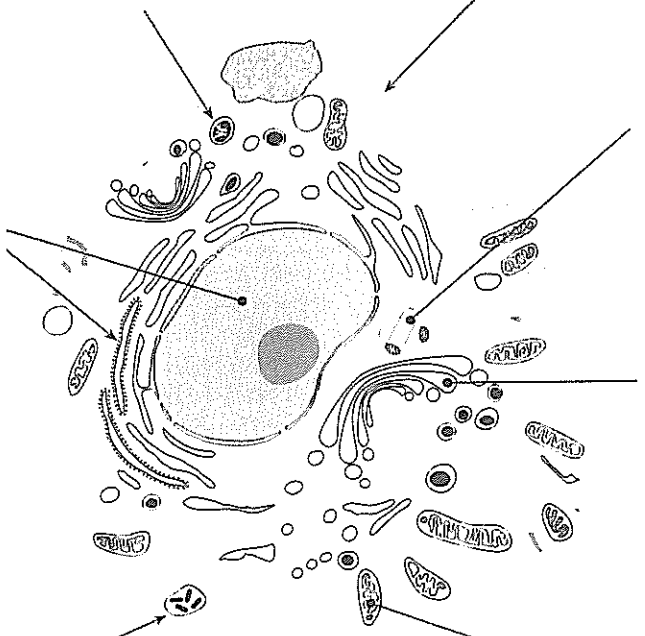
Cell Processes

All of the organelles and other structures in the cell have specific functions. The cell can be compared to a factory with an assembly line. Organelles in the cell provide the equivalent of the power supply, assembly line, packaging department, repair and maintenance, transport system, and the control centre.

The sum total of all the processes occurring in a cell is known as **metabolism**. Some of these processes store energy in molecules (**anabolism**) while others release that stored energy (**catabolism**). A summary of the major processes that take place in a cell are illustrated below.



Autolysis
Lysosomes contain powerful digestive enzymes that destroy unwanted cell organelles and foreign material entering the cell.

Transport in and out of the cell
Simple diffusion and active transport move substances into and out of the cell across the plasma (cell surface) membrane.

Protein synthesis
Chromosomes in the nucleus store the genetic instructions for the production of specific proteins. These proteins are constructed by ribosomes both on the endoplasmic reticulum and free in the cytoplasm.

Cell division
Centrioles control the movement of chromosomes during cell division.

Secretion
The Golgi apparatus is the packaging department of the cell. It produces secretory vesicles (small membrane-bound sacs) that are used to store useful chemicals, prepare substances for movement out of the cell (e.g. hormones), or to package digestive enzymes.

Phagocytosis
The plasma membrane can engulf objects (such as bacteria). The membrane pinches off to become a vesicle, and the enclosed material is digested by powerful enzymes.

Pinocytosis
The plasma membrane can pinch off to trap some of the surrounding watery fluid in a vesicle.

Cellular respiration
Respiration is a complex chemical process, which starts in the cytoplasm (with glycolysis) but is completed in the mitochondria. This process supplies the cell with energy to carry out the many other chemical reactions of metabolism.

1. For each of the processes listed below, identify the organelles or structures associated with that process (there may be more than one associated with a process):

   (a) Secretion: _____ (e) Protein synthesis: _____

   (b) Respiration: _____ (f) Cell division: _____

   (c) Pinocytosis: _____ (g) Autolysis: _____

   (d) Phagocytosis: _____ (h) Transport in/out of cell: _____

2. (a) Explain what is meant by **metabolism** and describe an example of a metabolic process: _____

   _____

   _____

   (b) Identify one catabolic process in the diagram above and explain your choice: _____

   _____

   (c) Identify one anabolic process in the diagram above and explain your choice: _____

   _____

Related activities: Basic Cell Structure

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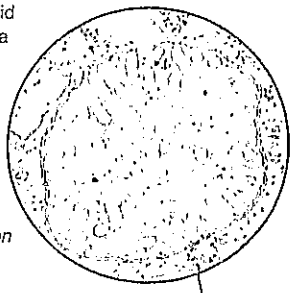
Basic Cell Structure

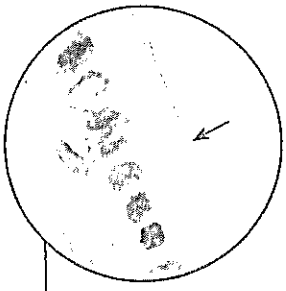
Cells have a similar basic structure, although they may vary tremendously in size, shape, and function. Certain features are common to almost all cells, including their three main regions: a **nucleus** (usually located near the center of the cell), surrounded by a watery **cytoplasm**, which is itself enclosed by the **plasma membrane**. Animal cells do not have a regular shape, and some (such as the phagocytic white blood cells) are quite mobile. The diagram below illustrates the basic ultrastructure of an **intestinal epithelial cell**. It contains organelles common to most relatively unspecialized human cells. The intestine is lined with these columnar epithelial cells. They are taller than they are wide, with the nucleus close to the base and hairlike projections (**microvilli**) on their free surface. Microvilli increase the surface area of the cell, greatly increasing the capacity for absorption.

Structures and Organelles in an Intestinal Epithelial Cell

Mitochondrion (pl. mitochondria): 1.5 µm X 2–8 µm. Ovoid organelle bounded by a double membrane. They are the cell's energy transformers, and convert chemical energy into ATP.

