A2.2 Cell Structure

Syllabus Content

1SL **Cells Are The Basic Structural Unit Of All Living Things**
NOS: Students should be aware that deductive reason can be used to generate predictions from theories. Based on cell theory, a newly discovered organism can be predicted to consist of one or more cells.

2SL **Microscopy Skills**
Skill: Students should have experience of making temporary mounts of cells and tissues, staining, measuring sizes using an eyepiece graticule, focusing with coarse and fine adjustments, calculating actual size and magnification, producing a scale bar and taking photographs. **NOS:** Students should appreciate that measurement using instruments is a form of quantitative observation.

3SL **Developments in Microscopy**
Include the advantages of electron microscopy, freeze fracture, cryogenic electron microscopy, and the use of fluorescent stains and immunofluorescence in light microscopy.

4SL **Structures Common To Cells In All Living Organisms**
Typical cells have DNA as genetic material and a cytoplasm composed mainly of water, which is enclosed by a plasma membrane composed of lipids. Students should understand the reasons for these structures.

5SL **Prokaryote Cell Structure**
Include these cell components: cell wall, plasma membrane, cytoplasm, naked DNA in a loop and 70S ribosomes. The type of prokaryotic cell structure required is that of Gram-positive eubacteria such as *Bacillus* and *Staphylococcus*. Students should appreciate that prokaryote cell structure varies. However, students are not required to know details of the variations such as the lack of cell walls in phytoplasmas and mycoplasmas.

6SL **Eukaryote Cell Structure**
Students should be familiar with features common to eukaryote cells: a plasma membrane enclosing a compartmentalized cytoplasm with 80S ribosomes; a nucleus with chromosomes made of DNA bound to histones, contained in a double membrane with pores; membrane-bound cytoplasmic organelles including mitochondria, endoplasmic reticulum, Golgi apparatus and a variety of vesicles or vacuoles including lysosomes; and a cytoskeleton of microtubules and microfilaments.

7SL **Processes Of Life In Unicellular Organisms**
Include these functions: homeostasis, metabolism, nutrition, movement, excretion, growth, response to stimuli and reproduction.

8SL **Differences In Eukaryotic Cell Structure Between Animals, Fungi And Plants**
Include presence and composition of cell walls, differences in size and function of vacuoles, presence of chloroplasts and other plastids, and presence of centrioles, cilia and flagella.

9SL **Atypical Cell Structure In Eukaryotes**
Use numbers of nuclei to illustrate one type of atypical cell structure in aseptate fungal hyphae, skeletal muscle, red blood cells and phloem sieve tube elements.

10SL **Cell Types And Cell Structures Viewed In Light And Electron Micrographs**
Skill: Students should be able to identify cells in light and electron micrographs as prokaryote, plant or animal. In electron micrographs, students should be able to identify these structures: nucleoid region, prokaryotic cell wall, nucleus, mitochondrion, chloroplast, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum, chromosomes, ribosomes, cell wall, plasma membrane and microvilli.

11SL	**Drawing And Annotation Based On Electron Micrographs** **Skill**: Students should be able to draw and annotate diagrams of organelles (nucleus, mitochondria, chloroplasts, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum and chromosomes) as well as other cell structures (cell wall, plasma membrane, secretory vesicles and microvilli) shown in electron micrographs. Students are required to include the functions in their annotations.
12HL	**Origin Of Eukaryotic Cells By Endosymbiosis** Evidence suggests that all eukaryotes evolved from a common unicellular ancestor that had a nucleus and reproduced sexually. Mitochondria then evolved by endosymbiosis. In some eukaryotes, chloroplasts subsequently also had an endosymbiotic origin. Evidence should include the presence in mitochondria and chloroplasts of 70S ribosomes, naked circular DNA and the ability to replicate. **NOS:** Students should recognize that the strength of a theory comes from the observations the theory explains and the predictions it supports. A wide range of observations are accounted for by the theory of endosymbiosis.
13HL	**Cell Differentiation As The Process For Developing Specialized Tissues In Multicellular Organisms** Students should be aware that the basis for differentiation is different patterns of gene expression often triggered by changes in the environment.
14HL	**Evolution Of Multicellularity** Students should be aware that multicellularity has evolved repeatedly. Many fungi and eukaryotic algae and all plants and animals are multicellular. Multicellularity has the advantages of allowing larger body size and cell specialization.

Guiding Questions
What are the features common to all cells and the features that differ?
How is microscopy used to investigate cell structure?

Linking Questions
What explains the use of certain molecular building blocks in all living cells?
What are the features of a compelling theory?

From all these observations, we discern most plainly the incomprehensible perfection, the exact order, and the inscrutable providential care with which the most wise Creator and Lord of the Universe had formed the bodies of these animalcules, which are so minute as to escape our sight,…
Antonie van Leeuwenhoek

Jan Verkolje

1SL Cells Are The Basic Structural Unit Of All Living Things

Until microscopes were invented no one knew what living tissues were made of.

Robert Hooke in 1665
Observed dead cork tissue. He named the hollow structures cells.

Antony van Leeuwenhoek 1676
Observed the first living cells in water.

Francesco Redi 1668
Noted that all life comes from life.

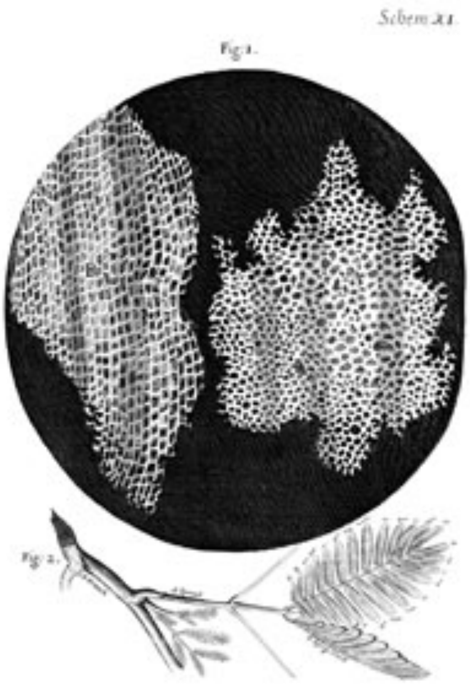
Mathias Schleiden 1837.
Realised all plants are made of cells.

Theodor Schwann 1839
Realised all animals are made of cells.

Robert Remak 1855
Discovered cell division.

Rudolf Virchow 1858
Popularises phrase- all cells come from pre-existing cells.

Louis Pasteur 1864
Disproves spontaneous generation.



Drawing of cork cells by Robert Hook

NOS
deductive reasoning – from a general rule specific conclusions and predictions are made

inductive reasoning - from *specific* limited observations general rules are made

From limited *specific* observations of parts of organisms, a general rule was made that all organisms were likely made of cells (inductive reasoning).

A theory developed that explained these *specific* observations – the cell theory.

Cell Theory
1. living things are made of cells
2. cells are the smallest unit of life
3. cells today come from pre-existing cells - by cell division

Good theories enable useful predictions to be made such as - newly discovered organisms will consist of one or more cells (deductive reasoning).

Inacio

NOS
Inductive reasoning has some uncertainty due to the limited number of observations.
However, the conclusions reached can be 100% disproved (falsified).
For example – all swans were considered likely to be white until black swans were discovered.
The uncertainty of much of science is so small that we trust it with our very lives on a daily basis.

Deductive reasoning is certain if the general rules or theory are true.
It allows testable predictions to be made to confirm, modify or reject a theory.

science - knowledge gained by a study of observed evidence

Science assumes order. If the universe is an illusion, controlled by unpredictable gods or behaves erratically not following fixed laws, then science is not possible.

The term *empirical* is from *empeiria* (Greek) and translates to *experiential* (Latin) from which we get the terms *experience* and *experiment*.

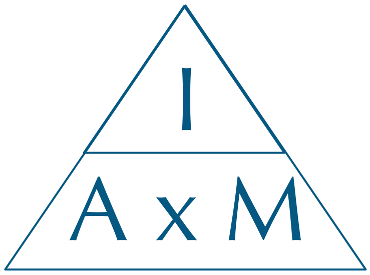
Science also involves human bias and imperfect objectivity.

aspect	example
experimental science is repeatable and testable	Does water boil at 100°C at sea level?
forensic science is not fully repeatable or testable and a scientists' worldview becomes important when interpreting the evidence	Did the Grand Canyon form very slowly or was there a dam burst event?
belief – an acceptance that something is true It may or may not be correct and cannot always be experimentally proven.	Stealing is wrong Eggs should be counted by the dozen
fact – a repeatable observation or measurement also called empirical evidence	Water boiled at 100°C again today
inference – conclusion drawn from the facts	On Earth, at sea-level, water boils at 100°C
hypothesis - a testable prediction of how a system will behave under certain conditions	That increasing salinity will decrease plant height, using certain seeds / soil type…
law - a rule for a pattern found in the natural world under certain conditions	($F=ma$)
theory – in science, is a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses	Germ theory of disease Collision theory Recapitulation theory

2SL Microscopy Skills

photomicrograph – a photograph of a microscope image
magnification – is how many times bigger an image is compared to the actual size

magnification M = image size I ÷ actual size A



Remember to convert all measurements to the same units.

1 cm = 10 mm
1 mm = 1000 μm (micrometers)
1 μm = 1000 nm (nanometers)

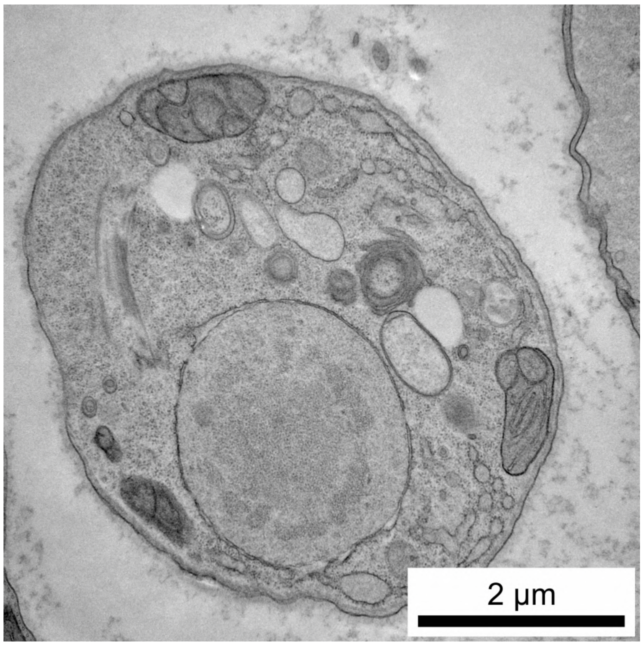
	(x1000) →		(x1000) →	
3 mm		3000 μm		3 000 000 nm
	← (÷1000)		← (÷1000)	

a) Calculate the magnification of the plant cell.
Measure the *scale bar* length in mm and convert this length to μm.

magnification = <u>image size (scale bar length)</u>
actual size of bar (2 μm)

magnification = …………………….. X

b) Calculate the actual size of the nucleus.
Measure the image width of the nucleus in mm and convert to μm.



Transmission electron micrograph (TEM) of an animal cell.
Wikimedia

Then use the magnification calculated earlier to find the actual size of the nucleus.

actual size =

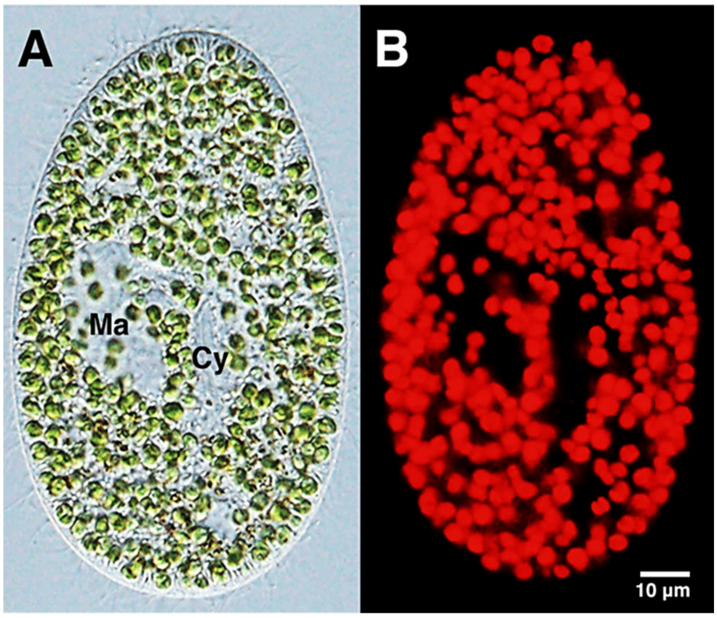
Practice Questions

1. A useful model organism for study is the *Paramecium* because it is easy to culture and observe.

   A - light microscope bright field image showing a *Paramecium* full of endosymbiotic *Chlorella* providing sugars in return for carbon dioxide.

