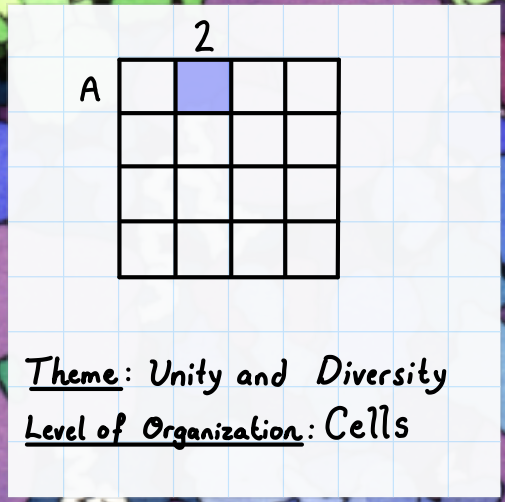
A2.2 Cell Structure

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?



Theme: Unity and Diversity
Level of Organization: Cells

Written and drawn by:
Peter Marier

NOTEWORTHY SCIENCE
MARIER

https://pdb101.rcsb.org/sci-art/goodsell-gallery/escherichia-coli

SL Learning Outcomes

A2.2.1	Cells as the basic structural unit of all living organisms	**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.
A2.2.2	Microscopy skills	**Application of skills:** 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.
A2.2.3	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.
A2.2.4	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.
A2.2.5	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.
A2.2.6	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.
A2.2.7	Processes of life in unicellular organisms	Include these functions: homeostasis, metabolism, nutrition, movement, excretion, growth, response to stimuli and reproduction.
A2.2.8	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.
A2.2.9	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.
A2.2.10	Cell types and cell structures viewed in light and electron micrographs	**Application of skills:** 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.
A2.2.11	Drawing and annotation based on electron micrographs	**Application of skills:** 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.

HL Learning Outcomes

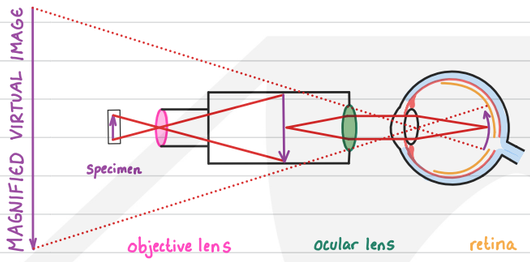
A2.2.12	Origin of eukaryotic cells by endosymbiosis	Evidence suggests that all eukaryotes evolved from a common unicellular ancestor that had a nucleus and reproduced sexually. Mitochondria then evolved by endosymbiosis. In some eukaryotes, chloroplasts subsequently also had an endosymbiotic origin. 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.
A2.2.13	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.
A2.2.14	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.

A2.2.2—Microscopy skills

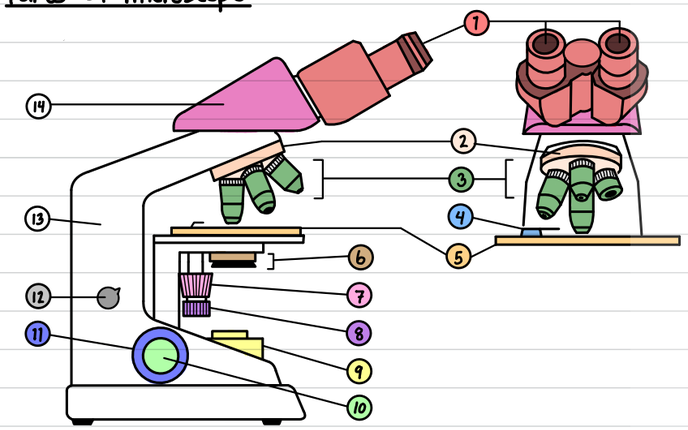
Application of Skills: using a microscope

compound light microscope : instrument which uses two lenses and visible light to produce a magnified image of a specimen too small to be viewed by naked eye

one which appears larger than its actual size ←



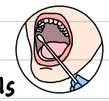
Parts of microscope



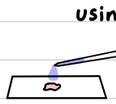
1. ocular lenses / eyepiece (10x) and tube
2. revolving nosepiece
3. objective lenses (4x, 10x, 40x, 100x)
4. stage clip
5. mechanical stage
6. iris diaphragm and condenser
7. stage knob: forward and back (y-axis)
8. stage knob: right and left (x-axis)
9. illuminator (light source)
10. fine focus knob
11. coarse focus knob
12. brightness control knob
13. arm and base (body)
14. head

Preparing temporary mounts of specimens

1 collect a thin sample of tissue and place on glass slide

ex: swab cheek cells  peel onion epidermis 

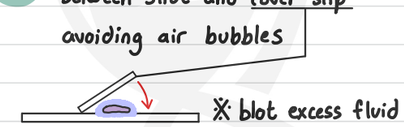
2 add drop of water or to increase contrast, add stain using a pipette



cheek: methylene blue

onion: Safranin / iodine

3 sandwich the dyed sample between slide and cover slip avoiding air bubbles



※ blot excess fluid

Using a microscope to view magnified sample

1 - turn the nosepiece to the lowest power objective lens (4x) in order to have largest field of view and to better locate specimen
2 - place prepared slide (cover-slip up) on the stage using clip
3 - using coarse focus knob, move stage as far up as possible without touching slide ※ this to prevent accidentally hitting it later
4 - while looking through ocular lens, turn coarse focus knob slowly, moving stage down until image comes into broad focus
5 - slowly turn fine focus knob until image is fully-focused
6 - use the stage knobs to view different parts of specimen
7 - if a higher magnification is desired, rotate to another objective lens. If unfocused, use fine focus knob only
※ if you can't focus, repeat steps 3-6

Troubleshooting

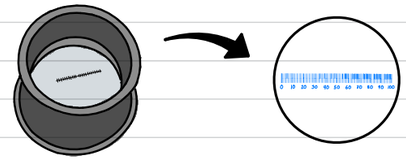
Problem: image is very dark / bleached
Solution: turn brightness control knob and adjust iris diaphragm to alter amount of light passing through

Problem: you see a circle with black rim
Solution: this is an air bubble. remove slide and gently try to squeeze it out

Problem: you can't find sample
Solution: slowly turn stage knobs to move sample under the lens

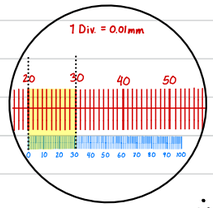
Measuring sizes using a microscope

eyepiece graticule : graduated scale placed inside eyepiece lens. Units are arbitrary

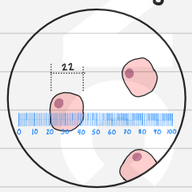


stage micrometer : microscope slide with divided scale marked on its surface used for calibration

