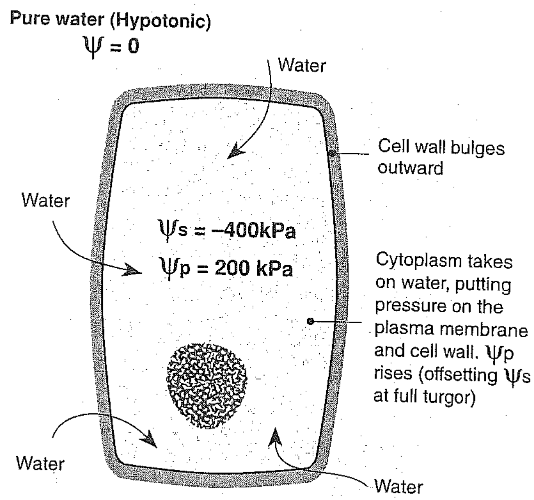
The plasma membrane of cells is a partially permeable membrane and osmosis is the principal mechanism by which water enters and leaves the cell. When the external water potential is the same as that of the cell there is no net movement of water. Two systems (cell and environment) with the same water potential are termed **isotonic**. The diagram below illustrates two different situations: when the external water potential is less negative than the cell (**hypotonic**) and when it is more negative than the cell (**hypertonic**).

Plasmolysis in a Plant Cell



In a **hypertonic** solution, the external water potential is more negative than the water potential of the cell ($\psi cell = \psi s + \psi p$). Water leaves the cell and, because the cell wall is rigid, the plasma membrane shrinks away from the cell wall. This process is termed **plasmolysis** and the cell becomes **flaccid** ($\psi p = 0$). Full plasmolysis is irreversible; the cell cannot recover by taking up water.

Turgor in a Plant Cell



In a **hypotonic** solution, the external water potential is less negative than the ψcell. Water enters the cell causing it to swell tight. A pressure potential is generated when sufficient water has been taken up to cause the cell contents to press against the cell wall. ψp rises progressively until it offsets ψs. Water uptake stops when $\psi cell = 0$. The rigid cell wall prevents cell rupture. Cells in this state are **turgid**.

4. Fluid replacements are usually provided for heavily perspiring athletes after endurance events.
   (a) Identify the preferable tonicity of these replacement drinks (isotonic, hypertonic, or hypotonic): ____________
   (b) Give a reason for your answer: ____

5. *Paramecium* is a freshwater protozoan. Describe the problem it has in controlling the amount of water inside the cell:
   ____

6. (a) Explain the role of pressure potential in generating cell turgor in plants: ____________________
   (b) Explain the purpose of cell turgor to plants: ____________________

7. Explain how animal cells differ from plant cells with respect to the effects of net water movements: ____________

8. Describe what would happen to an animal cell (e.g. a red blood cell) if it was placed into:
   (a) Pure water: ____________________
   (b) A hypertonic solution: ____________________
   (c) A hypotonic solution: ____________________

9. The malarial parasite lives in human blood. Relative to the tonicity of the blood, the parasite's cell contents would be hypertonic / isotonic / hypotonic (circle the correct answer).

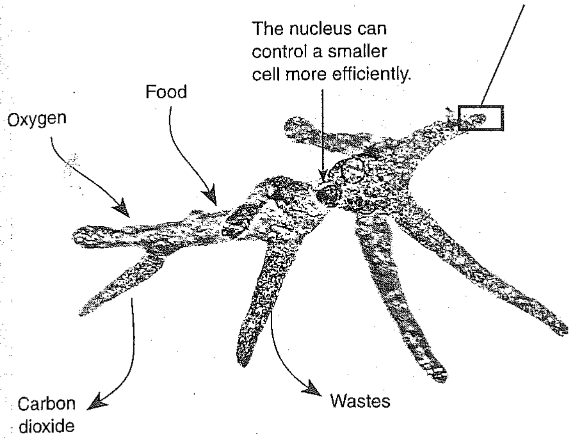
Surface Area and Volume

When an object (e.g. a cell) is small it has a large surface area in comparison to its volume. In this case diffusion will be an effective way to transport materials (e.g. gases) into the cell. As an object becomes larger, its surface area compared to its volume is smaller. Diffusion is no longer an effective way to transport materials to the inside. For this reason, there is a physical limit for the size of a cell, with the effectiveness of diffusion being the controlling factor.

Diffusion in Organisms of Different Sizes

Respiratory gases and some other substances are exchanged with the surroundings by diffusion or active transport across the plasma membrane.

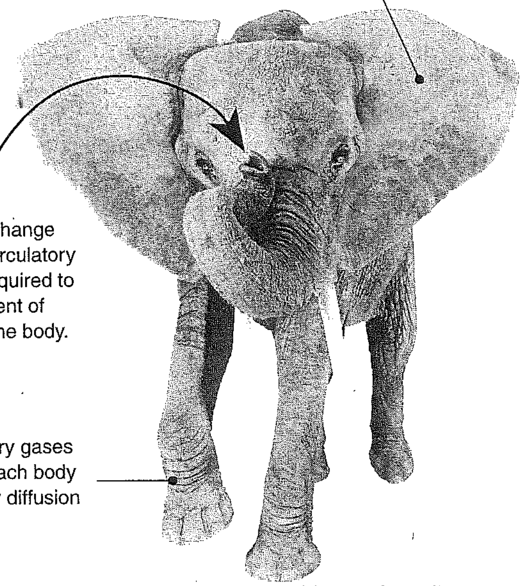
The **plasma membrane**, which surrounds every cell, functions as a selective barrier that regulates the cell's chemical composition. For each square micrometer of membrane, only so much of a particular substance can cross per second.



The surface area of an elephant is increased, for radiating body heat, by large flat ears.

A specialized gas exchange surface (lungs) and circulatory (blood) system are required to speed up the movement of substances through the body.

Respiratory gases cannot reach body tissues by diffusion alone.

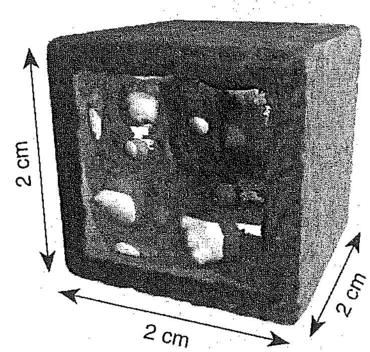


Amoeba: The small size of single-celled protists, such as *Amoeba,* provides a large surface area relative to the cell s volume. This is adequate for many materials to be moved into and out of the cell by diffusion or active transport.

Multicellular organisms: To overcome the problems of small cell size, plants and animals became multicellular. They provide a small surface area compared to their volume but have evolved various adaptive features to improve their effective surface area.

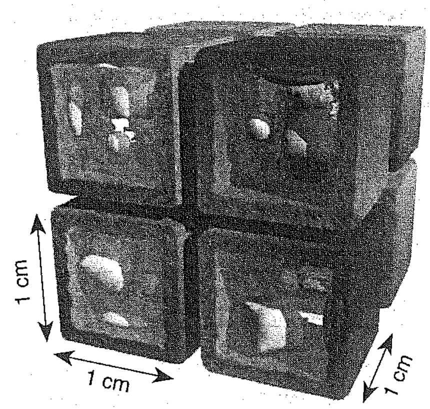
Smaller is Better for Diffusion

One large cube



Volume: = 8 cm^3
Surface area: = 24 cm^2

Eight small cubes

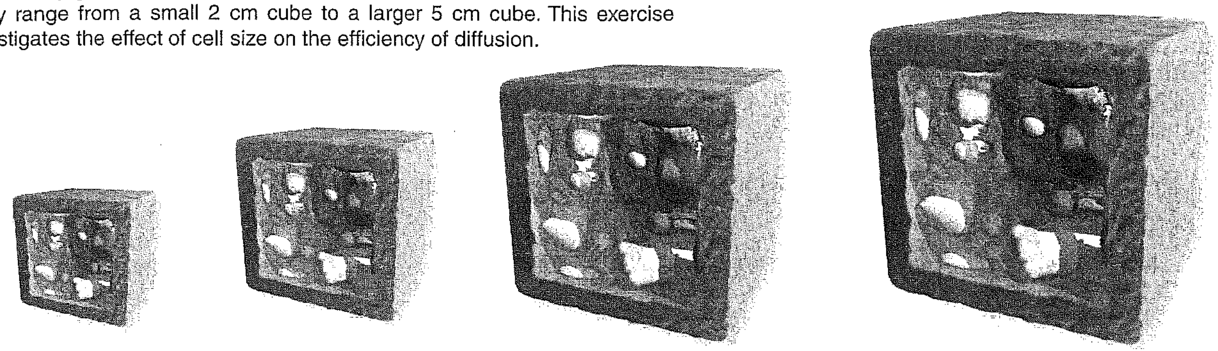


Volume: = 8 cm^3 for 8 cubes
Surface area: = 6 cm^2 for 1 cube
= 48 cm^2 for 8 cubes

The eight small cells and the single large cell have the same total volume, but their surface areas are different. The small cells together have twice the total surface area of the large cell, because there are more exposed (inner) surfaces. Real organisms have complex shapes, but the same principles apply.

The surface-area volume relationship has important implications for processes involving transport into and out of cells across membranes. For activities such as gas exchange, the surface area available for diffusion is a major factor limiting the rate at which oxygen can be supplied to tissues.