   B - light microscope dark field image of the same *Paramecium* with fluorescence by chlorophyll *a* – after receiving a specific wavelength of light.

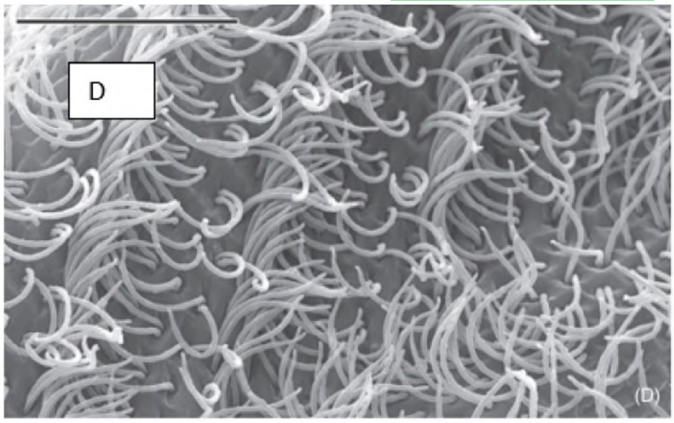
   Calculate the magnification of B - include the formula, working and units.



Kodama and Fujishima 2016

2. A scanning electron image SEM of the cilia on a *Paramecium* – scale bar represents 10 µm.

   Calculate the magnification.



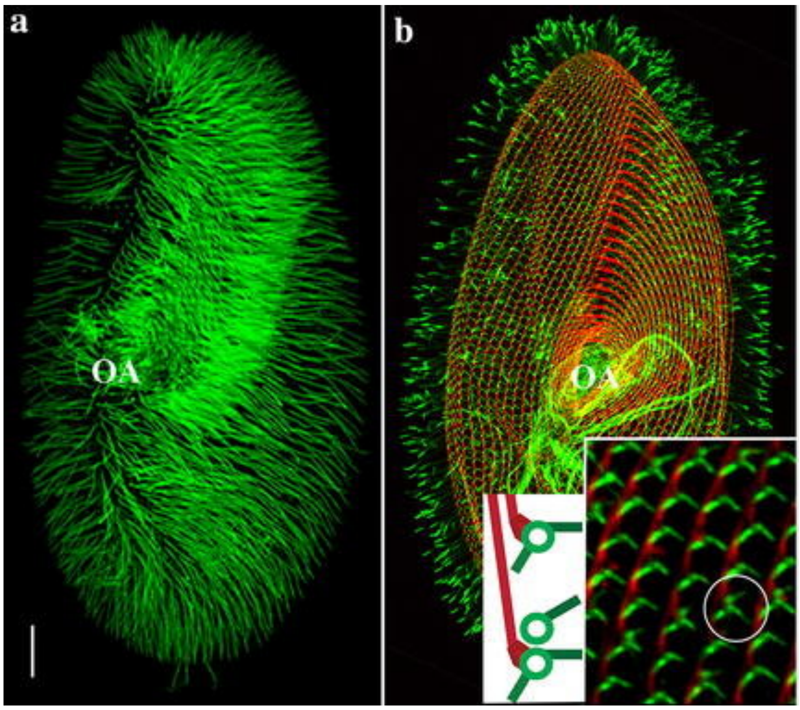
Fraenkel and Gunn

3. Light microscope dark field immunofluorescent antibody stains on the cilia of a *Paramecium*.

   OA – oral groove for feeding.
   Scale bar is 20 µm.

   Calculate the:
   a) magnification

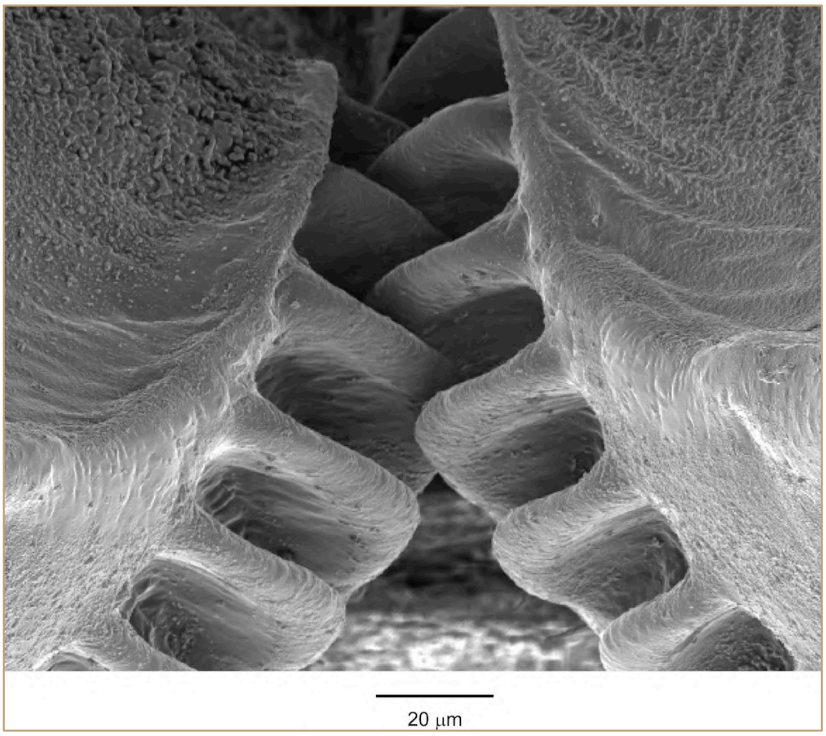
   b) cell length



Tassin et al 2016

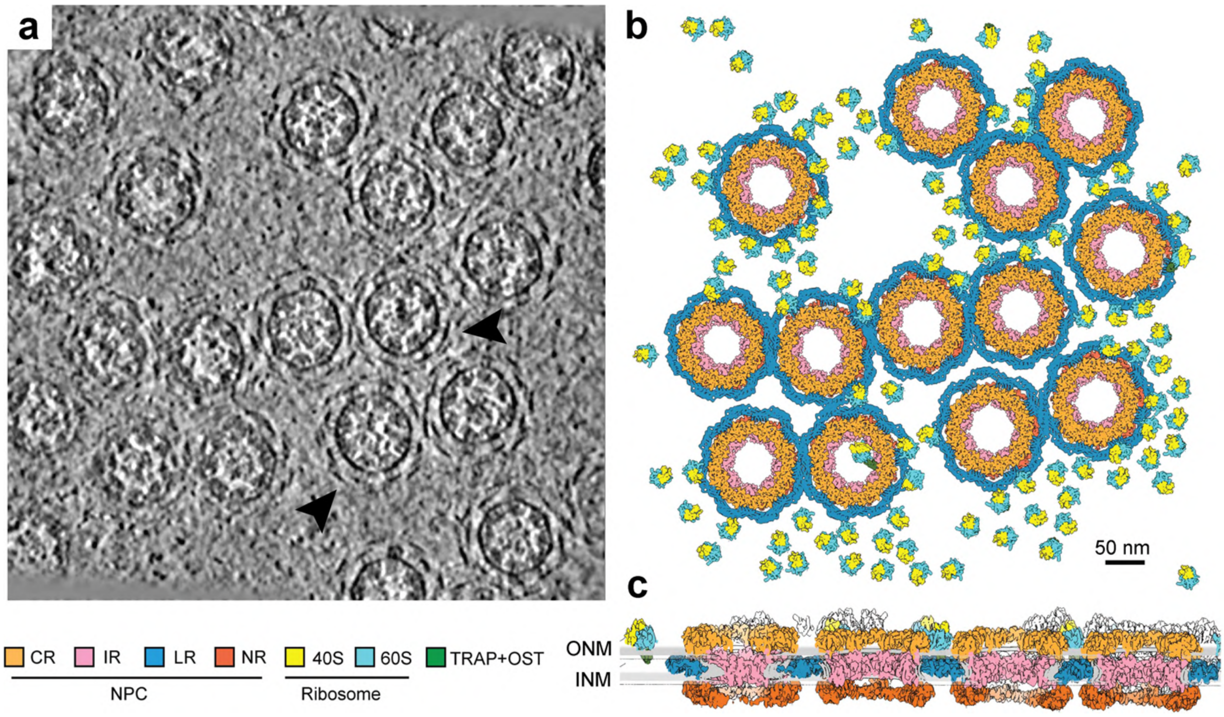
4. Find the magnification of these gears on the hindlegs of a planthopper.

   These cogs allow both legs to push down at the same time during a jump and prevents the plant hopper from spinning off to one side.



Credit Malcom Burrows

5. Use the cryoEM image B below to calculate the width of a nuclear pore complex (NPC) on the outer nuclear membrane (ONM) of a frog.

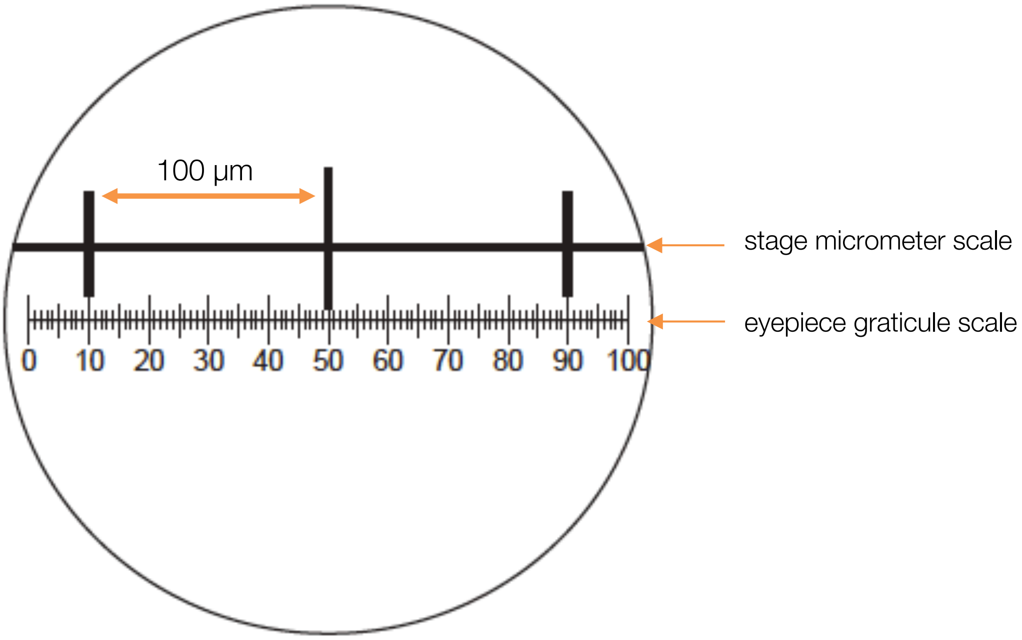


Zhang et al 2020

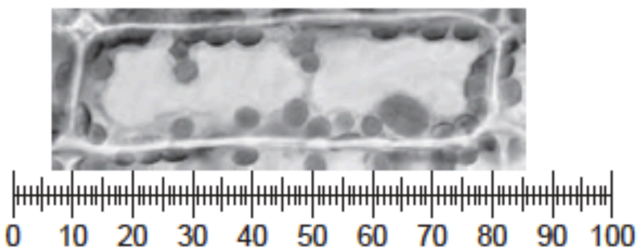
Measuring Size Using a Microscope

A stage micrometer of known length is used to determine the length of the eyepiece graticule scale.
This must be calculated for each magnification used.
Once the intervals on an eye piece graticule scale are known it can be used to measure a sample.

The field of view (FOV) of a microscope is shown below at 400x magnification.
The stage micrometer *intervals* in the example below represent 0.1 mm or (x1000) 100 μm each.
One interval of the stage micrometer represents 40 intervals on the eyepiece graticule (50 – 10 = 40).
Therefore, one interval on the eyepiece graticule scale is 2.5 μm (100 μm ÷ 40 = 2.5 μm).



The stage micrometer is replaced with a slide of a plant cell.



What is the length of the cell?