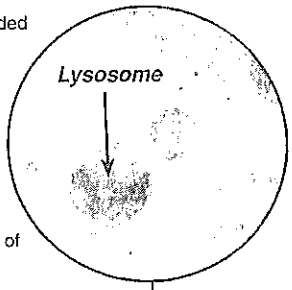


Transverse section through a mitochondrion

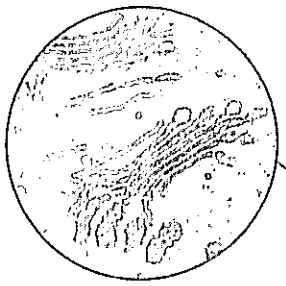


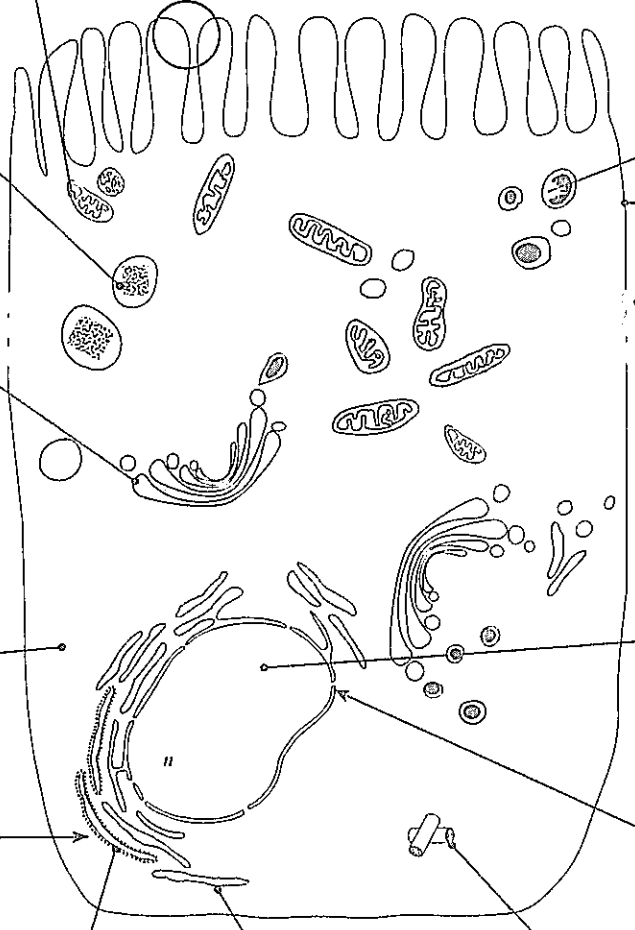
Each epithelial cell has many small projections, called microvilli, discernible in this photograph as a fuzzy brush border (arrowed).

Lysosome: A sac bounded by a single membrane. Lysosomes are pinched off from the Golgi and contain and transport enzymes that break down foreign material. Lysosomes show little internal structure but often contain fragments of degraded material.



Peroxisomes: Self-replicating organelles containing oxidative enzymes, which function to rid the body of toxic substances. They are distinguished from lysosomes by the crystalline core.





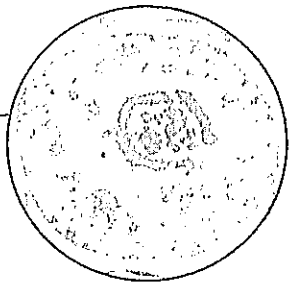
Plasma membrane: 3-10 nm thick phospholipid bilayer with associated proteins and lipids.

Tight junction: impermeable junction binding neighboring cells together.

Nucleus (below): 5 µm diameter. A large organelle containing most of the cell's DNA. Within the nucleus, the **nucleolus** (*n*) is a dense structure of crystalline protein and nucleic acid involved in ribosome synthesis.

Golgi apparatus (above): A series of flattened, disc-shaped sacs, stacked one on top of the other and connected with the ER. The Golgi stores, modifies, and packages proteins. It 'tags' proteins so that they go to their correct destination.

Cytoplasm: A watery solution containing dissolved substances, enzymes, and the cell organelles and structures.

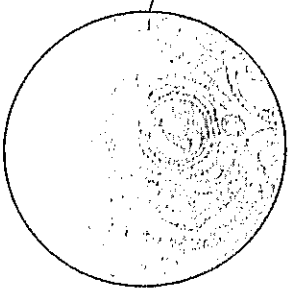


Ribosomes: These small (20 nm) structures manufacture proteins. Ribosomes are made of ribosomal RNA and protein. They may be free in the cytoplasm or associated with the surface of the endoplasmic reticulum.

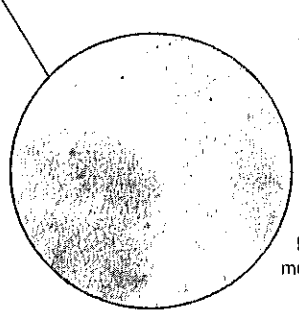
Nuclear pore: A hole in the nuclear membrane. It allows communication between the nucleus and the rest of the cell.

Centrioles: Microtubular structures associated with nuclear division. Under a light microscope, they appear as small, featureless particles, 0.25 µm diameter.

Rough ER: Endoplasmic reticulum with ribosomes attached to its surface. It is where the proteins destined for transport are synthesized.



Rough endoplasmic reticulum showing ribosomes (dark spots)



Endoplasmic reticulum (ER): Comprises a network of tubules and flattened sacs. ER is continuous with the plasma membrane and the nuclear membrane. **Smooth ER**, as shown here, is a site for lipid and carbohydrate metabolism, including hormone synthesis.