The diagram below shows four hypothetical cells of different sizes (cells do not actually grow to this size, their large size is for the sake of the exercise). They range from a small 2 cm cube to a larger 5 cm cube. This exercise investigates the effect of cell size on the efficiency of diffusion.



2 cm cube **3 cm cube** **4 cm cube** **5 cm cube**

1. Calculate the volume, surface area and the ratio of surface area to volume for each of the four cubes above (the first has been done for you). When completing the table below, show your calculations.

Cube size	Surface area	Volume	Surface area to volume ratio
2 cm cube	$2 \times 2 \times 6 = 24\ cm^2$ (2 cm x 2 cm x 6 sides)	$2 \times 2 \times 2 = 8\ cm^3$ (height x width x depth)	24 to 8 = 3:1
3 cm cube			
4 cm cube			
5 cm cube			

2. Create a graph, plotting the surface area against the volume of each cube, on the grid on the right. Draw a line connecting the points and label axes and units.

3. State which increases the fastest with increasing size: the **volume** or **surface area**.

____

4. Explain what happens to the ratio of surface area to volume with increasing size:

____

____

____

____

____

5. Diffusion of substances into and out of a cell occurs across the cell surface. Describe how increasing the size of a cell will affect the ability of diffusion to transport materials into and out of a cell:

____

____

____

____

____

____

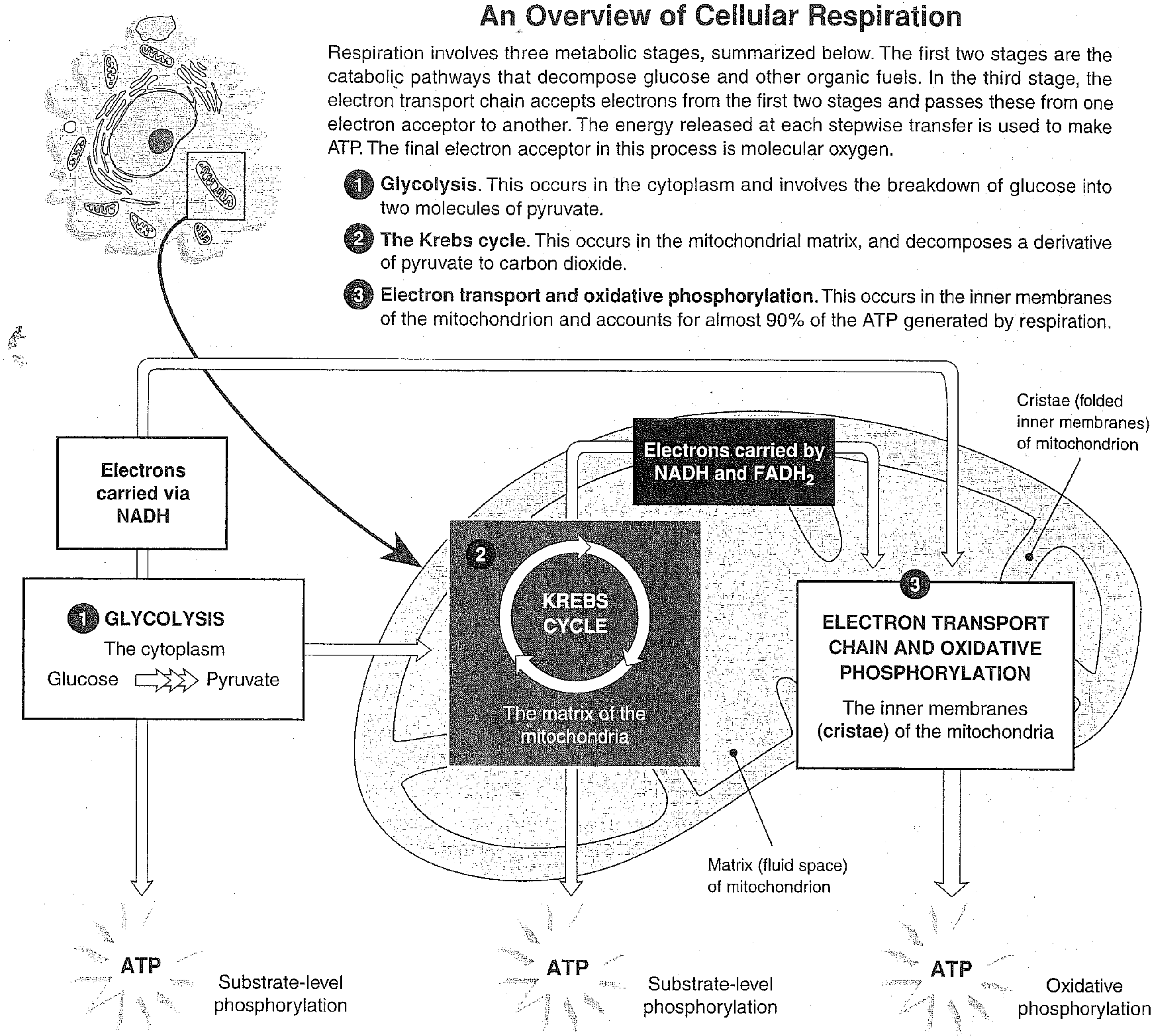
Cellular Respiration

Cellular respiration is the process by which organisms break down energy rich molecules (e.g. glucose) to release the energy in a usable form (ATP). All living cells respire in order to exist, although the substrates they use may vary. **Aerobic respiration** requires oxygen. Forms of cellular respiration that do not require oxygen are said to be **anaerobic**. Some plants and animals can generate ATP anaerobically for short periods of time. Other organisms use only anaerobic respiration and live in oxygen-free environments. For these organisms, there is some other final electron acceptor other than oxygen (e.g. nitrate or Fe^{2+}).

An Overview of Cellular Respiration

Respiration involves three metabolic stages, summarized below. The first two stages are the catabolic pathways that decompose glucose and other organic fuels. In the third stage, the electron transport chain accepts electrons from the first two stages and passes these from one electron acceptor to another. The energy released at each stepwise transfer is used to make ATP. The final electron acceptor in this process is molecular oxygen.

1. **Glycolysis.** This occurs in the cytoplasm and involves the breakdown of glucose into two molecules of pyruvate.
2. **The Krebs cycle.** This occurs in the mitochondrial matrix, and decomposes a derivative of pyruvate to carbon dioxide.
3. **Electron transport and oxidative phosphorylation.** This occurs in the inner membranes of the mitochondrion and accounts for almost 90% of the ATP generated by respiration.



1. Describe precisely in which part of the cell the following take place:

   (a) Glycolysis: ______________________________

   (b) Krebs cycle reactions: ______________________________

   (c) Electron transport chain: ______________________________

2. Provide a clear explanation of what is involved in each of the following processes:

   (a) Substrate-level phosphorylation: ______________________________

   ____

   ____

   (b) Oxidative phosphorylation: ______________________________

   ____

   ____

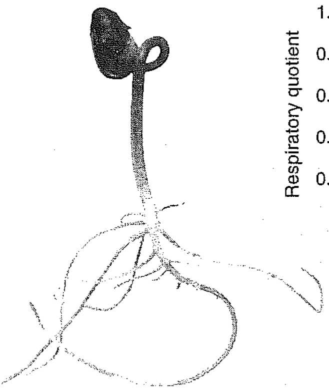
Measuring Respiration

In small animals or germinating seeds, the rate of cellular respiration can be measured using a simple respirometer: a sealed unit where the carbon dioxide produced by the respiring tissues is absorbed by soda lime and the volume of oxygen consumed is detected by fluid displacement in a manometer. Germinating seeds are also often used to calculate the **respiratory quotient** (RQ): the ratio of the amount of carbon dioxide produced during cellular respiration to the amount of oxygen consumed. RQ provides a useful indication of the respiratory substrate being used.

Respiratory Substrates and RQ

The respiratory quotient (RQ) can be expressed simply as:

$$RQ = \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}}$$



When pure carbohydrate is oxidized in cellular respiration, the RQ is 1.0; more oxygen is required to oxidize fatty acids (RQ = 0.7). The RQ for protein is about 0.9. Organisms usually respire a mix of substrates, giving RQ values of between 0.8 and 0.9 (see table 1, below).

Table 1: RQ values for the respiration of various substrates

RQ	Substrate
> 1.0	Carbohydrate with some anaerobic respiration
1.0	Carbohydrates e.g. glucose
0.9	Protein
0.7	Fat
0.5	Fat with associated carbohydrate synthesis
0.3	Carbohydrate with associated organic acid synthesis

Using RQ to determine respiratory substrate

Fig. 1: RQ in relation to germination stage in wheat

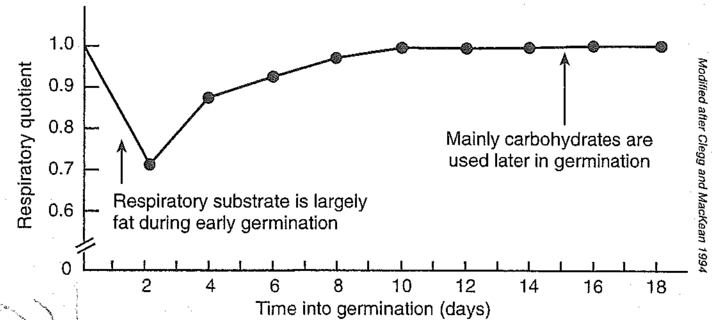
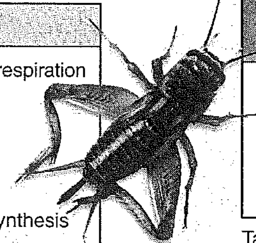


Fig. 1, above, shows how experimental RQ values have been used to determine the respiratory substrate utilized by germinating wheat seeds (*Triticum sativum*) over the period of their germination.