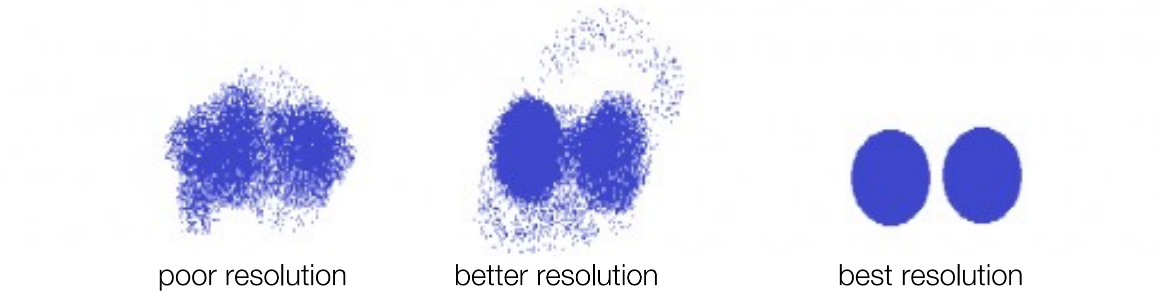
A camera pointed down the eyepiece lens can take a useful image of a specimen.
If the eyepiece graticule scale has been calibrated with a micrometer slide the actual size of the specimen image can be calculated.

Further detail:
How to calibrate a microscope with a stage micrometer basic and complete.

NOS
quantitative data – a numerical measurement
qualitative data – a descriptive observation

3SL Developments in Microscopy

resolution - is the ability to see separate parts of an object



The human eye can tell if two objects are separate if there is a gap of 0.1mm between them. Smaller than this and it may appear as one object.

Light microscope resolving power is limited by the wavelength of light to about 200nm (up to 1500x)
Electron microscope resolving power is the width of an electron wave 1nm. (up to 1 000 000x)

Electron microscopes images are not in colour and when placed in a vacuum they can dehydrate. CryoEM uses rapid freezing which helps retain the shape of cells and their components.

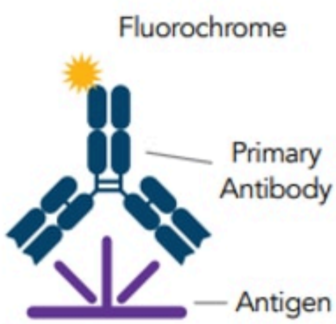
SEM – scanning electron micrograph – produces surface 3D images
TEM – transmission electron micrograph – produces cross-section images
CryoEM – cryogenic electron micrograph – produces 3D images of macromolecules

Fluorescent Stains and Immunofluorescence

Most cells are colourless and transparent.
Stains help features become visible such as methylene blue which binds to DNA and RNA.

fluorescence - when a substance absorbs light and then re-emits it at a longer wavelength
Fluorescent stains can bind to cell structures and re-emit certain colours.
Chlorophyll naturally emits red light when placed under UV light.

immunofluorescence – fluorescent stains attached to antibodies that bind to specific antigens
- can *identify* if a specific protein or RNA is being produced in a cell or has entered a cell
- can show *location* and movement of a substance



proteinntech

Freeze Fracture Electron Microscopy

1. Cell samples are frozen in liquid propane (-190C).
2. A steel blade is used to fracture the sample.
   The fracture passes through the weakest points – usually the middle of membranes.
3. Etching occurs where a little surface ice is removed by vaporization.
4. A platinum or carbon vapour is added to cover the sample - at a 35° angle.
   This forms a replica of the shape of the sample surface and can be used in electron microscopy.

Freeze fracture EM revealed transmembrane proteins that passed all the way through a membrane.

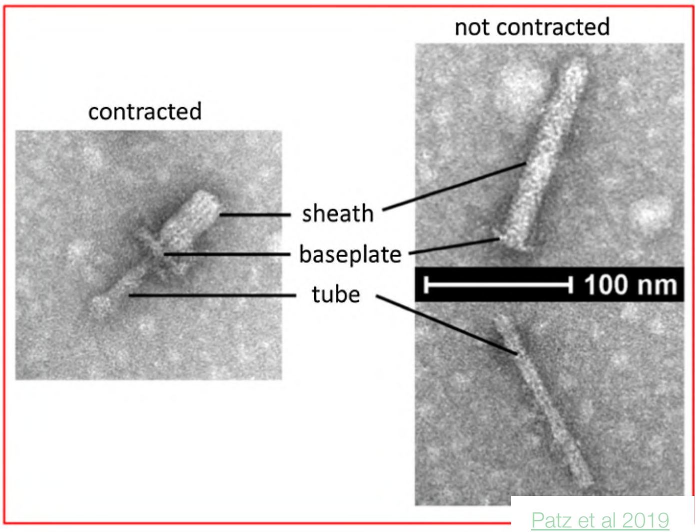
Cryogenic Electron Microscopy (Cryo EM)

Thin layer of pure protein is added to a grid.
Flash frozen using liquid ethane -182C
Grid is placed in an electron microscope.

Many reflected angles of an electron beam are analysed by computer to generate a 3D image.

The process can freeze proteins that are in the middle of changing shape.

Cryo EM is now accurate to 0.12nm making it possible to reveal the location of individual atoms.
CryoEM overview
CryoEM introduction



Patz et al 2019

CryoEM is unlocking protein structures and leading to bioinspired engineering – video UCLA.

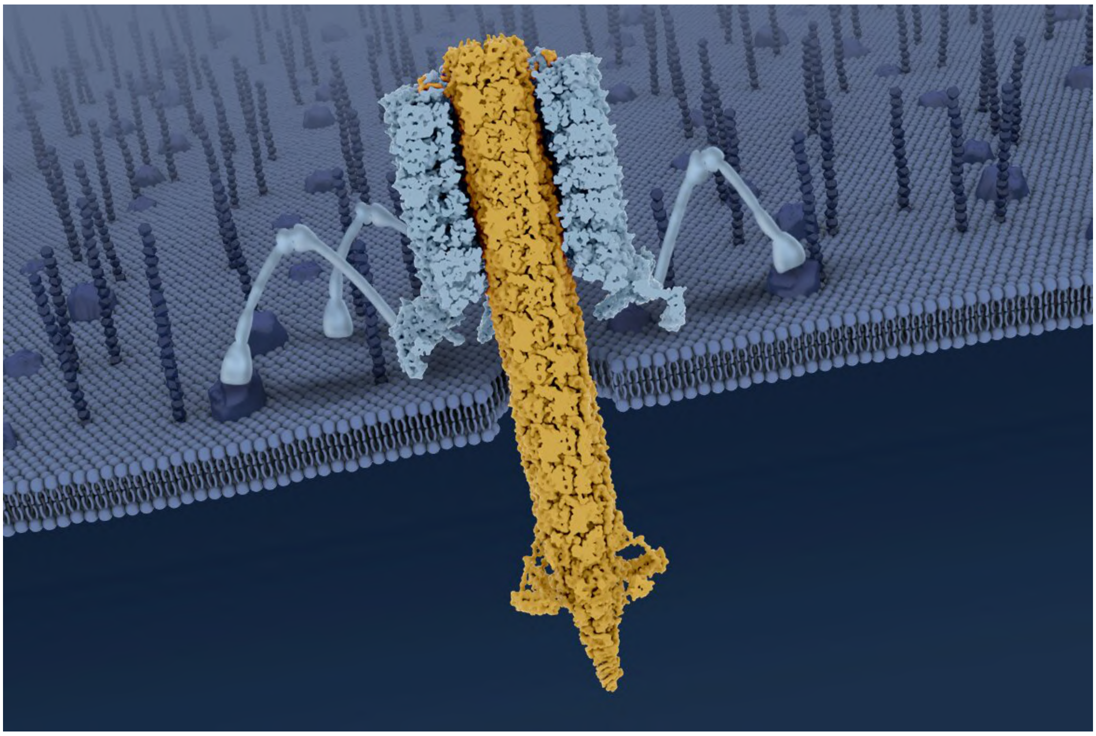


Image - Zhou Lab; Dan Weisman/UCLA CNSI

type of microscopy	advantages
light microscope bright field	living cells natural colour can observe movement and cell processes 1500x
light microscope dark field immunofluorescent stains	living cells selected proteins can be highlighted can observe movement and cell processes 2000x
transmission electron microscope TEM	non-living dehydrated cells black and white or false colour images cross section detail 100 000x or more
scanning electron microscope SEM	non-living dehydrated cells black and white or false colour images 3D surface detail 50 000x or more
freeze fracture electron microscopy	non-living cells black and white or false colour images 3D internal detail 100 000x or more
cryo-electron microscopy	non-living cells/proteins black and white or false colour images no staining / natural shape capture 3D detail, even rapid shape changes 200 000x or more with atomic level resolution

"If you tried to design a pyocin from scratch, you probably couldn't do it," … "It's good to learn from nature, because nature has developed and tested these systems over billions of years. That should help us from an engineering standpoint."

Z Hong Zhou UCLA

4SL Structures common to cells in all living organisms

Cells have many features in common:

1. plasma membrane made of lipids and proteins – controls entry and exit of substances
2. cytoplasm – has water, mineral ions, proteins, enzymes that allow metabolism
3. DNA is a universal code – an information store to control cell activity and allow inheritance.

These structures are needed for cells to survive and pass on their features.
It is thought these shared features are due to cells having descended from a common ancestral cell.
LUCA – last universal common ancestor

Optional Extension: (not required for the IB exam)

It can be predicted that if cells came from
- a common ancestor they would have certain features in common
- a common designer they would have certain features in common

Many features of a cell appear to be irreducibly complex.

irreducible complexity – where one missing part of a system makes it non-functional

How can DNA be read without enzymes?
How can enzymes be formed without DNA?

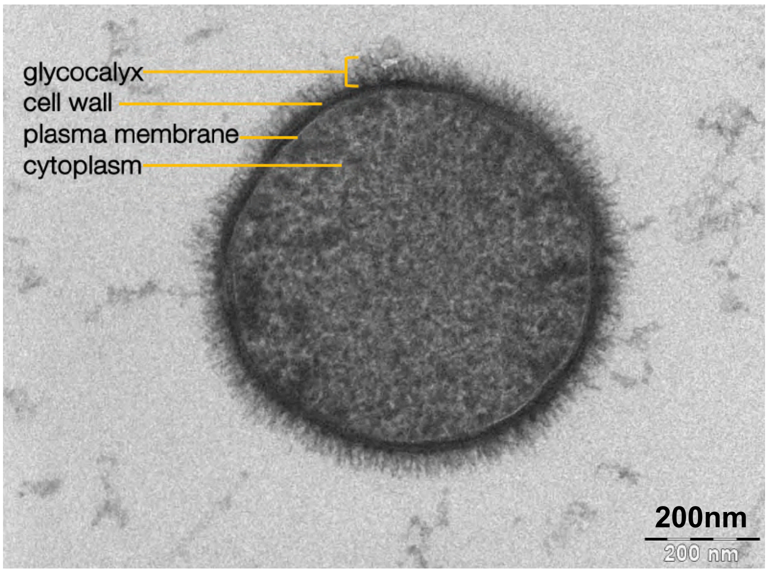
Can unguided natural processes randomly arrange simpler molecules into gradually more complex structures?

"If it could be demonstrated that any complex organ existed which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down."
--Charles Darwin, Origin of Species

5SL Prokaryote cell structure

Bacteria are prokaryotes – without a nucleus. They lack membrane bound organelles. Bacteria have a cell wall containing peptidoglycan.

Bacteria are not simple organisms. They are filled with complex machines just like all other cells.
Mobile phones do not have less complex technology than a laptop.
Mobile phones optimize functions within a smaller volume. In the same way bacteria are well adapted for their varied ecological roles.