1- Determine magnification (ocular × objective)
2- align eyepiece graticule with stage micrometer
3- count how many divisions on the graticule correspond to a set number of micrometer divisions
4- calculate value of one graticule division



in 10 stage micrometer divisions there are 31 graticule divisions
10 : 31
10(0.01mm) : 31 divisions
0.1 / 31 : 1 division
∴ 0.0032 mm or 3.2 μm = 1 division

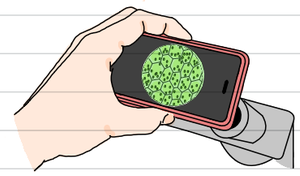
ex: 

cell length = 22 units
graticule division = 3.2 μm
22 × 3.2 μm = 70.4 μm

※ calibration needs to be done for each objective lens i.e. for each magnification

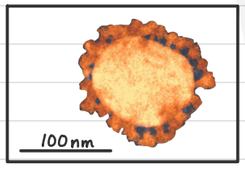
Taking photographs using a microscope

micrograph : photograph or digital image taken through a microscope
↳ can be done with a camera mount or using phone camera through the lens



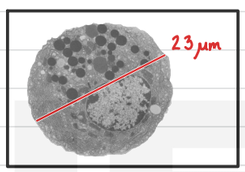
Calculating magnification and actual size of an image

number of times larger a specimen appears ← magnification (Mag) = measured size of image (M) / actual size of specimen (A) → in reality

ex: 

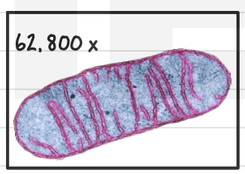
Determine the magnification (given scale bar)
1. measure scale bar with ruler → 25mm × 10^6 = 2.5×10^7 nm
2. convert into the units given
3. calculate using 'Mag MA'

$Mag = \frac{M}{A} = \frac{2.5 \times 10^7 nm}{100 nm} = 250000\times$

ex: 

Determine the magnification (given actual size)
1. measure length with ruler → 41 mm × 10^3 = 4.1×10^4 μm
2. convert into the units given
3. calculate using 'Mag MA'

$Mag = \frac{M}{A} = \frac{4.1 \times 10^4 \mu m}{23 \mu m} = 1800\times$

ex: 

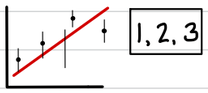
Determine the actual length (given magnification)
1. measure length with ruler → 94mm × 10^3 = 9.4×10^4 μm
2. convert to appropriate units
3. calculate using 'Mag MA'

$A = \frac{M}{Mag} = \frac{9.4 \times 10^4 \mu m}{62,800} = 1.5 \mu m$

A2.2.2—Microscopy skills A2.2.3—Developments in microscopy

NOS: In order to test hypotheses, experiments need to be conducted where data is collected for analysis

↳ **quantitative data**: numerical data (discrete or continuous) which can be measured or counted (typically with instruments) – data is analyzed using statistics



※ more common in natural sciences

ex: length (mm), mass (g), age (yr), number of cells, time (s)

↳ **qualitative data**: non-numerical data such as text, audio, or image gathered from interviews, observations, photography and printed materials – data can be analyzed by grouping it into meaningful categories ※ more common in humanities and social sciences

ex: visual observations (drawing, colour, shape, smell, feeling, emotions, etc.)

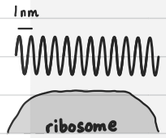
Knowledge gained through science is limited by our ability to observe and test. Advancements in microscopy have improved our ability to observe (in scale and detail) and thus better test and understand our universe → technology begets discovery

Electron microscope: instrument which uses beams of electrons focused by electromagnets to detect and magnify an image to high resolution (shortest distance 2 points can be distinguished)

- light microscopes use visible light (λ = ~400–700nm)
- electron microscopes use electrons (λ = ~1nm)

ribosomes not seen

∴ maximum resolution is 200nm specimens <200 nm will not be resolved and thus not observed clearly



∴ max resolution of SEM is 0.5nm specimens can be observed clearly at the atomic range!

↳ **Transmission Electron Microscopy (TEM)**: beam of electrons is transmitted through an ultra thin section of a specimen and focused on a detector to form a magnified 2D image

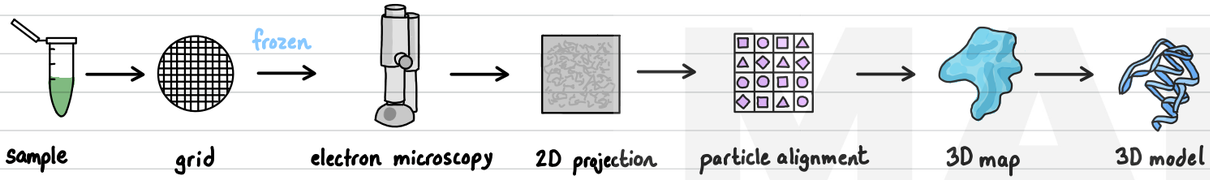
↳ **Scanning Electron Microscopy (SEM)**: electron beam is scanned back and forth across the surface of a specimen and detected to produce a detailed, magnified 3D image

✓ High resolution (SEM: 0.5nm, TEM: 0.1nm)
✓ High magnification (SEM: ~1-2 million, TEM: 50 million)
✓ SEM produces 3D images

× only dead specimens can be viewed
× black and white images (colour added after)
× images may contain artifacts from preparation

Cryogenic Electron Microscopy (CryoEM): technique where electron beams are fired at a frozen sample and focused to produce magnified 3D image Proteins B1.2

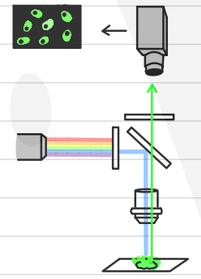
↳ sample (usually protein) applied to a grid is flash-frozen in liquid ethane (-183°C). 2D images of the sample are produced via electron microscopy which are aligned and merged to construct a 3D map. The protein sequence is fitted into map to form a detailed 3D model



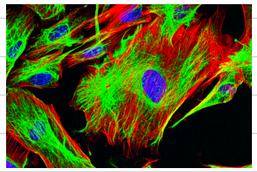
✓ very high resolution (0.12nm) allows atom-level detail
✓ as samples are frozen instantly, different protein forms can be observed, allowing insight into structure and function

※ as cell components are mainly transparent and colourless, adding colour markers increases visibility

Fluorescent stains: substances or dyes which bind to specific cellular components and fluoresce (absorb and re-emit light at a lower frequency) in order to increase visibility

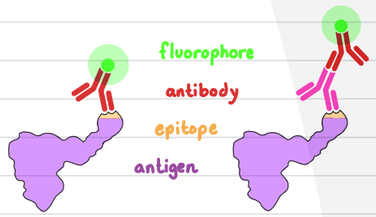


↳ specific stains are selected to bind to chosen cellular components, which will produce a single fluorophore (colour). Several stains can be used to induce different fluorescence for different parts