Table 2: Rates of O_2 consumption and CO_2 production in crickets



Time after last fed (h)	Temperature (°C)	Rate of O_2 consumption ($ml\,g^{-1}h^{-1}$)	Rate of CO_2 production ($ml\,g^{-1}h^{-1}$)
1	20	2.82	2.82
48	20	2.82	1.97
1	30	5.12	5.12
48	30	5.12	3.57

Table 2 shows the rates of oxygen consumption and carbon dioxide production of crickets kept under different experimental conditions.

1. Table 2 above shows the results of an experiment to measure the rates of oxygen consumption and carbon dioxide production of crickets 1 hour and 48 hours after feeding at different temperatures:

   (a) Calculate the RQ of a cricket kept at 20°C, 48 hours after feeding (show working): ______________________

   (b) Compare this RQ to the RQ value obtained for the cricket 1 hour after being fed (20°C). Explain the difference:

   ____

   ____

2. The RQs of two species of seeds were calculated at two day intervals after germination. Results are tabulated to the right:

   (a) Plot the change in RQ of the two species during early germination:

   (b) Explain the values in terms of the possible substrates being respired:

   ____

   ____

   ____

   ____

   ____

   ____

   ____

Days after germination	RQ	
	Seedling A	Seedling B
2	0.65	0.70
4	0.35	0.91
6	0.48	0.98
8	0.68	1.00
10	0.70	1.00

Cellular Energetics

Anaerobic Pathways

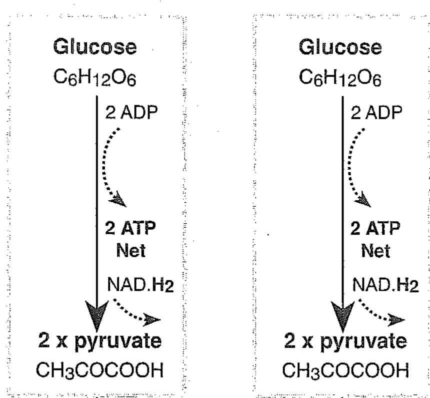
All organisms can metabolize glucose anaerobically (without oxygen) using glycolysis in the cytoplasm, but the energy yield from this process is low and few organisms can obtain sufficient energy for their needs this way. In the absence of oxygen, glycolysis soon stops unless there is an alternative acceptor for the electrons produced from the glycolytic pathway. In yeasts and the root cells of higher plants this acceptor is ethanal, and the pathway is called alcoholic fermentation. In the skeletal muscle of mammals, the acceptor is pyruvate itself and the end product is lactic acid. In both cases, the duration of the fermentation is limited by the toxic effects of the organic compound produced. Although fermentation is often used synonymously with anaerobic respiration, they are not the same. Respiration always involves hydrogen ions passing down a chain of carriers to a terminal acceptor, and this does not occur in fermentation. In anaerobic respiration, the terminal H^+ acceptor is a molecule other than oxygen, e.g. Fe^{2+} or nitrate.

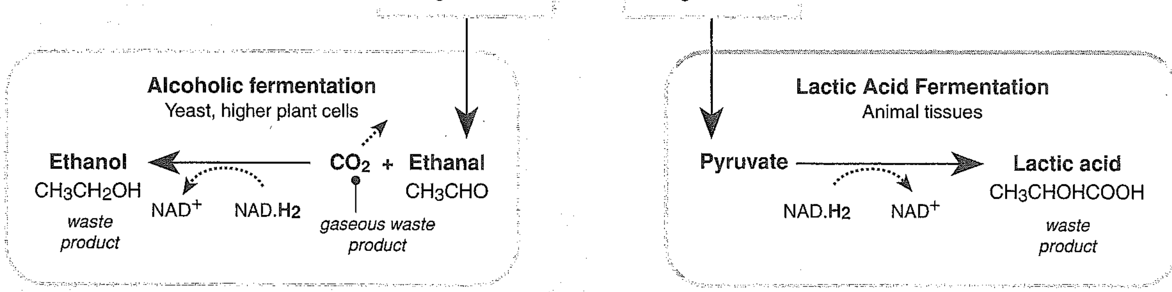
Alcoholic Fermentation

In alcoholic fermentation, the H^+ acceptor is ethanal which is reduced to ethanol with the release of CO_2. Yeasts respire aerobically when oxygen is available but can use alcoholic fermentation when it is not. At levels above 12-15%, the ethanol produced by alcoholic fermentation is toxic to the yeast cells and this limits their ability to use this pathway indefinitely. The root cells of plants also use fermentation as a pathway when oxygen is unavailable but the ethanol must be converted back to respiratory intermediates and respired aerobically.

Lactic Acid Fermentation

In the absence of oxygen, the skeletal muscle cells of mammals are able to continue using glycolysis for ATP production by reducing pyruvate to lactic acid (the H^+ acceptor is pyruvate itself). This process is called lactic acid fermentation. Lactic acid is toxic and this pathway cannot continue indefinitely. The lactic acid must be removed from the muscle and transported to the liver, where it is converted back to respiratory intermediates and respired aerobically.





CDC

Some organisms respire only in the absence of oxygen and are known as **obligate anaerobes**. Many of these organisms are bacterial pathogens and cause diseases such as tetanus (*above*), gangrene, and botulism.

Vertebrate skeletal muscle is **facultatively anaerobic** because it has the ability to generate ATP for a short time in the absence of oxygen. The energy from this pathway comes from glycolysis and the yield is low.

The products of alcoholic fermentation have been utilized by humans for centuries. The alcohol and carbon dioxide produced from this process form the basis of the brewing and baking industries.

1. Describe the key difference between aerobic respiration and fermentation: ____________________

____

2. (a) Refer to page 133 and determine the efficiency of fermentation compared to aerobic respiration: __________ %

   (b) In simple terms, explain why the efficiency of anaerobic pathways is so low: ____________________

   ____

3. Explain why fermentation cannot go on indefinitely: ____________________

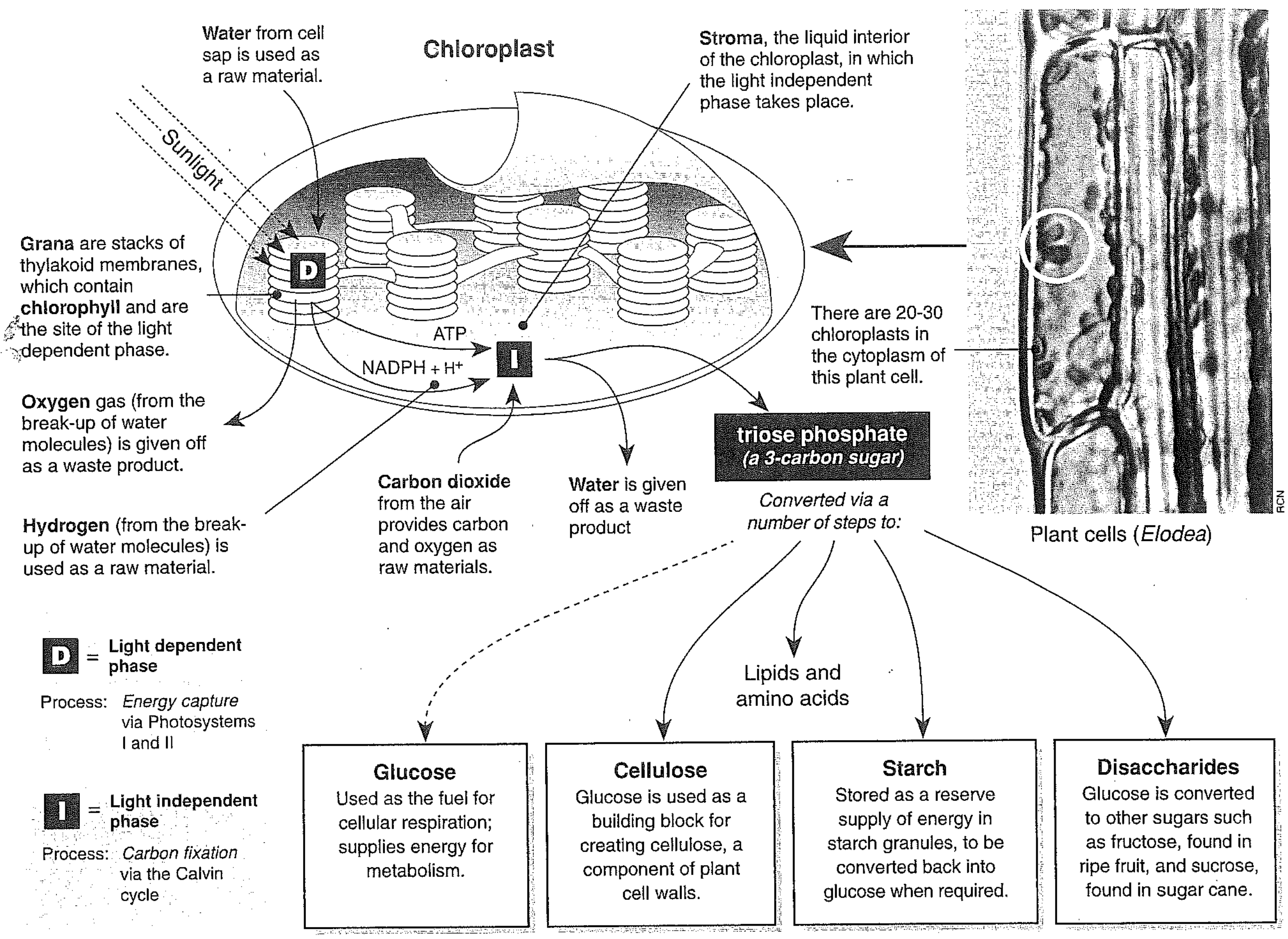
____

____

Photosynthesis

Photosynthesis is of fundamental importance to living things because it transforms sunlight energy into chemical energy stored in molecules. This becomes part of the energy available in food chains. The molecules that trap the energy in their chemical bonds are also used as building blocks to create other molecules. Finally, photosynthesis releases free oxygen gas, essential for the survival of advanced life forms. Below is a diagram summarizing the process of photosynthesis.