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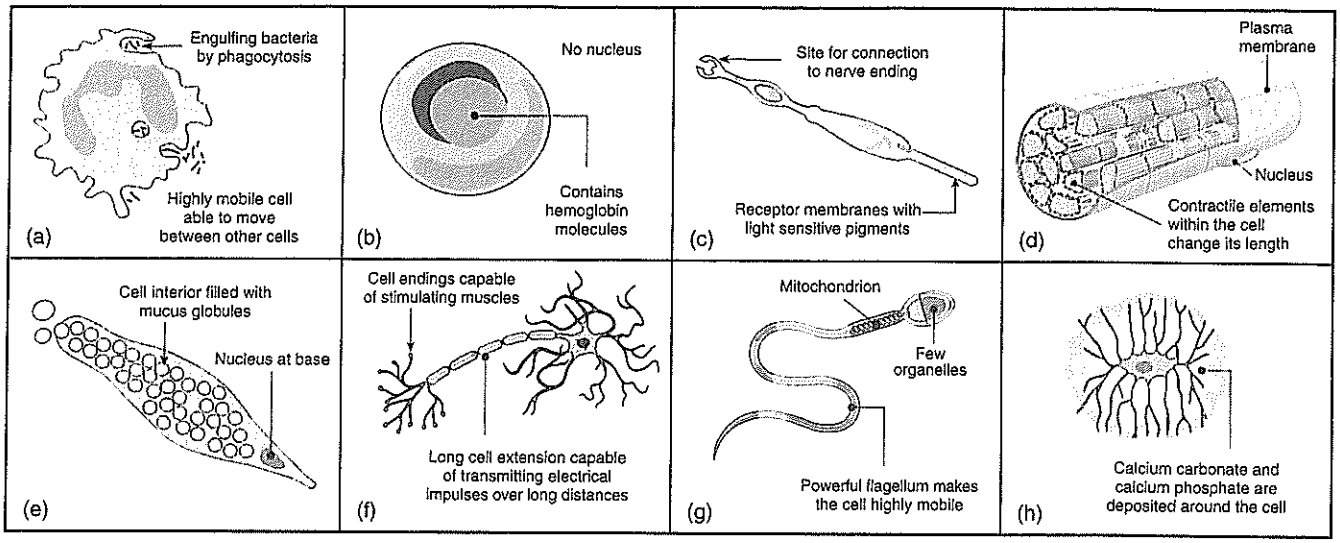
Related activities: Cell Structures & Organelles, Cell Processes

Web links: Eukaryotic Cells Interactive Animation



1. Explain what you understand by the term generalized cell: _____

2. Each of the cells (a) to (h) exhibits **specialized features** specific to its **functional role** in the body. For each, describe one specialized feature of the cell and its purpose:

   (a) Phagocytic white blood cell: _____

   (b) Red blood cell (erythrocyte) _____

   (c) Rod cell of the retina: _____

   (d) Skeletal muscle fiber (part of): _____

   (e) Intestinal globlet cell: _____

   (f) Motor neuron: _____

   (g) Spermatozoon: _____

   (h) Osteocyte: _____

3. Discuss how the shape and size of a specialized cell, as well as the number and types of organelles it has, is related to its functional role. Use examples to illustrate your answer:

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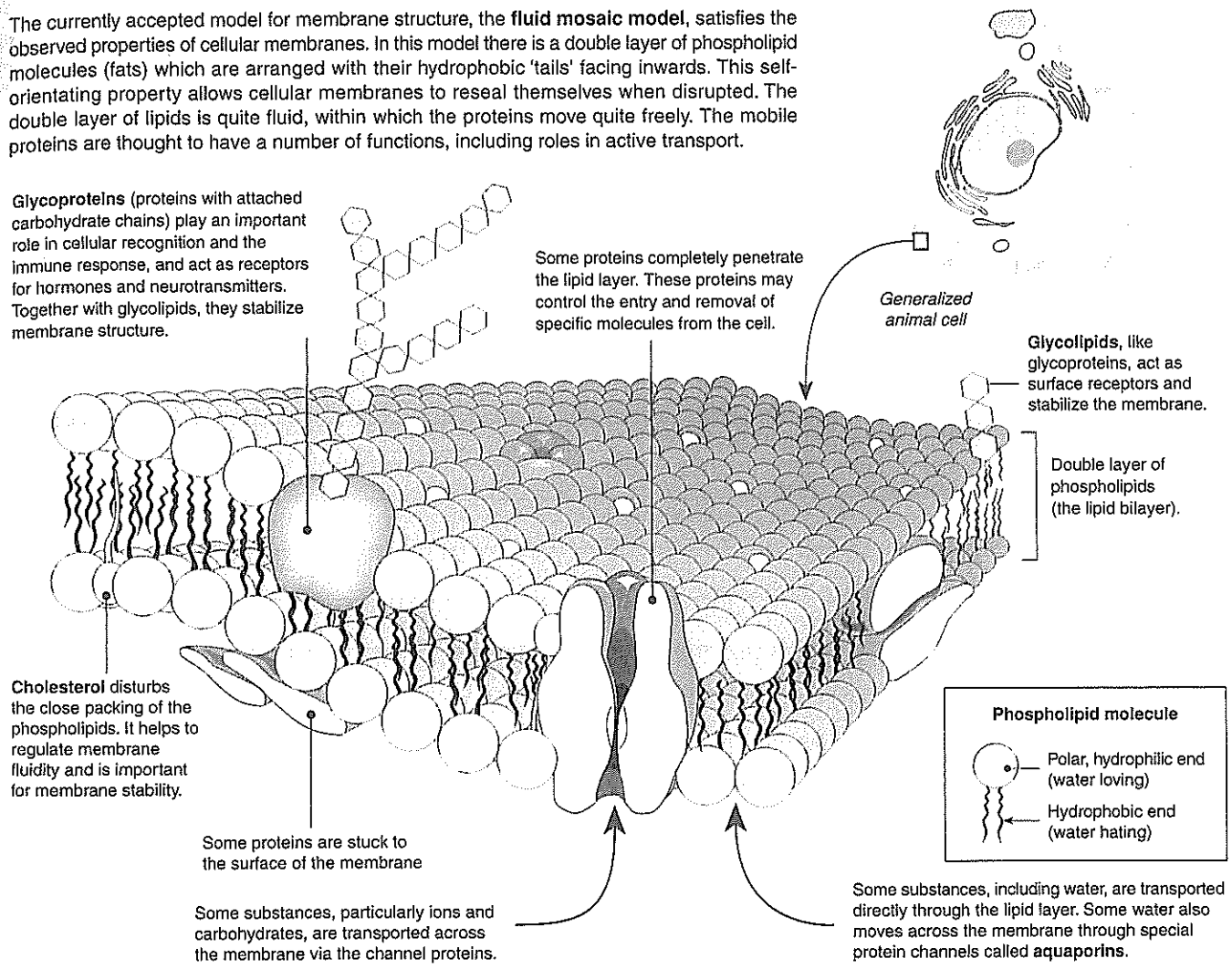
The Structure of Membranes

