River Valley High School
2025 JC1 H2 Biology

Lecture Topic 1: Organelles and Cellular Structures

Name: _____ ( ) Class: 25J__ Date: _____

References

Title	Authors
Campbell Biology (9th Edition)	Reece, Urry, Cain, Wasserman, Minorsky, Jackson
Molecular Biology of the Cell (5th edition)	Alberts, Johnson, Lewis, Raff, Roberts and Walter
Biological Science 1. Organisms, Energy and Environment (3rd Edition)	Taylor, Green, Stout and Soper
Advanced Biology: Principles and Applications (2nd edition)	Clegg and Mackean

H2 Biology Syllabus 9477 (2025)
Candidates should be able to use the knowledge gained in the following section(s) in new situations or to solve related problems.

Related Topics	Concepts
Genetics and Inheritance	The Structure of Nucleic Acids and Gene Expression
	Organisation of Genomes
	The Cell Cycle
Energy and Equilibrium	Transformation of Energy between the Environment and Organisms
Infectious Diseases	Viral diseases (e.g. Influenza, HIV)

Learning Outcomes

1A. Organelles and Cellular Structures

a. Outline the cell theory with the understanding that cells are the smallest unit of life, all the cells come from pre-existing cells; and living organisms are composed of cells.

b. interpret and recognise drawings, photomicrographs and electron micrographs of the cytoplasm (cytosol) and cellulose cell wall, and the following membrane systems and organelles: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus (for practical assessment, candidates may be required to operate a light microscope, mount slides and use an eyepiece graticule and a stage micrometer)

c. Outline the functions of the membrane systems and organelles listed in (b).

d. Describe the structure of a typical bacterial cell (small and unicellular, peptidoglycan cell wall, circular DNA, 70S ribosomes and lack of membrane-bound organelles) (*KIV: Organisation of Genomes – Prokaryotes*)

Lecture Outline

I. Cells: The Fundamental Units of Life

II. Techniques to Study Cell Structures
- A. Microscopy
- B. Cell Fractionation
- C. Autoradiography

III. Prokaryotic and Eukaryotic Cells

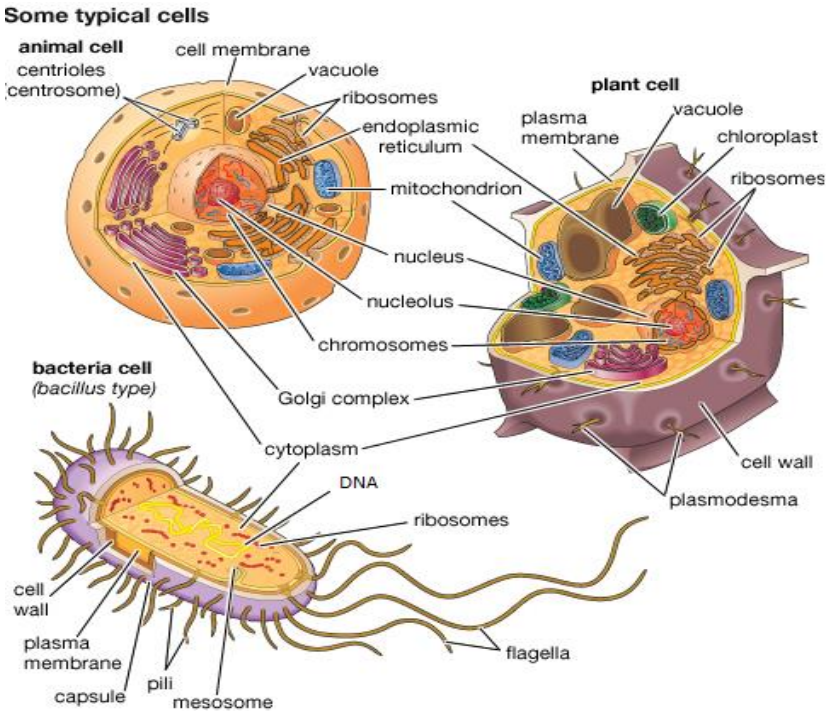
IV. Eukaryotic Cells
- A. Components of Eukaryotic Cells
- B. Cytosol
- C. Membranous Organelles
- D. Non-membranous Organelles
- E. Extracellular Structures
- F. Plant and Animal Cells

Websites

URL	Description
http://learn.genetics.utah.edu/	Select “Cells” for concise information, interactive animations and links to video resources on cell structure and function.
https://www.youtube.com/watch?v=wJyUtbn0O5Y	“The Inner Life of a Cell”. A 3D computer graphics animation on the various biological mechanisms occurring within a white blood cell.
http://www.cellsalive.com/cells/bactcell_js.htm	Interactive bacterial cell. Download the site here.

I. Cells: The Fundamental Units of Life

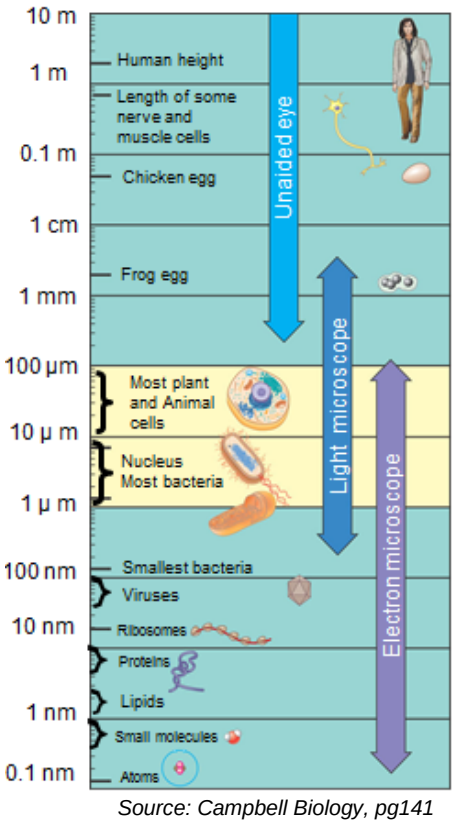
In the hierarchy of biological organisation, the cell is the simplest collection of matter that can live. There are diverse forms of life existing as **unicellular** organisms. More complex organisms are **multicellular** – their bodies are cooperatives of many kinds of specialised cells that are often arranged into higher levels of organisation (e.g. tissues, organs, organ systems), yet cells remain their basic units of structure and function.



Source: Encyclopaedia Britannica, Inc.

A **cell** *(Latin: cella – "a small room")* is

- the basic structural and functional unit of an organism
- a membrane bound structure containing biological molecules
- a self-contained and self-maintaining entity
  - take in nutrients, convert these nutrients into energy, carry out specialised functions, and reproduce as necessary.
- stores its own set of instructions for carrying out each of these activities



Source: Campbell Biology, pg141

The cell was first described by **Robert Hooke** in 1665. Subsequent observations by other scientists led to the development of the **modern cell theory**, which states that:

1. **The cell is the smallest unit of life.**
2. **All cells arise from pre-existing cells by dividing into two.**
3. **All known living things are made up of one or more cells.**
4. Energy flow (metabolism and biochemistry) occurs within cells.
5. Cells contain hereditary information (DNA) which is passed from cell to cell during cell division.
6. All cells are basically the same in chemical composition in organisms of similar species.
7. Some organisms are made up of only one cell and are known as unicellular organisms.
8. Others are multicellular, composed of several cells.
9. The activity of an organism depends on the total activity of independent cells.

II. Techniques to Study Cell Structures

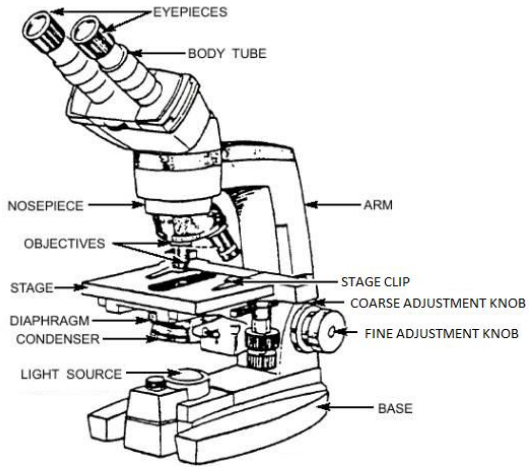
A. Microscopy

Microscopes are the most important tools of **cytology**, the study of cell structure.

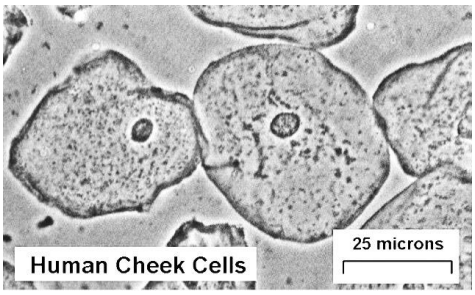
Important parameters in microscopy

- **Magnification**: ratio of an object's image size to its actual size
- **Resolution**: the minimum distance between two points at which they can be distinguished as two points

Light Microscopy
Light microscopy involves passing visible light through the specimen and then through glass lenses, which refract (bend) the light in a way such that the image of the specimen is magnified as it is projected into the eye, photographic film, or digital sensor.



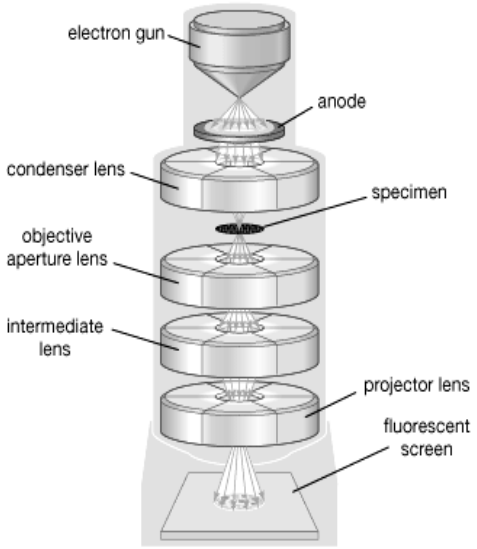
Source: http://www.tpub.com/



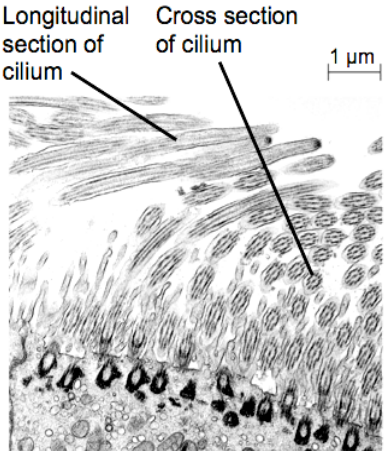
Source: http://teachers.saschina.org/

Electron Microscopy
Electron microscopy involves focusing a beam of electrons
i. through the specimen (**Transmission Electron Microscopy**) or
ii. onto its surface (**Scanning Electron Microscopy**).

Transmission Electron Microscopy (TEM)



Source: Encyclopaedia Britannica, Inc.



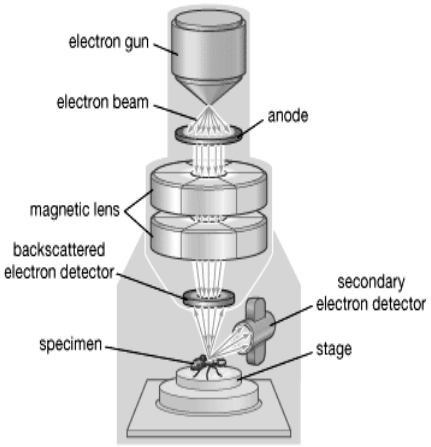
Source: Campbell Biology, pg142

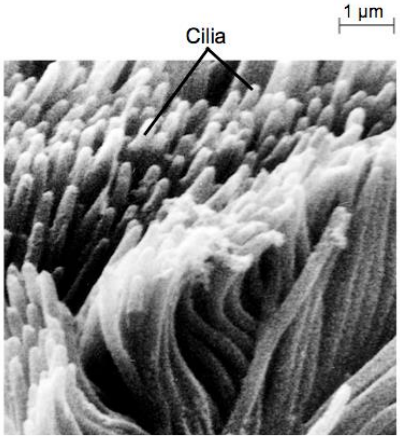
TEM is used to study the internal ultrastructure[1] of cells. The TEM aims an electron beam through a very thin section of the specimen.

Darker areas of the image represent regions of the specimen that is **electron dense**, where few electrons are transmitted. **Lighter areas** of the image represent regions of the specimen that is **less electron dense** where many electrons are transmitted.

Patterns of transmitted electrons can also be passed onto a photographic film to capture a permanent record. This photograph that is taken is called an **electron micrograph**.

Scanning Electron Microscopy (SEM)





SEM is used for detailed study of the surface of a specimen. Specimens need not be sectioned, can frequently be studied whole and intact. The electron beam scans the surface of the sample. SEM has great depth of field, resulting in a three-dimensional image.

