Learning Objectives

1. Compile your own glossary from the KEY WORDS displayed in bold type in the learning objectives below.

Cell Membranes (pages 88-90)
- 2. Draw a simple labelled diagram of the structure of the plasma membrane (cell surface membrane), clearly identifying the arrangement of the lipids and proteins.
- 3. Describe and explain the current fluid-mosaic model of membrane structure, including the terms lipid bilayer and partially permeable membrane. Explain the roles of phospholipids, cholesterol, glycolipids, proteins, and glycoproteins in membrane structure.
- 4. Describe the various functions of membranes in the cell. Outline the effect of changing temperature on membrane structure and permeability.

Cellular Transport (pages 92-98)
- 5. Summarise the types of movements that occur across membranes. Outline the role of proteins in membranes as receptors and carriers in membrane transport.
- 6. Describe diffusion, facilitated diffusion, and osmosis, identifying them as passive transport processes. Identify the types of substances moving in each case, and the role of membrane proteins and the concentration gradient in net movement.
- 8. Suggest why cell size is limited by the rate of diffusion. Discuss the significance of surface area to volume ratio to cells and relate this to organism size.
- 9. With respect to plant cells, define the terms: turgor and plasmolysis. With respect to solutions of differing solute concentration, distinguish between hypotonic, isotonic, and hypertonic. Comment on the importance of ion concentrations in maintaining cell turgor.
- 10. Distinguish between passive and active transport, clearly identifying the involvement of protein molecules and energy in active transport processes.
- 11. Describe the following active transport mechanisms: ion-exchange pumps, exocytosis, endocytosis, phagocytosis, and pinocytosis. Give examples of when and where (in the plant or animal body) each type of transport mechanism occurs.

Cell Division (pages 99-107)
- 12. Distinguish between the two kinds of cell division: mitosis and meiosis. Discuss the role of each in the life cycle of an organism.
- 13. Describe the cell cycle. Discuss the role of each in the life cycle of an organism.
- 14. Using labelled diagrams, summarise the main stages in mitosis, including reference to the events in prophase, metaphase, anaphase, and telophase. Explain where mitosis occurs in plants and in animals.
- 15. Describe the role of mitosis in growth and repair, and asexual reproduction (e.g. in yeast). Recognise the importance of daughter nuclei with chromosomes identical in number and type. Recognise cell division as a prelude to cellular differentiation.
- 16. Describe the role of cell specialisation and the development of tissues and organs in multicellular organisms. Describe the benefits of multicellularity in terms of functional efficiency.

Supplementary Texts
Addis, J., et al., 2003, Molecules and Cells, (NelsonThornes), chpt. 4 as reqd.
Many of the important structures and organelles in cells are composed of, or are enclosed by, membranes. These include: the endoplasmic reticulum, mitochondria, nucleus, Golgi body, chloroplasts, lysosomes, vesicles and the cell plasma membrane itself. All membranes within eukaryotic cells share the same basic structure as the plasma membrane that encloses the entire cell. They perform a number of critical functions in the cell: serving to compartmentalise regions of different function within the cell, controlling the entry and exit of substances, and fulfilling a role in recognition and communication between cells. Some of these roles are described below.

1. Explain the crucial role of membrane systems and organelles in the following:

   (a) Providing compartments within the cell: ____________________________________________

   (b) Increasing the total membrane surface area within the cell: _________________________

2. Explain the importance of the following components of cellular membranes:

   (a) Glycoproteins and glycolipids: __________________________________________________

   (b) Channel proteins and carrier proteins: _____________________________________________

3. Explain how cholesterol can play a role in membrane transport: ________________________
All cells have a plasma membrane that forms the outer limit of the cell. Bacteria, fungi, and plant cells have a cell wall outside this, but it is quite distinct and outside the cell. Membranes are also found inside eukaryotic cells as part of membranous organelles. Present day knowledge of membrane structure has been built up as a result of many observations and experiments. The original model of membrane structure, proposed by Davson and Danielli, was the unit membrane; a lipid bilayer coated with protein. This model was later modified after the discovery that the protein molecules were embedded within the bilayer rather than coating the outside. The now-accepted model of membrane structure is the fluid-mosaic model described below.

The Fluid Mosaic Model

The currently accepted model for the structure of membranes is called the fluid mosaic model. In this model there is a double layer of lipids (fats) which are arranged with their 'tails' facing inwards. The double layer of lipids is thought to be quite fluid, with proteins ‘floating’ in this layer. The mobile proteins are thought to have a number of functions, including a role in active transport.