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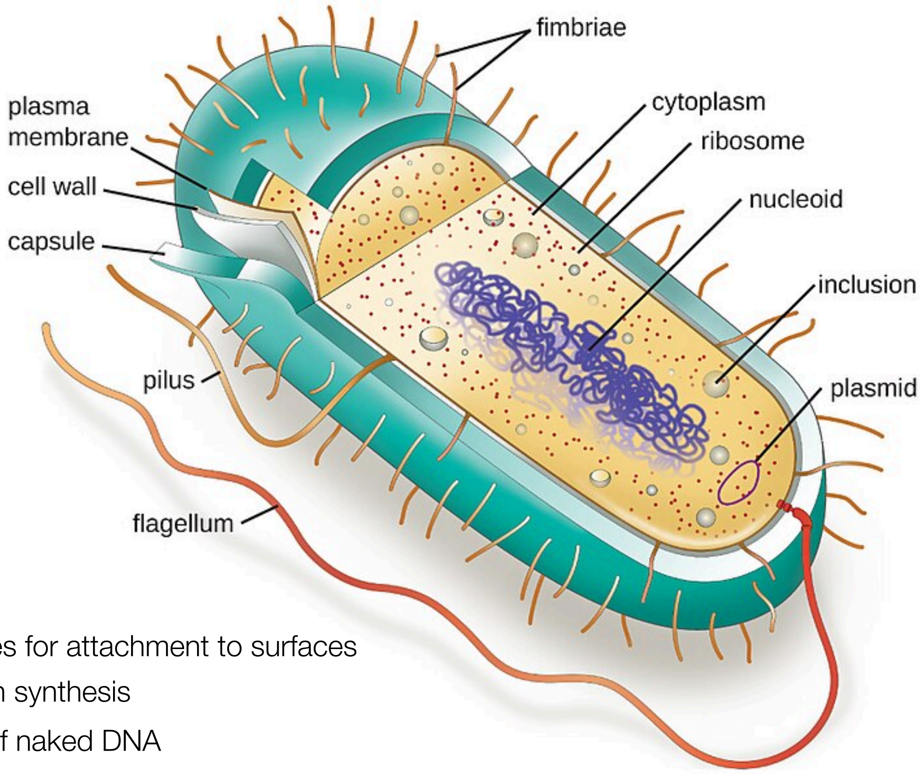
Bacillus subtilis TEM cross section – some bacteria have a glycocalyx (capsule or slime layer)

Holzinger et al 2011

Bacillus subtilis TEM longitudinal section



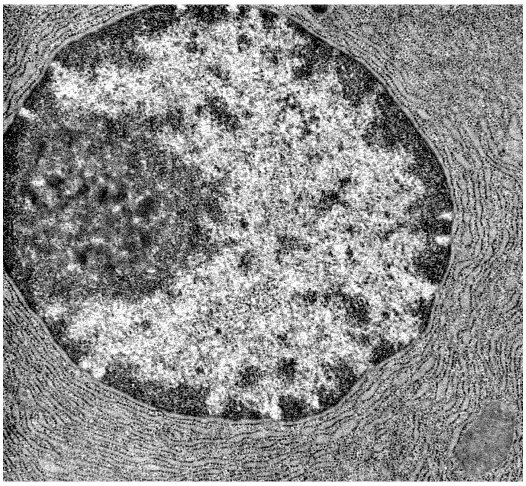
Freely available at Openstax via Hutchins et al

fimbriae – hair-like bristles for attachment to surfaces
ribosomes – 70s for protein synthesis
nucleoid – holds a loop of naked DNA
plasmid – a small loop of naked DNA
flagellum – rotates for locomotion animation
cytoplasm – where cell metabolism occurs
plasma membrane – controls entry and exit of materials
cell wall – provides structural support

6SL Eukaryote cell structure

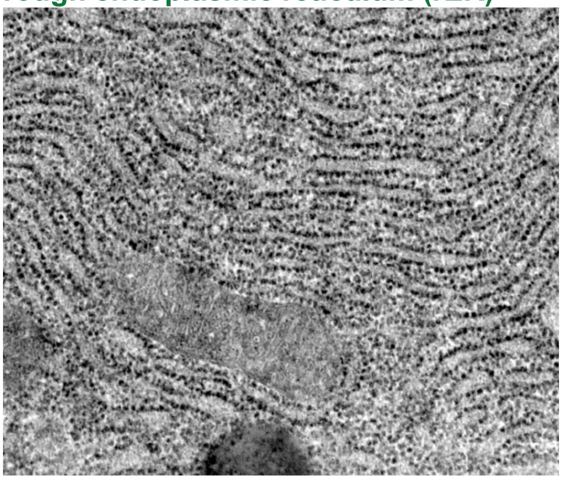
eukaryote - cells containing a nucleus and membrane bound organelles (compartmentalized)
organelle - a distinct structure with a specific function

nucleus



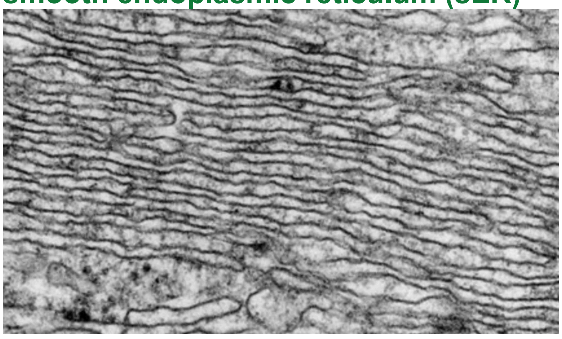
- controls cell functions by gene expression
- linear chromosomes
- DNA is bound to histone proteins
- double membrane with nuclear pores for release of mRNA
- coiled chromosomes appear darker
- nucleolus is where ribosomal RNA is transcribed

rough endoplasmic reticulum (rER)



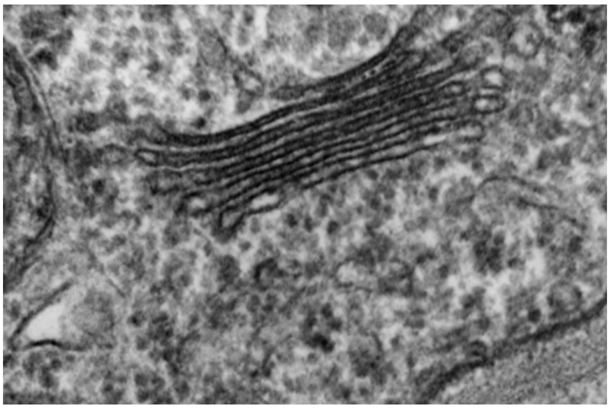
- protein synthesis and packaging into vesicles which bud off for transport
- appears rough due to 80S ribosomes
- forms rows of membrane called cisternae

smooth endoplasmic reticulum (sER)



- has no ribosomes
- makes lipids, phospholipids and steroids

Golgi



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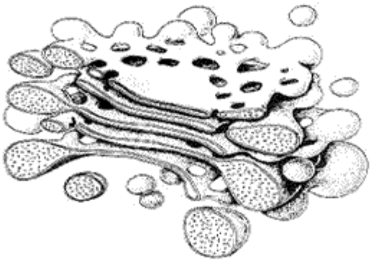
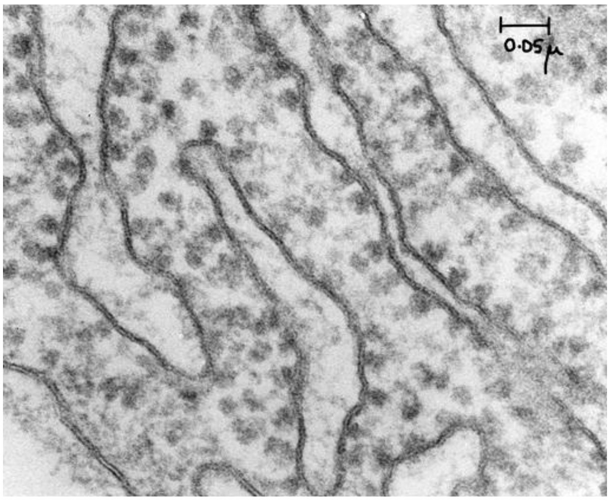
- modifies and packages proteins into vesicles, often for secretion
- cryotomography of Golgi



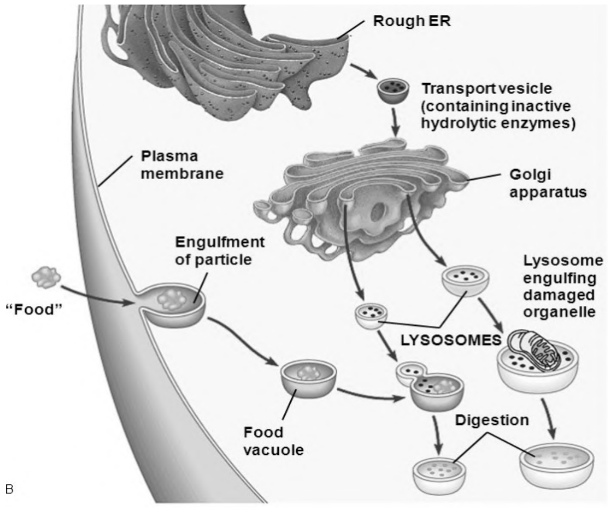
ribosomes



George E. Palade EM Slide Collection

- carry out protein synthesis
- may be attached or floating free
- prokaryote – smaller 70S
- eukaryote – larger 80S
  - mammalian mitochondria – 55S
  - plant mitochondria – 78S

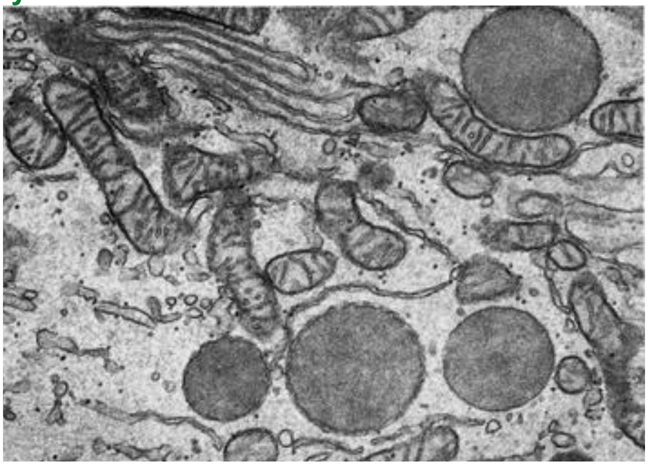
vacuoles and vesicles



Pearson Ed 2003

- fluid filled, single membrane
- vacuoles are larger (sap vacuoles are found in plant cells) (food vacuoles and contractile vacuoles in animal cells)
- also note transport vesicles, secretory vesicles, synaptic vesicles
- lysosomes vesicles hold digestive enzymes

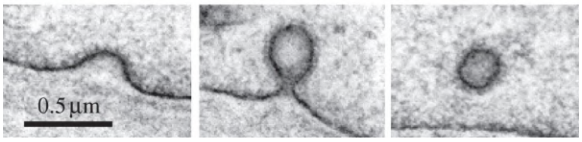
lysosome



Fawcett The Cell

- spherical vesicle containing digestive enzymes to breakdown food or parts of the cell
- densely packed proteins are stained dark
- found in animal cells

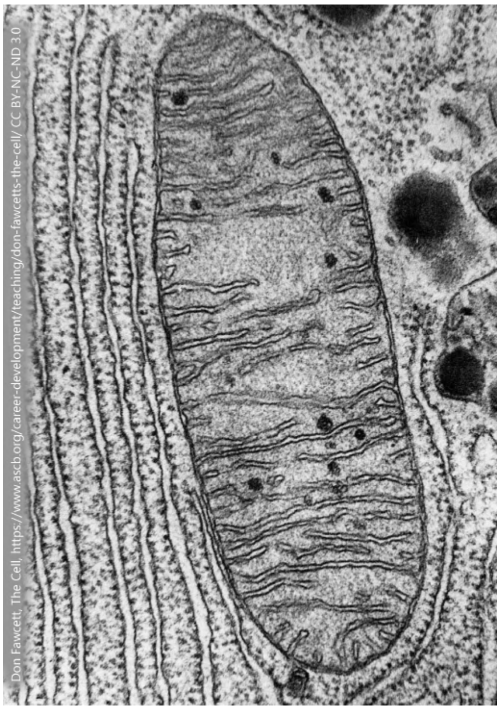
plasma membrane (showing pinocytosis)