Exposed areas of the specimen is coated with gold so it is **electron dense** while **sheltered areas** remain uncoated, thus are **less electron dense**. Exposed areas of the specimen are lighter on the image while sheltered areas of the specimen are darker on the image.

[1] Cellular anatomy revealed by an electron microscope.

Advantages of Electron Microscopy

- Much higher resolution (0.5 nm for TEM and 5-20 nm for SEM) is achieved than by light microscopy (around 200 nm);
- Much higher magnification of specimens (x250 000) than in light microscopy (x1500).

Disadvantages of Electron Microscopy

- Cannot be used to observe living specimens. Methods used to prepare specimens kill the cells; furthermore specimens are viewed in a vacuum;
- Expensive to purchase and run;
- Preparation of material is time-consuming and requires specialised expertise;
- Specimen gradually deteriorates in electron beam; photographs must therefore be taken to allow further study of the particular specimen.

Calculating Magnification

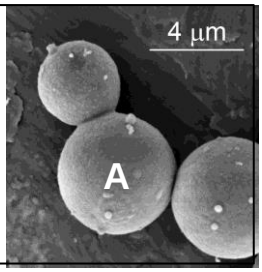
The magnification of various cells in an image can be calculated as shown below.

$$Magnification = \frac{Measured\ Size}{Actual\ Size}$$

Note: Answers should be given to 1d.p.

Lecture Practice 1

Calculate the magnification of the yeast cell labelled **A**.

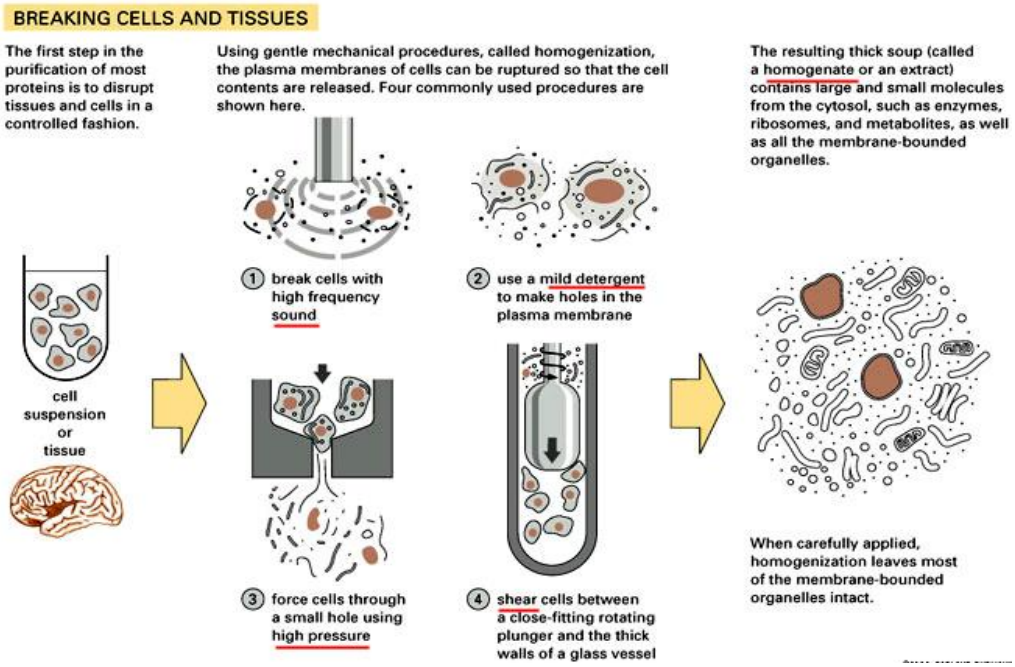


B. Cell Fractionation

Cell fractionation is the physical process by which cells are taken apart and its major organelles and other subcellular structures separated by their sedimentation coefficients, which depend on factors such as the particle's size and density. This technique allows specific cell components to be isolated and prepared in bulk for the study of their chemical composition and functions.

Cell fractionation involves three consecutive steps, **homogenisation**, **centrifugation,** and **resuspension**.

1. Homogenisation



Source: http://www.garlandscience.com/

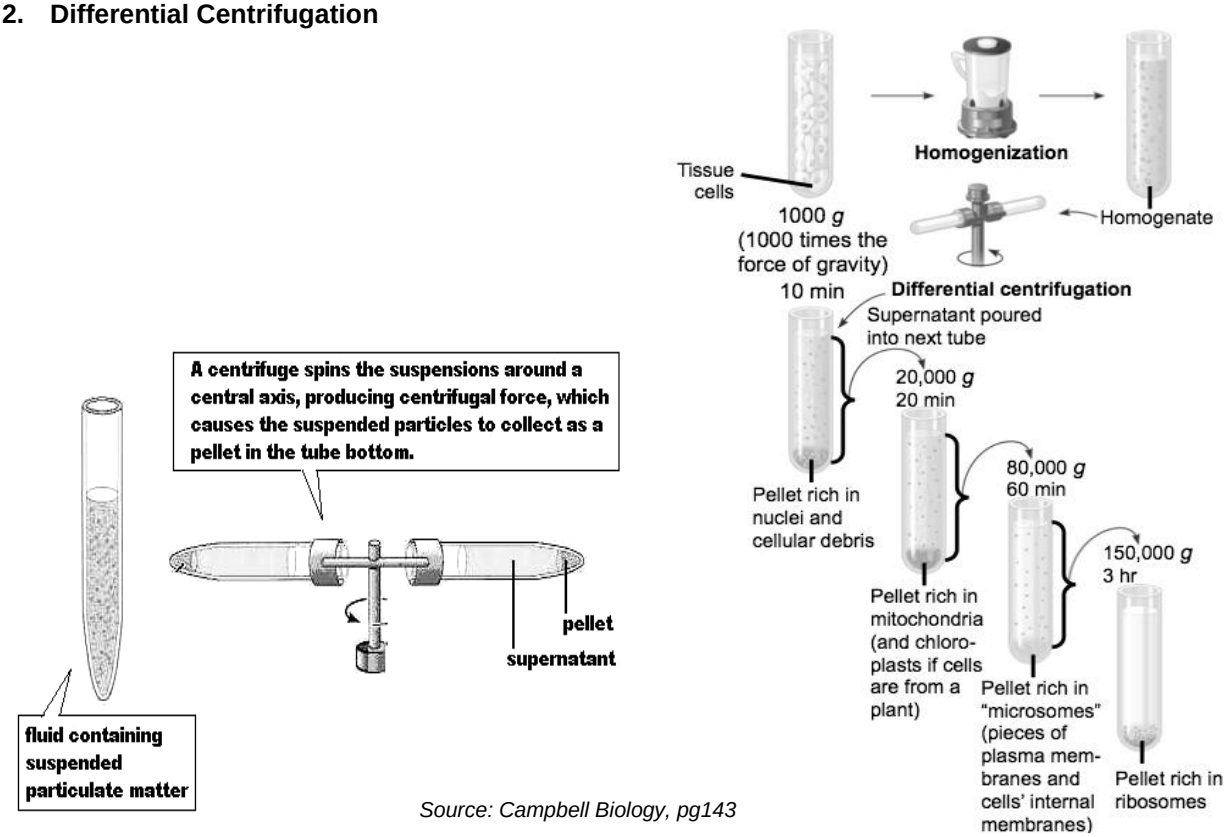
Homogenisers, e.g. kitchen blenders or ultrasound devices, can be used to rupture cells, thus releasing their cell contents.

The process is very sensitive so cold (0-4°C), isotonic buffer solution is added to prevent mechanical damage on the cell components:

i. Low temperature inactivates enzymes (e.g. protease), preventing damage to cellular components, and reduces heat damage generated by mechanical force.
ii. Isotonic solution (e.g. sucrose), which has the same water potential as the cell content, prevents osmotic damage to the cells.
iii. Buffer solution contains a mixture of salts that serves to maintain a constant pH.

If carefully carried out, the disruption procedures leave organelles such as nuclei and mitochondria largely intact. A suspension of cellular components (called **homogenate** or **extract**) is then obtained. It is a mixture of organelles, debris of membranes and molecules from the broken cells.

2. Differential Centrifugation



Source: Campbell Biology, pg143

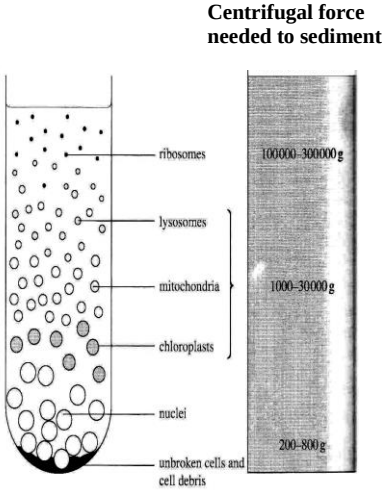
The different components of the homogenate must then be separated. This is done by performing by a series of spins at varying speeds in an instrument called a **centrifuge**.

This treatment separates cell components by **size** and **density**. The centrifugal forces cause a fraction of the cell components to settle to the bottom of the centrifuge tube, forming a **pellet**.

In general, at lower speeds the pellet that is formed comprises larger and denser components; at higher speeds it comprises smaller and less dense components.

After each spin, the **supernatant** (= liquid above pellet) is decanted and re-centrifuged at a higher speed.

The process continues with increasing the speed and/or duration of each spin until a series of pellets containing organelles of smaller size and density is obtained.

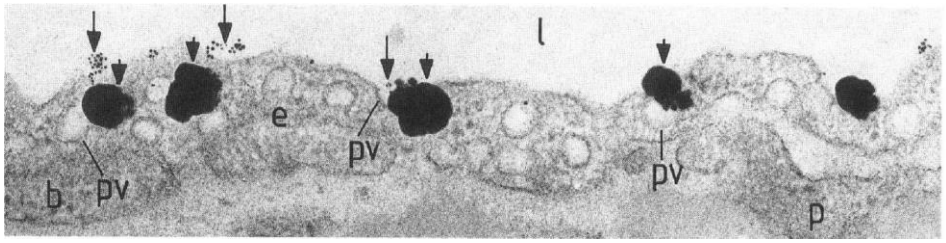


Source: Biological Science 1, pg134

3. Resuspension

Each pellet can be re-suspended as a cell organelle fraction to be analysed further. By determining which cell fractions are associated with particular metabolic processes, various functions can then be tied to specific organelles.

C. Autoradiography



Dark spots in the figure identify the location of radioactive compounds

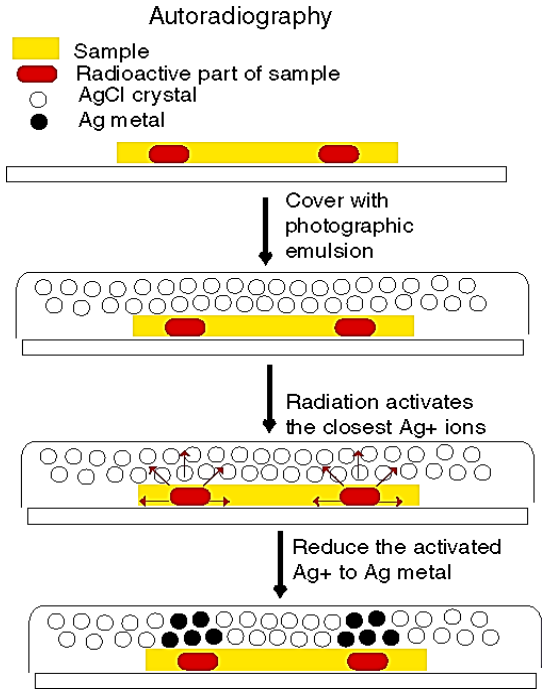
Autoradiography can be used in a cell to locate a radioactive compound in sections of whole cells or tissues. In this procedure, living cells are briefly exposed to a specific radioactive compound and then incubated for a variable period. The cells are then fixed and processed for light or electron microscopy. Each preparation is then overlaid with a thin film of photographic emulsion and left in the dark for several days. The emulsion is then developed and the position of radioactivity in each cell will be shown in film.

In biological research, **radioactive isotopes** commonly serve as radioactive tracers in autoradiography. They are used to label certain chemical compounds in an organism to:

i. follow steps of a metabolic process/pathway, or
ii. locate the compound within an organism.