1. (a) Describe the modern fluid mosaic model of membrane structure:
(b) Explain how the fluid mosaic model accounts for the observed properties of cellular membranes:

_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

2. Discuss the various functional roles of membranes in cells: ________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

3. (a) Name a cellular organelle that possesses a membrane: ________________________________________
(b) Describe the membrane’s purpose in this organelle: ________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

4. (a) Describe the purpose of cholesterol in plasma membranes: ________________________________________
_________________________________________________________________________________
(b) Suggest why marine organisms living in polar regions have a very high proportion of cholesterol in their membranes:
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

5. List three substances that need to be transported into all kinds of animal cells, in order for them to survive:
   (a) ____________________________________ (b) ____________________________ (c) ____________________________

6. List two substances that need to be transported out of all kinds of animal cells, in order for them to survive:
   (a) ____________________________________ (b) ____________________________

7. Use the symbol for a phospholipid molecule (below) to draw a simple labelled diagram to show the structure of a plasma membrane (include features such as lipid bilayer and various kinds of proteins):
Cells have a need to move materials both into and out of the cell. Raw materials and other molecules necessary for metabolism must be accumulated from outside the cell. Some of these substances are scarce outside of the cell and some effort is required to accumulate them. Waste products and molecules for use in other parts of the body must be ‘exported’ out of the cell. Some materials (e.g. gases and water) move into and out of the cell by passive transport processes, without the expenditure of energy on the part of the cell. Other molecules (e.g. sucrose) are moved into and out of the cell using active transport. Active transport processes involve the expenditure of energy in the form of ATP, and therefore use oxygen.

### Passive Transport
- **Diffusion**
  - Molecules of liquids, dissolved solids, and gases are able to move into or out of a cell without any expenditure of energy. These molecules move because they follow a concentration gradient.

- **Facilitated diffusion**
  - Diffusion involving a carrier system but without any energy expenditure.

- **Osmosis**
  - Water can also follow a concentration gradient, across a partially permeable membrane, by diffusion. This is called osmosis. Osmosis causes cells in fresh water to puff up as water seeps in. This water must be continually expelled.

### Active Transport
- **Ion pumps**
  - Some cells need to control the amount of a certain ion inside the cell. Proteins in the plasma membrane can actively accumulate specific ions on one side of the membrane.

- **Exocytosis**
  - Vesicles budded off from the Golgi apparatus or endoplasmic reticulum can fuse with the plasma membrane, expelling their contents. Common in secretory cells e.g. in glands.

- **Pinocytosis**
  - Ingestion of a fluid or a suspension into the cell. The plasma membrane encloses some of the fluid and pinches off to form a vesicle.

- **Phagocytosis**
  - Ingestion of solids from outside the cell. The plasma membrane encloses a particle and buds off to form a vacuole. Lysosomes will fuse with it to enable digestion of the contents.

1. In general terms, describe the energy requirements of passive and active transport:

2. Name two gases that move into or out of our bodies by diffusion:

3. Name a gland which has cells where exocytosis takes place for the purpose of secretion:

4. Phagocytosis is a process where solid particles are enveloped by the plasma membrane and drawn inside the cell.
   (a) Name a protozoan (single-celled protist) that would use this technique for feeding:
   (b) Describe how it uses the technique:
   (c) Name a type of cell found in human blood that uses this technique for capturing and destroying bacteria:
Diffusion

The molecules that make up substances are constantly moving about in a random way. This random motion causes molecules to disperse from areas of high to low concentration; a process called diffusion. The molecules move along a concentration gradient. Diffusion and osmosis (diffusion of water molecules across a partially permeable membrane) are passive processes, and use no energy. Diffusion occurs freely across membranes, as long as the membrane is permeable to that molecule (partially permeable membranes allow the passage of some molecules but not others). Each type of molecule diffuses along its own concentration gradient. Diffusion of molecules in one direction does not hinder the movement of other molecules. Diffusion is important in allowing exchanges with the environment and in the regulation of cell water content.

Diffusion of Molecules Along Concentration Gradients

Diffusion is the movement of particles from regions of high to low concentration (the concentration gradient), with the end result being that the molecules become evenly distributed. In biological systems, diffusion often occurs across partially permeable membranes. Various factors determine the rate at which this occurs (see right).