Dahm et al 2011

- controls entry and exit of substances
- water repellent layer

mitochondria

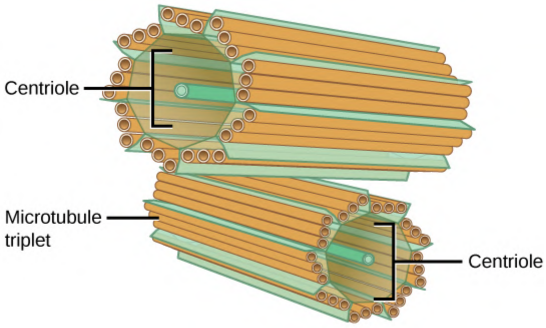


D Fawcett 1966

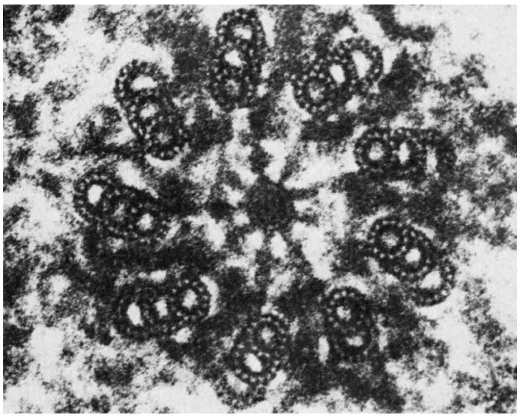
- site of ATP synthesis by aerobic respiration
- double membrane
- inner membrane has folds called cristae
- active cells have more mitochondria

microtubules and **centrioles**

microtubules

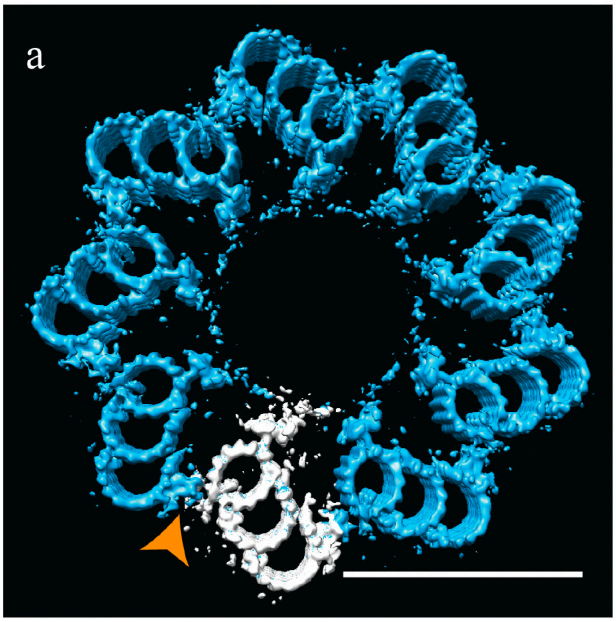


OpenEd CUNY



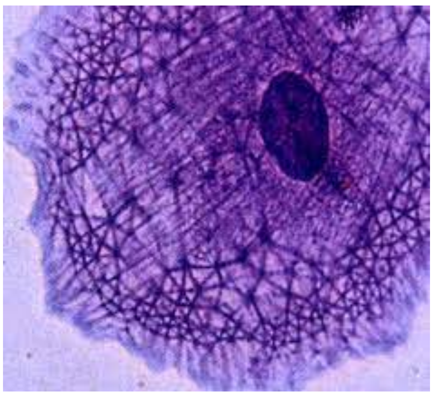
D Fawcett 1966

- centrioles are made from microtubules
- in animal cells a centriole pair called a centrosome pulls chromosomes apart during cell division
- centrioles have a 9 by 3 + 0 pattern of microtubules
- centrioles form the basal body of cilia and flagella
- microtubules form structures in cilia and flagella with 9 by 2 and 9 by 1 patterns



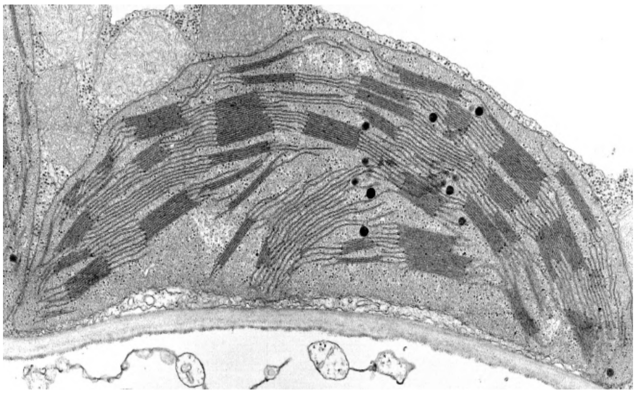
Greenan et al 2018 eLife

cytoskeleton



- cytoskeleton helps maintain cell shape
- guides delivery of substances
- microtubules made from tubulin are continuously made and broken down
- microfilaments made from actin

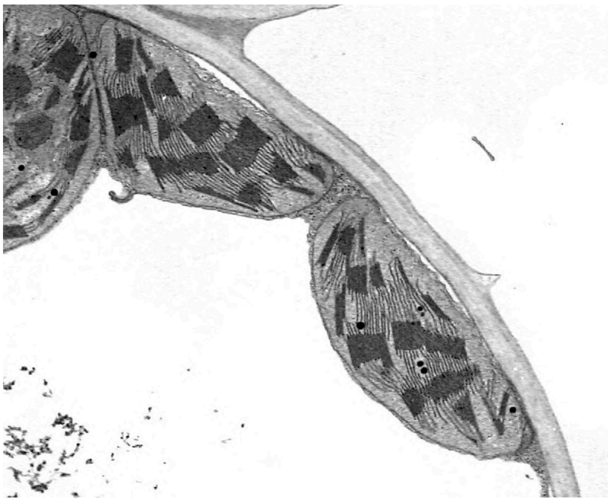
chloroplast (plants)



Newcomb UWDC

- site of photosynthesis
- contain chlorophyll
- double membrane
- have thylakoids, grana, stroma and starch grains

cell wall (plants)



Newcomb UWDC

- maintains structure of plant cell
- fully permeable
- made of cellulose fibers
- prevent cell from bursting

Comparison Table

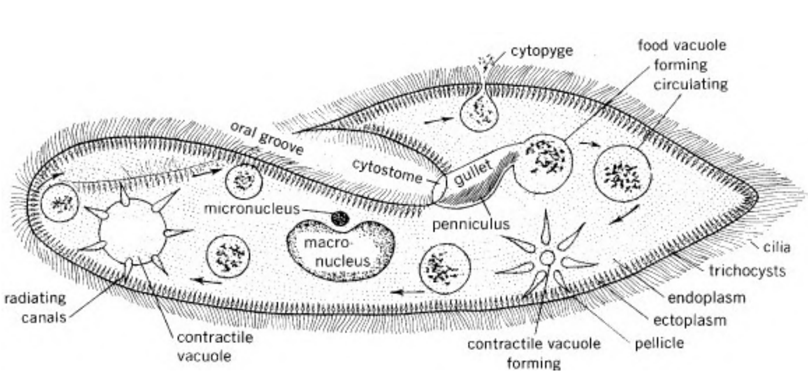
prokaryote	eukaryote
unicellular	unicellular and multicellular
no membrane bound organelles	has membrane bound organelles
no nucleus present	nucleus present
small ribosomes 70S	large ribosomes 80S
1-10 μm	10-100μm
carry out binary fission	carry out cell division
circular DNA	linear DNA
naked DNA (no protein covering)	DNA packaged with proteins

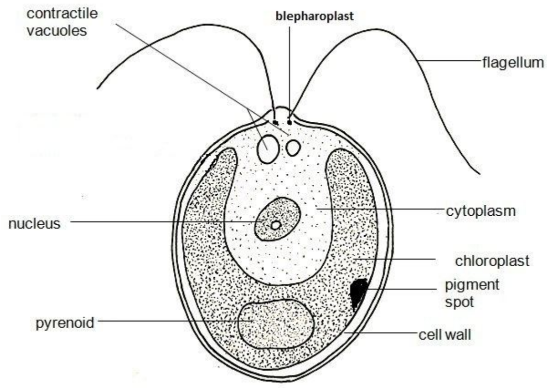
7SL Processes of Life in Unicellular Organisms

metabolism - all the enzyme-catalyzed reactions in an organism
response to stimuli - living things can respond to stimuli from the environment
homeostasis - maintaining the internal environment of the body between limits
growth - living things can increase in cell size (biomass) or cell number
reproduction - living things produce offspring, either sexually or asexually
excretion - the removal of metabolic waste
nutrition - obtaining food for energy and growth

Viruses are non-living as they require the cellular machinery of a host cell to replicate.

Function	*Paramecium* a heterotrophic unicellular protist that lives in pond water	*Chlamydomonas* is an autotrophic unicellular alga that lives in pond water
Metabolism	both by enzyme catalyzed pathways in cytoplasm	
Reproduction	both can divide asexually or form gametes sexually	
Homeostasis	both contractile vacuoles pump out water entering the cell	
Growth	both increase in biomass and size before cell division	
Response	cilia move the cell toward chemical food trails and away from solid objects	flagellum move the cell toward light detected from its surroundings
Excretion	metabolic waste diffuses out (CO_2)	metabolic waste diffuses out (O_2)
Nutrition	consume algae in food vacuoles	by photosynthesis using a chloroplast





Chlamydomonas

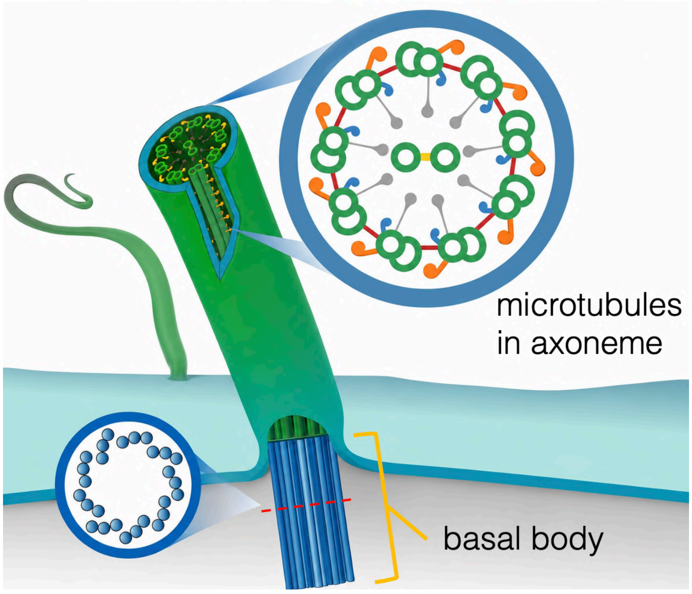
Mackean

Some *Paramecium* species, corals, and sea slugs can engulf algae and leave them undigested to produce sugars by photosynthesis which are then shared with the host organism.

8SL Differences in eukaryote cell structure between animals, fungi and plants

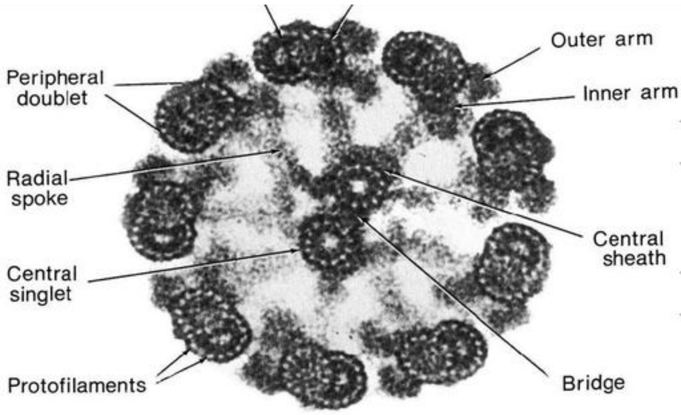
feature	animals	fungi	plants
plastids	none	none	Chloroplasts and amyloplasts (for starch storage) and others.
cell wall	none	chitin	cellulose
vacuole	Many small temporary food and waste vacuoles and contractile vacuoles.	fungal vacuole few large permanent for storage and homeostasis	plant sap vacuole few large permanent for storage and turgor pressure
centrioles	present in centrosome and basal body of cilia and flagella	absent except in gametes of some aquatic fungi that have a flagellum	absent except in gametes of mosses and ferns that have a flagellum
carbohydrate storage	glycogen	glycogen	starch

Flagella and Cilia

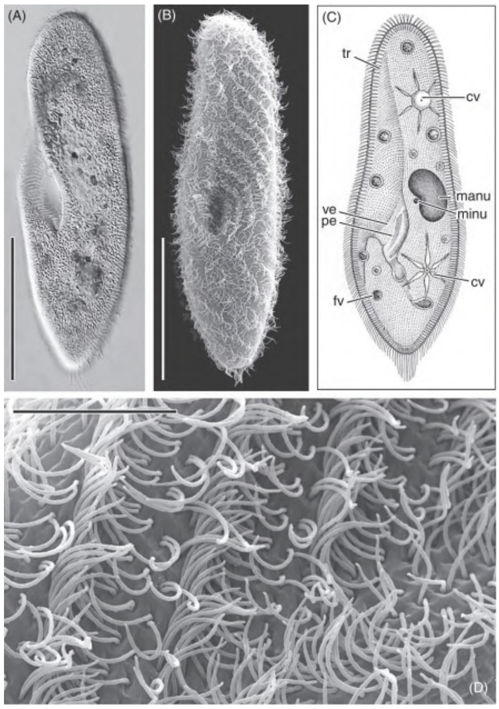


Public domain

- flagella for locomotion
- motile cilia for locomotion or sweeping particles
- eukaryotic flagella and motile cilia contain a core of microtubules with a 9 by 2 + 2 pattern
- flagella and motile cilia have a basal body with microtubules in a 9 by 3 + 0 pattern



D Fawcett 1966



Scale bar A, B 100 µm and D 10 µm

van Houten 2023

9SL Atypical cell structures in eukaryotes.