↳ fluorescence microscopy is then used to induce and capture fluorescence of a stained sample. Multiple single-colour pictures are combined to produce multicoloured micrographs

Immunofluorescence (IF): use of antibody proteins, bound to a fluorescent marker to specifically bind to a biomolecule target to induce fluorescence



↳ Antibodies are produced which binds specifically to a chemical of interest, (such as a protein) at its antigen. The antibody can be bound to a fluorophore (primary) or may be detected by another bound to a fluorophore (secondary)

↳ The sample of interest is incubated with the antibodies and then viewed using fluorescence microscopy - causing the targets to fluoresce

✓ as this technique allows targets to be located precisely in living tissue, it can be used to observe the life cycle of cells and which proteins are produced, cell structure, viral infections, and even for medical diagnoses

Freeze-fracture: technique which samples are frozen, split-open, and observed using electron microscopy

↳ Sample is flash-frozen in liquid propane or nitrogen (-190°C - 196°C) and then split-open with a blade. Ice is then removed from the exposed surface and is etched by covering it with metal (gold or platinum)

✓ allows the inside of structures to be observed such as the plasma membrane

A2.2.1—Cells as the basic structural unit of all living organisms. A2.2.4—Structures common to cells in all living organisms. A2.2.7—Processes of life in unicellular organisms. A2.2.9—Atypical cell structure in eukaryotes

Cell Theory the traditionally-accepted fundamental explanation of life

↳ All living organisms are composed of one or more cells (organisms can be unicellular or multicellular) — origin of cells A2.1
↳ Cells are the smallest/fundamental unit of self-sustaining life
↳ All cells arise from pre-existing cells (at least under current conditions)

NOS: Deductive reasoning can be used to generate predictions from theories

- theories are based on observed patterns and hypotheses that have been tested
- theories are general explanations that can be applied widely
- predictions can be generated from theories by deduction
- when predictions are tested, theory is either corroborated or falsified

nucleic acids A1.2

ex: cells are widely observed in organisms
ex: all organisms are composed of ≥1 cells
ex: newly discovered organism predicted to be composed of ≥1 cells
ex: cell theory repeatedly corroborated with some exceptions

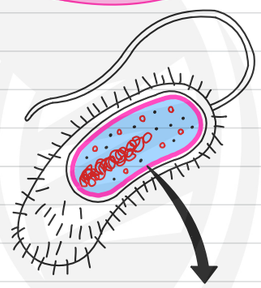
While cells are very variable (both within and across organisms) they share common structures: → there are exceptions. A eukaryotic cell typically has DNA stored in a single nucleus. Below are atypical examples:

- **DNA as genetic material** ※ DNA is located in nucleus in eukaryotes and in cytoplasm in prokaryotes

↳ DNA (in the form of genes) contains the information needed for cells to carry out its functions; importantly the instructions to synthesize proteins. These are crucial for metabolism (enzymes), structure, sensation, movement, etc
DNA is required for reproduction in order to pass on information to offspring

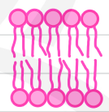
- **Cytoplasm** (composed mainly of water)

↳ Many substances dissolved or suspended in the watery cytoplasm of cells such as biomolecules, enzymes, and ribosomes. Enzymes catalyze metabolic reactions here due to abundance of substrates and optimal conditions provided by water.



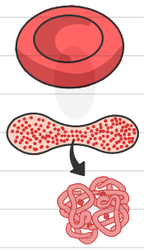
- **Plasma membrane** (composed of lipids, surrounding cytoplasm)

↳ The boundary of the cell which encloses all of its contents, allowing internal conditions to be different from surroundings (crucial for metabolism). Is selectively permeable, controlling entry and exit of substances using membrane proteins.
Also contains embedded structures used for sensitivity and communication. — membranes + transport B2.1



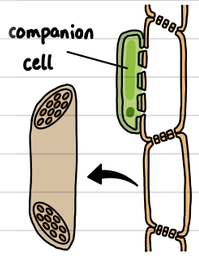
↳ Some cells are **anucleated** (lack a nucleus) and thus cannot synthesize protein or replicate via division

Red Blood Cells (Erythrocytes) – in mammals



Their function is to deliver O_2. Being anucleated is adaptive: ① more room for the O_2 carrying protein haemoglobin ② causes its shape to be biconcave, increasing its SA:vol for better gas exchange ③ makes it smaller and more flexible

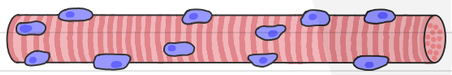
Phloem Sieve Tube Elements – in vascular plants



They make up the tube portion of the phloem – responsible for transporting sugars (sap) in vascular plants. They have gaps (sieve plates) on either end and are anucleated, allowing easier transport. Adjacent companion cells support them

↳ Some cells are **multinucleated** (many nuclei) allowing increased transcription and thus protein synthesis

Skeletal Muscle Cell – in humans



These cells grow very long by fusing together, resulting in hundreds of nuclei per cell. Advantageous due to high protein demand for growth and repair

Aseptate Fungal Hyphae – in coenocytic fungi

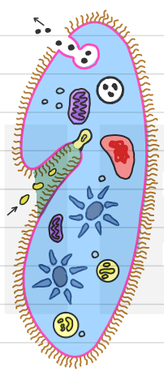
Some fungi (like the mold *Mucor*) form long filaments called hyphae for absorption. However, as these grow, rather than form partitions (septa) between cells, they form one long continuous multinucleated aseptate cell

All living organisms (unicellular and multicellular) carry out 8 Key processes of life:

- **M**etabolism: interdependent network of all chemical reactions occurring within an organism
- **M**ovement: ability to move or change position
- **R**eproduction: production of offspring, either sexually or asexually
- **H**omeostasis: maintenance of a constant internal environment
- **G**rowth: increase in size/mass/number of cells or development of an organism
- **R**esponse to Stimuli: perception and reaction to changes in the environment
- **E**xcretion: removal of metabolic waste products
- **N**utrition: process by which organisms take in/synthesize nutrients

※ "MMR H GREN"

ex: *Paramecium* (unicellular heterotrophic eukaryote)



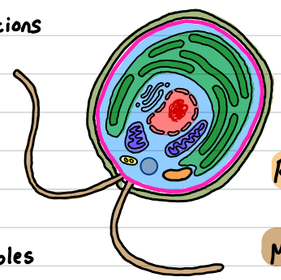
E expels waste products such via diffusion and exocytosis

RtS respond to heat, chemicals, food by swimming using cilia

N feeds on organisms by ingesting and digesting them via endocytosis

Mo cilia propels the cell

ex: *Chlamydomonas* (unicellular autotrophic eukaryote)