Factors affecting rates of diffusion

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration gradient</td>
<td>Diffusion rates will be higher when there</td>
</tr>
<tr>
<td></td>
<td>is a greater difference in concentration</td>
</tr>
<tr>
<td></td>
<td>between two regions.</td>
</tr>
<tr>
<td>The distance involved</td>
<td>Diffusion over shorter distances occurs</td>
</tr>
<tr>
<td></td>
<td>at a greater rate than diffusion over larger</td>
</tr>
<tr>
<td></td>
<td>distances.</td>
</tr>
<tr>
<td>The area involved</td>
<td>The larger the area across which</td>
</tr>
<tr>
<td></td>
<td>diffusion occurs, the greater the rate of</td>
</tr>
<tr>
<td></td>
<td>diffusion.</td>
</tr>
<tr>
<td>Barriers to diffusion</td>
<td>Thicker barriers slow diffusion rate.</td>
</tr>
<tr>
<td></td>
<td>Pores in a barrier enhance diffusion.</td>
</tr>
</tbody>
</table>

These factors are expressed in Fick’s law, which governs the rate of diffusion of substances within a system. It is described by:

$$\text{Surface area of membrane} \times \frac{\text{Difference in concentration across the membrane}}{\text{Length of the diffusion path (thickness of the membrane)}}$$

Diffusion through Membranes

Each type of diffusing molecule (gas, solvent, solute) moves along its own concentration gradient. Two-way diffusion (below) is common in biological systems, e.g. at the lung surface, carbon dioxide diffuses out and oxygen diffuses into the blood. Facilitated diffusion (below, right) increases the diffusion rate selectively and is important for larger molecules (e.g. glucose, amino acids) where a higher diffusion rate is desirable (e.g. transport of glucose into skeletal muscle fibres, transport of ADP into mitochondria). Neither type of diffusion requires energy expenditure because the molecules are not moving against their concentration gradient.

Facilitated diffusion occurs when a substance is aided across a membrane by a special molecule called an ionophore. Ionophores allow some molecules to diffuse but not others, effectively speeding up the rate of diffusion of that molecule.

1. Describe two properties of an exchange surface that would facilitate rapid diffusion rates:
   (a) ___________________________________________ (b) _______________________________________

2. Identify one way in which organisms maintain concentration gradients across membranes: ________________________________________________________________

3. State how facilitated diffusion is achieved: __________________________________________________________
Osmosis in Cells

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 previous activity). In animal biology and medicine, the terms osmotic potential and osmotic pressure are often used to express the water relations of animal cells (which, unlike plant cells, lack a rigid cell wall). The osmotic potential of a solution is a measure of the tendency of the solution to gain water by osmosis. The osmotic pressure is a measure of the tendency for water to move into a solution by osmosis. Because water movements in plant cells are also affected by the pressure exerted by the rigid cell wall, they are often described in terms of the water potential (\(\psi\)) of the solutions involved. Water potential takes account of the influence of the water concentration and the wall pressure, and is particularly appropriate for explaining water movements in plant cells. We have not used this terminology here, but coverage of water potential is provided for those who want it on web links and the TRC: Osmosis and Diffusion.

**Osmotic Gradients and Water Movement**

Osmosis is the diffusion of water molecules, across a partially permeable membrane, from higher to lower concentration of water molecules (sometimes described as from lower to higher solute concentration). The direction of net movement can be predicted on the basis of the relative concentrations of water and solute molecules in the solutions involved. Water always diffuses from regions of higher concentration to lower concentration of water molecules (from lower to higher solute concentration).

The cytoplasm contains dissolved substances (solute). When cells are placed in a solution of different concentration, there is an osmotic gradient between the external environment and the inside of the cell. In plant cells, the rigid cell wall is also important. When a plant cell takes up water, it swells until the cell contents exert a pressure on the cell wall. The cell wall is rigid and the pressure exerted on it by the cytoplasm is sometimes called the wall or turgor pressure. Turgor is important in plant support.

1. Explain what is meant by partially permeable membrane:

2. Identify the factors influencing the net direction of water movement in:
   (a) Animal cells:
   (b) Plant cells:

3. Explain how animal cells differ from plant cells with respect to the effects of net water movements:
Water Relations in Plant Cells

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

<table>
<thead>
<tr>
<th>Water Relations in Plant Cells</th>
</tr>
</thead>
</table>

**Plasmolysis in a plant cell**

In a hypertonic solution, the external water concentration is lower than the water concentration of the cell. Water leaves the cell and, because the cell wall is rigid, the cell membrane shrinks away from the cell wall. This process is termed plasmolysis and the cell becomes flaccid (turgor pressure = 0). Complete plasmolysis is irreversible; the cell cannot recover by taking up water.