Summary of Photosynthesis in a C_3 Plant



1. Describe the three things of fundamental biological importance provided by photosynthesis:

   (a) ______________________________

   (b) ______________________________

   (c) ______________________________

2. Write the overall chemical equation for photosynthesis using:

   (a) Words: ______________________________

   (b) Chemical symbols: ______________________________

3. Discuss the potential uses for the end products of photosynthesis: ______________________________

   ____

   ____

4. Distinguish between the two different regions of a chloroplast and describe the biochemical processes that occur in each:

   ____

   ____

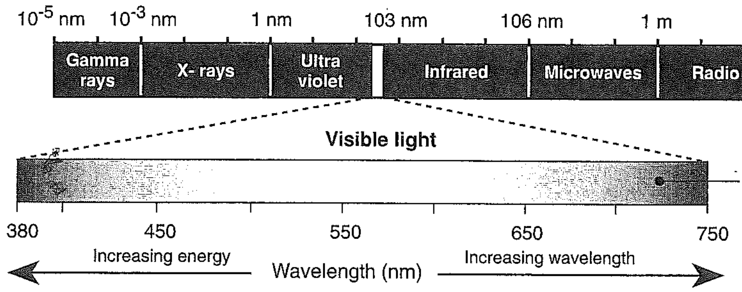
   ____

Pigments and Light Absorption

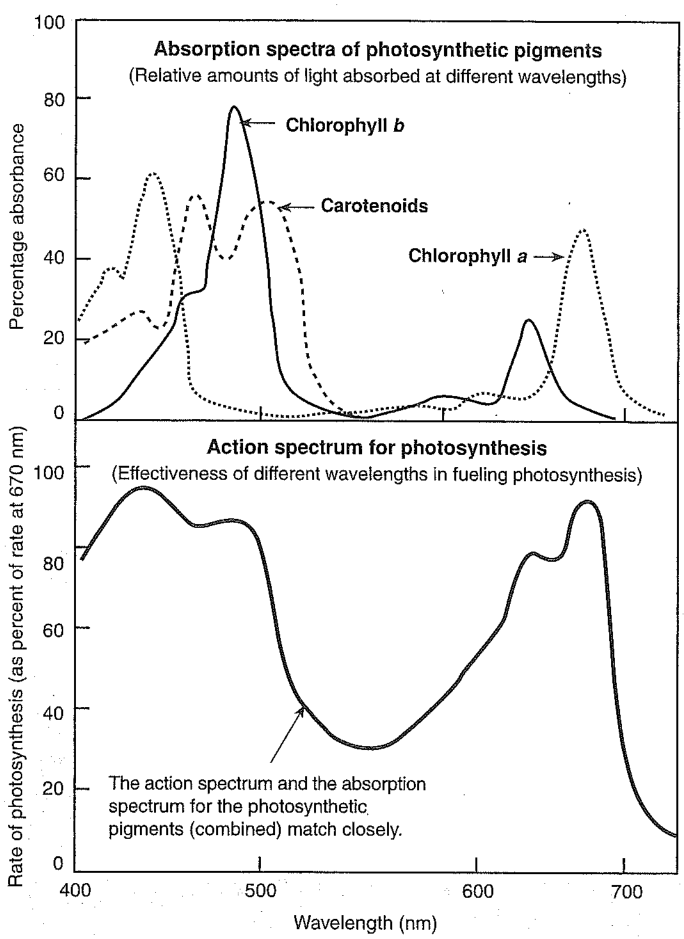
As light meets matter, it may be reflected, transmitted, or absorbed. Substances that absorb visible light are called **pigments**, and different pigments absorb light of different wavelengths. The ability of a pigment to absorb particular wavelengths of light can be measured with a spectrophotometer. The light absorption vs the wavelength is called the **absorption spectrum** of that pigment. The absorption spectrum of different photosynthetic pigments provides clues to their role in photosynthesis, since light can only perform work if it is absorbed. An **action spectrum** profiles the effectiveness of different wavelength light in fuelling photosynthesis. It is obtained by plotting wavelength against some measure of photosynthetic rate (e.g. CO_2 production). Some features of photosynthetic pigments and their light absorbing properties are outlined below.

The Electromagnetic Spectrum

Light is a form of energy known as electromagnetic radiation. The segment of the electromagnetic spectrum most important to life is the narrow band between about 380 and 750 nanometres (nm). This radiation is known as visible light because it is detected as colors by the human eye (although some other animals, such as insects, can see in the ultraviolet range). It is the visible light that drives photosynthesis.

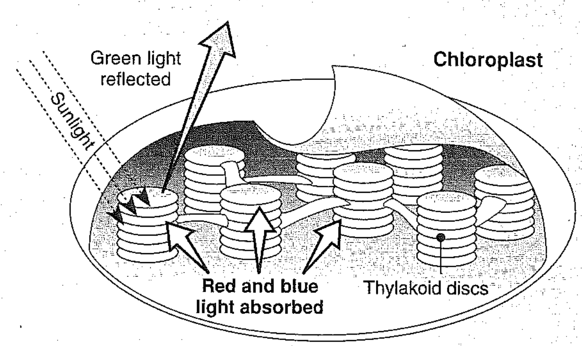


Electromagnetic radiation (EMR) travels in waves, where wavelength provides a guide to the energy of the photons; the greater the wavelength of EMR, the lower the energy of the photons in that radiation.



The Photosynthetic Pigments of Plants

The photosynthetic pigments of plants fall into two categories: **chlorophylls** (which absorb red and blue-violet light) and **carotenoids** (which absorb strongly in the blue-violet and appear orange, yellow, or red). The pigments are located on the chloroplast membranes (the thylakoids) and are associated with membrane transport systems.



The pigments of chloroplasts in higher plants (above) absorb blue and red light, and the leaves therefore appear green (which is reflected). Each photosynthetic pigment has its own characteristic **absorption spectrum** (left, top graph). Although only chlorophyll *a* can participate directly in the light reactions of photosynthesis, the **accessory pigments** (chlorophyll *b* and carotenoids) can absorb wavelengths of light that chlorophyll *a* cannot. The accessory pigments pass the energy (photons) to chlorophyll *a*, thus broadening the spectrum that can effectively drive photosynthesis.

Left: Graphs comparing absorption spectra of photosynthetic pigments compared with the action spectrum for photosynthesis.

1. Explain what is meant by the absorption spectrum of a pigment: ______________________

____

2. Explain why the action spectrum for photosynthesis does not exactly match the absorption spectrum of chlorophyll *a*:

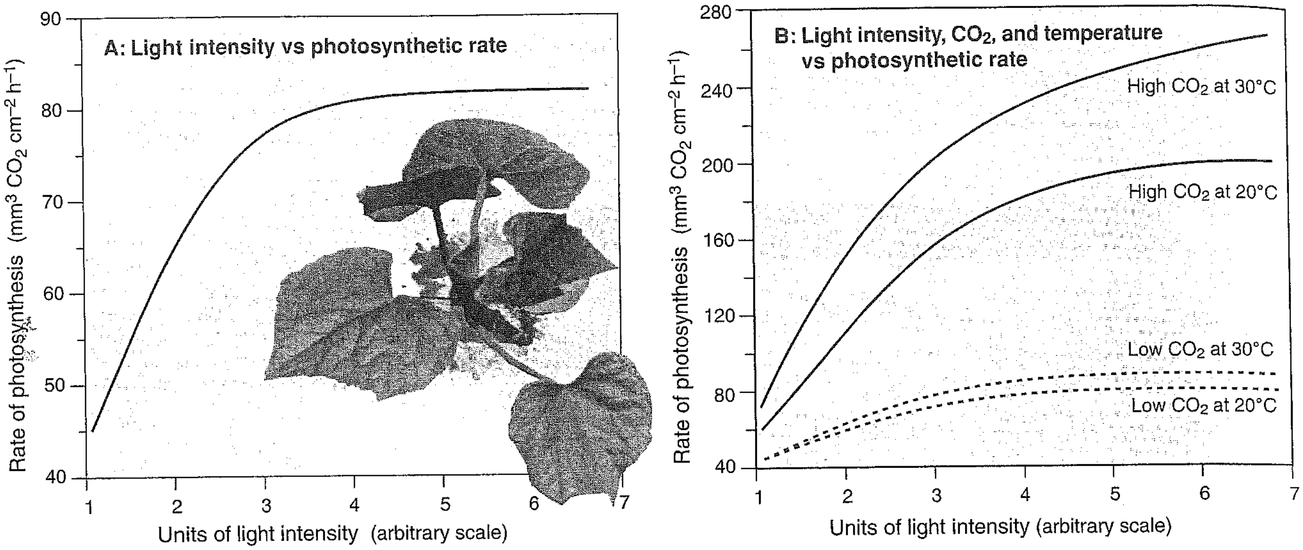
____

____

Photosynthetic Rate

The rate at which plants can make food (the photosynthetic rate) is dependent on environmental factors, particularly the amount of **light** available, the level of **carbon dioxide** (CO_2) and the **temperature**. The effect of these factors can be tested experimentally by altering one of the factors while holding others constant (a controlled experiment). In reality, a plant is subjected to variations in all three factors at the same time. The interaction of the different factors can also be examined in the same way, as long as only one factor at a time is altered. The results can be expressed in a graph.

