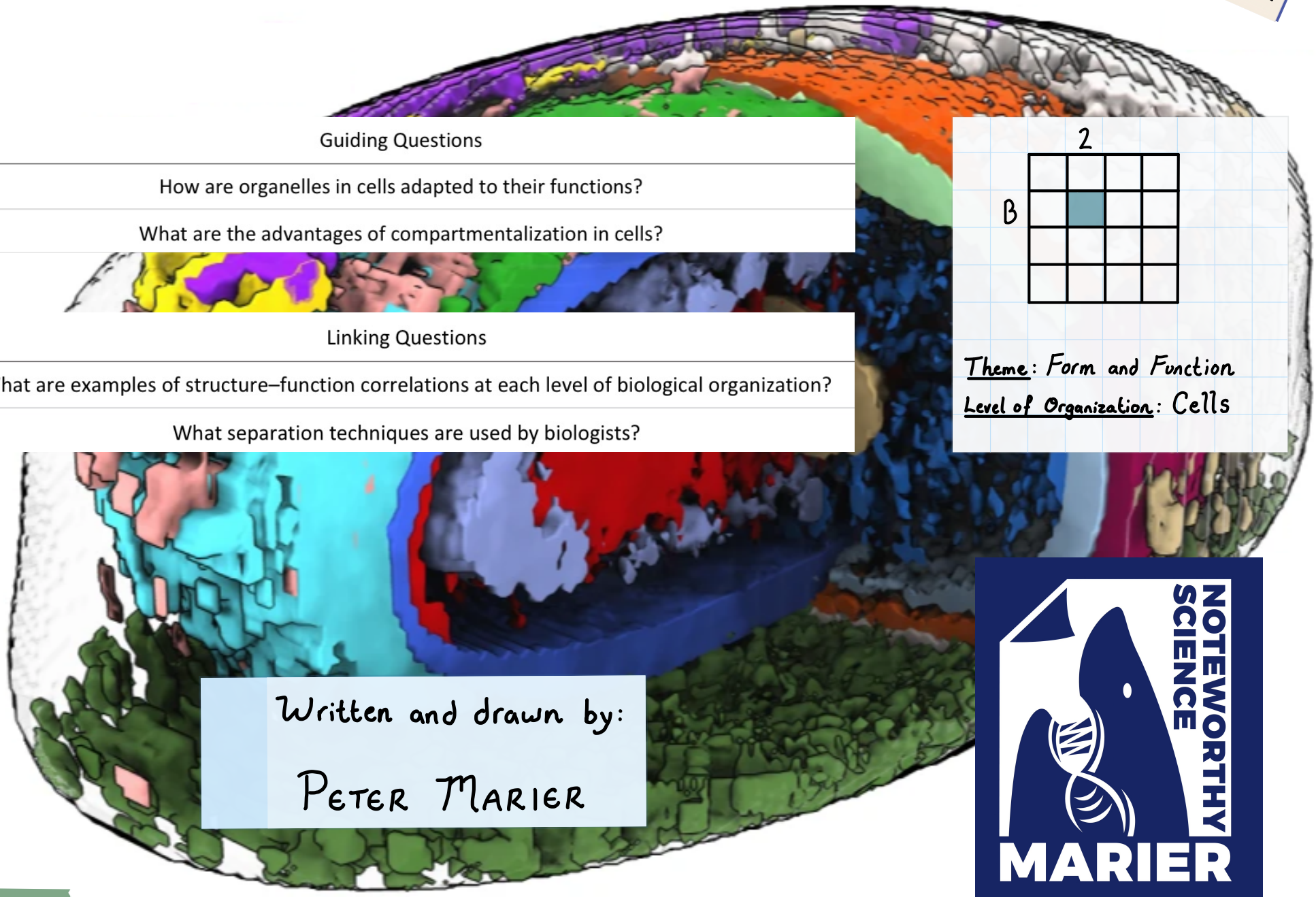
B2.2 ORGANELLES AND COMPARTMENTALIZATION

Ver. 2



Guiding Questions
How are organelles in cells adapted to their functions?
What are the advantages of compartmentalization in cells?

Linking Questions
What are examples of structure–function correlations at each level of biological organization?
What separation techniques are used by biologists?