**Turgor in a plant cell**

In a hypotonic solution, the external water concentration is higher than the cell cytoplasm. Water enters the cell, causing it to swell tight. A wall (turgor) pressure is generated when enough water has been taken up to cause the cell contents to press against the cell wall. Turgor pressure rises until it offsets further net influx of water into the cell (the cell is turgid). The rigid cell wall prevents cell rupture.

4. 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: ____________________________

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

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

6. 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: ____________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

7. 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).

8. (a) Explain the role of cell wall pressure in generating cell turgor in plants: ____________________________

(b) Discuss the role of cell turgor to plants: ____________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
Limitations to Cell Size

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 micrometre of membrane, only so much of a particular substance can cross per second.

A specialised 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

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.

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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.

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.

<table>
<thead>
<tr>
<th>Cube size</th>
<th>Surface area</th>
<th>Volume</th>
<th>Surface area to volume ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 cm cube</td>
<td>$2 \times 2 \times 6 = 24 \text{ cm}^2$</td>
<td>$2 \times 2 \times 2 = 8 \text{ cm}^3$</td>
<td>24 to 8 = 3:1</td>
</tr>
<tr>
<td>3 cm cube</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 cm cube</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 cm cube</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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:
Diffusion alone cannot supply the cell's entire requirements for molecules (and ions). Some molecules (e.g. glucose) are required by the cell in higher concentrations than occur outside the cell. Others (e.g. sodium) must be removed from the cell in order to maintain fluid balance. These molecules must be moved across the plasma membrane by active transport mechanisms. **Active transport** requires the expenditure of energy because the molecules (or ions) must be moved **against** their concentration gradient. The work of active transport is performed by specific carrier proteins in the membrane. These transport proteins harness the energy of ATP to pump molecules from a low to a high concentration. When ATP transfers a phosphate group to the carrier protein, the protein changes its shape in such a way as to move the bound molecule across the membrane. Three types of membrane pump are illustrated below. The sodium-potassium pump (below, centre) is almost universal in animal cells and is common in plant cells also. The concentration gradient created by ion pumps such as this and the proton pump (left) is frequently coupled to the transport of molecules such as glucose (e.g. in the intestine) as shown below right.

<table>
<thead>
<tr>
<th>Proton pump</th>
<th>Sodium-potassium pump</th>
<th>Cotransport</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATP driven proton pumps use energy to remove hydrogen ions (H⁺) from inside the cell to the outside. This creates a large difference in the proton concentration either side of the membrane, with the inside of the plasma membrane being negatively charged. This potential difference can be coupled to the transport of other molecules.</td>
<td>The sodium-potassium pump is a specific protein in the membrane that uses energy in the form of ATP to exchange sodium ions (Na⁺) for potassium ions (K⁺) across the membrane. The unequal balance of Na⁺ and K⁺ across the membrane creates large concentration gradients that can be used to drive transport of other substances (e.g. cotransport of glucose).</td>
<td>Cotransport (coupled transport) in the intestine, a gradient in sodium ions is used to drive the active transport of glucose. The specific transport protein couples the return of Na⁺ down its concentration gradient to the transport of glucose into the intestinal epithelial cell. A low intracellular concentration of Na⁺ (and therefore the concentration gradient) is maintained by a sodium-potassium pump.</td>
</tr>
</tbody>
</table>

1. Explain why the ATP is required for membrane pump systems to operate: ____________________________________________________________

2. (a) Explain what is meant by cotransport: ____________________________________________________________

(b) Explain how cotransport is used to move glucose into the intestinal epithelial cells: ____________________________________________________________

(c) Explain what happens to the glucose that is transported into the intestinal epithelial cells: ____________________________________________________________

3. Describe two consequences of the extracellular accumulation of sodium ions: ____________________________________________________________
Most cells carry out **cytosis**: a form of **active transport** involving the in- or outfolding of the plasma membrane. The ability of cells to do this is a function of the flexibility of the plasma membrane. Cytosis results in the bulk transport into or out of the cell and is achieved through the localised activity of microfilaments and microtubules in the cell cytoskeleton. Engulfment of material is termed **endocytosis**. Endocytosis typically occurs in protozoans and certain white blood cells of the mammalian defence system (e.g. neutrophils, macrophages). **Exocytosis** is the reverse of endocytosis and involves the release of material from vesicles or vacuoles that have fused with the plasma membrane. Exocytosis is typical of cells that export material (secretory cells).