Factors Affecting Photosynthetic Rate



The two graphs above illustrate the effect of different variables on the rate of photosynthesis in cucumber plants. Graph A (above, left) shows the effect of different intensities of light. In this experiment, the level of carbon dioxide available and the temperature were kept constant. Graph B (above, right) shows the effect of different light intensities at two temperatures and two carbon dioxide (CO_2) concentrations. In each of these experiments either the carbon dioxide level or the temperature was raised at each light intensity in turn.

1. (a) Describe the effect of increasing light intensity on the rate of photosynthesis (temperature and CO_2 constant):

   (b) Give a possible explanation for the shape of the curve:

2. (a) Describe the effect of increasing the temperature on the rate of photosynthesis:

   (b) Suggest a reason for this response:

3. Explain why the rate of photosynthesis declines when the CO_2 level is reduced:

4. (a) In the graph above right, explain how the effects of CO_2 level were separated from the effects of temperature:

   (b) State which of the two factors, CO_2 level or temperature, has the greatest effect on photosynthetic rate:

   (c) Explain how you can tell this from the graph:

Acquired Immunity

We have natural or **innate resistance** to certain illnesses: examples include most diseases of other animal species. **Acquired immunity** refers to the protection an animal develops against certain types of microbes or foreign substances. Immunity can be acquired either passively or actively and is developed during an individual's lifetime. **Active immunity** develops when a person is exposed to microorganisms or foreign substances and the immune system responds. **Passive immunity** is acquired when antibodies are transferred from one person to another. Recipients do not make the antibodies themselves and the effect lasts only as long as the antibodies are present; usually several weeks or months. Immunity may also be **naturally acquired**, through natural exposure to microbes, or **artificially acquired** as a result of medical treatment.

Acquired immunity

Naturally acquired

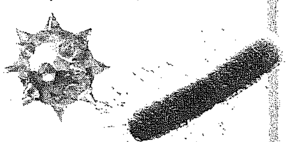
Active

Antigens enter the body naturally, as in cases where:

¥ Microbes cause the person to actually catch the disease

¥ Sub-clinical infections (those that produce no evident symptoms).

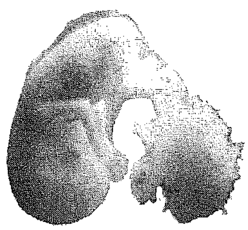
The body produces antibodies and specialised lymphocytes.



Passive

Antibodies pass from the mother to the foetus via the placenta during pregnancy, or to her infant through her milk.

The infant's body does not produce any antibodies of its own.

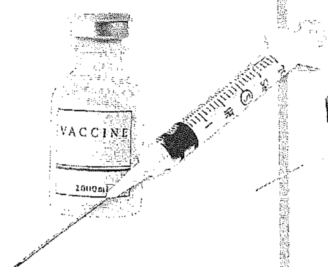


Artificially acquired

Active

Antigens (weakened, dead, or fragments of microbes) are introduced in **vaccines**.

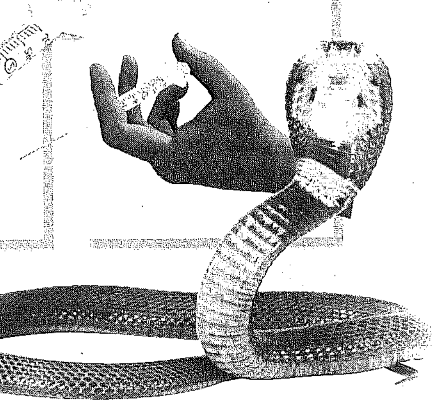
The body produces antibodies and specialised lymphocytes.



Passive

Preformed antibodies in an **immune serum** are introduced into the body by injection (e.g. antivenom used to treat snake bites).

The body does not produce any antibodies.



1. (a) Explain what is meant by **active immunity**:

____

(b) Distinguish between naturally and artificially acquired active immunity and give an example of each:

____

2. (a) Explain what is meant by **passive immunity**:

____

(b) Distinguish between naturally and artificially acquired passive immunity and give an example of each:

____

3. (a) Explain why a newborn baby needs to have received a supply of maternal antibodies prior to birth:

____

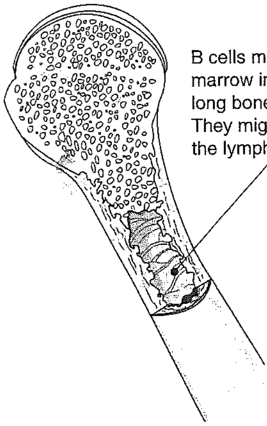
(b) Explain why this supply is supplemented by antibodies provided in breast milk:

____

The Immune System

The efficient internal defense provided by the immune system is based on its ability to respond specifically against a foreign substance and its ability to hold a memory of this response. There are two main components of the immune system: the humoral and the cell-mediated responses. They work separately and together to protect us from disease. The **humoral immune response** is associated with the serum (non-cellular part of the blood) and involves the action of **antibodies** secreted by B cell lymphocytes. Antibodies are found in extracellular fluids including lymph, plasma, and mucus secretions. The humoral response protects the body against circulating viruses, and bacteria and their toxins. The **cell-mediated immune response** is associated with the production of specialized lymphocytes called **T cells.** It is most effective against bacteria and viruses located within host cells, as well as against parasitic protozoa, fungi, and worms. This system is also an important defense against cancer, and is responsible for the rejection of transplanted tissue. Both B and T cells develop from stem cells located in the liver of fetuses and the bone marrow of adults. T cells complete their development in the thymus, whilst the B cells mature in the bone marrow.

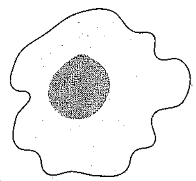
Lymphocytes and their Functions



B cells mature in the bone marrow in the shaft of the long bones (e.g. the femur). They migrate from here to the lymphatic organs.

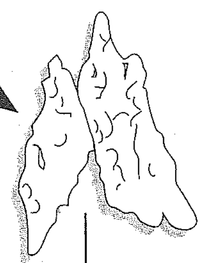
Stem cell

Stem cells in the bone marrow and fetal liver give rise to T cells and B cells.

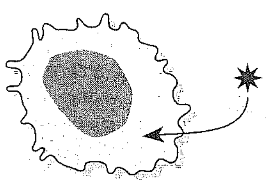


Thymus gland

The thymus gland is located above the heart on the wind pipe. It is large in infants but regresses with age. Immature T cells move to the thymus to mature before migrating to other lymphatic organs.

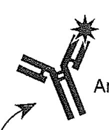


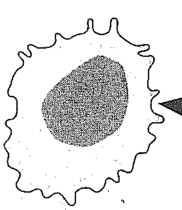
B cell



B cells recognize and bind antigens. Each B cell recognizes one specific antigen. Helper T cells recognize specific antigens on B cell surfaces and induce their maturation and proliferation. A mature B cell may carry as many as 100 000 antigenic receptors embedded in its surface membrane. B cells defend against bacteria and viruses outside the cell and toxins produced by bacteria (free antigens).

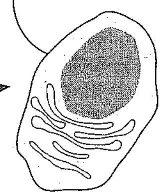
Differentiate into 2 kinds of cells:





Memory cells

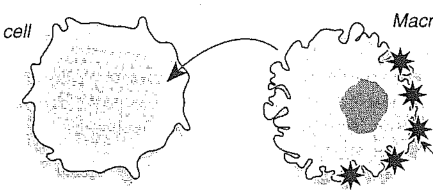
Some B cells differentiate into long-lived memory cells (see opposite). When these cells encounter the same antigen again (even years or decades later), they rapidly differentiate into antibody-producing plasma cells.



Plasma cells

When stimulated by an antigen (see *Clonal Selection*, opposite), some B cells differentiate into plasma cells, which secrete antibodies into the blood system. The antibodies then inactivate the circulating antigens.

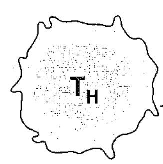
T cell



T cells respond only to antigen fragments that have been processed and presented by infected cells or macrophages (phagocytic cells). They defend against:

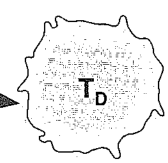
- Intracellular bacteria and viruses
- Protozoa, fungi, flatworms, and roundworms
- Cancerous cells and transplanted foreign tissue

Differentiate into 4 kinds of cells:



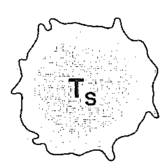
Helper T cell

Activates cytotoxic T cells and other helper T cells. They are necessary for B cell activation.