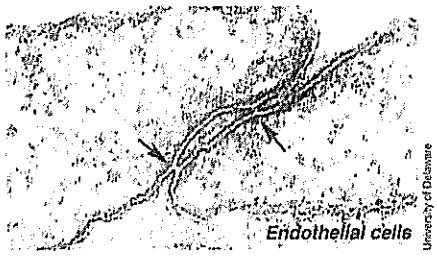
All cells have a **plasma membrane** forming the outer limit of the cell. Cellular membranes are also found inside eukaryotic cells as part of membranous **organelles**, such as the endoplasmic reticulum. Present day knowledge of membrane structure has been built up as a result of many observations and experiments. The now-accepted model of membrane structure is the **fluid-mosaic model** (below). The plasma membrane is more than just a passive envelope; it is a dynamic structure actively involved in cellular activities. Specializations of the plasma membrane, including microvilli and membrane junctions (e.g. desmosomes and tight junctions), are particularly numerous in epithelial cells, which line hollow organs such as the small intestine.

The Fluid Mosaic Model

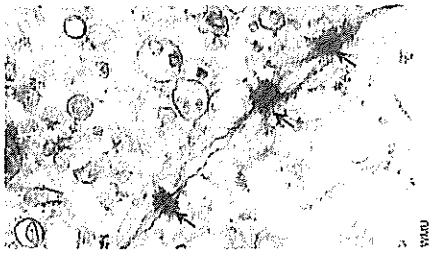
The currently accepted model for membrane structure, the **fluid mosaic model**, satisfies the observed properties of cellular membranes. In this model there is a double layer of phospholipid molecules (fats) which are arranged with their hydrophobic 'tails' facing inwards. This self-orientating property allows cellular membranes to reseal themselves when disrupted. The double layer of lipids is quite fluid, within which the proteins move quite freely. The mobile proteins are thought to have a number of functions, including roles in active transport.



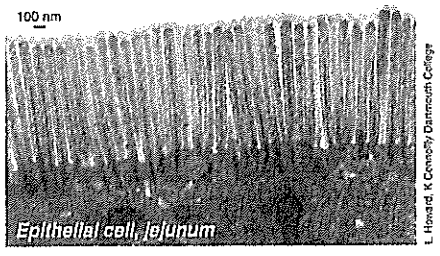
Membrane Specializations



Tight junctions bind the membranes of neighboring cells together to form a virtually impermeable barrier to fluid. Tight junctions prevent molecules passing through the spaces between cells.



Desmosomes (arrowed) are anchoring junctions that allow cell-to-cell adhesion. Desmosomes help to resist shearing forces in tissues subjected to mechanical stress (such as skin cells).



Microvilli are microscopic protrusions of the plasma membrane that increase the surface area of cells. Microvilli are involved in a wide variety of functions, including absorption (e.g. in the intestine).

1. (a) Explain how phospholipids organize themselves into a bilayer in an aqueous environment: _____

_____

_____

_____

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Related activities: The Role of Membranes in Cells

Web links: Membrane Structure Tutorial, Animal Cell Junctions

(b) Explain how the fluid mosaic model accounts for the observed properties of cellular membranes:

2. Explain how the membrane surface area is increased within cells and organelles:

3. Discuss the importance of each of the following to cellular function:

   (a) High membrane surface area:

   (b) Channel proteins and carrier proteins in the plasma membrane:

4. (a) Name a cellular organelle that possesses a membrane:

   (b) Describe the membrane's purpose in this organelle:

5. Describe the purpose of cholesterol in the plasma membrane:

6. Describe the role of each of the following membrane junctions and give an example of where they commonly occur. The first example is completed for you:

   (a) **Gap junctions**: Communicating junctions linking the cytoplasm of neighboring cells. They allow rapid passage of signals between cells, e.g. electrical messages in cardiac muscle cells.