Theme: Form and Function

Level of Organization: Cells

Written and drawn by:

Peter Marier

NOTEWORTHY SCIENCE

MARIER

https://www.nature.com/articles/s41586-022-05563-7

SL LEARNING OUTCOMES

B2.2.1	Organelles as discrete subunits of cells that are adapted to perform specific functions	Students should understand that the cell wall, cytoskeleton and cytoplasm are not considered organelles, and that nuclei, vesicles, ribosomes and the plasma membrane are. **NOS:** Students should recognize that progress in science often follows development of new techniques. For example, study of the function of individual organelles became possible when ultracentrifuges had been invented and methods of using them for cell fractionation had been developed.
B2.2.2	Advantage of the separation of the nucleus and cytoplasm into separate compartments	Limit to separation of the activities of gene transcription and translation—post-transcriptional modification of mRNA can happen before the mRNA meets ribosomes in the cytoplasm. In prokaryotes this is not possible—mRNA may immediately meet ribosomes.
B2.2.3	Advantages of compartmentalization in the cytoplasm of cells	Include concentration of metabolites and enzymes and the separation of incompatible biochemical processes. Include lysosomes and phagocytic vacuoles as examples.

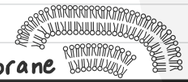
HL LEARNING OUTCOMES

B2.2.4	Adaptations of the mitochondrion for production of ATP by aerobic cell respiration	Include these adaptations: a double membrane with a small volume of intermembrane space, large surface area of cristae and compartmentalization of enzymes and substrates of the Krebs cycle in the matrix.
B2.2.5	Adaptations of the chloroplast for photosynthesis	Include these adaptations: the large surface area of thylakoid membranes with photosystems, small volumes of fluid inside thylakoids, and compartmentalization of enzymes and substrates of the Calvin cycle in the stroma.
B2.2.6	Functional benefits of the double membrane of the nucleus	Include the need for pores in the nuclear membrane and for the nucleus membrane to break into vesicles during mitosis and meiosis.
B2.2.7	Structure and function of free ribosomes and of the rough endoplasmic reticulum	Contrast the synthesis by free ribosomes of proteins for retention in the cell with synthesis by membrane-bound ribosomes on the rough endoplasmic reticulum of proteins for transport within the cell and secretion.
B2.2.8	Structure and function of the Golgi apparatus	Limit to the roles of the Golgi apparatus in processing and secretion of protein.
B2.2.9	Structure and function of vesicles in cells	Include the role of clathrin in the formation of vesicles.

B2.2.1—Organelles as discrete subunits of cells that are adapted to perform specific functions.
B2.2.2—Advantage of the separation of the nucleus and cytoplasm into separate compartments.
B2.2.3—Advantages of compartmentalization in the cytoplasm of cells

Organelle: discrete subunit of a cell adapted to perform specific functions cell structure A2.2

↳ The plasma membrane itself is an organelle and may or may not encapsulate organelles:

Not enclosed by membrane	Enclosed by single membrane 	Enclosed by double membrane 
ribosome	vesicles and vacuoles	nucleus
centrioles	lysosomes	mitochondria
	Golgi apparatus	chloroplasts
	rough endoplasmic reticulum	amyloplasts
	smooth endoplasmic reticulum	

↳ Structures not considered organelles:
- ✗ cell wall ▶ extracellular (outside the plasma membrane of cell)
- ✗ cytoskeleton ▶ composed of many components spread throughout cell and not a discrete structure
- ✗ cytoplasm ▶ not discrete structure or specialized to perform specific function

In eukaryotes, the cytoplasm is compartmentalized using separate membrane-bound organelles

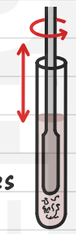
NOS: Progress in science often follows development of new techniques → spun at very high speeds (10^5-10^6 x g)
ex: study of individual organelles became possible with ultracentrifugation allowing cell fractionation

cell fractionation: process of separating cellular components while preserving their functions/structures for study

1 Homogenization

cells are lysed to release contents using a blender/homogenizer in a solution which is:
- cold - reduces enzyme activity and damage
- isotonic - prevents osmotic damage to organelles
- buffered - prevents denaturation and damage

→ forms homogenate

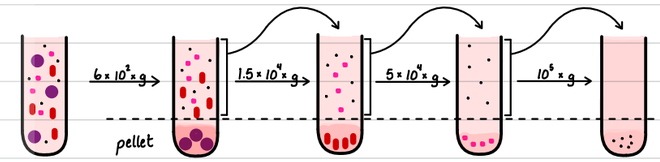


2 Filtration

Homogenate is filtered to remove larger cellular debris such as unbroken cells. Homogenate is now prepared for separation

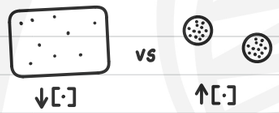
3 Purification via differential centrifugation

the homogenate is placed in a centrifuge and spun. Centrifugal force causes more dense particles to sediment forming a pellet. Higher speeds results in smaller particles sedimenting. After each round, pellet is removed and supernatant spun at a higher speed, thus incrementally separating and isolating structures ▶ LARGE → small