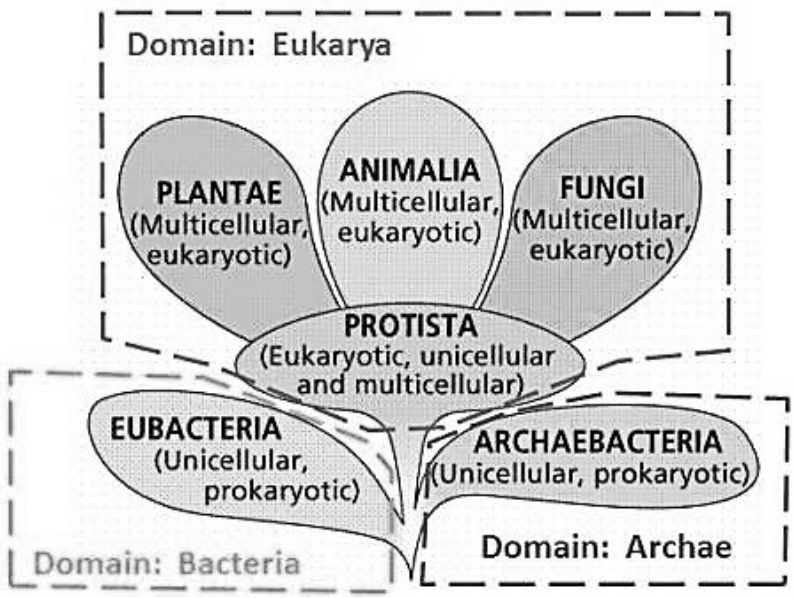
Common isotopes used in radioactive labelling include ^{3}H, ^{14}C, ^{32}P and ^{35}S. Well known applications of radioactive tracers include:

- investigating translocation of nutrients in plant via the use of radioactive $^{14}CO_2$;
- investigating the sites of DNA and RNA synthesis in cells via the use of radioactive ^{3}H-thymidine and ^{3}H-uridine respectively;
- determining the sequence of intermediate compounds formed at various stages in the Calvin cycle of photosynthesis.



Source: http://lifeofplant.blogspot.sg/2011/12/autoradiography.html

Figure shows areas in the sample containing radioactive isotopes reducing Ag+ (in photographic emulsion) to insoluble Ag metal which appear as black dots in the film.



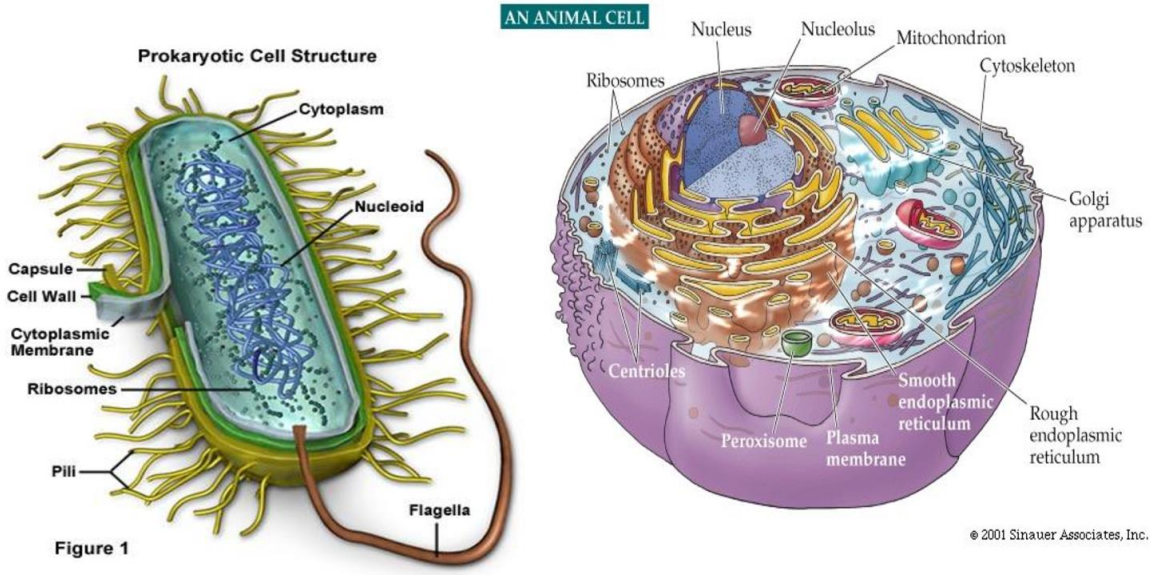
Source: texasgateway.org/resource/taxonomy-major-groups

Cells can be one of two fundamental types – **prokaryotic** or **eukaryotic**.

Prokaryotes *(Greek: pro – "before"; karyon – "nut/kernel", referring to the cell nucleus)*
- Organisms of the domains Bacteria and Archaea: Kingdom Eubacteria and Kingdom Archaebacteria.
- No true nucleus, genetic material is concentrated in a region called the **nucleoid** and no membrane separates this region from the rest of the cell
- No membrane-bound organelles

Eukaryotes *(Greek: eu – "true"; karyon – "nut/kernel", referring to the cell nucleus)*
- Comprise organisms of the domain Eukarya: Kingdom Protista, Kingdom Fungi, Kingdom Animalia and Kingdom Plantae
- Contain true nucleus enclosed by membranous nuclear envelope
- Contain membrane-bound organelles, each with its own specialised structure, function and biochemistry

Comparison of Prokaryotic and Eukaryotic cells



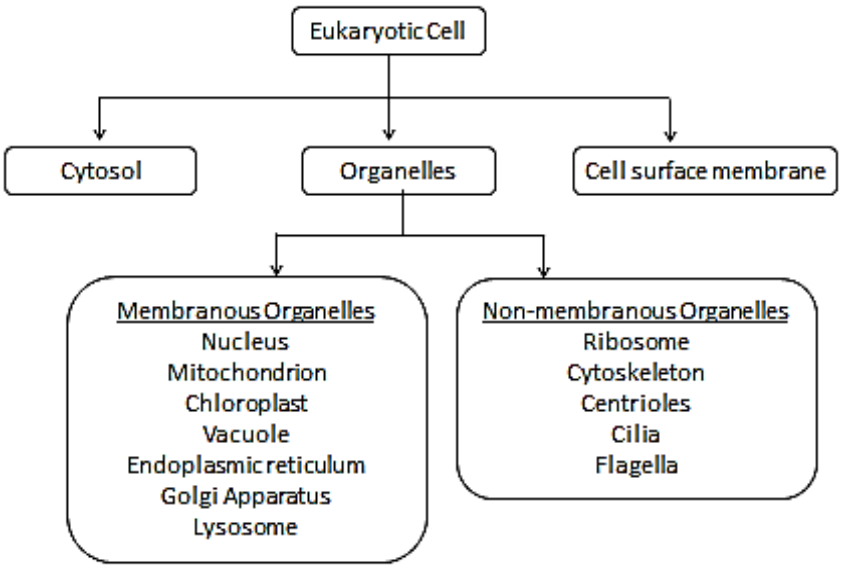
Source: Sinauer Associates Inc.

Features	Prokaryotic cells	Eukaryotic cells
Cell size	Smaller, with diameter ranging from 0.5 μm to 10 μm	Larger, with diameter ranging from 10 μm to 100 μm
Cell wall	Cell wall is made of murein or peptidoglycan. Peptidoglycan animation / Gram-positive / negative bacteria	Plant cell wall is made of cellulose while fungal cell wall is made of chitin.
Organelles	Few organelles No membrane-bound organelle	Many organelles Membrane-bound organelles are present
Genetic material	No nucleus Circular DNA molecule lying free in the cytoplasm. DNA is not associated with proteins.	Nucleus is present. DNA molecule is linear. DNA molecule is associated with proteins (histones) to form chromosome.
Ribosomes	Smaller, with sedimentation coefficient of 70*S*	Larger, with sedimentation coefficient of 80*S* *(70S in chloroplasts & mitochondria)*
Flagellum	Simple, lacking microtubules and extracellular (i.e. not enclosed by a cell surface membrane).	Complex, with "9+2" arrangement of microtubules and intracellular (i.e. surrounded by cell surface membrane).
Respiration	Mesosome present for respiration.	Mitochondrion present for respiration.
Photosynthesis	Photosynthetic membranes present for photosynthesis	Chloroplast present for photosynthesis
Cell division mode	By simple binary fission	By mitosis and/or meiosis

IV. Eukaryotic Cells

A. Components of Eukaryotic Cells

The components of eukaryotic cells can be summarised as follow:



B. Cytosol

Structure

- An aqueous, semi-fluid matrix in which suspends a complex, highly organised system of organelles, and the cytoskeleton network that holds the former together.
- Collective term used to refer to all the organelles and cytosol within the cell membrane, except for the nucleus, is the **cytoplasm**
- About 90% water
- A solution containing ions and small molecules such as salts, sugars, amino acids, fatty acids, nucleotides, vitamins, dissolved gases. Also contains large molecules such as proteins that form colloidal mixtures.

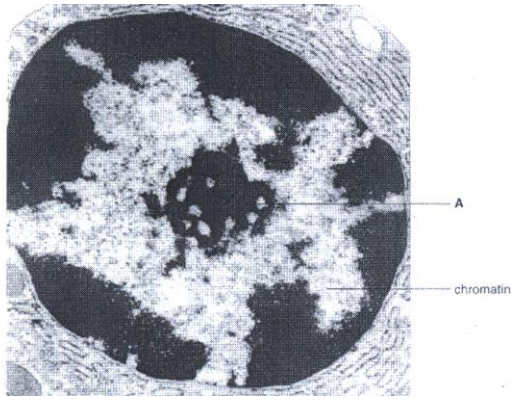
Functions

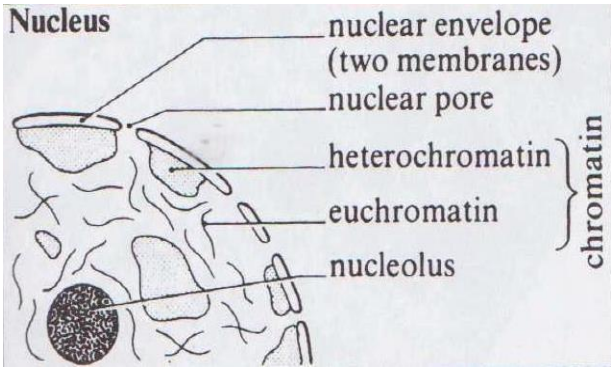
- Store of vital chemicals
- Site of most of the metabolism in prokaryotes, and a large proportion of the metabolism in eukaryotes

C. Membranous Organelles

In addition to the cell surface membrane, a eukaryotic cell has extensive and elaborately arranged internal membranes, which divide the cell into **compartments** (i.e. the organelles).

Nucleus (plural: nuclei)

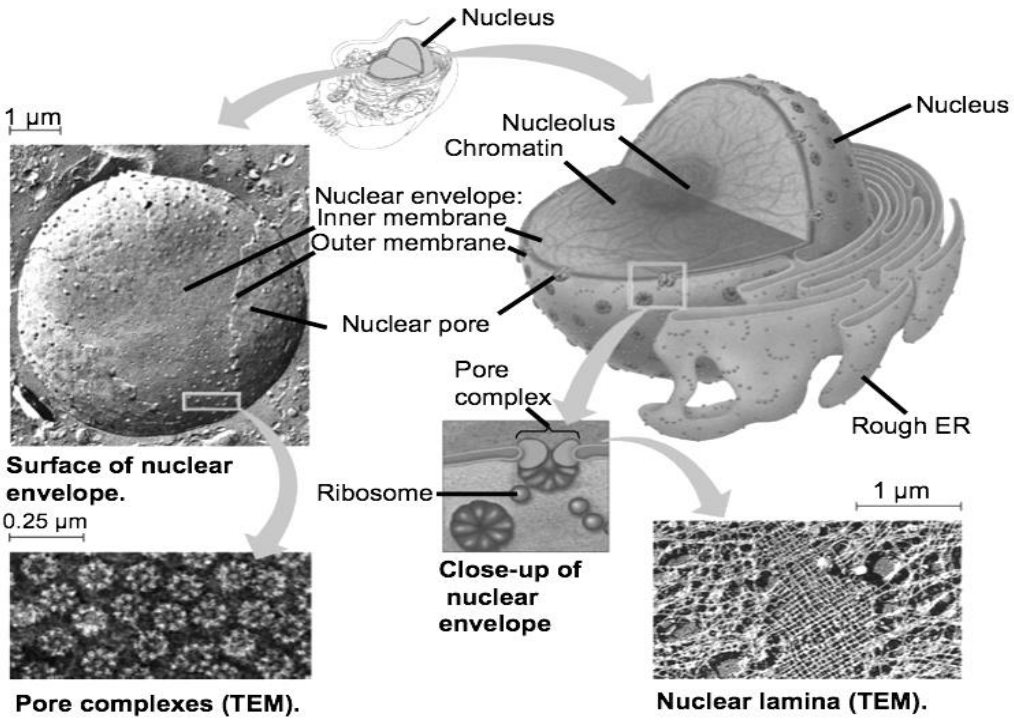




Occurrence

- Found in all eukaryotic cells except mature phloem sieve tube cells and mature mammalian red blood cells

Structure



Source: Campbell Biology, pg149

Nuclear lamina is a netlike array of protein filaments that lined the nuclear side of the envelope. It helps to maintain the shape of the nucleus by mechanically supporting the nuclear envelope

- **Size**: 5-20 µm in diameter, largest organelle, easily seen under the light microscope
- **Shape**: Spherical to ovoid
- **Diagnostic features**:
  1. Enclosed by **nuclear envelope**
     - Nuclear envelope is a **double membrane**. The two membranes are separated by a narrow space (**perinuclear space**)
     - Outer membrane continuous with the endoplasmic reticulum
     - Perforated by **nuclear pores**, that regulate entry and exit of substances (proteins, RNAs and large complexes of macromolecules) into and out of the nucleus
       - The nuclear pore is lined with proteins to form a cylindrical ring-like structure known as **nuclear pore complex**
     - **Nucleoplasm**, semi-fluid matrix that fills the nucleus

2. Contains **chromatin,** coils of negatively charged DNA wrapped around positively charged histone proteins.
    - Two types of chromatin:
        i. **Heterochromatin** – chromatin that is more tightly packed and generally not transcribed. It appears as an electron-dense structure in an electron microscopic image of the nucleus.
        ii. **Euchromatin** – a less compact form of chromatin that is available for transcription.
    - In dividing cells, chromatin fibres condense and become thick enough to be distinguished as separate structures (i.e. **chromosomes**)

3. Contains **nucleolus** (plural: nucleoli), a prominent, dense spherical structure in the non-dividing nucleus:
    - Comprises large loops of DNA coming from a number of chromosomes. Loops contain genes for a particular type of RNA called ribosomal RNA (rRNA).