   (b) **Tight junctions**:

   (c) **Desmosomes**:

7. Explain why tight junctions are especially abundant in epithlelial cells, e.g. in the skin and intestine:

8. 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):

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The Role of Membranes in Cells

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 apparatus, lysosomes, peroxisomes, and the 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 compartmentalize 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 and electron micrographs of the organelles involved are on the following page.

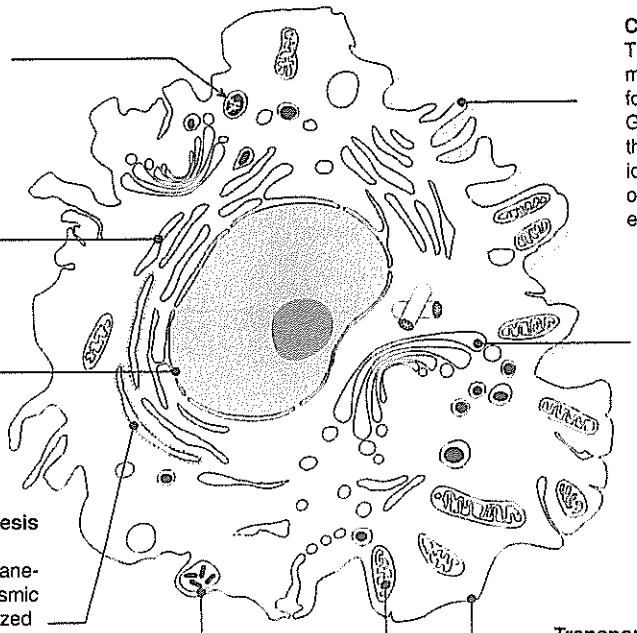
Isolation of enzymes Membrane-bound lysosomes contain enzymes for the destruction of wastes and foreign material. Peroxisomes are the site for destruction of the toxic and reactive molecule, hydrogen peroxide (formed as a result of some cellular reactions).

Role in lipid synthesis
The smooth ER is the site of lipid and steroid synthesis.

Containment of DNA
The nucleus is surrounded by a nuclear envelope of two membranes, forming a separate compartment for the cell's genetic material.

Role in protein and membrane synthesis
Some protein synthesis occurs on free ribosomes, but much occurs on membrane-bound ribosomes on the rough endoplasmic reticulum. Here, the protein is synthesized directly into the space within the ER membranes. The rough ER is also involved in membrane synthesis, growing in place by adding proteins and phospholipids.

Entry and export of substances The plasma membrane may take up fluid or solid material and form membrane-bound vesicles (or larger vacuoles) within the cell. Membrane-bound transport vesicles move substances to the inner surface of the cell where they can be exported from the cell by exocytosis.



Cell communication and recognition
The proteins embedded in the membrane act as receptor molecules for hormones and neurotransmitters. Glycoproteins and glycolipids stabilize the plasma membrane and act as cell identity markers, helping cells to organize themselves into tissues, and enabling foreign cells to be recognized.

Packaging and secretion
The Golgi apparatus is a specialized membrane-bound organelle which produces lysosomes and compartmentalizes the modification, packaging and secretion of substances such as proteins and hormones.

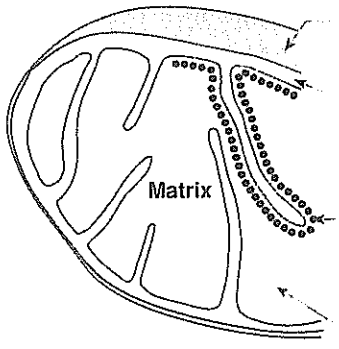
Transport processes
Channel and carrier proteins are involved in selective transport across the plasma membrane. Cholesterol in the membrane can help to prevent ions or polar molecules from passing through the membrane (acting as a plug).

Energy transfer The reactions of cellular respiration (and photosynthesis in plants) take place in the membrane-bound energy transfer systems occurring in mitochondria and chloroplasts respectively. See the example explained below.

Compartmentation within Membranes

Membranes play an important role in separating regions within the cell (and within organelles) where particular reactions occur. Specific enzymes are therefore often located in particular organelles. Reaction rates are controlled by controlling the rate at which substrates enter the organelle. This regulates the availability of the raw materials required for the metabolic reactions.

Example: *The enzymes involved in cellular respiration are arranged in different parts of the mitochondria. The various reactions are localized and separated by membrane systems.*



Cross-section of a mitochondrion

Amine oxidases and other enzymes on the outer membrane surface

Adenylate kinase and other phosphorylases between the membranes

Respiratory assembly enzymes embedded in the membrane (ATPase)

Many soluble enzymes of the Krebs cycle floating in the matrix, as well as enzymes for fatty acid degradation.

1. Discuss the various functional roles of membranes in cells: _____

_____

_____

_____

_____

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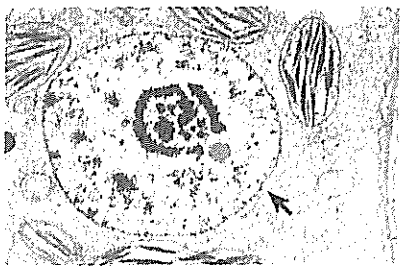
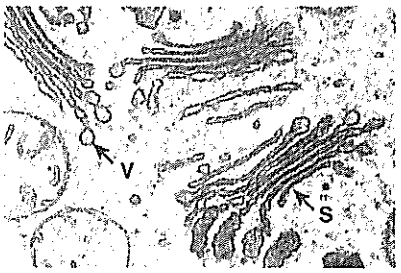
Related activities: The Structure of Membranes, Cell Structures & Organelles
Web links: Cell Membranes

Functional Roles of Membranes in Cells

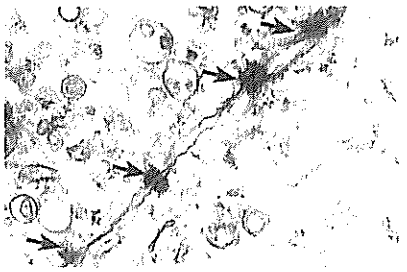


The **nuclear membrane**, which surrounds the nucleus, regulates the passage of genetic information to the cytoplasm and may also protect the DNA from damage.