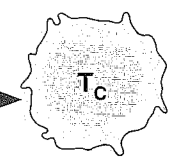
T cell for delayed hypersensitivity

Protects against pathogens. Causes transplant rejection and inflammation in allergic reactions.



Suppressor T cell

Regulates immune response by turning it off when no more antigen is present.



Cytotoxic T cell

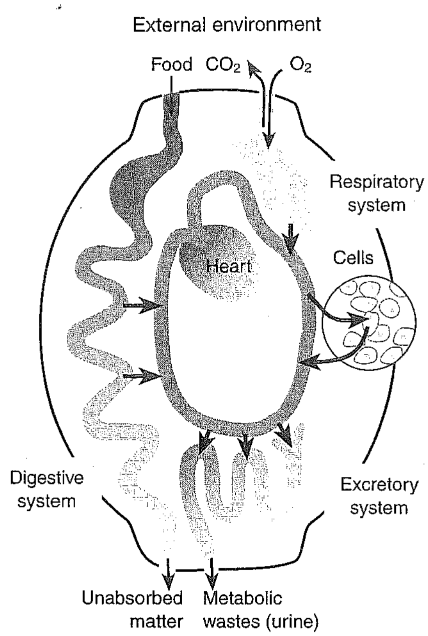
Destroys target cells on contact. Recognizes tumor (cancer) or virus infected cells by their surface (antigens and MHC markers).

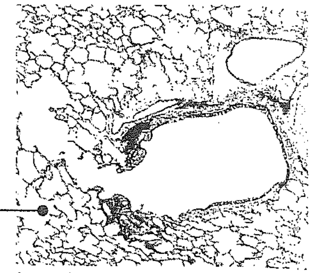
Defense Against Disease

Principles of Homeostasis

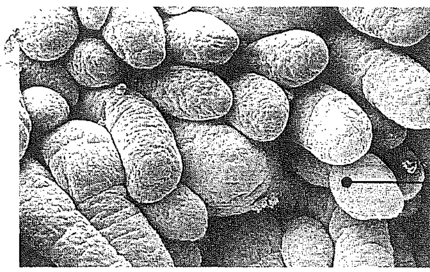
Homeostasis is the condition where the body's internal environment remains relatively constant, despite external fluctuations. Homeostasis of the internal environment is an essential feature of complex animals and it is the job of the body's **organ systems** to maintain it, even as they make necessary exchanges with the environment. Homeostatic control systems have three functional components: a receptor to detect change, a control centre, and an effector to direct an appropriate response. In negative feedback systems, movement away from an ideal state triggers a mechanism to counteract further change in that direction. Using feedback systems, the body counteracts disturbances and restores the steady state.

Organ systems maintain a constant internal environment that provides for the needs of all the body's cells, making it possible for animals to move through different and often highly variable external environments.This representation of a mammal shows how organ systems permit exchanges with the environment. The exchange surfaces of organ systems are usually internal, but may be connected to the environment via openings on the body surface.

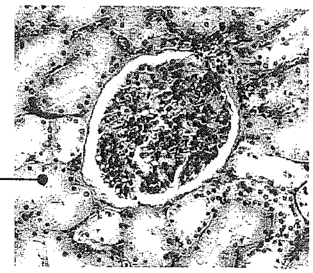




Lung tissue provides an expansive, moist surface for gas exchange.

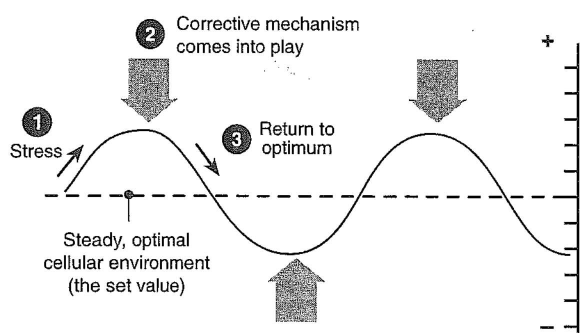


The finger-like villi of the small intestine greatly expand the surface area for nutrient absorption.

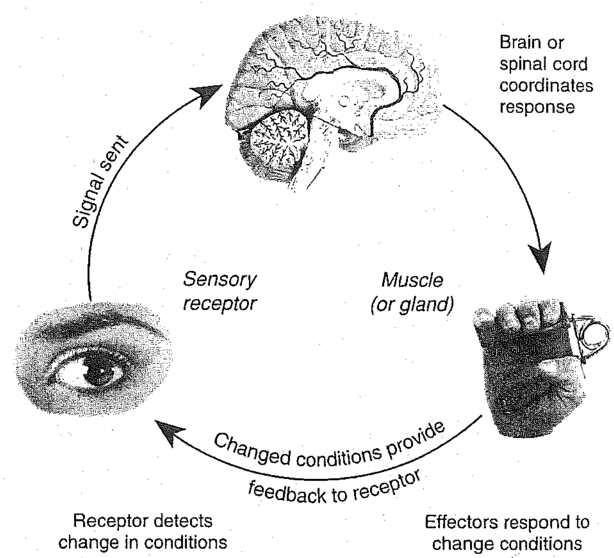


Kidney tubules exchange chemicals with the blood through capillaries.

Negative Feedback and Control Systems



1. A stress or disturbance takes the internal environment away from optimum
2. Stress is detected by receptors and corrective mechanisms are activated
3. The corrective mechanisms act to restore conditions back to the set value



Negative feedback acts to eliminate any deviation from preferred conditions. It is part of almost all the control systems in living things. The diagram (above left) shows how a stress or disturbance is counteracted by corrective mechanisms that act to restore conditions back to an optimum value. The diagram (above right) illustrates this principle for a biological system.

1. Identify the three main components of a regulatory control system in the human body: ______________________

____

2. Explain how animals use feedback mechanisms to maintain a steady state despite their constant exchanges with a variable environment:

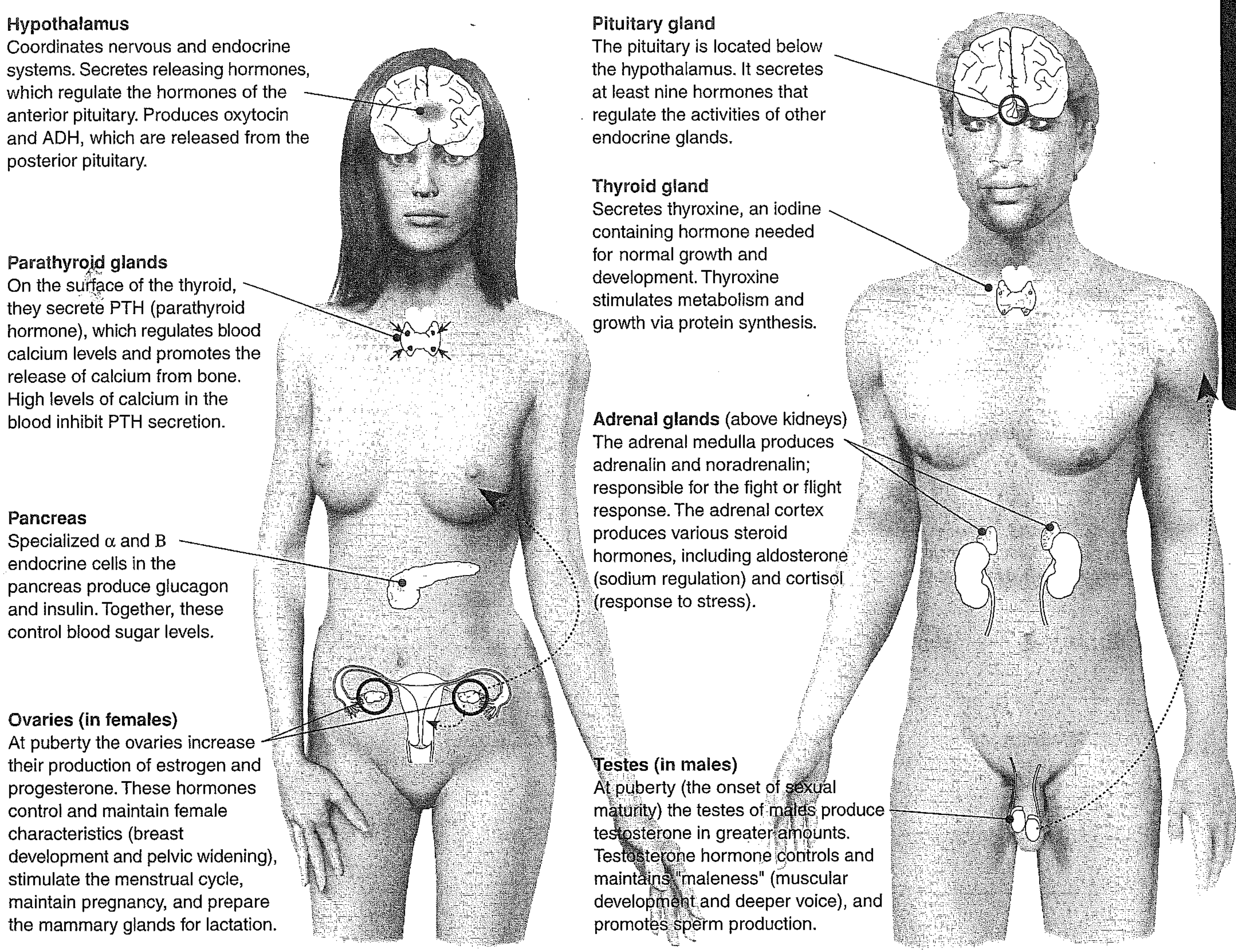
____

____

____

The Endocrine System

Homeostasis is achieved through the activity of the nervous and endocrine systems, which interact in the regulation of the body's activities. The nervous system is capable of rapid responses to stimuli. Slower responses, and long term adjustments of the body (growth, reproduction, and adaptation to stress), are achieved through endocrine control. The endocrine system comprises **endocrine glands** and their **hormones**. Endocrine glands are ductless glands that are distributed throughout the body. Under appropriate stimulation (see below), they secrete **hormones**: chemical messengers that are carried in the blood to **target** cells, where they have a specific metabolic effect. After exerting their effect, hormones are broken down and excreted from the body. Although a hormone circulates in the blood, only the targets will respond. Hormones may be amino acids, peptides, proteins (often modified), fatty acids, or steroids. Some basic features of the human endocrine system are explained below and on the next page.