Functions

Nucleus:

1. Stores hereditary material (DNA)
2. Nuclear envelope protecting DNA from metabolically active cytoplasm
3. Controls gene expression. Site for transcription in which messenger RNA (mRNA) is synthesised for protein synthesis, and ribosomal RNA (rRNA) is synthesised for the production of ribosomes

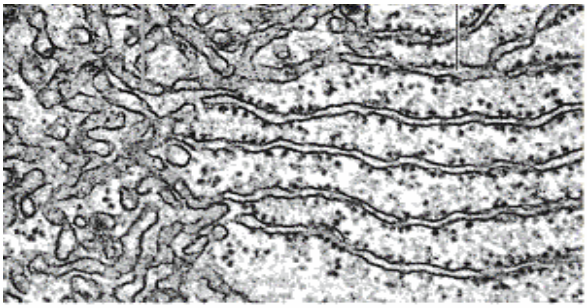
Nucleolus:

1. Site of rRNA synthesis
2. Assembly of proteins and rRNA to form ribosomal subunits, where proteins imported from the cytoplasm assembled with rRNA into large and small ribosomal subunits

Nuclear pore:

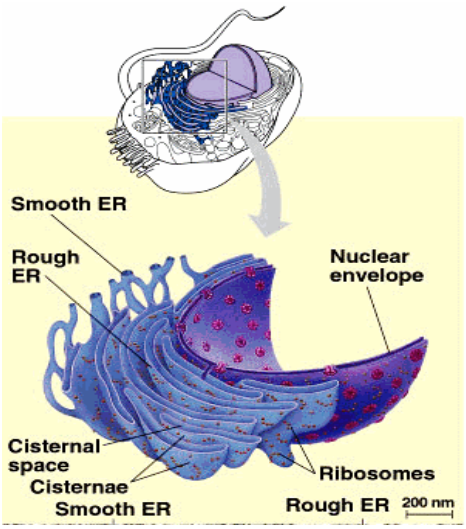
1. regulates exchange of substances between nucleus and cytoplasm, thus controlling processes on either side of the nuclear membrane

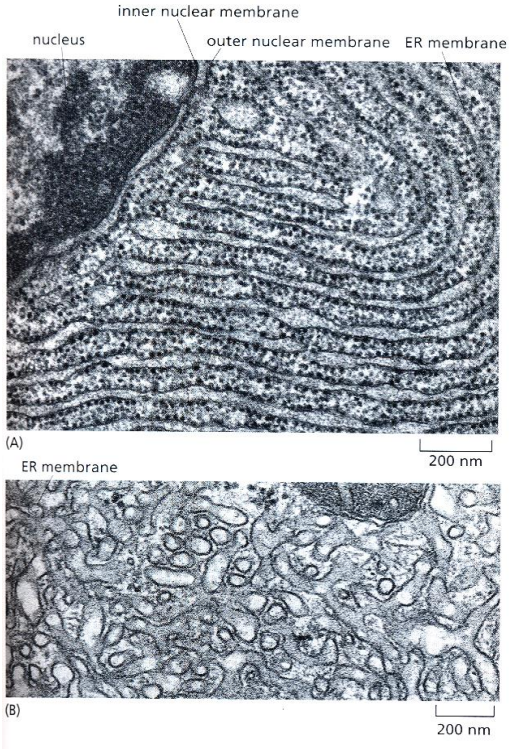
Endoplasmic Reticulum (*endoplasmic – "in cytoplasm"*; *Latin: reticulum – "little net"*)

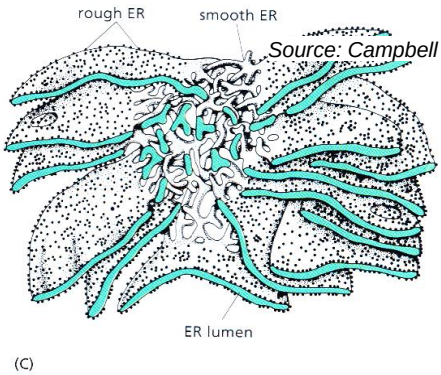


ER structure

- Extensive network of folded membranes forming tubules and sheets called **cisternae** (singular: cisterna)
- ER membrane separates its internal compartment (**ER lumen** or **cisternal space**) from the cytosol
- ER membrane is continuous with outer nuclear envelope, hence perinuclear space is continuous with ER lumen
- Two types of ER:
    i. **Rough Endoplasmic Reticulum (RER)**
    ii. **Smooth Endoplasmic Reticulum (SER)**







Source: Campbell Biology, pg150

Figure 12–36 The rough and smooth ER. (A) An electron micrograph of the rough ER in a pancreatic exocrine cell that makes and secretes large amounts of digestive enzymes every day. The cytosol is filled with closely packed sheets of ER membrane studded with ribosomes. At the top left is a portion of the nucleus and its nuclear envelope; note that the outer nuclear membrane, which is continuous with the ER, is also studded with ribosomes. (B) Abundant smooth ER in a steroid-hormone-secreting cell. This electron micrograph is of a testosterone-secreting Leydig cell in the human testis. (C) A three-dimensional reconstruction of a region of smooth ER and rough ER in a liver cell. The rough ER forms oriented stacks of flattened cisternae, each having a lumenal space 20–30 nm wide. The smooth ER membrane is connected to these cisternae and forms a fine network of tubules 30–60 nm in diameter. (A, courtesy of Lelio Orci; B, courtesy of Daniel S. Friend; C, after R.V. Krstić, Ultrastructure of the Mammalian Cell. New York: Springer-Verlag, 1979.)

Rough Endoplasmic Reticulum (RER)

Occurrence of RER

1. All cells tend to have a significant amount
2. Particularly **abundant in cells that are active in protein secretion**, e.g. pancreatic cells that secrete digestive enzymes, white blood cells that produce antibodies.

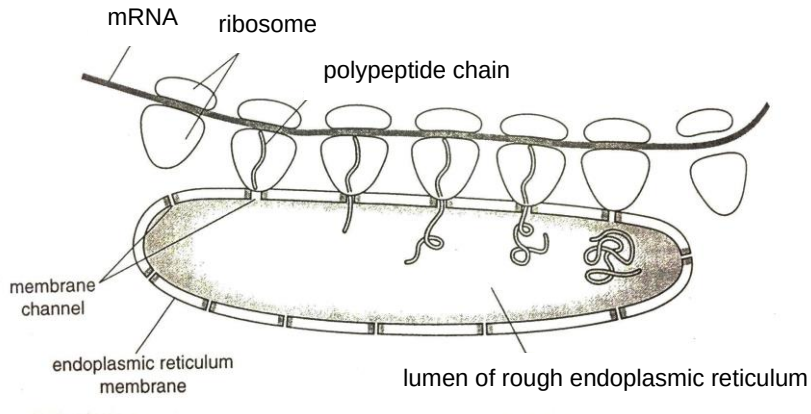
Structure

1. Comprises continuous network of sheets of membrane
2. Outer surface of the membrane is studded with ribosomes

Functions of RER

1. Site for synthesis of proteins destined for secretion, or incorporation into membranes.
   - The proteins are transported to other compartments in the cell via transport vesicles that bud off from RER membrane.

2. Facilitation of folding of polypeptide chain
   - As the polypeptide chain enters the ER lumen, it folds into its native shape. Correct folding is guided by ER proteins and enzymes.
   - Carbohydrates may be attached to the proteins (glycosylation) to form glycoproteins.



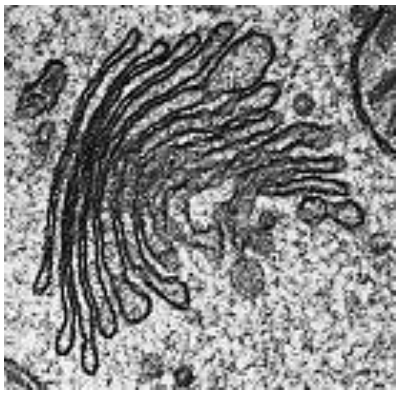
Smooth Endoplasmic Reticulum (SER)

Occurrence of SER
- Many cells have very little SER
- Tends to be abundant in liver cells, and other cells that are active in hormone secretion, e.g. in testes and ovaries

Structure
1. Comprises network of membranous tubules
2. Lacks ribosomes

Functions of SER
1. Synthesis of lipids, including oils, phospholipids and steroids (e.g. sex hormones of vertebrates, steroid hormones secreted by adrenal glands)
2. Detoxification of drugs and poisons (e.g. in liver cells)
    - Adding hydroxyl groups to drug molecules, rendering them more soluble and easier to remove from the body.

Golgi Apparatus



Occurrence of GA
- Extensive in cells specialised for secretion, e.g. pancreatic cells that secrete digestive enzymes

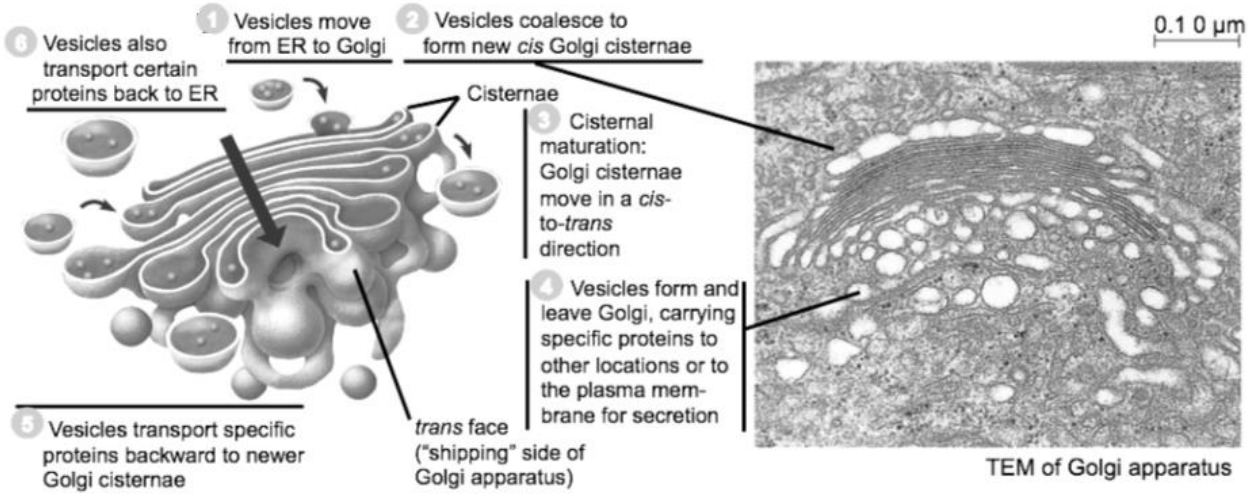
Structure
1. Consists of stack of flattened membrane-bound sacs (**cisternae**),
    - A Golgi stack has distinct structural polarity (cis face and trans face)
    - The ***cis* face** (forming face) is located nearest the nucleus or near the ER; it receives transport vesicles containing newly synthesised proteins and lipids from the ER
    - The ***trans* face** (maturing face) is closest to the cell surface membrane; it ships vesicles containing mature proteins and lipids to other parts of the cell

2. Comprises a system of associated vesicles (**Golgi vesicles**)
    - Golgi vesicles are engaged in transfer of material within the GA, and between the GA and other structures