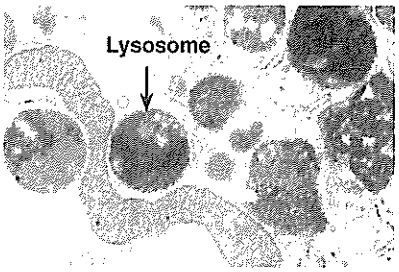
Mitochondria have an outer membrane (**O**) which controls the entry and exit of materials involved in aerobic respiration. Inner membranes (**I**) provide attachment sites for enzyme activity.



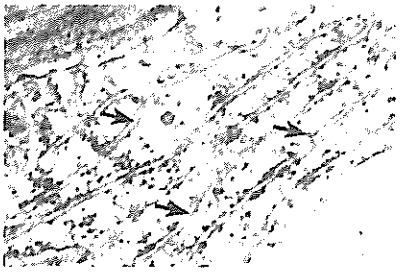
The **Golgi apparatus** comprises stacks of membrane-bound sacs (**S**). It is involved in packaging materials for transport or export from the cell as secretory vesicles (**V**).



The **plasma membrane** surrounds the cell. In this photo, intercellular junctions called **desmosomes**, which connect neighbouring cells, are indicated with arrows.



Lysosomes are membrane-bound organelles containing enzymes capable of digesting worn-out cellular structures and foreign material. They are abundant in phagocytes.



This EM shows stacks of rough endoplasmic reticulum (arrows). The membranes are studded with ribosomes, which synthesize proteins into the intermembrane space.

2. Match each of the following organelles with the correct description of its functional role in the cell:

   peroxisome, *rough endoplasmic reticulum*, *lysosome*, *smooth endoplasmic reticulum*, *mitochondrion*, *Golgi apparatus*

   (a) Active in synthesis, sorting, and secretion of cell products: _____

   (b) Digestive organelle where macromolecules are hydrolyzed: _____

   (c) Organelle where most cellular respiration occurs and most ATP is generated: _____

   (d) Active in membrane synthesis and synthesis of secretory proteins: _____

   (e) Active in lipid and hormone synthesis and secretion: _____

   (f) Small organelle responsible for the destruction of toxic substances: _____

3. Explain the importance of membrane systems and organelles in providing compartments within the cell:

   _____

   _____

4. (a) Explain why non-polar (lipid-soluble) molecules diffuse more rapidly through membranes than polar molecules:

   _____

   _____

   (b) Explain the implications of this to the transport of substances into the cell through the plasma membrane:

   _____

   _____

5. Identify three substances that need to be transported **into** all kinds of human cells, in order for them to survive:

   (a) _____ (b) _____ (c) _____

6. Identify two substances that need to be transported **out** of all kinds of human cells, in order for them to survive:

   (a) _____ (b) _____

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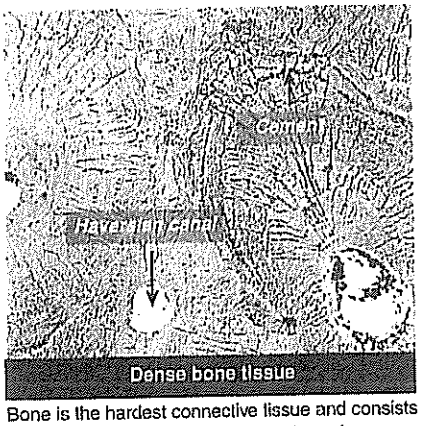
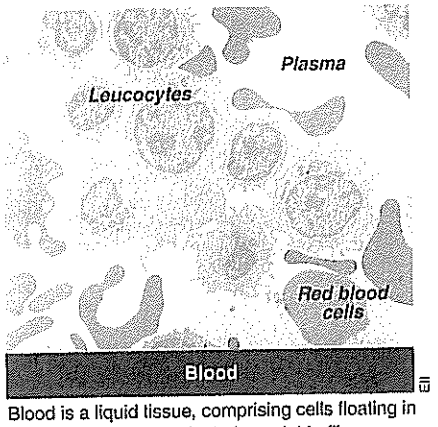
Connective tissue

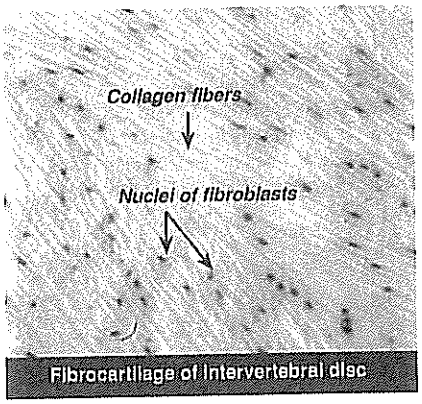
Connective tissue is the major supporting tissue of the body. It is made of living cells widely dispersed in a semi-fluid extracellular matrix. Connective tissues bind other structures together and provide support and protection against damage, infection, or heat loss. Most connective tissues have a plentiful blood supply, although tendons and ligaments are poorly vascularized and cartilage is avascular. Connective tissues range from very hard to fluid: classified as bone, cartilage, dense connective tissue (e.g. tendons, ligaments), loose connective tissue, and blood.