### Exocytosis and Endocytosis

**Endocytosis**

Endocytosis (left) occurs by invagination (infolding) of the plasma membrane, which then forms vesicles or vacuoles that become detached and enter the cytoplasm. There are two main types of endocytosis:

**Phagocytosis**: “cell-eating”

Examples: Feeding method of Amoeba, phagocytosis of foreign material and cell debris by neutrophils and macrophages. Phagocytosis involves the engulfment of **solid material** and results in the formation of vacuoles (e.g. food vacuoles).

**Pinocytosis**: “cell-drinking”

Examples: Uptake in many protozoa, some cells of the liver, and some plant cells. Pinocytosis involves the uptake of **liquids** or fine suspensions and results in the formation of pinocytic vesicles.

**Exocytosis**

Exocytosis (left) is the reverse process to endocytosis. In multicellular organisms, various types of cells are specialised to manufacture and export products (e.g. proteins) from the cell to elsewhere in the body or outside it. Exocytosis occurs by fusion of the vesicle membrane and the plasma membrane, followed by release of the vesicle contents to the outside of the cell.

---

1. Distinguish between **phagocytosis** and **pinocytosis**:

   **phagocytosis** involves the engulfment of solid material and results in the formation of vacuoles (e.g. food vacuoles).

   **pinocytosis** involves the uptake of liquids or fine suspensions and results in the formation of pinocytic vesicles.

2. Describe an example of phagocytosis and identify the cell type involved:

   Phagocytosis involves the engulfment of solid material and results in the formation of vacuoles (e.g. food vacuoles).

3. Describe an example of exocytosis and identify the cell type involved:

   Exocytosis is the reverse of endocytosis and involves the release of material from vesicles or vacuoles that have fused with the plasma membrane.

4. Explain why cytosis is affected by changes in oxygen level, whereas diffusion is not:

   Cytosis results in the bulk transport into or out of the cell and is achieved through the localised activity of microfilaments and microtubules in the cell cytoskeleton. Engulfment of material is cytosis, which is affected by changes in oxygen level, whereas diffusion is not.

5. Identify the processes by which the following substances enter a living macrophage (for help, see page on diffusion):

   (a) Oxygen: **endocytosis**

   (b) Cellular debris: **endocytosis**

   (c) Water: **diffusion**

   (d) Glucose: **endocytosis**
The life cycle of diploid sexually reproducing organisms (such as humans) is illustrated in the diagram below. Gametogenesis is the process responsible for the production of male and female gametes for the purpose of sexual reproduction. The difference between meiosis in males and in females should be noted (see spermatogenesis and oogenesis in the box below).

Somatic growth occurs by mitosis. The term somatic means ‘body’, and mitosis creates new body cells (as opposed to gametes or sex cells). The 2N or diploid number refers to how many whole sets of chromosomes are present in each body cell. For a normal human embryo, all cells will have a diploid number of 46.

Mitosis is also used for cell replacement and tissue repair. Blood cells are replaced by the body at a rate of two million per second, and a layer of skin cells is lost and replaced about every 28 days.

Gamete production begins at puberty, and lasts until menopause for women, and indefinitely for men. Gametes are produced by meiosis, which halves the chromosome number. Human males produce about 200 million sperm per day (whether they are used or not), while females usually release a single egg only once a month.

1. Describe the purpose of the following types of cell division:
   (a) Mitosis: ____________________________________________________________
   (b) Meiosis: ___________________________________________________________

2. Explain the significance of the zygote: ____________________________________

3. Describe the basic difference between the cell divisions involved in spermatogenesis and oogenesis: _______________________________________________________________
Mitosis is part of the 'cell cycle' in which an existing cell (the parent cell) divides into two new ones (the daughter cells). Mitosis does not result in a change of chromosome numbers (unlike meiosis): the daughter cells are identical to the parent cell. Although mitosis is part of a continuous cell cycle, it is divided into stages (below). In plants and animals mitosis is associated with growth and repair of tissue, and it is the method by which some organisms reproduce asexually. The example below illustrates the cell cycle in a plant cell. Note that in animal cells, cytokinesis involves the formation of a constriction that divides the cell in two. It is usually well underway by the end of telophase and does not involve the formation of a cell plate.

1. The five photographs below were taken at various stages through the process of mitosis in a plant cell. They are not in any particular order. Study the diagram above and determine the stage that each photograph represents (e.g. anaphase).