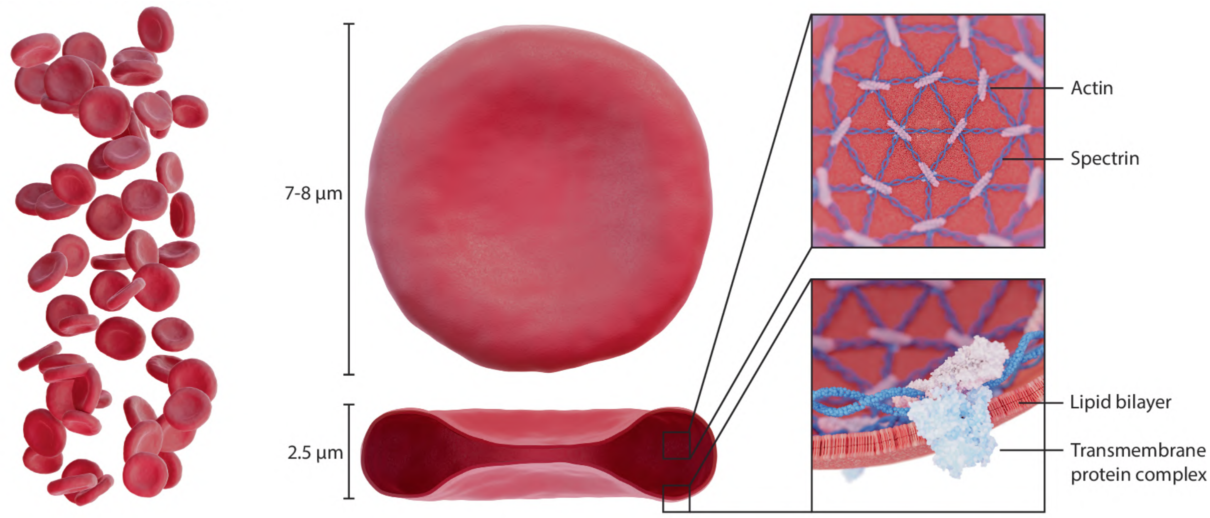
Testing the Cell Theory

Are there exceptions to the cell theory?

Eukaryotic cells normally contain a nucleus and organelles.
Multicellular organisms can support specialized *atypical* cells that would not survive on their own.
Do these modified cells challenge the idea that living things are made of separate cell units?

Red blood cells (RBCs) in mammals:

- nucleus removed during development in bone marrow to carry more hemoglobin
- unable to repair or replicate – last about 100 days



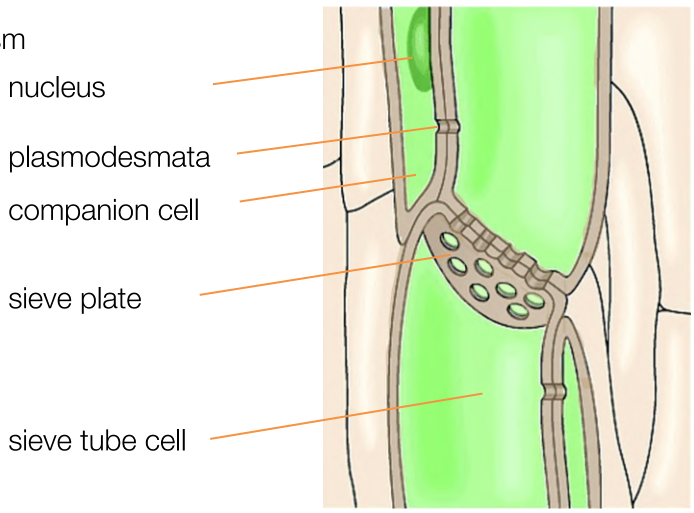
25 trillion RBCs, 70% of all cells

Biconcave flexible disc shape
Squeezes through capillaries

Actin-spectrin hexagonal cytoskeletal network linked to the lipid membrane via transmembrane protein complexes
Waeterschoot et al 2024

Phloem sieve tube elements:

- nucleus and organelles removed to form a hollow tube for sap flow
- plasma membrane remains
- companion cells provide metabolism

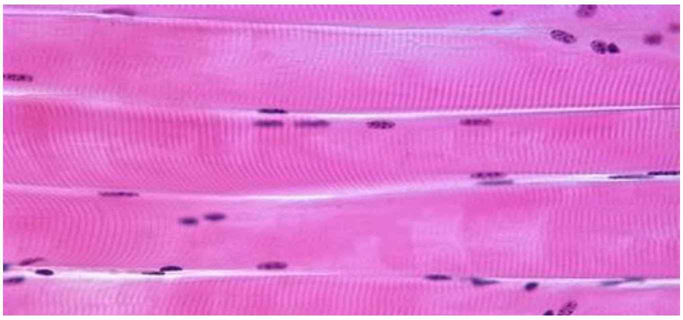


adapted from Pearson Ed

phloem longitudinal view

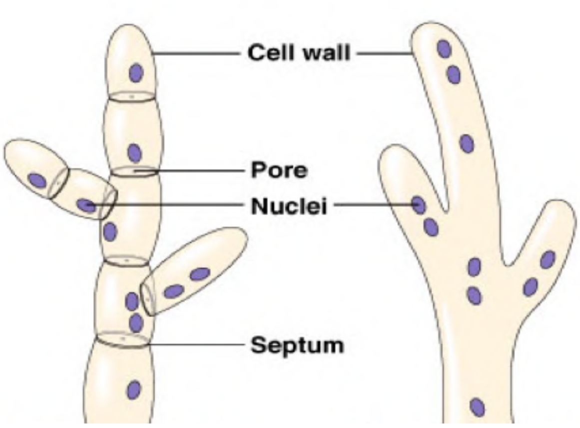
Striated muscle fibers:

- cells fuse together to become multinucleated
- enable long fibers to form for muscle contraction



Aseptate fungal hyphae:

- hyphae contain many nuclei within one long tube with shared cytoplasm
- usually fungi have cross walls (septa) between cells



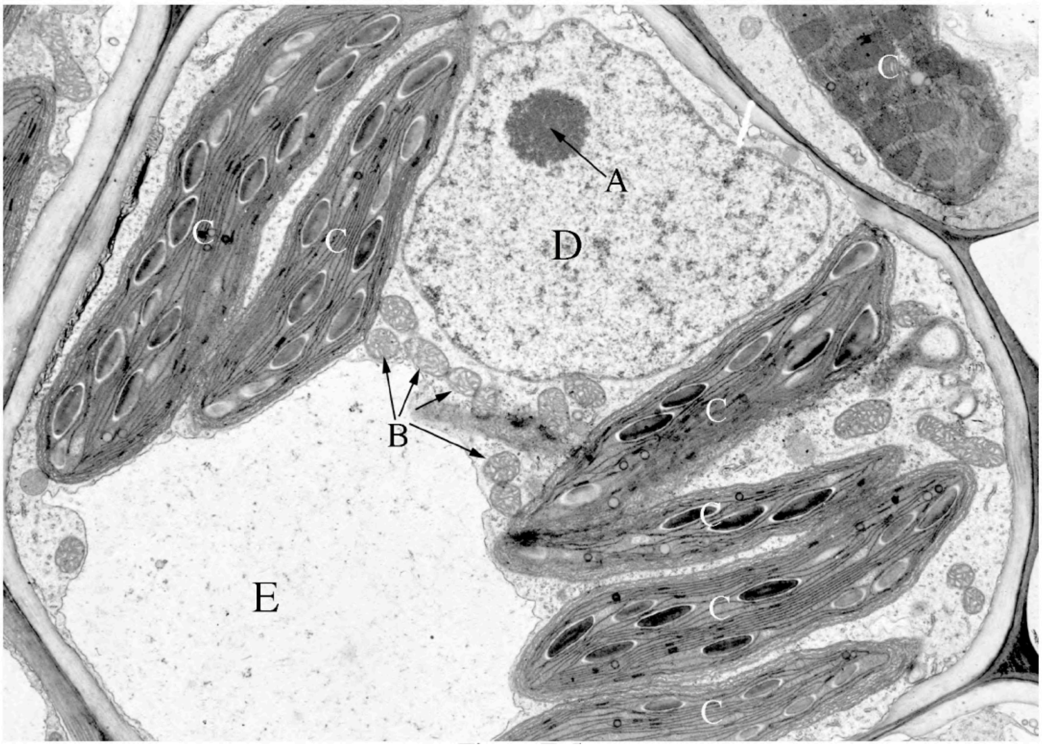
These examples are all possible exceptions to cell theory.
Viruses and organelles are not considered to be alive because they do not independently carry out all the functions of life.

Do these cases of specialized cells still fulfill each part of cell theory?

Some biomaterials are not made up of cells for example hair, feathers, shells, horn, mucus and tooth enamel. They are made by cells. Cells that live in 'mucus houses' are not exceptions to cell theory.

10SL Cell types and structures viewed under a light and electron microscope

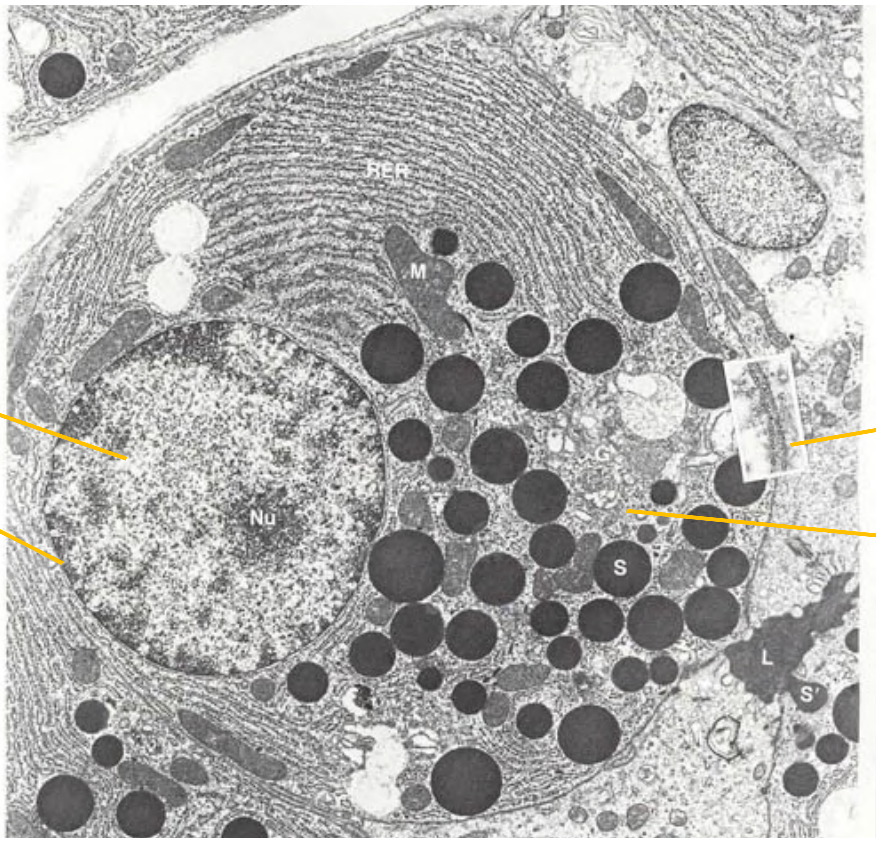
Plant Cell TEM



Botany UWC

A - nucleolus B - mitochondria C - chloroplasts + starch grains + lipid droplets D - nucleus E - vacuole

Animal Cell TEM



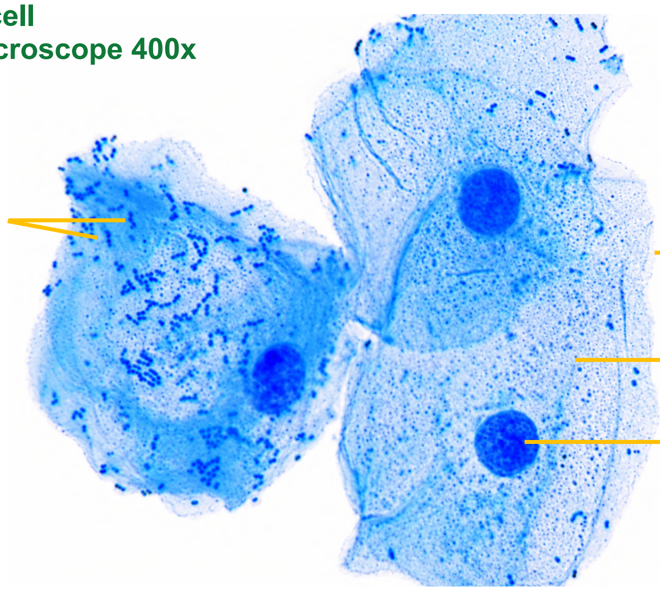
source visual histology

Nu – nucleolus M – mitochondria RER – rough endoplasmic reticulum S – secretory vesicle