Me enzyme-catalyzed metabolic reactions occur in cytoplasm and organelles

R reproduces sexually and asexually involving the nucleus

G assimilates biomass into food vacuoles

H contractile vacuole maintains osmolarity by filling and expelling water

N chloroplast undergoes photosynthesis to synthesize biomolecules

RtS eyespot used to detect light

Mo Flagella are used to move

E plasma membrane controls removal of waste such as O_2 (from photosynthesis) via diffusion

A2.2.5—Prokaryote cell structure. A2.2.10—Cell types and cell structures viewed in light and electron micrographs A2.2.11—Drawing and annotation based on electron micrographs. A2.2.2—Microscopy skills

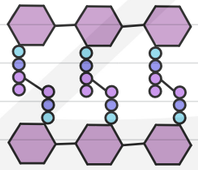
Prokaryote : unicellular organisms, simple in structure (no membrane-bound organelles) which lack a nucleus. Contain the domains Bacteria and Archaea. Below are structures found in gram-positive eubacteria

↳ pro (before) karyon (nucleus)

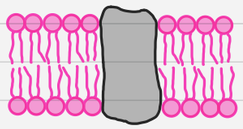
size: 1 - 10 μm

Cell components always present

Cell Wall (Peptidoglycan)
- ↳ semi-rigid structure made of peptidoglycan
- ↳ resists internal turgor pressure and prevents bursting
- ↳ very thick layer provides protection



Plasma membrane
- ↳ semi-permeable phospholipid bilayer containing proteins
- ↳ controls entry and exit of materials passively and actively



Nucleoid
- ↳ region in cytoplasm where the genetic material (DNA) is concentrated
- ↳ Bacterial DNA :
  - single chromosome: supercoiled
  - looped : circular
  - mostly coding : virtually no non-coding sections
  - naked : not wrapped around histone proteins

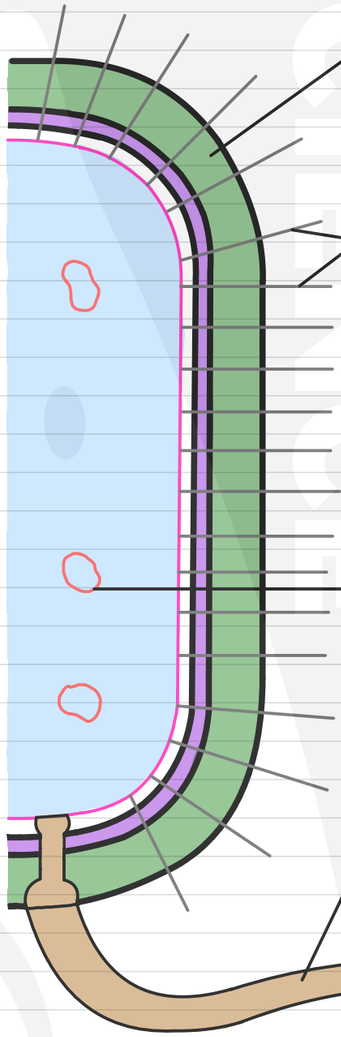
- ↳ DNA genes provide information to synthesize proteins

Cytoplasm
- ↳ gel-like fluid substance containing mostly water with dissolved substances
- ↳ site of all metabolic reactions (many proteins and enzymes present)

70s ribosomes
- ↳ site of protein synthesis
- ↳ composed of two subunits. Smaller than ribosomes in eukaryotes
- ※ 's' = Svedberg unit : indirect measure of size based on time it takes particle to settle at the bottom of a solution

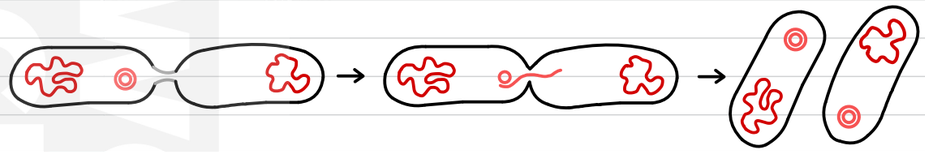
Cell components sometimes present

bacteria with single membrane and thick peptidoglycan cell wall



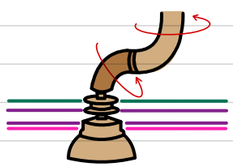
Capsule
- ↳ outermost structure typically made of polysaccharides
- ↳ provides protection from damage / toxins and from drying out
- ↳ allows adhesion to surfaces

Pili ※ singular: pilus
- ↳ protein hollow tube appendages on the outside of the cell
- ↳ aid in adhesion to surfaces
- ↳ initiates conjugation (horizontal gene transfer) : the donation of a plasmid from one cell to another

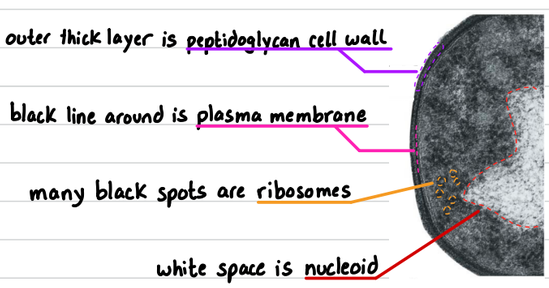


Plasmids
- ↳ small, circular extrachromosomal DNA
- ↳ can replicate independently and be shared among individuals
- ↳ does not contain essential genes (like the chromosome) but ones that confer selective advantage (ex: antibiotic resistance)

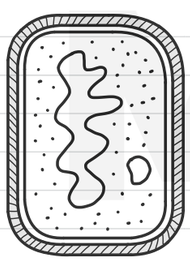
Flagellum ※ plural : flagella
- ↳ protein hairlike structure protruding from the cell. May be several.
- ↳ moves like a propellor to provide locomotion



Micrograph of gram-positive bacterium



How to draw typical gram-positive bacterium



- Cell wall as two lines (lightly shaded)
- plasma membrane as one line, adjacent but separate from cell wall
- ribosomes as many dots
- chromosome as one, big loop
- plasmid as small loop
- ※ drawings always in pencil

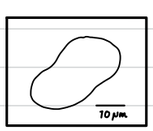
Adding scale bars to drawings - scale bars allow sizes of structures in images to be deduced

1 - determine distance between 2 markings on graticule
2 - measure length of specimen using graticule
3 - convert length to μm
※ scale bar - ~20% of specimen length and whole number
4 - draw specimen and measure length of drawing
5 - calculate length of scale bar
6 - draw line for scale bar 20% the length of drawing

ex: graticule unit = 25 μm
length of specimen = 2.1 graticule units
2.1 x 25 μm = 52.5 μm | 20% = 10.5 μm = ~10 μm
ℓ drawing = 96 mm

$\frac{10\ \mu m}{52.5\ \mu m} = \frac{x}{96\ mm} = 18.3\ mm$

∴ bar 18.3 mm represents 10 μm



A2.2.6—Eukaryote cell structure A2.2.10—Cell types and cell structures viewed in light and electron micrographs A2.2.11—Drawing and annotation based on electron micrographs

Eukaryote: unicellular or multicellular organisms, with compartmentalized membrane-bound organelles and DNA contained in a nucleus. organelles B2.2 Contain the Kingdoms Animalia, Plantae, Fungi and Protista.