   (a) ____________  (b) ____________  (c) ____________  (d) ____________  (e) ____________

2. State two important changes that chromosomes must undergo before cell division can take place:

   ________________________________________________________________

3. Briefly summarise the stages of the cell cycle by describing what is happening at the points (A-F) in the diagram above:

   A. ____________________________________________________________

   B. ____________________________________________________________

   C. ____________________________________________________________

   D. ____________________________________________________________

   E. ____________________________________________________________

   F. ____________________________________________________________
1. Briefly describe what is happening to the plant cells at each of the points labelled (a) to (c) in the diagram above:

(a) 

(b) 

(c) 

2. The light micrograph (below) shows a section of the cells of an onion root tip, stained to show up the chromosomes.

(a) State the mitotic stage of the cell labelled A and explain your answer:

(b) State the mitotic stage just completed in the cells labelled B and explain:

(c) If, in this example, 250 cells were examined and 25 were found to be in the process of mitosis, state the proportion of the cell cycle occupied by mitosis:

3. Identify the cells that divide and specialise when a tree increases its girth (diameter): 

In plants, cell division for growth (mitosis) is restricted to growing tips called **meristematic** tissue. These are located at the tips of every stem and root. This is unlike mitosis in a growing animal where cell divisions can occur all over the body. The diagram below illustrates the position and appearance of developing and growing cells in a plant root. Similar zones of development occur in the growing stem tips, which may give rise to specialised structures such as leaves and flowers.
Cellular Differentiation

As the tissues and organs of an embryo take form, their cells become modified and specialised to perform particular functions. This process is known as **cellular differentiation**. Cellular differentiation begins as soon as cells have been formed by cell division. It is achieved via the action of regulatory genes (and, in some cases, hormones) that turn specific genes on or off. Cell differentiation is a serial process; the developmental options of a cell become more and more restricted as its development proceeds. Once the fate of a cell has been determined, it cannot alter its path and change into another cell type.

As the tissues and organs of an embryo take form, their cells become modified and specialised for particular functions. This process, called **cellular differentiation**, begins as soon as cells have been formed by cell division. It is achieved via the action of regulatory genes (and, in some cases, hormones) that turn specific genes on or off. Cell differentiation is a serial process; the developmental options of a cell become more and more restricted as its development proceeds. Once the fate of a cell has been determined, it cannot alter its path and change into another cell type.

The zygote (fertilised egg) has all the information stored in the chromosomes to make a complete new individual.

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**Cell word list**
- Sperm cell
- Sensory neurone
- Smooth muscle cell
- Pancreatic secretory cell
- Pigment cell
- Skin (epithelial) cells
- Egg cell (oocyte)
- White blood cell (leucocyte)
- Striated muscle cell

At certain stages in the sequence of cell divisions, some genes are switched on, while others are switched off, depending on the destined role of the cell.

### 1. Identify the cells illustrated (A to I) in the diagram above by choosing names from the word list and state their function:

<table>
<thead>
<tr>
<th>Cell Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Striated muscle cell</td>
<td>Contractile element of skeletal muscle; creates movement</td>
</tr>
<tr>
<td>(b)</td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td></td>
</tr>
<tr>
<td>(e)</td>
<td></td>
</tr>
<tr>
<td>(f)</td>
<td></td>
</tr>
<tr>
<td>(g)</td>
<td></td>
</tr>
<tr>
<td>(h)</td>
<td></td>
</tr>
<tr>
<td>(i)</td>
<td></td>
</tr>
</tbody>
</table>

### 2. Describe two cells that continue dividing throughout an individual’s life:


### 3. Explain how so many different types of cell can arise from one unspecialised cell (the zygote):


---

**Related activities:** Mitosis

**Use RESTRICTED to schools where students have their own copy of this workbook**
Specialisation in Plant Cells

Plants show a wide variety of cell types. The vegetative plant body consists of three organs: stems, leaves, and roots. Flowers, fruits, and seeds comprise additional organs that are concerned with reproduction. The eight cell types illustrated below are representatives of these plant organ systems. Each has structural or physiological features that set it apart from the other cell types. The differentiation of cells enables each specialised type to fulfill a specific role in the plant.

1. Using the information given above, describe the specialised features and role of each of the cell types (b)-(h) below:

(a) **Guard cell**: Features: Curved, sausage shaped cell, unevenly thickened.
Role in plant: Turgor changes alter the cell shape to open or close the stoma.