Bacteria Cell
TEM

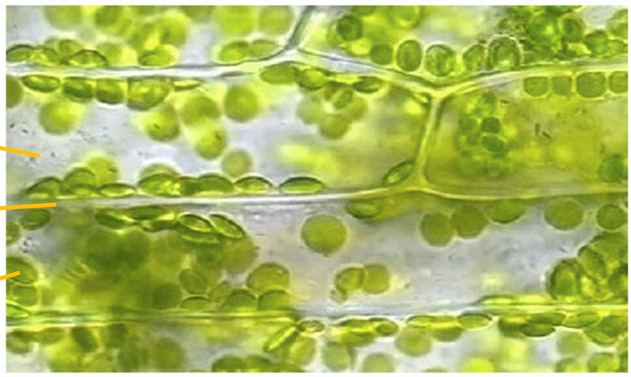
Escherichia coli TEM Shafiq et al 2022

Animal cell
Light Microscope 400x



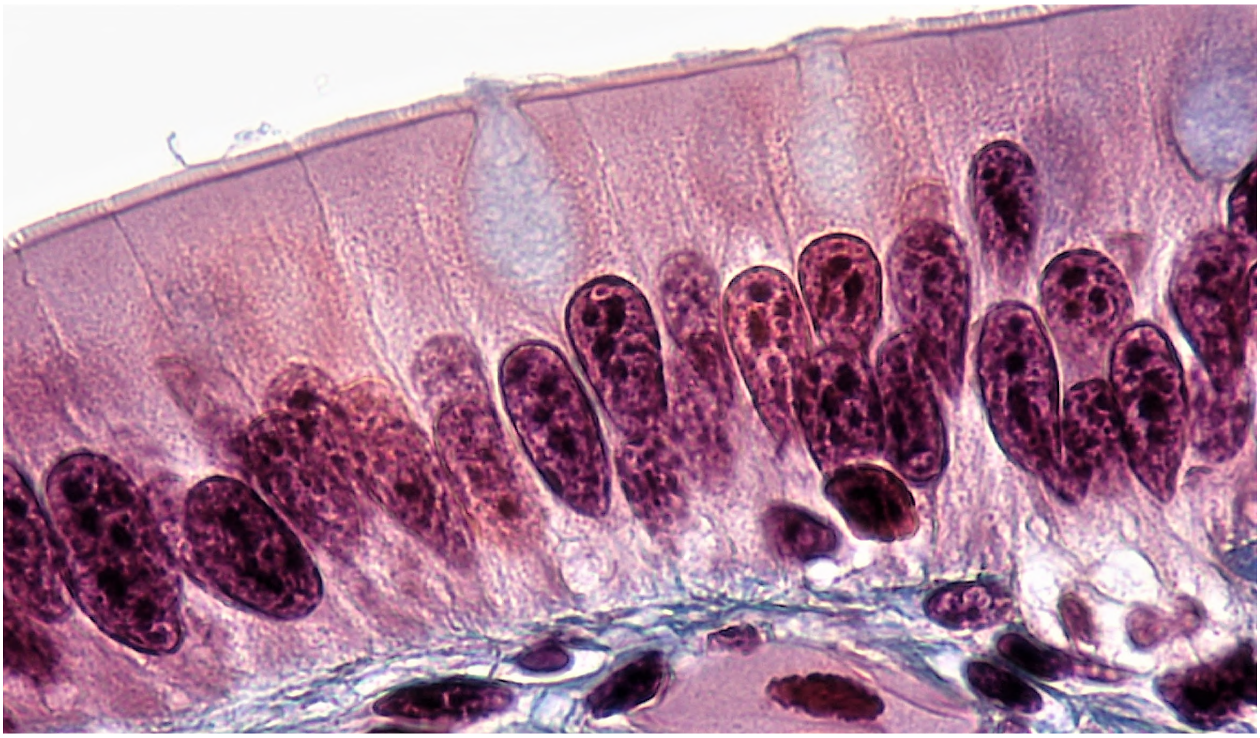
stained cheek epithelial cells

Plant cell
Light Microscope 100x



Elodea pond weed leaf cells

Animal tissue
Light Microscope 400x
Stained intestinal epithelial cells with microvilli brush border.



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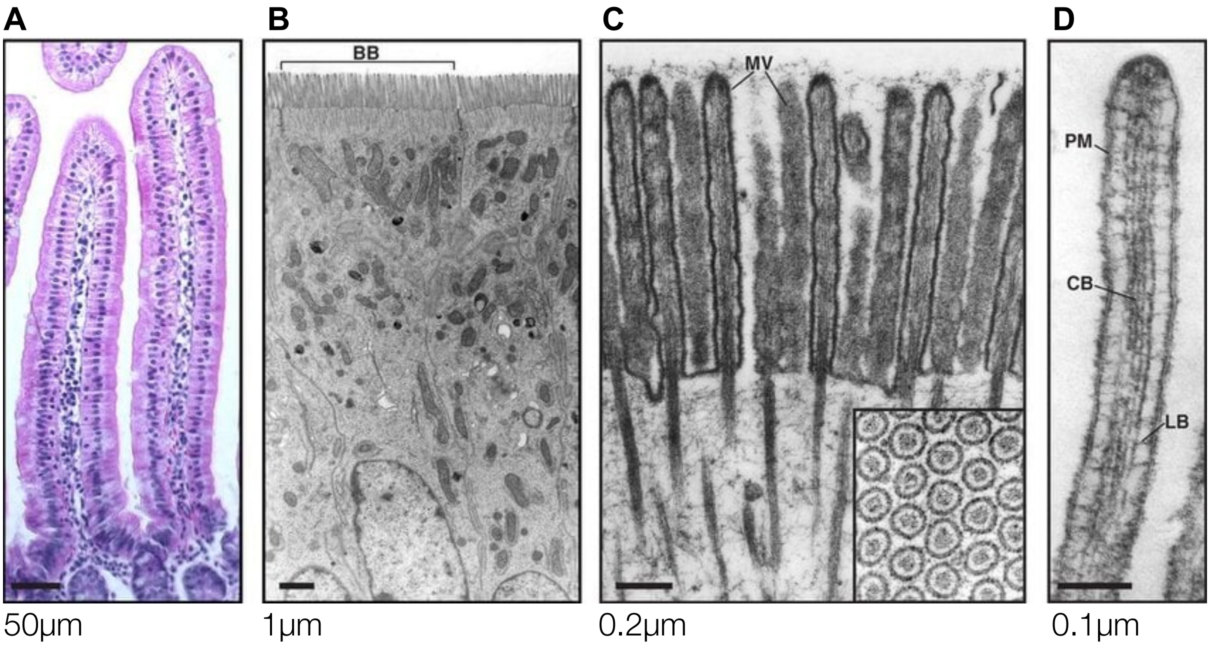


Crawley et al 2014

A villi – light microscope
B microvilli brush border on epithelial cells – TEM
C micovilli longitudinal and cross section – TEM
D microvillus – TEM

Microvilli are non-motile and shaped to increase surface area for absorption.
They contain actin filaments and have a glycocalyx layer and are smaller than cilia.

11SL Drawing and annotation based on electron micrographs

Draw, label and annotate a prokaryote cell - *Escherishia coli*.

Include cell wall, capsule, plasma membrane, cytoplasm, pili, flagella, ribosomes, and the nucleoid and plasmids.

Draw and label an animal cell and a plant eukaryote cell.

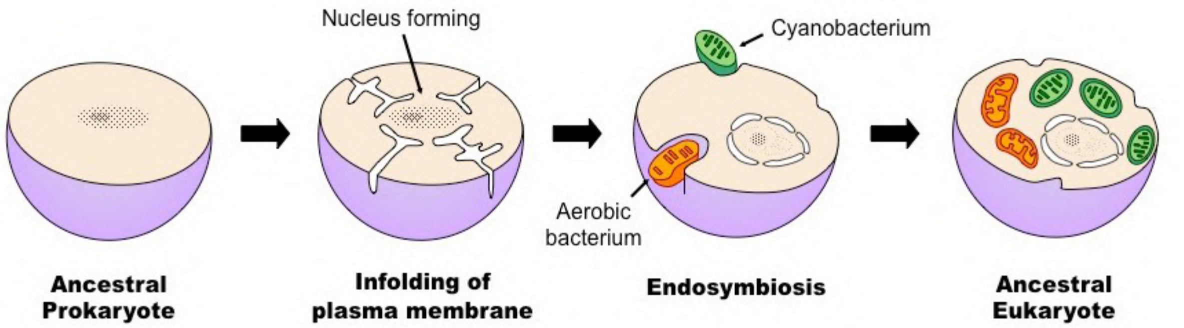
12HL Origin of eukaryotic cells by endosymbiosis

symbiosis - organisms living together in close association
mutualism - interaction where both organisms benefit
endosymbiosis - one organism (endosymbiont) living inside of another (host)
endosymbiont - a cell which lives inside another cell with mutual benefit

Prokaryotes lack membrane bound organelles found in eukaryotes.
Endosymbiotic theory explains the origin of eukaryotes by endosymbiosis of prokaryotes.

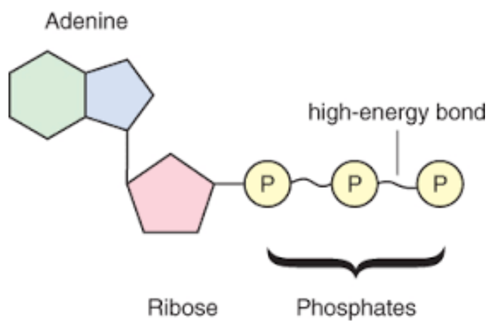
The prokaryote–eukaryote divide is "the greatest single evolutionary discontinuity to be found in the present-day world".
Stanier et al. (1963)

Development of endoplasmic reticulum, Golgi body and nucleus:
A prokaryote grows in size and develops folds in the membrane to maintain an efficient SA:Vol ratio.
Some of the in-folding is pinched off to form an internal membrane.
The nucleoid region is enclosed in the internal membrane and hence becomes the nucleus.



bioninja

Development of Mitochondria:
1. An aerobic bacterium enters a larger anaerobic prokaryote (as prey or as a parasite).
2. It survives digestion to become an endosymbiont.
3. The endosymbiont provides a source of ATP to the host cell enabling it to out-compete other anaerobic prokaryotes.
4. As the host cell grows and divides so does the aerobic bacterium therefore subsequent generations automatically contain the aerobic bacterium.
5. The endosymbiont evolves and is assimilated to become a mitochondrion.



The development of chloroplasts by endocytosis of photosynthetic cyanobacteria would be a very similar process except the benefit to the cell would be glucose and starch instead of ATP.

Supporting Evidence for endosymbiosis of mitochondria and chloroplasts:

- have their own DNA - which is naked and circular
- have ribosomes that are similar to prokaryotes (70S)
- have a double membrane and the inner membrane has proteins and lipids similar to prokaryotes
- are roughly the same size as bacteria and are susceptible to the antibiotic chloramphenicol
- transcribe their DNA into mRNA and synthesize some of their own proteins
- reproduce by binary fission

NOS

A strong theory explains a wide range of observations, relevant facts and can enable useful predictions to be made. A strong theory can be tested and can be falsified.
A wide range of observations are accounted for by the theory of endosymbiosis as shown above.

The origin of eukaryotes is one of the most daunting and captivating problems in all biology...
Mills 2020

Optional Extension: (not required for the IB exam)

Testing the Endosymbiotic Theory
The endosymbiont theory is not directly testable or falsifiable as it occurred in the distant past but it can be tested indirectly from cell biology, genetics and phylogenetics.
Currently the microbial fossil record lacks clear transitional fossils of these cells.

Prokaryotes cannot carry out phagocytosis.
Phagocytosis requires a cytoskeleton and actin filaments - when this evolved is not clear.
The host cell may have been an early prokaryote that lost the cell wall or the host cell may have engulfed the prokaryote by outward blebbing of the membrane through a hole in the cell wall.

What mechanism prevented the host cell from digesting the endosymbiont?

Mitochondrial genes are predicted to be left-overs from prokaryotes however:

- they have many unique sequences and contain introns which bacteria do not have
- 90% of proteins used by the mitochondria are coded by the cell nucleus, therefore it is thought numerous genes of the endosymbiont made their way into the nucleus
- over 96% of the original bacterial genes would need to be lost over time

Mitochondrial ribosomes were predicted to be 70S as they came from a prokaryote, however:

- mammalian mitochondrial ribosomes are 55S – thought due to reductive evolution
- plant mitochondrial ribosomes are 78S – thought due to constructive evolution

Like the nuclear-encoded COX subunits, the majority of genes required for mitochondrial function are encoded by the nuclear genome. … Although the evolutionary origin of the nuclear-encoded subunits remains a mystery, they have subsequently evolved specialized functions.
Das et al 2004

Costasiella kuroshimae the Sea Leaf Sheep Kittisak Songprakob; istock
It is not a true symbiont as it can only temporarily retain chloroplasts taken from ingested algae.