↳ eu (true) karyon (nucleus) Cell size: 10 - 100 μm

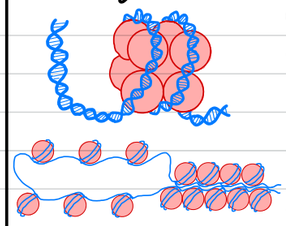
Common components present in eukaryotic cells

※ Common structures with prokaryotes. Plasma membrane and Cytoplasm

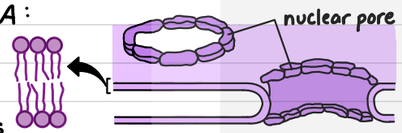
Nucleus

↳ large compartment holding the cell's chromosomal DNA

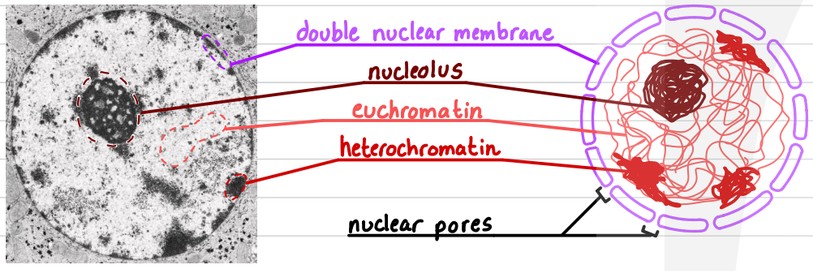
↳ Eukaryotic DNA:
- multiple chromosomes (number is species-specific)
- linear chromosomes
- mostly non-coding sections with many introns
- wrapped around histone proteins (chromatin)
- euchromatin is uncondensed and highly expressed heterochromatin is highly condensed and rarely expressed
- only condenses into visible chromosomes during replication



↳ nuclear envelope surrounds the DNA:
- two phospholipid bilayer membranes
- many nuclear pores, allowing import and export of molecules from nucleus



↳ nucleolus: dark-coloured region where rRNA and ribosomes are synthesized

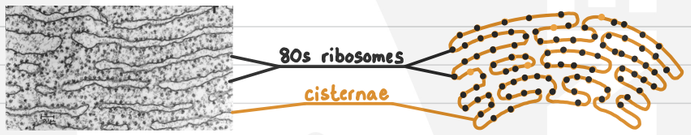


Rough Endoplasmic Reticulum (rER)

↳ membrane flattened sacs (cisternae) with ribosomes embedded

↳ contiguous (connected) to nuclear envelope

↳ site of protein synthesis for secretion / extracellular use
- proteins are synthesized on 80s ribosomes which are then packaged in vesicles and moved for processing and exocytosis

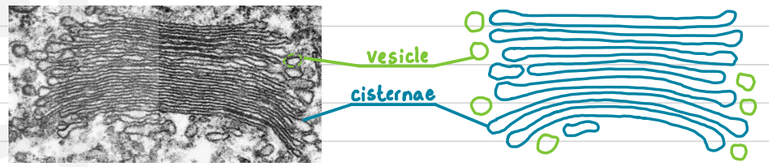


Golgi Apparatus

↳ stacks of shorter curved cisternae with many vesicles nearby

↳ typically located near plasma membrane for faster export

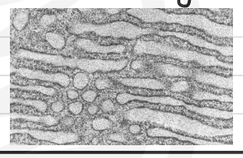
↳ products of the ER are recieved, modified, stored, and packaged into vesicles, usually for secretion out of the cell

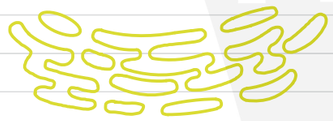


Smooth Endoplasmic Reticulum (sER)

↳ branched network of tubular membranes, forming ovals.

↳ site of lipid synthesis (such as oils, phospholipids, and steroids) detoxification of drugs and poisons, and Ca^{2+} storage in muscle cells

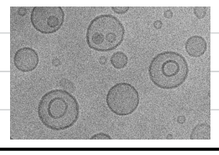


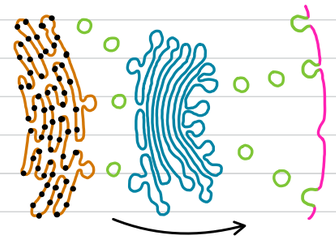


Vesicles

↳ small membrane-bound sacs

↳ formed from cisternae of ER and Golgi and used to transport materials within cell



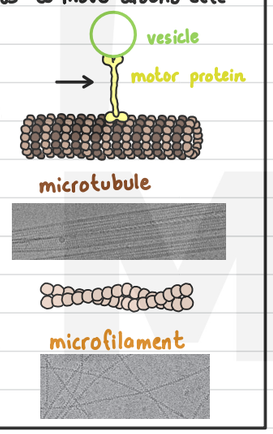


Cytoskeleton

↳ network of fibres in the cytoplasm that gives cell its shape and organization

↳ it provides anchorage for organelles and allows components to move around cell

↳ composed of several protein components:
- **microtubules**: thick hollow rods made from tubulin. Used to shape and support the cell. Acts as tracks for motor proteins to move components. Involved in chromosome movement in cell division
- **microfilaments**: small solid rods made from actin which resists tension. Maintain cell's shape. Involved in cytokinesis in cell division. Plays a part in cell motility (especially in muscle cells)

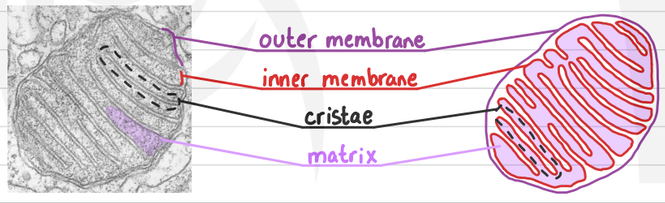


Mitochondria

※ singular: mitochondrion

↳ spherical or ovoid double-membraned organelle; smooth outer membrane, highly folded inner membrane forming cristae

↳ site of aerobic cellular respiration (link reaction, Krebs cycle, ETC)