(b) **Pollen grain**: Features:
Role in plant:

(c) **Palisade parenchyma cell**: Features:
Role in plant:

(d) **Epidermal cell**: Features:
Role in plant:

(e) **Vessel element**: Features:
Role in plant:

(f) **Stone cell** (sclereids): Features:
Role in plant:

(g) **Sieve tube member** (of phloem): Features:
Role in plant:

(h) **Root hair cell**: Features:
Role in plant:
Specialisation in Human Cells

Animal cells are often specialised to perform particular functions. The eight specialised cell types shown below are representative of some 230 different cell types in humans. Each has specialised features that suit it to performing a specific role.

1. Identify each of the cells (b) to (h) pictured above, and describe their **specialised features** and **role** in the body:

(a) **Type of cell:** Phagocytic white blood cell (neutrophil)

   Specialised features: Engulfs bacteria and other foreign material by phagocytosis

   Role of cell within body: Destroys pathogens and other foreign material as well as cellular debris

(b) **Type of cell:**

   Specialised features:

   Role of cell within body:

(c) **Type of cell:**

   Specialised features:

   Role of cell within body:

(d) **Type of cell:**

   Specialised features:

   Role of cell within body:

(e) **Type of cell:**

   Specialised features:

   Role of cell within body:

(f) **Type of cell:**

   Specialised features:

   Role of cell within body:

(g) **Type of cell:**

   Specialised features:

   Role of cell within body:

(h) **Type of cell:**

   Specialised features:

   Role of cell within body:
Levels of Organisation

Organisation and the emergence of novel properties in complex systems are two of the defining features of living organisms. Organisms are organised according to a hierarchy of structural levels (below), each level building on the one below it. At each level, novel properties emerge that were not present at the simpler level. Hierarchical organisation allows specialised cells to group together into tissues and organs to perform a particular function. This improves efficiency of function in the organism.

In the spaces provided for each question below, assign each of the examples listed to one of the levels of organisation as indicated.

1. Animals: adrenaline, blood, bone, brain, cardiac muscle, cartilage, collagen, DNA, heart, leucocyte, lysosome, mast cell, nervous system, neuron, phospholipid, reproductive system, ribosomes, Schwann cell, spleen, squamous epithelium.

(a) Organ system: ______________________
(b) Organs: ______________________
(c) Tissues: ______________________
(d) Cells: ______________________
(e) Organelles: ______________________
(f) Molecular level: ______________________

2. Plants: cellulose, chloroplasts, collenchyma, companion cells, DNA, epidermal cell, fibres, flowers, leaf, mesophyll, parenchyma, pectin, phloem, phospholipid, ribosomes, roots, sclerenchyma, tracheid.

(a) Organs: ______________________
(b) Tissues: ______________________
(c) Cells: ______________________
(d) Organelles: ______________________
(e) Molecular level: ______________________

The Organism

A complex, functioning whole that is the sum of all its component parts.

Organ System Level

In animals, organs form parts of even larger units known as organ systems. An organ system is an association of organs with a common function e.g. digestive system, cardiovascular system, and the urinogenital system.

Organ Level

Organs are structures of definite form and structure, comprising two or more tissues.

Animal examples include: heart, lungs, brain, stomach, kidney.

Plant examples include: leaves, roots, storage organs, ovary.

Tissue Level

Tissues are composed of groups of cells of similar structure that perform a particular, related function.

Animal examples include: epithelial tissue, bone, muscle.

Plant examples include: phloem, chlorenchyma, endodermis, xylem.

Cellular Level

Cells are the basic structural and functional units of an organism. Each cell type has a different structure and function; the result of cellular differentiation during development.

Animal examples include: epithelial cells, osteoblasts, muscle fibres.

Plant examples include: sclereids, xylem vessels, sieve tubes.

Organelle Level

Many diverse molecules may associate together to form complex, highly specialised structures within cells called cellular organelles e.g. mitochondria, Golgi apparatus, endoplasmic reticulum, chloroplasts.