13HL Cell differentiation is the process for developing specialized multicellular tissues

tissues - are made up of the same type of cell working together, for example muscle tissue

differentiation - is the development of cells along particular pathways to form specialized cells

specialized cell – a cell that is well adapted to a particular function

Specialized cells allow certain tasks in a multicellular organism to occur more efficiently.
For example: a red blood cell is specialized to carry oxygen around the body.

The nucleus of each cell in a multicellular organism contains all the genes to make every type of cell found in the organism.
Many of these genes are switched off if they are not needed in a cell and others are switched on.
This method of control is known as gene expression.
Skin cells do not need to produce hemoglobin like red blood cells so this information is turned off.
About 4000 'house-keeping genes' are left switched on in each cell type of the human body for cell division, metabolism and other tasks.

14HL Evolution of multicellularity

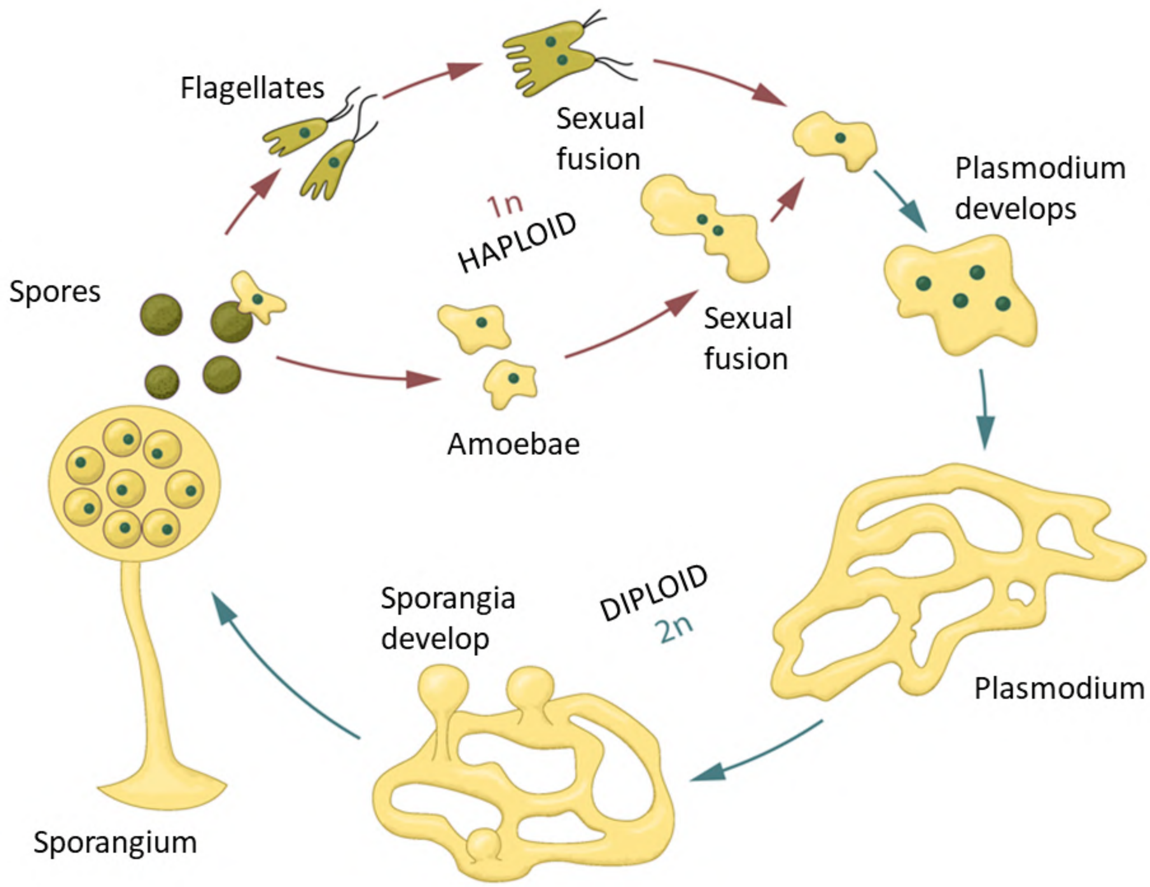
All plants and animals, and many fungi and algae are multicellular.
Therefore multicellularity has evolved independently many times in eukaryotes.

Advantages:
- longer life span as death of one cell does not prevent survival of the others
- usually, larger size allows other niches to be exploited
- allows for specialized cell types that are more efficient in their role

However, most life forms are unicellular suggesting certain advantages for this mode of life.

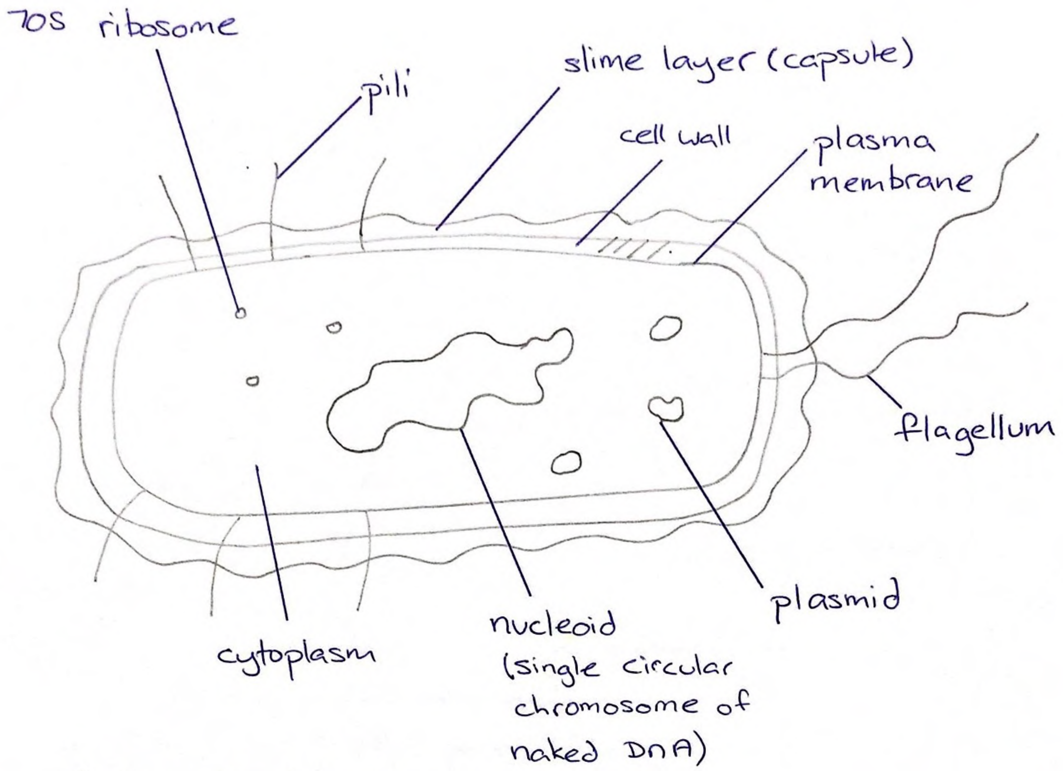
Bacteria can also behave as multicellular organisms by sticking together and moving in a swarm.

A slime mold is a unicellular protist. However, individual cells can fuse together to form a moving slug, a plasmodium and a spore tower.



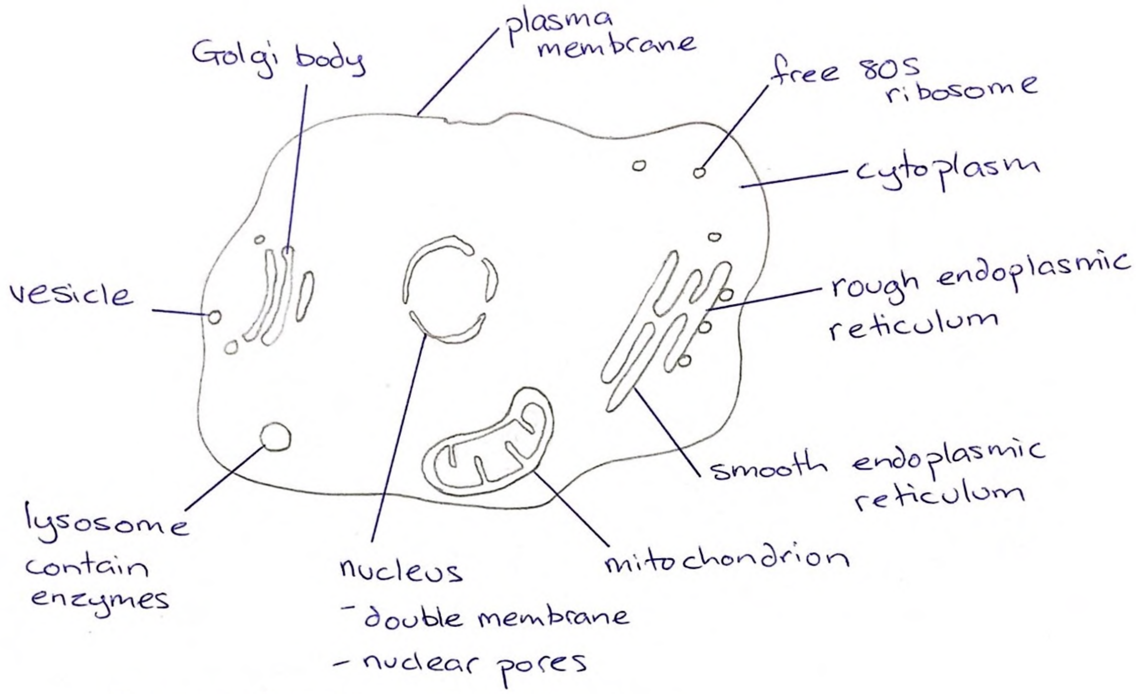
Wikimedia

Prokaryote drawing

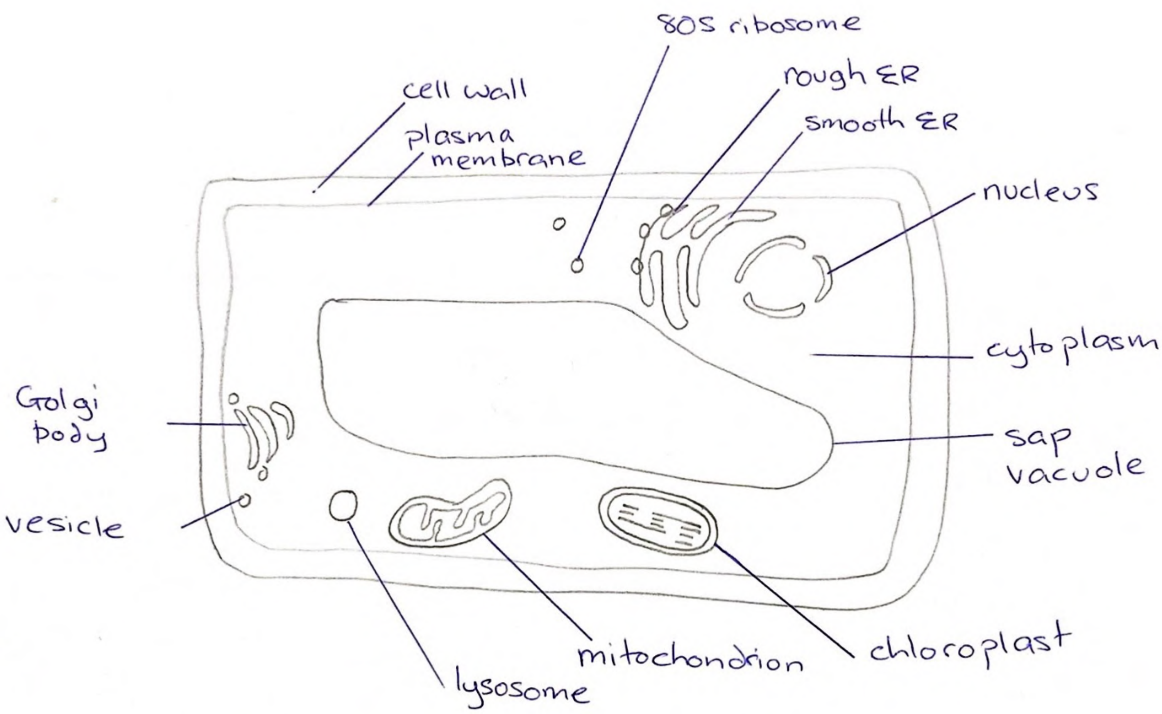


Prokaryote 1-2 µm in length

Eukaryote drawings



Eukaryote liver cell 10-100μm



Eukaryote Plant cell 100μm