1. Distinguish between a neurotransmitter and a hormone: ______________________________

____

____

2. Explain why it is an advantage for hormones to be carried in the blood: ______________________________

____

____

3. The dotted arrows in the diagram above indicate the development of secondary sexual characteristics. Identify the male and female hormones involved in the development of these characteristics and state their role:

(a) Male: ______________________________

____

(b) Female: ______________________________

____

Signal Transduction

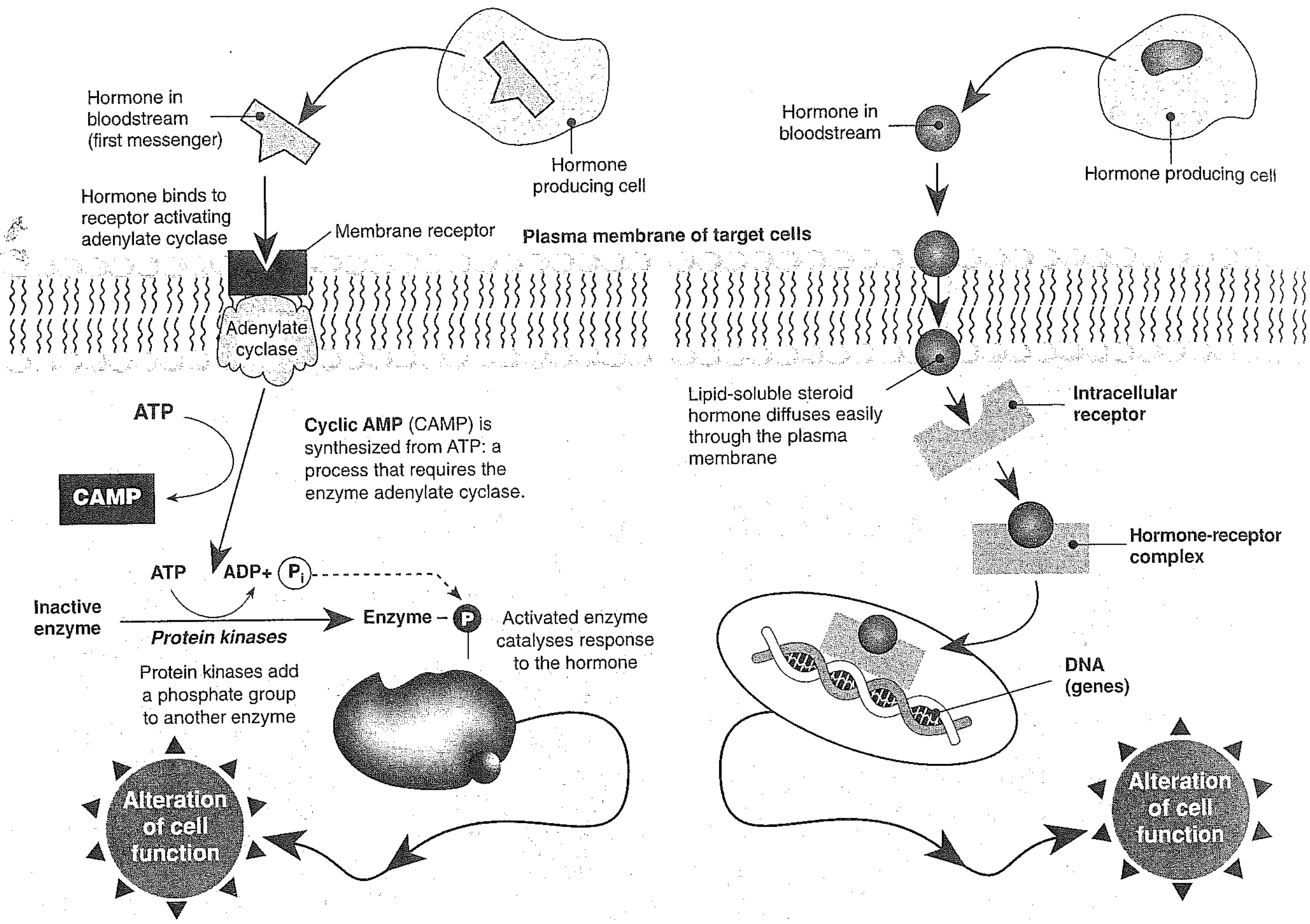
Once a hormone signal is released, it is carried in the blood to target cells that respond specifically to that hormone. Water soluble hormones are carried free in the blood, whilst steroid and thyroid hormones are carried bound to plasma proteins. Target cells possess receptors that bind the hormone and initiate a cascade of reactions ending in an alteration of function in the target cell (e.g. secretion, change in membrane permeability, protein synthesis, or enzyme activation). Hormones may bind by interacting with transmembrane receptors and activating a second messenger, or they may interact directly with intracellular cytoplasmic receptors. Once the target cell responds, the response is recognized by the hormone-producing cell through a feedback signal and the hormone is degraded.

Hormone Action By Second Messenger

Cyclic AMP is a **second messenger** linking the hormone to the cellular response. Cellular concentration of CAMP increases markedly once a hormone binds and the cascade of enzyme-driven reactions is initiated.

Gene Activation by Steroids

Steroid hormones alter cell function through direct activation of genes. Once inside the target cell, they bind to intracellular receptor sites, creating hormone-receptor complexes that activate specific genes.



1. Describe the two mechanisms by which a hormone can bring about a cellular response:

   (a) ______________________________

   (b) ______________________________

2. State in what way these two mechanisms are alike: ______________________________

3. Explain how a very small amount of hormone is able to exert a disproportionately large effect on a target cell:

   ____

4. Explain how the binding of a hormone to a target cell can be likened to an enzyme-substrate reaction: ______________________________

The Liver's Homeostatic Role

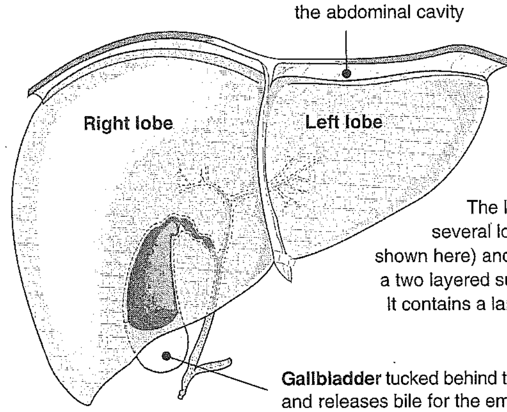
The liver, located just below the diaphragm and making up 3-5% of body weight, is the largest homeostatic organ. It performs a vast number of functions including production of bile, storage and processing of nutrients, and detoxification of poisons and metabolic wastes. The liver has a **unique double blood supply** and up to 20% of the total blood volume flows through it at any one time. This rich vascularization makes it the central organ for regulating activities associated with the blood and circulatory system. In spite of the complexity of its function, the liver tissue and the liver cells themselves are structurally relatively simple. Features of liver structure and function are outlined below. The histology of the liver in relation to its role is described on the next page.