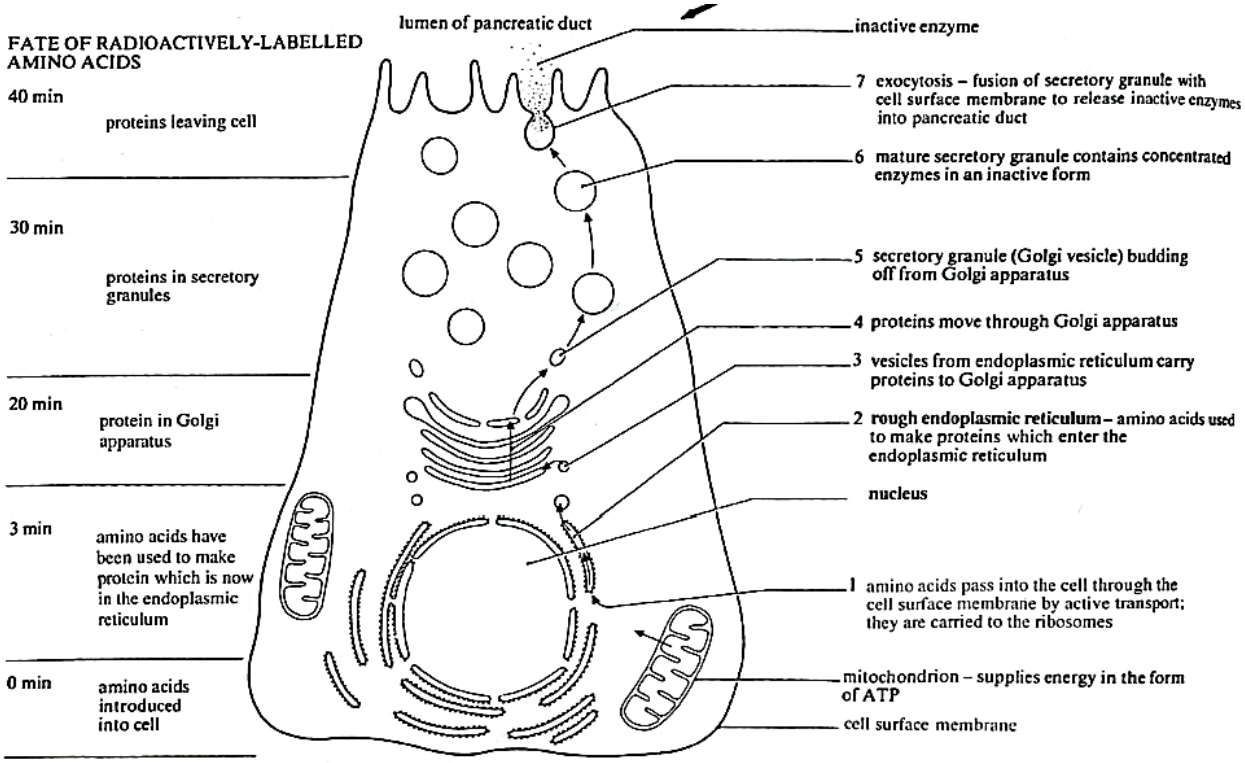
Functions
1. Further **modifies** products (including proteins) of the ER, **sorts** and **packages** these proteins in vesicles and **transports** them to other parts of the cell or release out of the cell.
    - Modifications include glycosylation (adds the carbohydrates) to proteins and lipids to form glycoproteins and glycolipids, respectively. Glycoproteins formed in the ER are progressively modified as they move from *cis* to *trans* face.
    - Secretory vesicles containing the protein products move to the cell surface membrane, and fuse with the cell surface membrane, releasing their contents to the exterior via exocytosis.

2. Synthesis of secretory polysaccharides (e.g. mucus, cell wall materials such as pectin)

3. Synthesis of lysosomes – via budding from the *trans* face



Source: Campbell Biology, pg152



Source: Biological Science, pg152

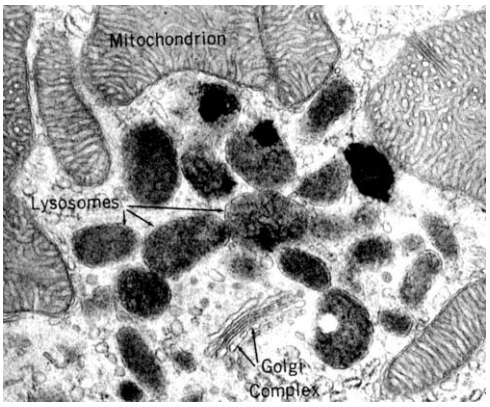
Lecture Practice 2

Outline the path of a polypeptide destined for secretion by a cell.

Lysosomes

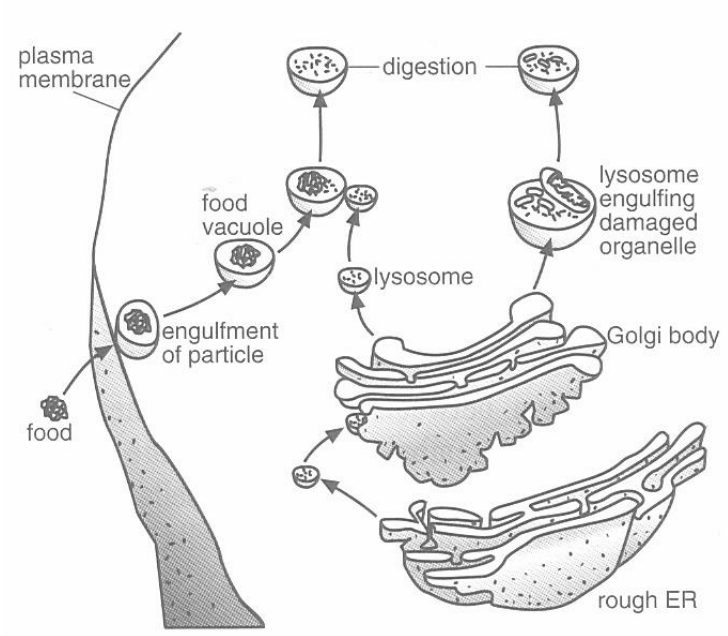
Structure

- **Size**: Small, 0.2 µm to 0.5 µm in diameter
- **Shape**: Diverse shapes, usually spherical
- **Diagnostic features**:
  1. Spherical sac bound by a single membrane
  2. Uniformly granular electron-dense appearance in electron micrographs
  3. Contains hydrolytic enzymes (lysosomal enzymes) that digest various macromolecules (e.g. proteases, nucleases, lipases)
     - Lysosomal enzymes synthesised in RER and then further modified in GA and packaged as lysosomes, which arise from budding of vesicles from *trans* face of GA.
     - Proteins in inner surface of lysosomal membrane are highly glycosylated to prevent self-destruction by lysosomal protease
  4. Acidic internal pH of 4-5, caters to lysosomal enzymes which have acidic optimum pH



Source: http://12borganelles.wikispaces.com/Lysosomes

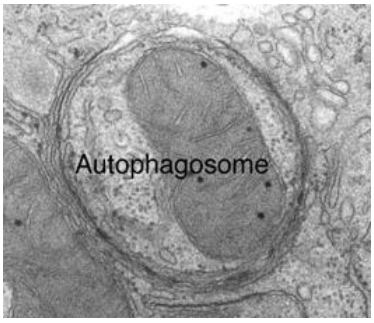
Functions



Source: Longman A-Level Course in Biology

1. **Digestion** of material taken in from the environment by <u>endocytosis</u>:
   - Lysosomes fuse with vacuoles formed from endocytosis, releasing their enzymes into the vacuole and digesting the material inside. Substances might be taken in for food (e.g. **food vacuoles** of some protozoans), or for defensive purposes (e.g. **phagocytic vacuoles** formed by white blood cells when engulfing bacteria).
   - Products of digestion are then absorbed and assimilated by the cytoplasm

2. **Autophagy** – degradation of unwanted structures within the cell
   - Unwanted structures in the cell (e.g. damaged organelles) are first enclosed by a membrane originating from the ER
   - This structure fuses with a lysosome to form an **autophagic vacuole/ autophagosome**.
   - Lysosomal enzymes hydrolyse ingested material and the products of digestion are returned to the cytosol for re-use.
   - Important for cell renewal through organelle and membrane turnover

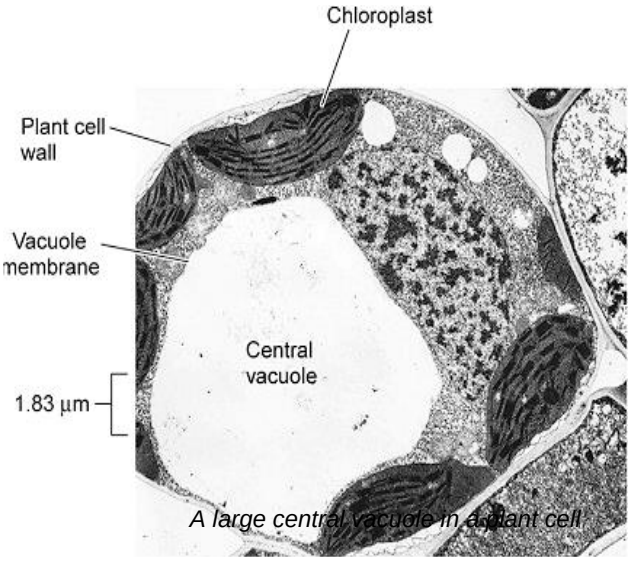


3. **Autolysis** (self-destruction of a cell)
    - Many lysosomes in the cell release their contents en masse, resulting in significant destruction of the cell
    - E.g. Reduction of tadpole tails during metamorphosis
    - E.g. Removal of webbing on hands of human embryos

Vacuoles

Occurrence

- Animal cells contain relatively small vacuoles such as phagocytic, food and contractile vacuoles
- Mature plant cells contain a large central vacuole



A large central vacuole in a plant cell

Structure

1. Fluid-filled sacs bounded by a single membrane.
2. Plant vacuole is surrounded by a selectively permeable membrane called the **tonoplast**, which separates vacuolar content from the cell cytoplasm content.
3. Fluid in plant vacuole is called **cell sap** – concentrated solution of mineral salts, sugars, organic acids, pigments and waste products of metabolism

Functions

In animal cells:

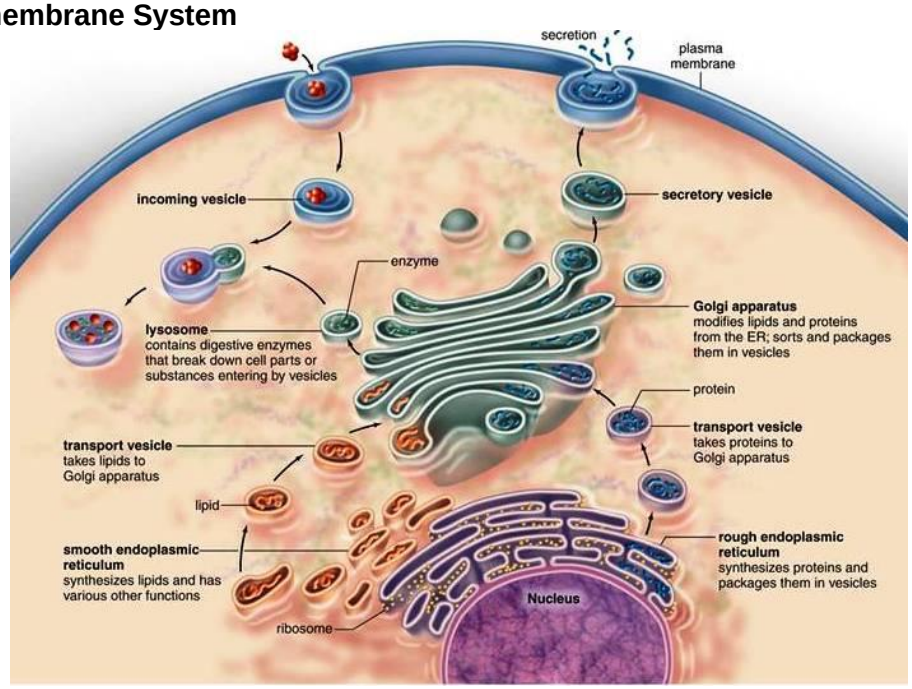
1. Food vacuole – contain food reserves
2. Contractile vacuole – contract to pump excess water out of protoctist cells, to maintain a suitable concentration of ions and minerals inside the cell

In plant cells:

1. Depository site for metabolic waste products
2. Contains pigments, e.g. anthocyanins in purple/blue/dark red flowers and fruit which help to attract animal agents for pollination and dispersal respectively
3. Contains food reserves such as protein which may be utilised by the cytoplasm when necessary
4. Protection against predators by containing compounds that are unpalatable or poisonous to animals
5. Maintains cell turgidity
    - Water enters by osmosis into the concentrated cell sap, building up pressure in the cell and resulting in turgor
6. Cell growth and elongation as water accumulates in vacuoles
    - Allows plant cells to increase in size with minimal investment in cytoplasm synthesis and without sacrificing surface area to volume ratio[2], as cytoplasmic contents are kept at the periphery of the cell

[2] A high surface area to volume ratio facilitates the exchange of materials between a cell and its environment.