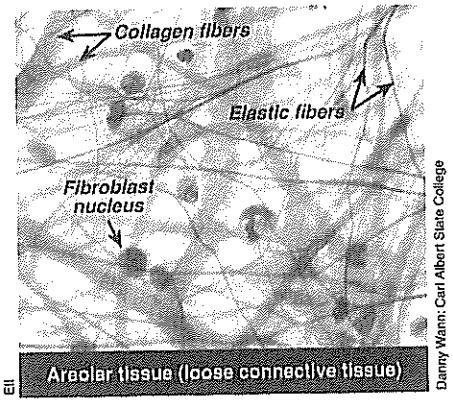
Bone is the hardest connective tissue and consists of bone cells surrounded by a hard matrix.



Blood is a liquid tissue, comprising cells floating in a liquid matrix, which includes soluble fibers.



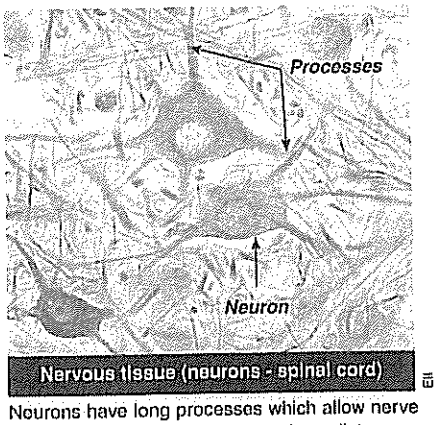
Cartilage is more flexible than bone and forms supporting structures in the skeleton. Fibrocartilage forms the cushiony disks between vertebrae.



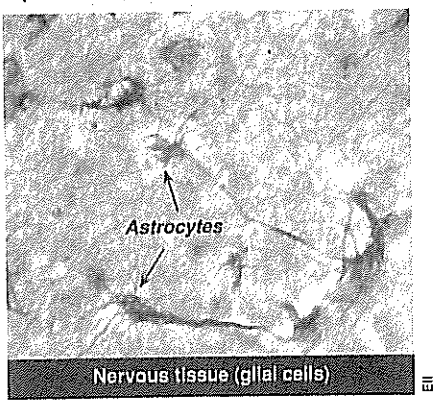
Loose connective tissues have more cells and fewer fibers than harder connective tissues. Areolar tissue helps to hold internal organs in position.

Nervous tissue

Nervous tissue makes up the structures of the nervous system. It contains densely packed nerve cells (neurons), specialized for transmitting electrochemical impulses. Neurons are usually associated with supporting cells (**neuroglia**) and connective tissue containing blood vessels.



Neurons have long processes which allow nerve impulses to be transmitted over long distances.



Astrocytes (astroglia) provide physical and metabolic support to the neurons of the CNS and help maintain the composition of the extracellular fluid.

1. (a) Describe the basic components of a tissue: _____

_____

(b) 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: _____ (c) Muscle tissue: _____

(b) Nervous tissue: _____ (d) Connective tissue: _____

3. Describe the particular features that contribute to the particular functional role of each of the following tissue types:

(a) Muscle tissue: _____

_____

(b) Nervous tissue: _____

_____

(c) Connective tissue: _____

_____

(d) Epithelial tissue: _____

_____

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Tissues and Organs

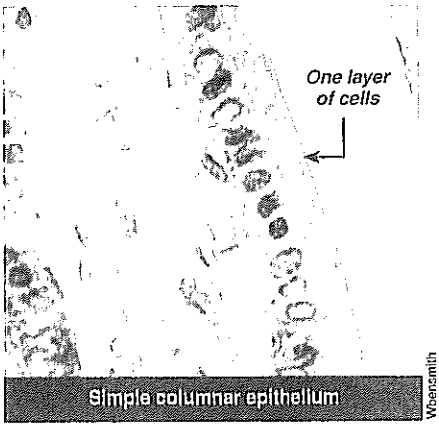
The microscopic study of tissues is called **histology**. The cells of a tissue, and their associated extracellular substances, e.g. collagen, are grouped together to perform particular functions. Tissues improve the efficiency of operation because they enable tasks to be shared amongst various specialized 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 neurons, which direct the contractions of the cardiac muscle. The features of some of the more familiar tissues of the human body are described below.

Epithelial Tissue

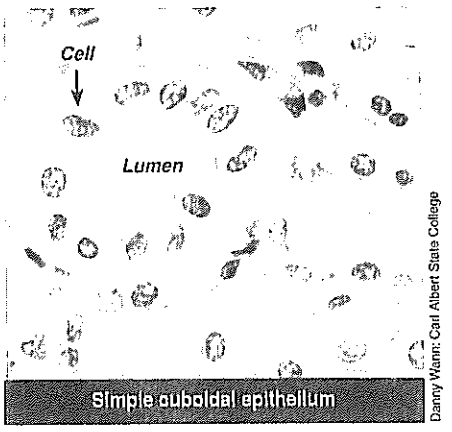
Epithelial tissues line internal and external surfaces (e.g. blood vessels, ducts, gut lining) and protect the underlying structures from wear and tear, infection, and pressure.