Homeostatic Functions of the Liver

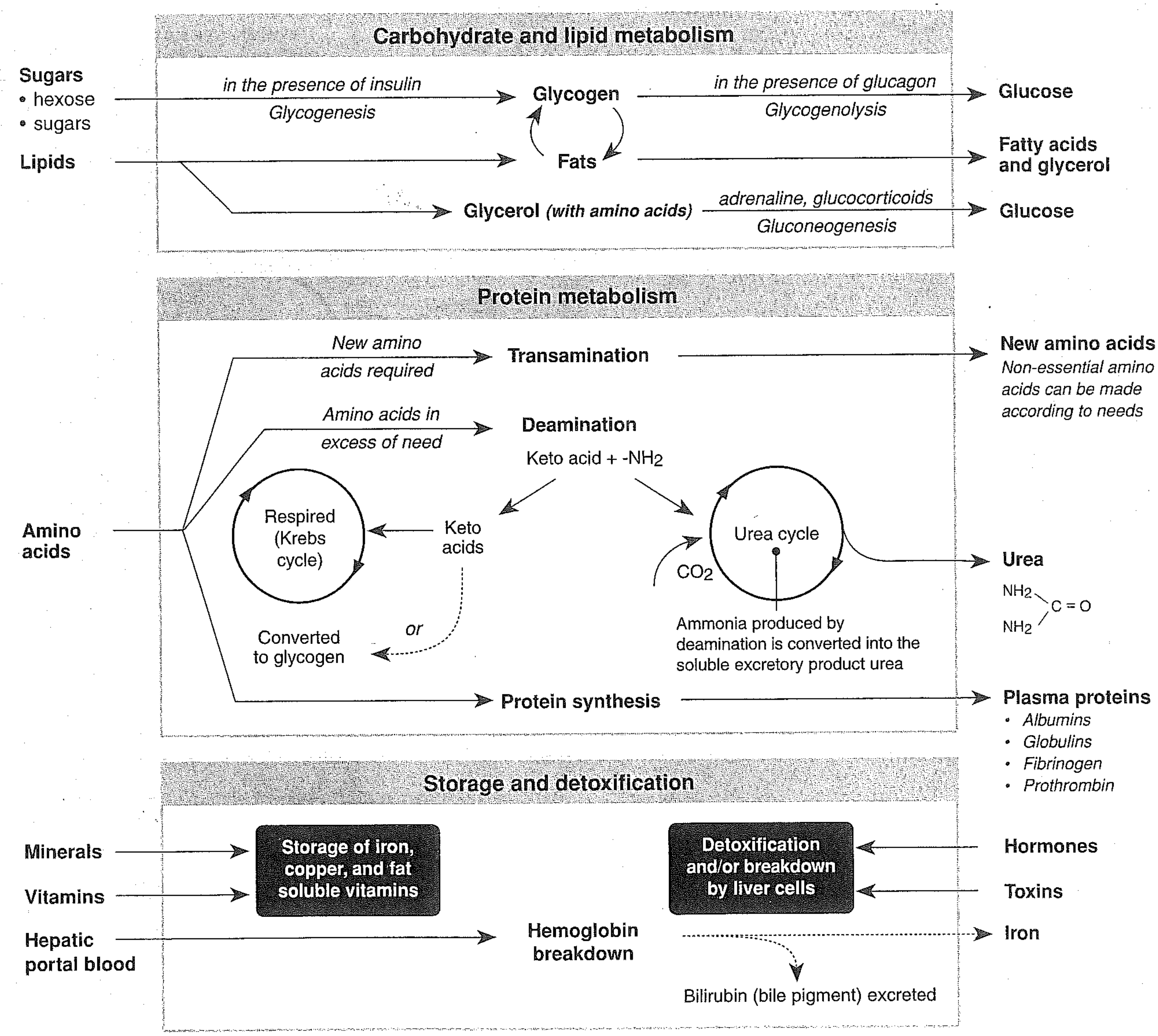
The liver is one of the largest and most complex organs in the body. It has a central role as an organ of homeostasis and performs many functions, particularly in relation to the regulation of blood composition. General functions of the liver are outlined below. Briefly summarized, the liver:

1. Secretes bile, important in emulsifying fats in digestion.
2. Metabolizes amino acids, fats, and carbohydrates (below).
3. Synthesizes glucose from non-carbohydrate sources when glycogen stores are exhausted (gluconeogenesis).
4. Stores iron, copper, and some vitamins (A, D, E, K, B_{12}).
5. Converts unwanted amino acids to urea (urea cycle).
6. Manufactures heparin and plasma proteins (e.g. albumin).
7. Detoxifies poisons or turns them into less harmful forms.
8. Some liver cells phagocytose worn-out blood cells.
9. Synthesizes cholesterol from acetyl coenzyme A.

External appearance of the human liver



Summary of Liver Functions

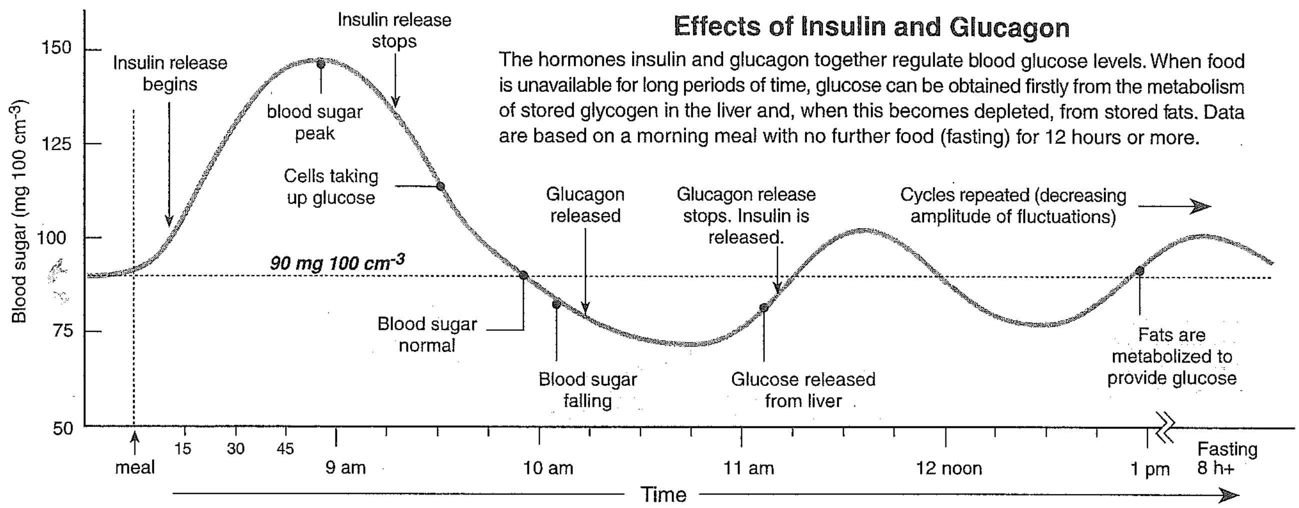


Control of Blood Glucose

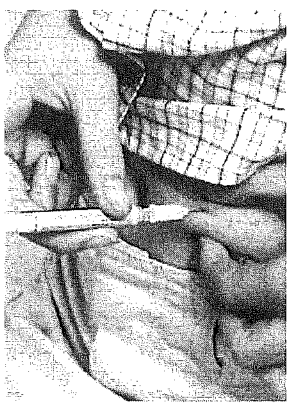
The endocrine portion of the **pancreas** produces the hormones that regulate blood glucose. Two hormones, insulin and glucagon, maintain blood glucose at a steady state through **negative feedback**. Insulin promotes a decrease in blood glucose synthesizing glycogen and promoting cellular uptake of glucose. Glucagon promotes an increase in blood glucose through the breakdown of glycogen and the synthesis of glucose from amino acids. When normal blood glucose levels are restored, negative feedback stops hormone secretion. Regulating blood glucose to within narrow limits allows energy to be available to cells as needed. Extra energy is stored, as glycogen or fat, and is mobilized to meet energy needs as required. The liver is pivotal in these carbohydrate conversions. One of the consequences of a disruption to this system is the disease **diabetes mellitus**. In type 1 diabetes, the insulin producing β cells of the pancreatic tissue are destroyed as a result of autoimmune activity and insulin is not produced. In type 2 diabetes, the pancreatic cells produce insulin, but the body's cells cease responding its message.

Effects of Insulin and Glucagon

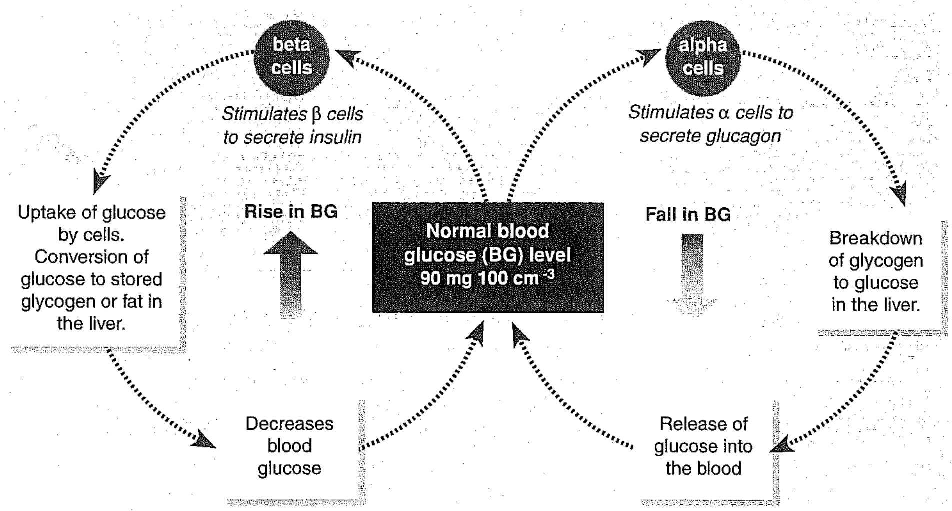
The hormones insulin and glucagon together regulate blood glucose levels. When food is unavailable for long periods of time, glucose can be obtained firstly from the metabolism of stored glycogen in the liver and, when this becomes depleted, from stored fats. Data are based on a morning meal with no further food (fasting) for 12 hours or more.



Negative Feedback in Blood Glucose Regulation



In type 1 diabetes mellitus, the β cells of the pancreas are destroyed and insulin must be delivered to the bloodstream by injection. Type 2 diabetics produce insulin, but their cells do not respond to it.



1. (a) Identify the stimulus for the release of insulin: ______

   (b) Identify the stimulus for the release of glucagon: ______

   (c) Explain how glucagon brings about an increase in blood glucose level: ______

   (d) Explain how insulin brings about a decrease in blood glucose level: ______

2. Outline the role of negative feedback in the control of blood glucose: ______

3. Explain why fats are metabolized after a long period without food: ______