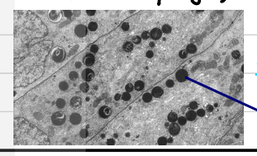
Lysosomes

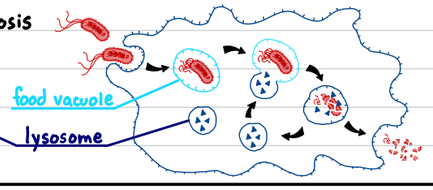
*not found in plants

↳ membrane-bound vesicles containing hydrolytic enzymes

↳ enzymes formed in rER and processed in Golgi

↳ digest unneeded/damaged content within the cell or materials taken up from phagocytosis

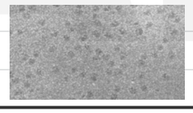




free 80s ribosomes

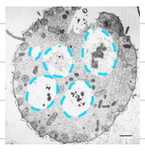
↳ site of protein synthesis for intracellular use

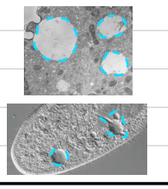
↳ composed of two subunits. Larger than ribosomes in prokaryotes



Vacuoles

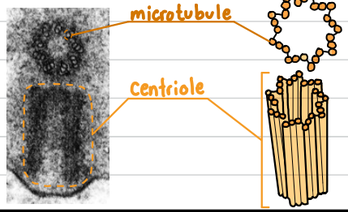
↳ membrane-bound sacs typically containing fluids
- contractile vacuoles used to osmoregulate
- temporary food vacuoles to store and digest materials



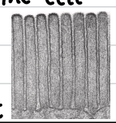


A2.2.8—Differences in eukaryotic cell structure between animals, fungi and plants
A2.2.11—Drawing and annotation based on electron micrographs

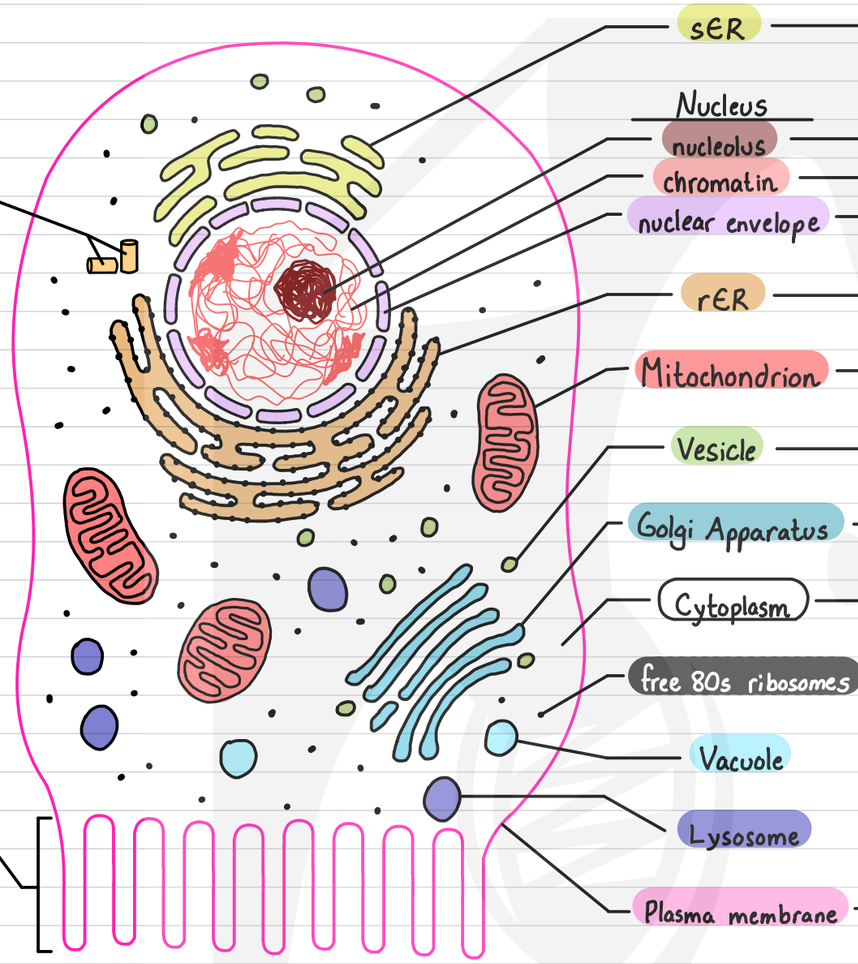
Centrioles
- made of 9 sets of triplet microtubules arranged in a ring, forming a tube
- Occurs in pairs as a centrosome
- act as anchor point for microtubules which attach and move chromosomes during cell division

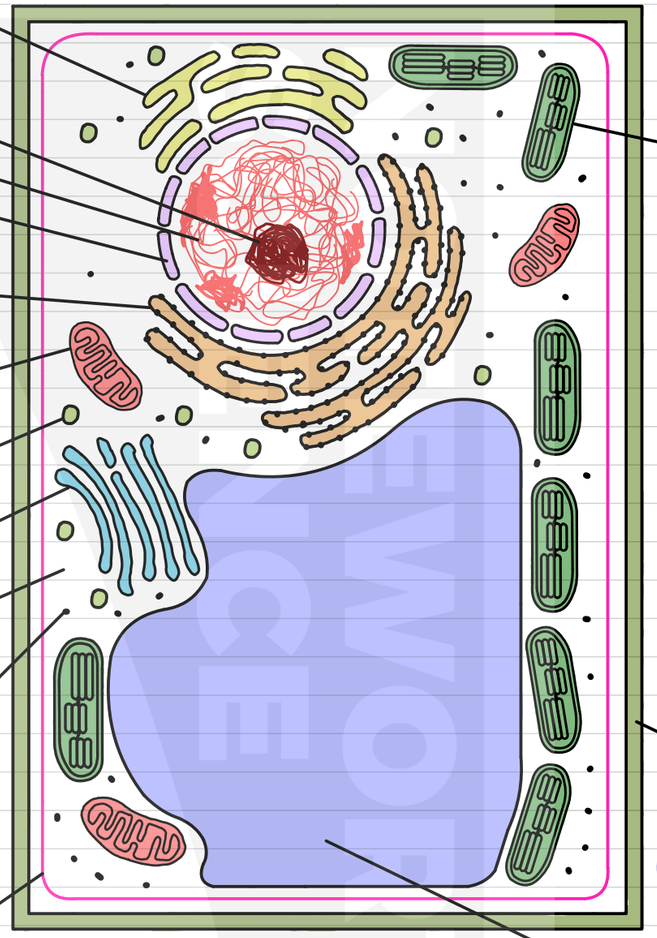


Microvilli ※ singular: microvillus
- finger like foldings in the plasma membrane on one side of the cell
- increases the surface area: volume of the cell increasing rate of transport