Features of epithelial tissues

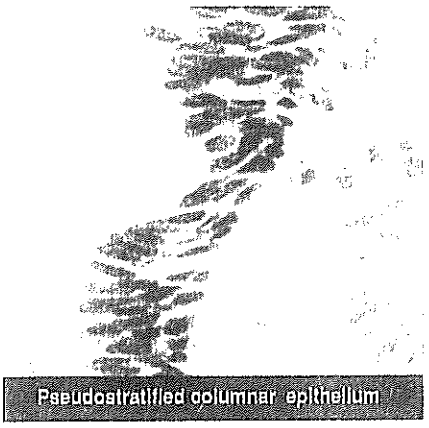
- Epithelium always has one free surface called the **apical surface**. On the lower **basal surface**, the epithelial cells are anchored on a **basement membrane** of collagen fibers held together by a carbohydrate-based glue.
- Except for glandular epithelium, epithelial cells form fitted continuous sheets, held in place by desmosomes and tight junctions.
- Epithelial tissues are **avascular**, i.e. they have no blood supply and rely on diffusion from underlying capillaries.
- Epithelia are classified as **simple** (single layered) or **stratified** (two or more layers), and the cells may be **squamous** (flat), **cuboidal**, or **columnar** (rectangular). Thus at least two adjectives describe any particular epithelium (e.g. stratified cuboidal).
- **Pseudostratified epithelium** is a type of simple epithelium that appears layered because the cells are of different heights. All cells rest on the basement membrane.
- **Transitional epithelium** is a type of stratified epithelium which is capable of considerable stretching. It lines organs such as the urinary bladder.
- Epithelia may be modified, e.g. ciliated or specialized for secretion, absorption, or filtration.
- Glandular epithelium is specialized for secretion. Epithelia may be also be ciliated e.g. in the respiratory tract or specialized for absorption or filtration.



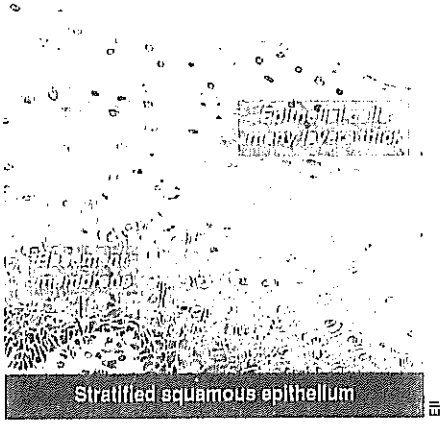
The simple epithelium of the gastrointestinal tract is easily recognized by the regular column-like cells. It is specialized for secretion and absorption.



Simple cuboidal epithelium is common in glands and their ducts and also lines the kidney tubules (above) and the surface of the ovaries.

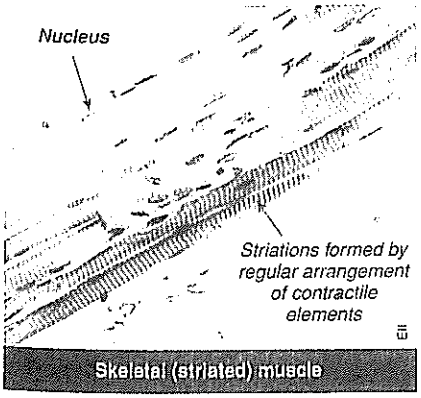


This type of epithelium lines most of the respiratory tract (above). Mucus produced by goblet cells in the epithelium traps dust particles.

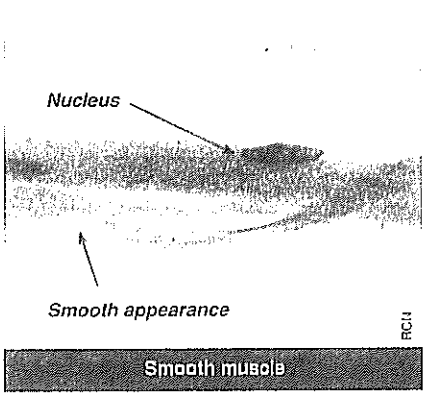


Stratified epithelium is more durable than simple epithelium because it has several layers. It has a protective role, e.g. in the vagina above.

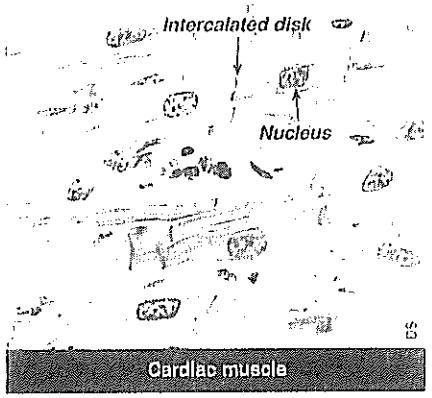
Muscle Tissue



Muscle tissue consists of very highly specialized cells called fibers, held together by connective tissue. Muscle tissues are specialized to contract. Skeletal muscle (above) brings about voluntary movements. Note the multinucleated cells.



The spindle shaped cells of **smooth muscle** have only one nucleus per cell. The contractile elements are not regularly arranged so the tissue appears smooth. Smooth muscle is responsible for involuntary movements (e.g. in the gut wall).



Cardiac muscle is found only in the heart. It has striations, but the cells are short with only one nucleus, and they are held together by specialized intercalated disks with gap junctions to allow rapid communication between the cells.

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