The Endomembrane System



Many of the different membranes of the eukaryotic cell are part of an endomembrane system. These include the **outer nuclear membrane, endoplasmic reticulum, Golgi apparatus, lysosomes, various kinds of vacuoles and the cell surface membrane**. These membranes are related either through direct physical continuity or by the transfer of membrane segments as tiny vesicles. Despite these relationships, the various membranes differ in structure and function.

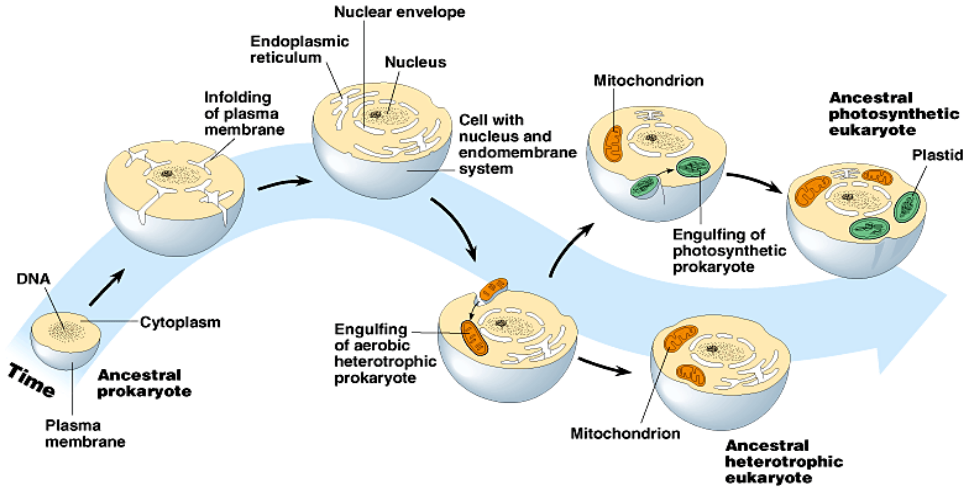
Energy Transducers

Mitochondria and **chloroplasts** serve to convert energy to forms that cells can use to power cellular work.

- They are not part of the endomembrane system as their membrane proteins are not made by the ER, but by free ribosomes in the cytosol and by ribosomes contained within themselves.
- In contrast to organelles of the endomembrane system, mitochondria have two membranes separating their innermost space from the cytosol, while chloroplasts typically have three.
- In addition, these organelles contain ribosomes and a small amount of DNA that programmes the synthesis of some of their proteins. They are semiautonomous organelles that are able to grow and reproduce themselves within the cell.

The Endosymbiont Hypothesis

Symbiosis = two organisms living closely together.
Endosymbiosis = one organism living inside another (e.g. intestinal bacteria in human).



Biologists commonly believe that at least two organelles in eukaryotic cells – mitochondria and chloroplasts – are descendants of prokaryotic organisms that took up residence inside hosts that were cell precursors of eukaryotes.

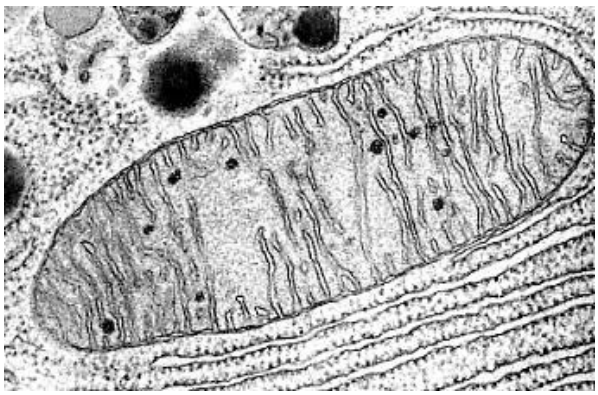
This hypothesis assumes that about 1.5 billion years ago, a prokaryotic cell captured a bacterium through endocytosis. Bacterium resisted digestion, lived symbiotically inside its host, and divided independently of the host.

Later, some of the genes of the symbiont were moved into the nucleus of its host cell, which then took control from its guest. From this partnership, all present-day mitochondrion-containing eukaryotic organisms, including fungi, protozoans, plants and animals, may have evolved. Similarly, different photosynthetic bacteria met the same fate, forming several lineages of chloroplast-containing organisms, i.e. algae and plants.

Evidence supporting Endosymbiotic Hypothesis:

1. Chloroplasts and mitochondria are both about the same size as prokaryotic cell.
2. They divide by binary fission like bacteria.
3. They have circular DNA which lies freely in the interior, neither coiled around histone protein nor enclosed by an additional membrane (though the diameter of this DNA is smaller than prokaryotic DNA).
4. Internal organisation of organelle's genes is similar to that of prokaryotes and very different from that of eukaryotes.
5. They possess 70S ribosomes similar to those in prokaryotic cells.
6. They build their own membrane systems.
7. DNA and ribosomes in both organelles produce proteins which are quite different from those produced by the rest of the cell.
8. This protein production is inhibited by the antibiotic chloramphenicol, which also inhibits protein production in prokaryotic cells but not in eukaryotic cells.

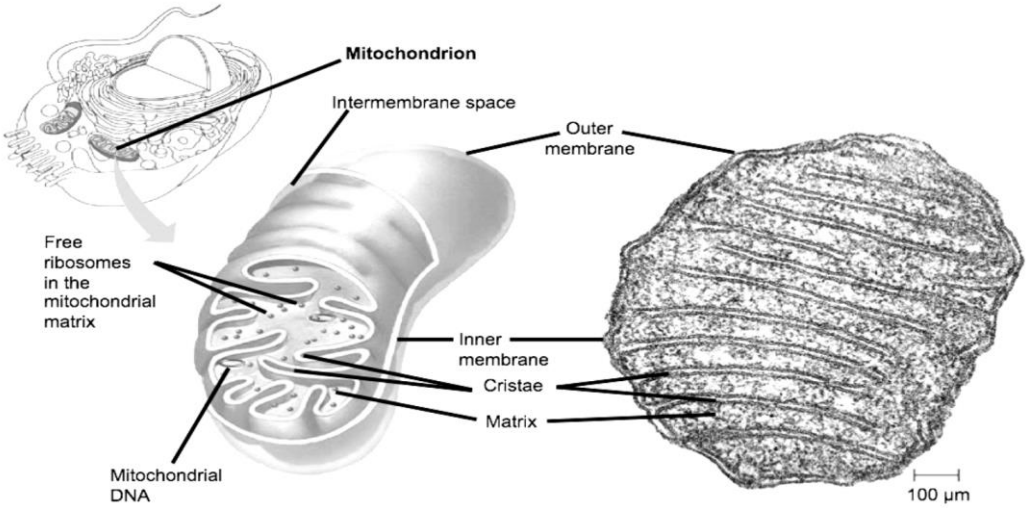
Mitochondria



Structure

- **Size:** Width of 0.5 – 1.5 µm and length of 3 – 10 µm
- **Shape:** Cylindrical or rod shaped organelles

- **Diagnostic features:**
  1. Wall comprises 2 membranes separated by an extremely narrow fluid-filled space called the **intermembrane space**
     - Outer membrane is smooth
     - Inner membrane is highly convoluted with numerous infoldings called **cristae** (singular: crista).
  2. Interior of mitochondria is an organic, semifluid matrix (**mitochondrial matrix**), with 70S ribosomes, circular DNA and various enzymes
  3. The mitochondrial space is divided into two compartments: the intermembrane space and mitochondrial matrix



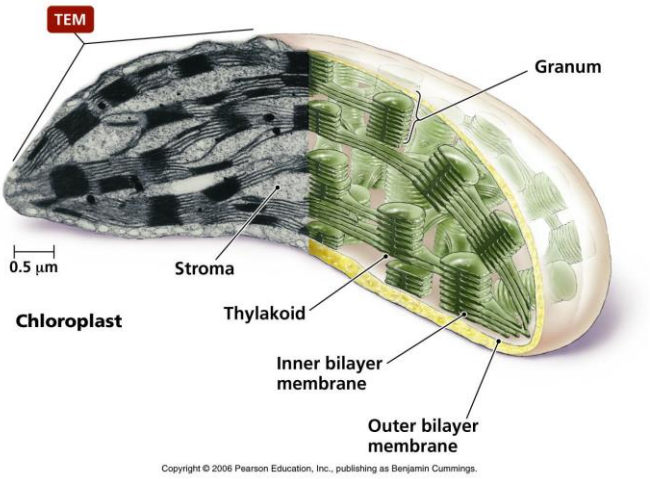
Source: Campbell Biology, pg156

Function

1. Main site of ATP production during aerobic respiration – an oxygen-requiring process that synthesises ATP using energy released from the oxidation of organic acids
    - Matrix contains enzymes of Krebs cycle
    - Cristae maximise surface area to accommodate the proteins and enzymes responsible for ATP synthesis (e.g. ATP synthase)

2. Heat production.about 55% of energy released from the above processes is given off as heat

Chloroplasts



Occurrence

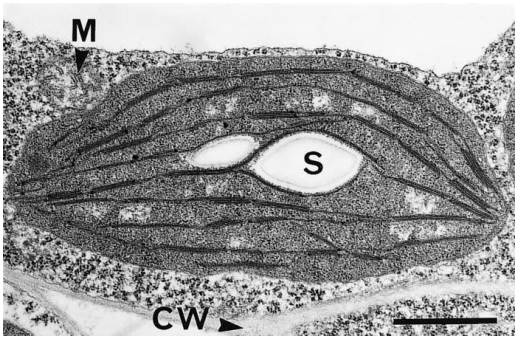
- In all eukaryotic photosynthetic cells – generally 20-100 chloroplasts per cell

Structure

- **Size:** About 5-10 µm in length
- **Shape:** Disc-shaped structures in plants, visible under the light microscope

- **Diagnostic features:**
    1. Enclosed by a double membrane known as the **chloroplast envelope**, with a very narrow intermembrane space separating the two membranes
        - Inner membrane encloses a semi-fluid material known as the **stroma**
        - Stroma contains enzymes, circular DNA, 70S ribosomes, starch grains, sugars and lipid droplets

2. In the stroma is another membranous system in the form of flattened, interconnected disc-like sacs called **thylakoids**.
    - The thylakoids are arranged in stacks called **grana** (singular: granum)
    - Stacks of grana are linked by **intergranal lamellae** (singular: intergranal lamella)
    - **Photosynthetic pigments** (chlorophyll and carotenoids) and enzyme systems involved in photosynthesis are embedded in the thylakoid membranes
3. The membranes of the chloroplast divide the chloroplast space into three compartments: the <u>intermembrane space</u>, <u>stroma</u> and <u>thylakoid space</u>.



Function

1. Site of photosynthesis:
    - Light dependent reactions occur on thylakoid membranes
    - Light independent reactions occur in stroma

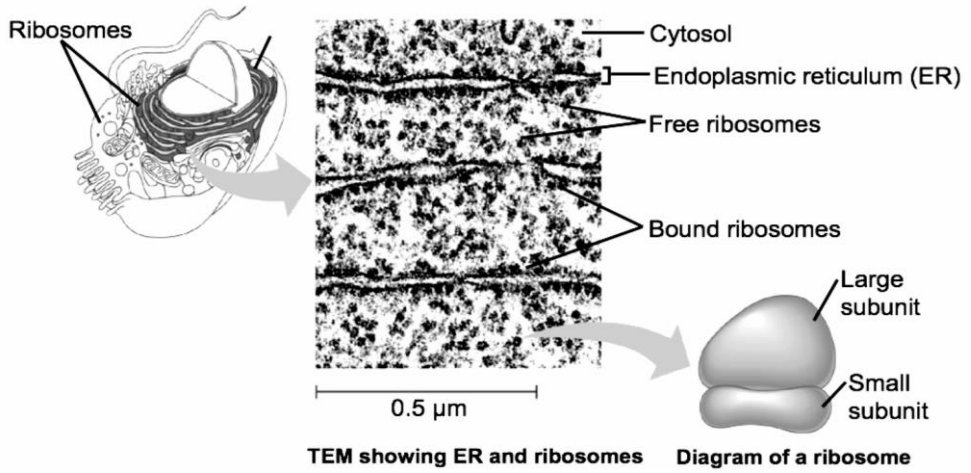
D. Non-membranous Organelles

<u>Ribosomes</u>

Occurrence

- Cells with particularly high rates of protein synthesis tend to have great numbers of ribosomes (e.g. pancreatic acinar cells that secrete digestive enzymes)
- Ribosomes present in both eukaryotes and prokaryotes

Structure



Source: Campbell Biology, pg150

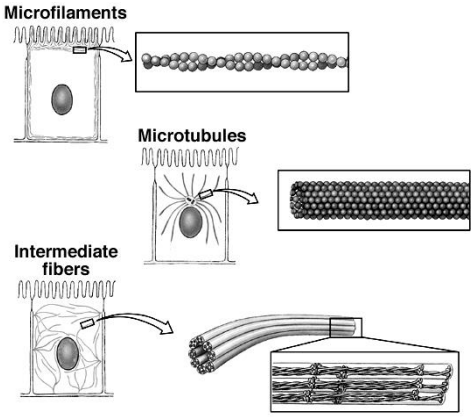
- **Size**: Diameter of around 20 nm
- **Shape**: Small, spherical and dense bodies
- **Diagnostic features:**
    1. Complexes of ribosomal RNA (rRNA) and protein
    2. 80S eukaryotic ribosome consists of small (40S) and large (60S) subunits
        - Ribosomal subunits are each assembled in the nucleoli using rRNA made in the nucleoli and proteins imported from the cytoplasm.
        - The large and small subunits come together to form functional ribosomes only when they attach to mRNA in the cytosol during the process of translation.