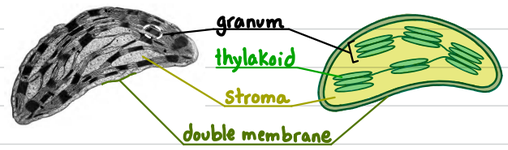


Cilia ※ singular: cilium
- whip-like surface projection
- ring of 9 microtuble pairs with pair in the center connected to basal body
- beating allows movement

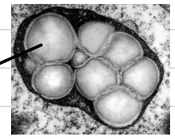




Chloroplast ※ in photosynthesizing cells
- double-membraned plastid containing flattened sacs (thylakoids) arranged in stacks (grana) within stroma
- site of photosynthesis where light energy is converted into chemical energy (biomolecules)



Amyloplast ※ in non-photosynthesizing cells
- plastid responsible for synthesizing and storing starch



Cell Wall (Cellulose)
- semi-rigid structure made of cellulose
- permeable but strong- resists internal turgor pressure and prevents bursting

Sap Vacuole
- large, permanent vacuole enclosed by tonoplast, separating it from cytoplasm
- stores biomolecules, pigments and has hydrolytic functions, digesting content
- creates turgor pressure keeping cell shape

	Bacterial cell	Animal cell	Plant cell	Fungal cell
DNA structure	singular looped, naked	many linear chromosomes wrapped around histones		
DNA location	in cytoplasm: concentrated in nucleoid	contained in double-membraned nucleus		
ribosomes	✓ - 70s (free in cytoplasm)	✓ - 80s (free in cytoplasm and bound in endoplasmic reticulum)		
membrane-bound organelles	✗	✓ - nucleus, mitochondria, rER, sER, Golgi apparatus, vesicles		
vacuoles	✗	✓ - small and temporary	✓ - large and permanent	
cell wall	✓ - made of peptidoglycan	✗	✓ - made of cellulose	✓ - made of chitin
plastids	✗	✗	✓ - chloroplasts and amyloplasts	✗
centrioles	✗	✓ - found in centrosome	✗	✗
cilia	✗	✓ - some cells (in airway and oviduct)	✗	✗
flagellum	✓ in some	✓ - sperm cells	✓ - sperm in ferns and mosses	✗ (generally)
carbohydrate storage	glycogen	glycogen	starch (amylose and amylopectin)	glycogen

HL

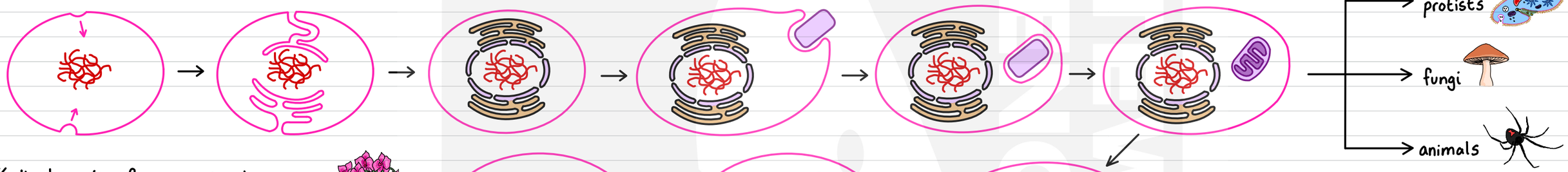
A2.2.12—Origin of eukaryotic cells by endosymbiosis. A2.2.13—Cell differentiation as the process for developing specialized tissues in multicellular organisms. A2.2.14—Evolution of multicellularity

→ endo (inside) + sym (with, together) + bio (living) = living inside together (mutualistically)

Endosymbiotic Theory: mitochondria and plastids such as chloroplasts are descended from former free-living prokaryotes which have been taken endosymbiotically into a host cell forming the first eukaryotic cell

1 Unicellular prokaryotic cell (capable of sexual reproduction) underwent plasma membrane infolding to increase its surface area to volume ratio. Part of the membrane pinched off forming an endoplasmic reticulum and double-membrane nuclear envelope, creating a nucleus

2 An aerobic bacterium is taken into the host cell via phagocytosis and is not destroyed but remains as an endosymbiont. As the bacterium can produce ATP through aerobic respiration this was advantageous for the cell, allowing it to thrive in an oxygen-rich environment and produce far more ATP. Overtime, it evolved into the mitochondrion organelle.



※ the transition from organism to organelle was not instantaneous but very gradual requiring many mutations over generations where eventually neither could survive without the other

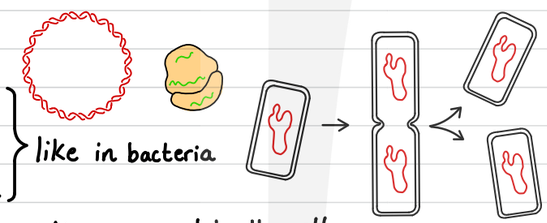
3 At a later point, an early unicellular eukaryote took in a photosynthetic cyanobacterium via phagocytosis and similarly was not destroyed as they were able to synthesize organic compounds via photosynthesis. Overtime, it evolved into the chloroplast organelle.

NOS: as a **theory**, endosymbiosis is a well-substantiated explanation based on evidence and repeatedly confirmed through testing and observation

Mitochondria and chloroplasts:

- have single, naked, circular DNA
- have 70s ribosomes
- self-replicates via binary fission
  - → can only be produced from pre-existing ones, not by the cell

  } like in bacteria
- double-membrane:
  - inner membrane is similar in composition to bacterial cell membranes
  - outer membrane is originally derived from the membrane vacuole of host cell



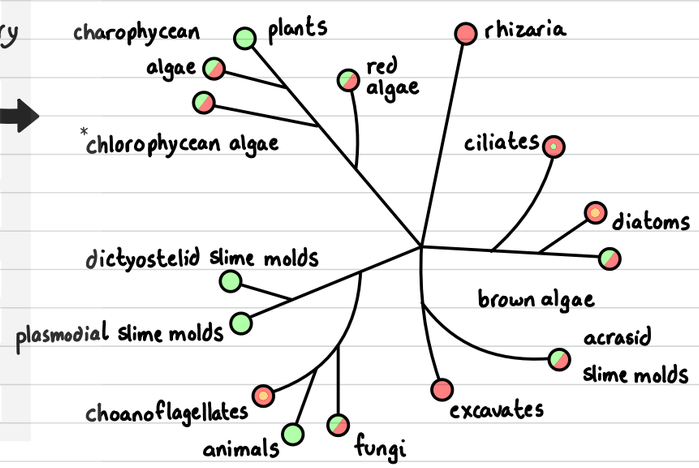
Cell differentiation i.e. specialization is when a cell's pattern of gene expression is altered: some genes are switched ON and others switched OFF causing the cell's proteome (all proteins produced) to change without altering its genome

environmental chemical signal → stem cells → cardiac muscle cells → cardiac muscle tissue → heart

cell specialization B2.3

Multicellularity has evolved repeatedly throughout evolutionary history

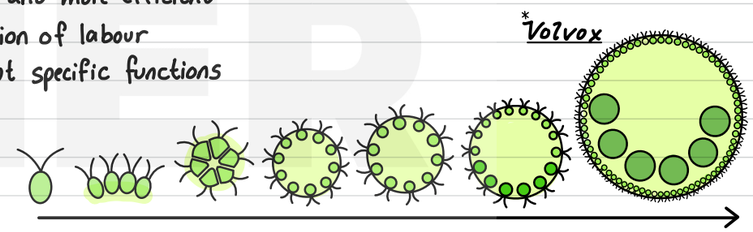
→ suggests it is advantageous and not a rare event