Chemical and Molecular Level

Atoms and molecules form the most basic level of organisation. This level includes all the chemicals essential for maintaining life e.g. water, ions, fats, carbohydrates, amino acids, proteins, and nucleic acids.
Animal Tissues

The study of tissues (plant or animal) is called histology. The cells of a tissue, and their associated intracellular substances, e.g. collagen, are grouped together to perform particular functions. Tissues improve the efficiency of operation because they enable tasks to be shared amongst various specialised cells. Animal tissues can be divided into four broad groups: epithelial tissues, connective tissues, muscle, and nervous tissues. Organs usually consist of several types of tissue. The heart mostly consists of cardiac muscle tissue, but also has epithelial tissue, which lines the heart chambers to prevent leaking, connective tissue for strength and elasticity, and nervous tissue, in the form of neurones, which direct the contractions of the cardiac muscle. The features of some of the more familiar animal tissues are described below.

Connective tissue is the major supporting tissue of the animal body. It comprises cells, widely dispersed in a semi-fluid matrix. Connective tissues bind other structures together and provide support, and protection against damage, infection, or heat loss. Connective tissues include dentine (teeth), adipose (fat) tissue, bone (above) and cartilage, and the tissues around the body's organs and blood vessels. Blood (above, left) is a special type of liquid tissue, comprising cells floating in a liquid matrix.

Nervous tissue contains densely packed nerve cells (neurones) which are specialised for the transmission of nerve impulses. Associated with the neurones there may also be supporting cells and connective tissue containing blood vessels.

Muscle tissue consists of very highly specialised cells called fibres, held together by connective tissue. The three types of muscle in the body are cardiac muscle, skeletal muscle (above), and smooth muscle. Muscles bring about both voluntary and involuntary (unconscious) body movements.

1. Explain how the development of tissues improves functional efficiency: ______________________________________
   ______________________________________

2. Describe the general functional role of each of the following broad tissue types:
   
   (a) Epithelial tissue: ______________________________________
   (b) Nervous tissue: ______________________________________
   (c) Muscle tissue: ______________________________________
   (d) Connective tissue: ______________________________________

3. Identify the particular features that contribute to the particular functional role of each of the following tissue types:
   
   (a) Muscle tissue: ______________________________________
   (b) Nervous tissue: ______________________________________
Plant tissues are divided into two groups: simple and complex. **Simple tissues** contain only one cell type and form packing and support tissues. **Complex tissues** contain more than one cell type and form the conducting and support tissues of plants. Tissues are in turn grouped into tissue systems which make up the plant body. Vascular plants have three systems; the dermal, vascular, and ground tissue systems. The **dermal system** is the outer covering of the plant providing protection and reducing water loss. **Vascular tissue** provides the transport system by which water and nutrients are moved through the plant. The **ground tissue** system, which makes up the bulk of a plant, is made up mainly of simple tissues such as parenchyma, and carries out a wide variety of roles within the plant including photosynthesis, storage, and support.

**Simple Tissues**

Simple tissues consist of only one or two cell types. **Parenchyma tissue** is the most common and involved in storage, photosynthesis, and secretion. **Collenchyma tissue** comprises thick-walled collenchyma cells alternating with layers of intracellular substances (pectin and cellulose) to provide flexible support. The cells of **sclerenchyma** tissue (fibres and sclereids) have rigid cell walls which provide support.

**Complex Tissues**

Xylem and phloem tissue (above left), which together make up the plant **vascular tissue** system, are complex tissues. Each comprises several tissue types including tracheids, vessel members, parenchyma and fibres in xylem, and sieve tube members, companion cells, parenchyma and sclerenchyma in phloem. **Dermal tissue** is also complex tissue and covers the outside of the plant. The composition of dermal tissue varies depending upon its location on the plant. Root epidermal tissue consist of epidermal cells which extend to root hairs (trichomes) for increasing surface area. In contrast, the epidermal tissue of leaves (above right) are covered by a waxy cuticle to reduce water loss, and specialised guard cells regulate water intake via the stomata (pores in the leaf through which gases enter and leave the leaf tissue).

1. The table below lists the major types of simple and complex plant tissue. Complete the table by filling in the role each of the tissue types plays within the plant. The first example has been completed for you.

<table>
<thead>
<tr>
<th>Simple Tissue</th>
<th>Cell Type(s)</th>
<th>Role within the Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parenchyma</td>
<td>Parenchyma cells</td>
<td>Involved in respiration, photosynthesis, storage and secretion.</td>
</tr>
<tr>
<td>Collenchyma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sclerenchyma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root endodermis</td>
<td>Endodermal cells</td>
<td></td>
</tr>
<tr>
<td>Pericycle</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Complex Tissue</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf mesophyll</td>
<td>Spongy mesophyll cells, palisade mesophyll cells</td>
<td></td>
</tr>
<tr>
<td>Xylem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phloem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epidermis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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