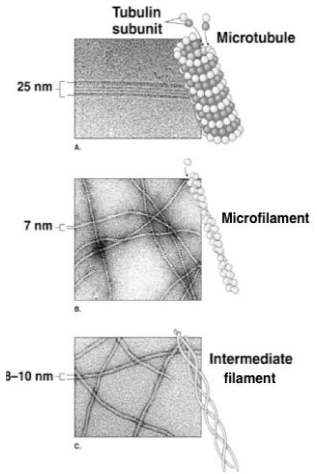
3. Four different locations in the eukaryotic cell:
    i. (As bound ribosomes attached to) rough ER. These ribosomes generally make proteins destined for inclusion into membranes or for export from the cell
    ii. (As free ribosomes suspended in) cytosol. These ribosomes generally make proteins that will function within the cytosol
    iii. Mitochondrial matrix
    iv. Chloroplast stroma

Functions
1. Site of polypeptide synthesis
2. Key role in translation of mRNA base sequence into specific amino acid sequence of a polypeptide chain

Cytoskeleton

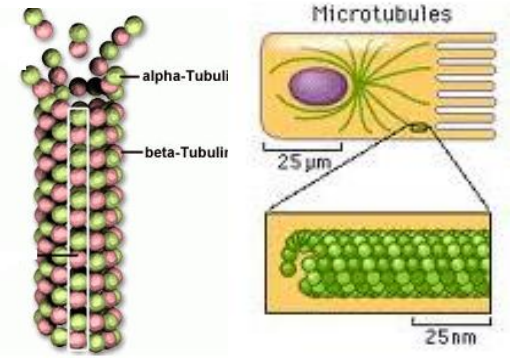
- **Cytoskeleton** are cellular "scaffolding" or "skeleton" that is composed of a dynamic network of fibrous protein structures throughout the cytoplasm
- Consists of three main kinds of fibres: **microtubules**, **intermediate filaments** and **microfilaments**. Each has a distinct set of organisations and functions. Each is composed of a polymer of subunits, which undergoes regulated assembly and disassembly.



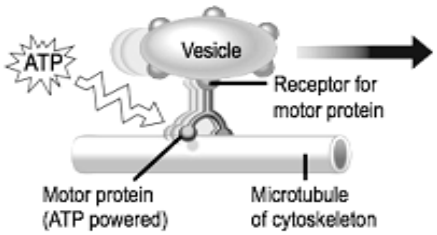


Microtubules

Diagnostic feature:
1. Walls are composed of globular proteins called **tubulin**
    - Elongate via addition of tubulin proteins to one end of the tubule. Disassembly allows tubulin units to be used for assembling microtubules elsewhere in the cell.

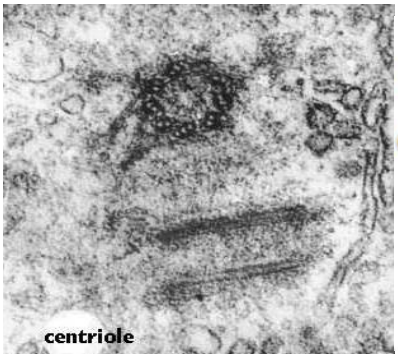


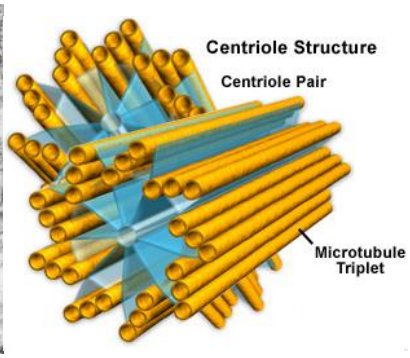
Functions
1. Maintain cell shape
2. Serve as tracks along which organelles and materials move within cells
3. Form spindle fibres, which are responsible for the separation of chromosomes during cell division
4. Major structural components of centrioles, which function as microtubules organising centres (MTOCs) in lower plants and animals
5. Major structural components of cilia and flagella which are responsible for cell motility



(a) Motor proteins that attach to receptors on organelles can "walk" the organelles along microtubules or, in some cases, microfilaments.

Centrioles





Occurrence

- Found in animals and lower plants

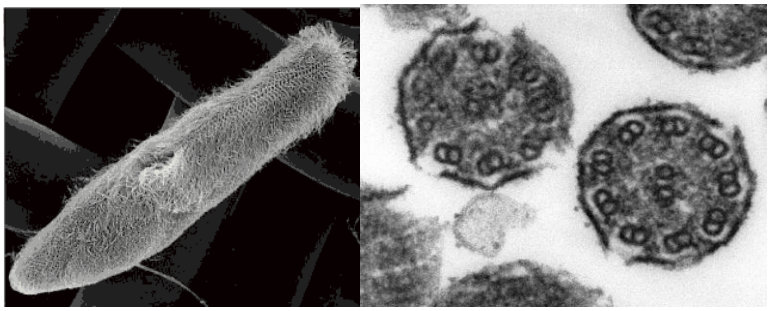
Diagnostic features:

1. Located in a region near the nucleus called the **centrosome** (contains specialised proteins required for microtubule assembly)
2. Exist as a pair of rod-like structures positioned at right angles to each other
3. Transverse section reveals 9 triplets of microtubules arranged in a ring

Function

1. Key role in nuclear division in animal cells by acting as microtubules organising centres (MTOCs).
    - Centrioles produce a system of microtubules called spindle fibres that radiates towards the equator of the cell.
    - Spindle fibres attach to kinetochore proteins found in centromere region of chromosomes.

Cilia



Structure

1. Cilia are composed of bundle of microtubules arranged in a 9+2 pattern, 9 pairs of microtubules arranged in a ring with 2 microtubules in the centre of the ring

Function

1. Used to move an entire organism or to move material within an organism:

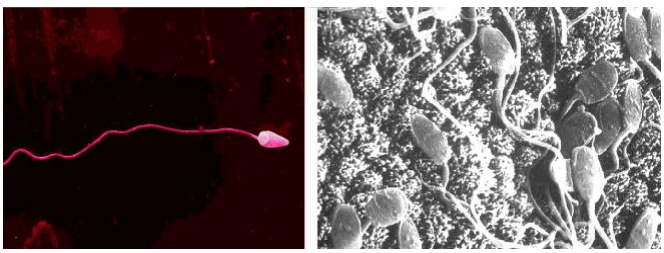
Flagella

Structure
Diagnostic features:

1. Composed of same 9+2 arrangement of microtubules as motile cilia**.**

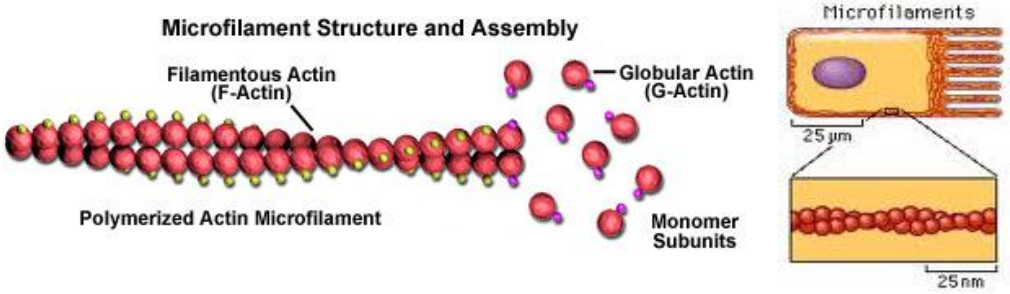
Function

1. Cell movement only



Flagella on sperm cell

Microfilaments

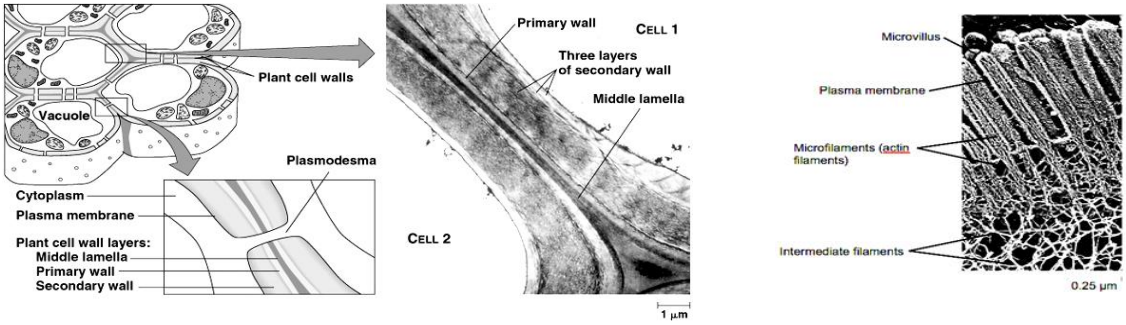


Functions

1. Involved in maintaining cell shape
2. Involved in formation of cleavage furrow during cytokinesis in animal cells
3. Involved in cell motility
    - E.g. Part of contractile apparatus of muscle cells
    - E.g. Responsible for amoeboid movement via extension and contraction of pseudopodia
4. Component of microvilli (increase surface area in cells specialised for absorption)

E. Extracellular Structures

Plant Cell Wall – cellulose cell wall



Structure

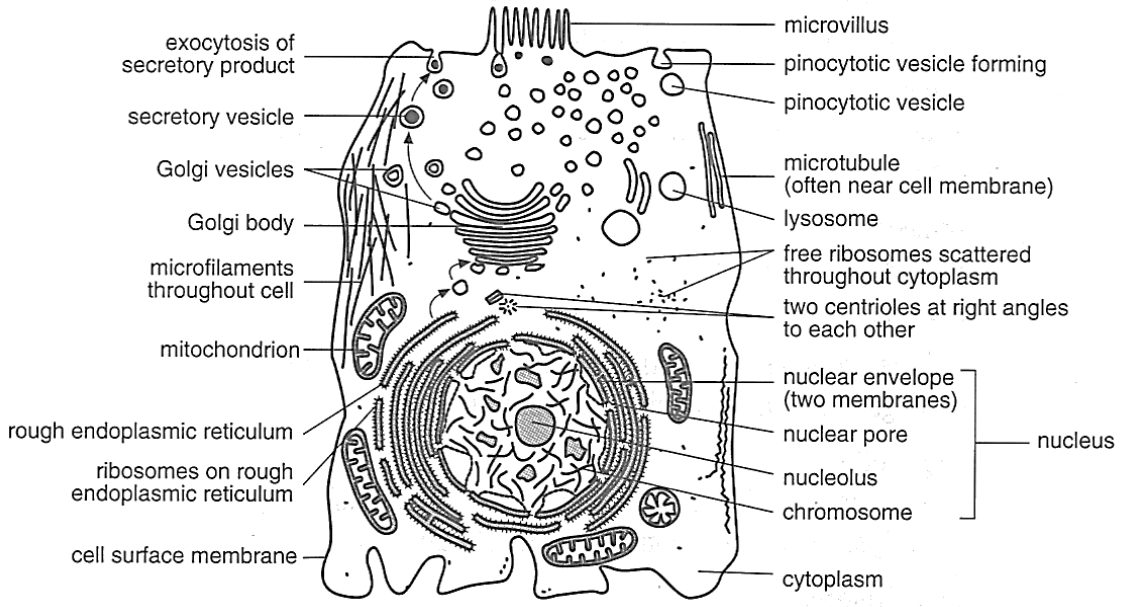
1. A rigid layer surrounding the cell, composed of insoluble **cellulose fibres** embedded in a **matrix** of other polysaccharides and proteins
2. **Middle lamella** allows for adjacent cell walls to adhere to each other
3. Cell walls perforated with channels called **plasmodesmata** (singular: plasmadesma)
    - Cell surface membranes of adjacent cells are continuous through each plasmodesma
    - Cytosol of adjacent cells continuous, allowing water and small solutes to pass freely between the cells