Advantages to multicellularity

- ✓ multicellular organisms tend to have longer lifespans (death of one cell does not mean death of organism)
- ✓ multicellular organisms tend to be LARGER than unicellular organisms, allowing new niche exploitation
- ✓ allows for cell differentiation and more efficient use of resources through division of labour where specialized cells carry out specific functions

Example of multicellular evolution in the green algae *Volvox*

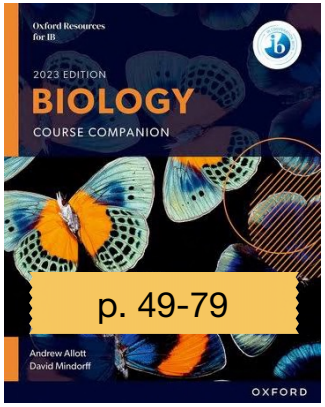


- all multicellular
- some multicellular, some unicellular
- most unicellular, some multicellular
- most unicellular, some colonial

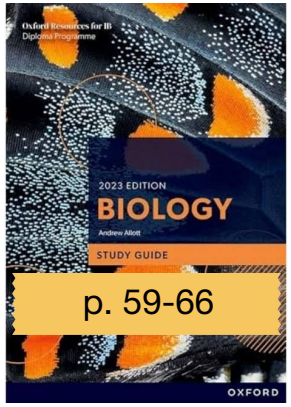
Resource Links

each resource is hyperlinked

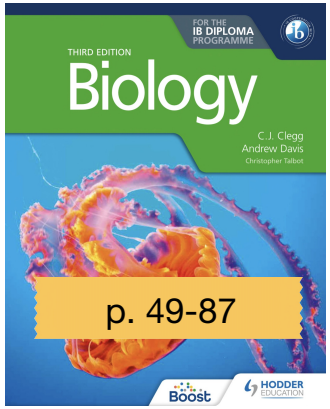
Textbooks



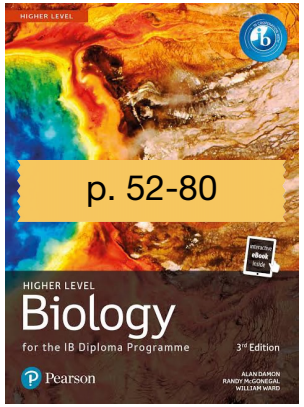
p. 49-79



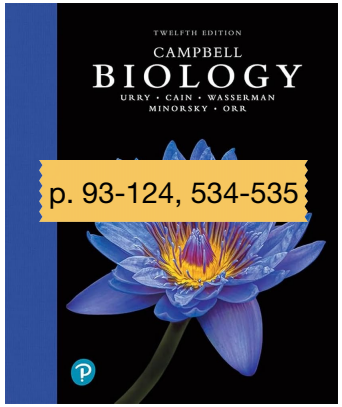
p. 59-66



p. 49-87

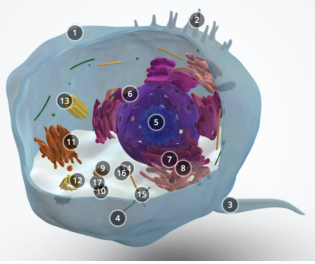


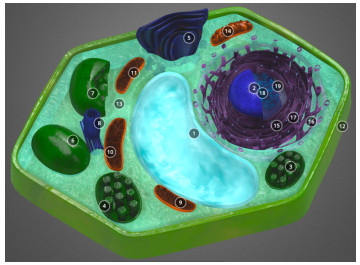
p. 52-80

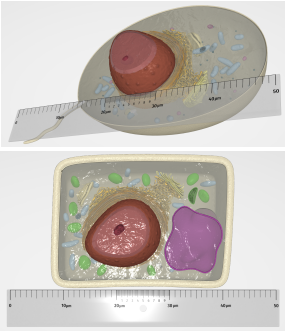


p. 93-124, 534-535

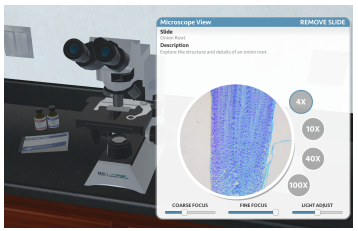
3D models


Eukaryotic animal cell

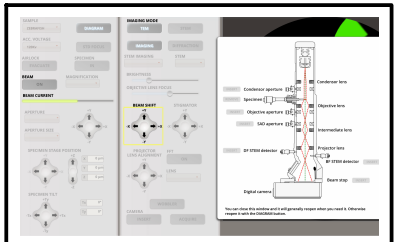

Eukaryotic plant cell

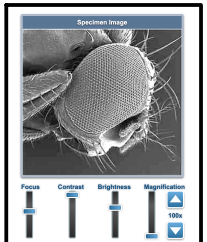

Eukaryotic cells

Simulators / Interactives



Light microscope


TEM



SEM

Articles

Archibald J. M. (2015). Endosymbiosis and Eukaryotic Cell Evolution. Current biology : CB, 25(19), R911–R921. https://doi.org/10.1016/j.cub.2015.07.055

Kaiser, D. (2001). Building a multicellular organism. Annual Review of Genetics, 35(1), 103–123. https://doi.org/10.1146/annurev.genet.35.102401.090145

Sathe, S., Beier, S., & Becks, L. (2025). Endosymbiont escape as a mechanism to increase the rate of endosymbiosis formation. Symbiosis. https://doi.org/10.1007/s13199-025-01038-1

Skalidis, I., Kyrilis, F. L., Tüting, C., Hamdi, F., Chojnowski, G., & Kastritis, P. L. (2022). Cryo-EM and artificial intelligence visualize endogenous protein community members. Structure (London, England : 1993), 30(4), 575–589.e6. https://doi.org/10.1016/j.str.2022.01.001