Functions

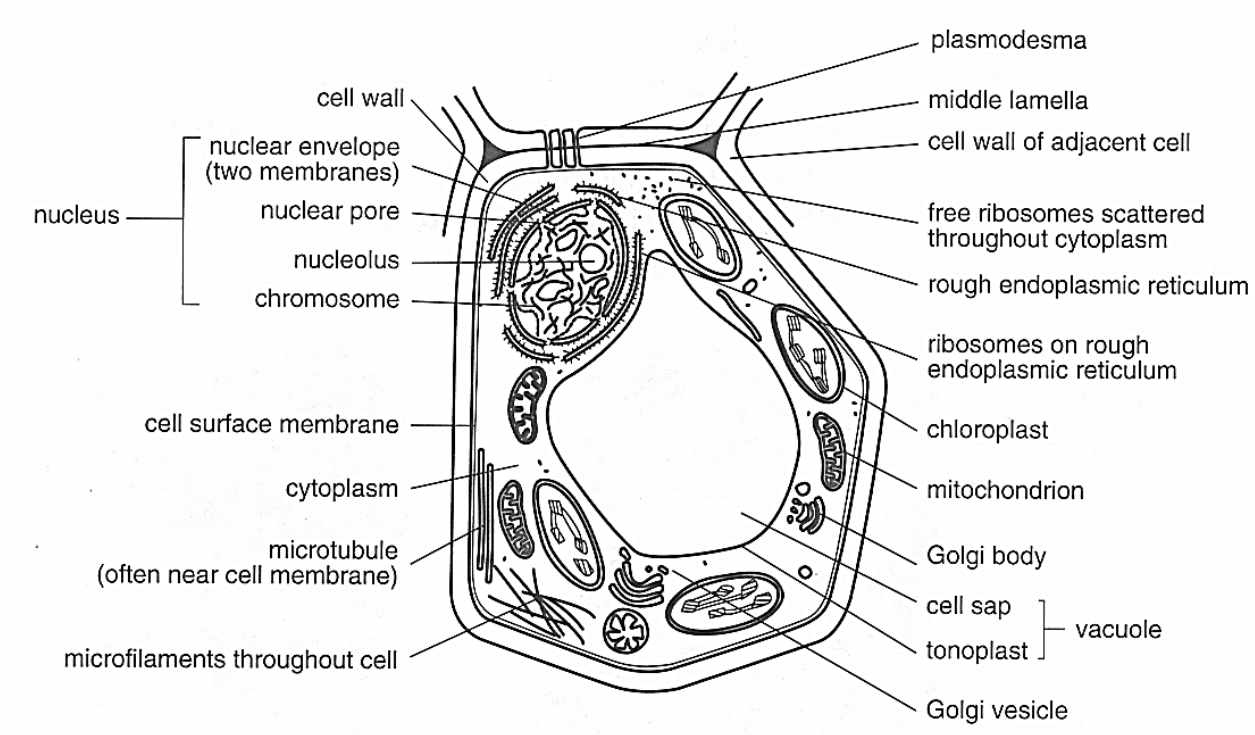
1. Provides mechanical support to plant cells and maintain their shape
2. Allows development of turgor when water enters the plant cells by osmosis
3. Prevents excessive uptake of water

F. Plant and Animal Cells

Ultrastructure of a generalized animal cell



Ultrastructure of a generalized plant cell



Source: Longman A-Level Course in Biology

Electron micrograph of an animal cell

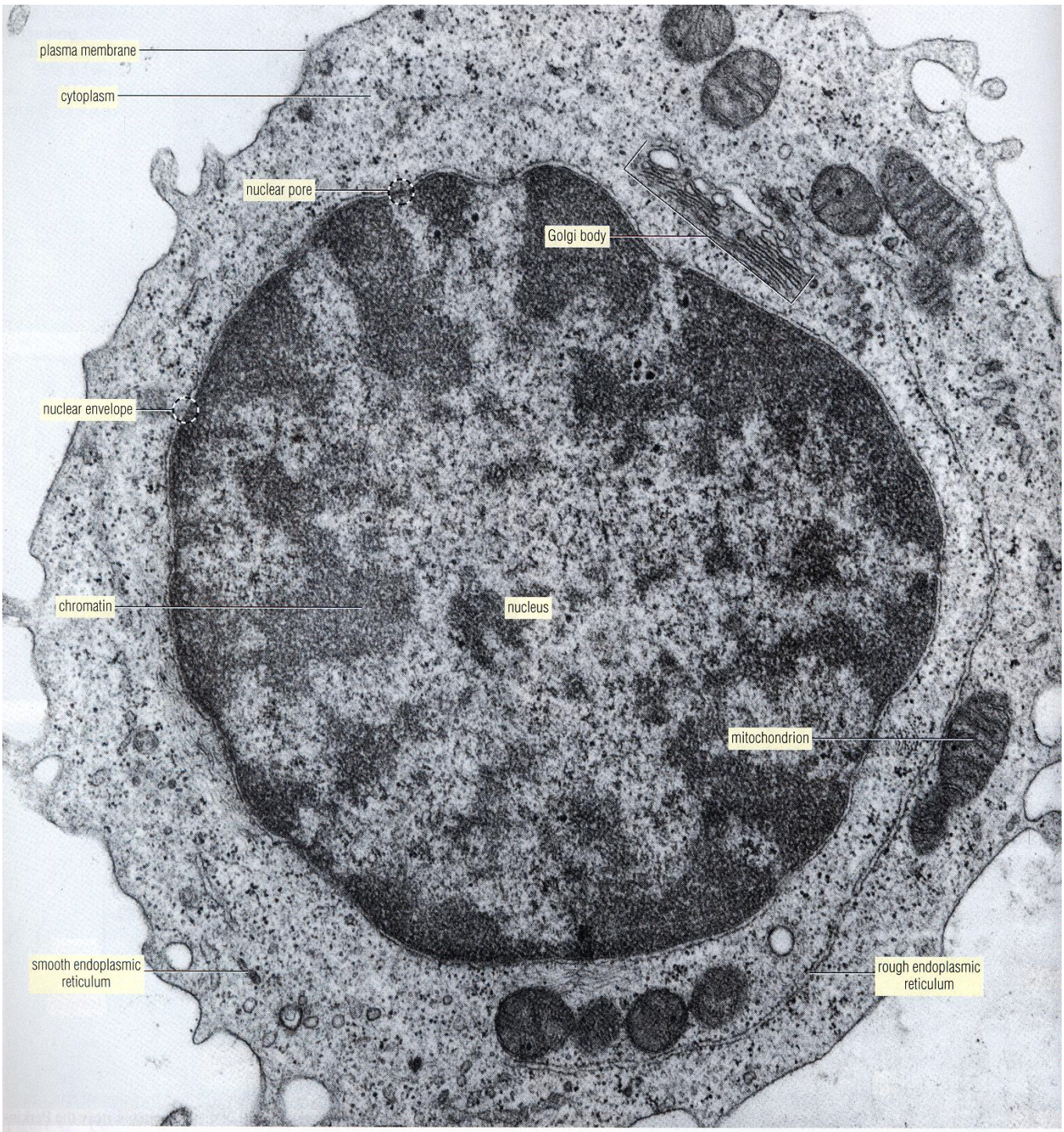


Figure 6a Electron micrograph of an **animal cell** (3,000×). (Photo courtesy W. R. Hargreaves)

Electron micrograph of a plant cell

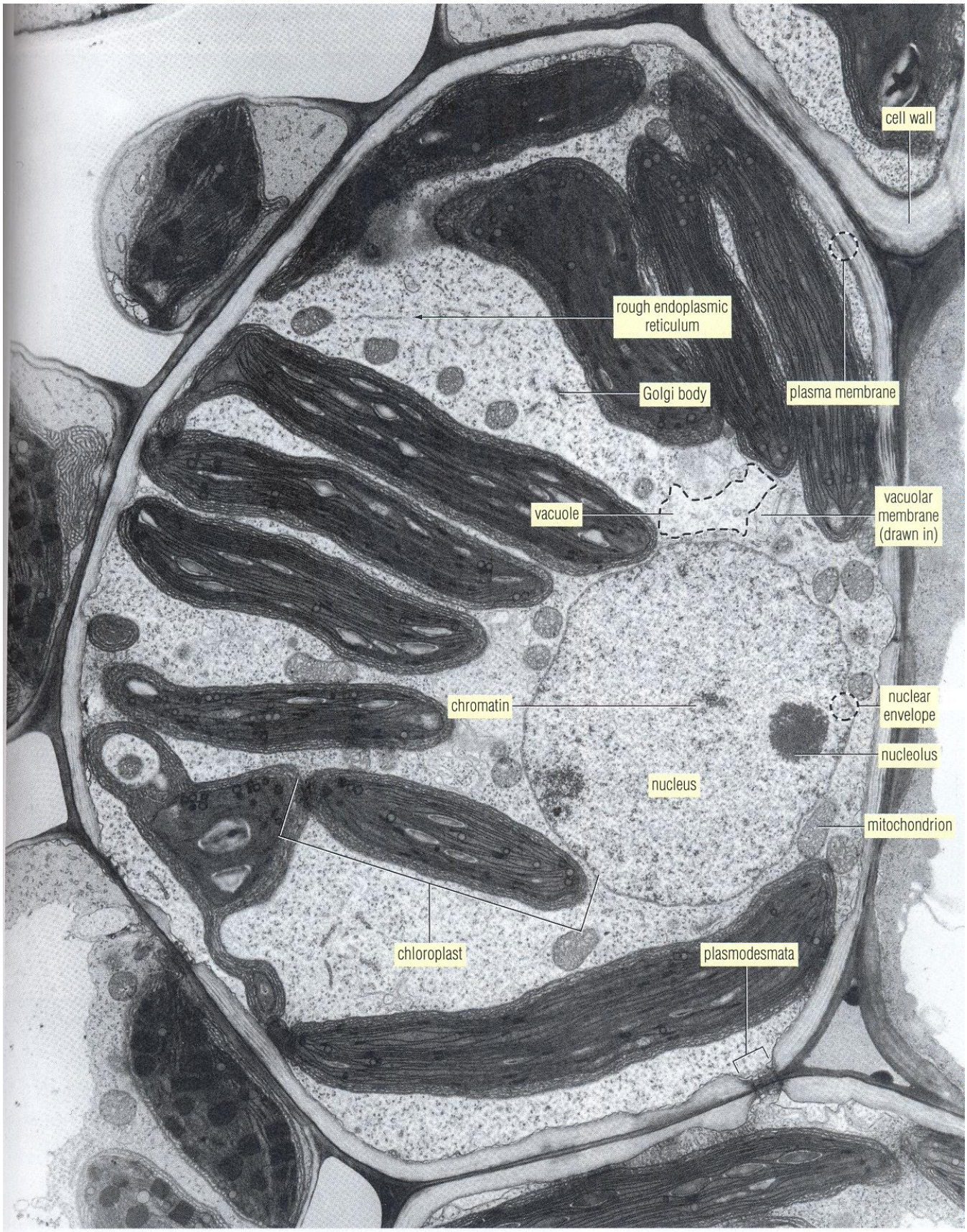


Figure 7a Electron micrograph of a **plant cell** (c.s., 3,400×). (Photo courtesy R. F. Evert and M. A. Walsh)

Comparison of plant and animal cells

Feature	Plant cell	Animal cell
Cell wall	Cellulose cell wall present Pits and plasmodesmata present in cell wall Middle lamella join cell walls of adjacent cells	Cell wall absent No pits or plasmodesmata No middle lamella – cells joined by intercellular cement
Plastids[3]	Present in large numbers (e.g. chloroplast present in large numbers)	Plastids absent (i.e. chloroplast absent)
Vacuole(s)	Mature cells typically have a large, single, central vacuole filled with cell sap Tonoplast present around vacuole	Vacuoles (e.g. contractile vacuoles), if present, are small and scattered throughout the cell Tonoplast absent
Centrioles	Found in lower plants (primitive, non-vascular) but absent in higher plants (vascular plants)	Present
Lysosome	Not normally present	Almost always present
Cell shape	Rigid or fixed shape Regular	Rigid or fixed shape Spherical or irregular
Location of nucleus	Near edge of cell	Found anywhere in cell but often central
Cytoplasm	Normally confined to a thin layer at edge of cell	Present throughout the cell
Energy reserves	Starch grains used for storage	Glycogen granules used for storage

[3] Plastids are a family of double-membrane-bound, semi-autonomous organelles common to plant cells. They are often the sites of manufacturing and/or storing for important chemical components used by the cell. Plastids contain their own DNA in the form of double-stranded circular DNA and replicate by binary fission. Examples of plastids include chloroplast and chromoplast.