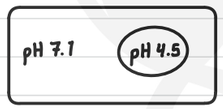


sizes: nuclei > chloroplasts > mitochondria > membranes > ribosomes

- ✓ Enzymes and substrates for metabolic processes can be far more concentrated within a membrane-bound organelle than spread around the cytoplasm, thus greatly increasing the rate of reaction

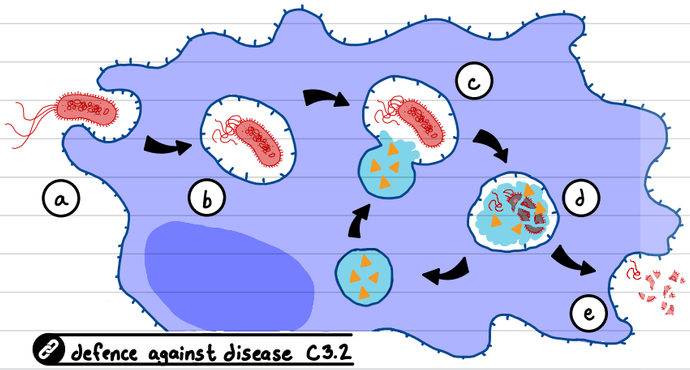


- ✓ Conditions within the organelles can be different from that of the cytoplasm and optimal for specific enzymes and chemical reactions (ex: acidic lysosomes)



- ✓ Substances can be easily moved from one part of the cell to the other using vesicles

- ✓ Harmful substances and destructive chemical reactions can be separated from the rest of the cell to prevent damage (such as those in lysosomes)



defence against disease C3.2

ⓐ Phagocytic cell engulfs pathogen via phagocytosis (ex: macrophage)
ⓑ pathogen trapped in phagocytic vacuole - isolating it from rest of cell
ⓒ lysosome fuses with vacuole, forming phagolysosome - isolated compartment
ⓓ hydrolytic enzymes break down pathogen in isolated, ideal conditions
ⓔ waste released via exocytosis

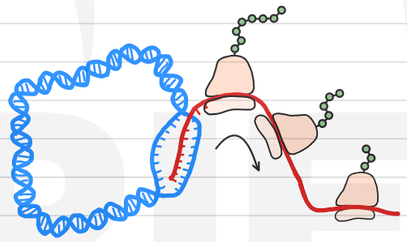
In eukaryotes, DNA is held in the nucleus, separate from the cytoplasm. This is advantageous:

- ✓ nucleus protects DNA from potential damage from chemical reactions in the cytoplasm
- ✓ allows for gene transcription and translation to be kept separate

protein synthesis D1.2

※ in gene transcription an mRNA transcript is made using a template DNA base sequence
in translation a polypeptide is synthesized using the code on the mRNA transcript

In prokaryotes, the mRNA is translated immediately by 70s ribosomes as both processes occur in the cytoplasm

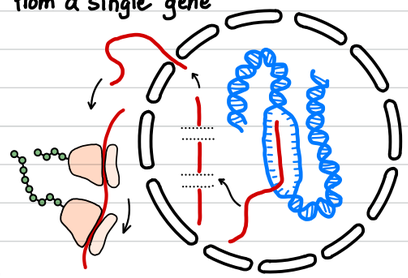


↳ prokaryotic DNA is nearly all coding with little/no introns so post-transcriptional modification is not needed

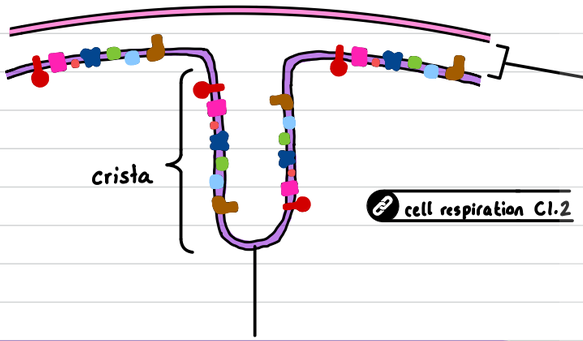
In eukaryotes, transcription occurs in the nucleus and results in pre-mRNA which needs to be modified before translation. Part of this includes splicing where introns (non-coding) are removed + exons (coding) are joined. Alternative splicing joins exons in different combinations → many mature mRNA and thus many different polypeptides from a single gene

↳ mature, modified mRNA is exported out of the nucleus where it can then be translated by 80s ribosomes

↳ nuclear pores control entry and exit of substances, improving organization and efficiency



Mitochondrion is organelle responsible for aerobic cellular respiration. Its structure has many adaptations which allow it to effectively and efficiently carry out this function:



cell respiration Cl.2

Small inter-membrane space

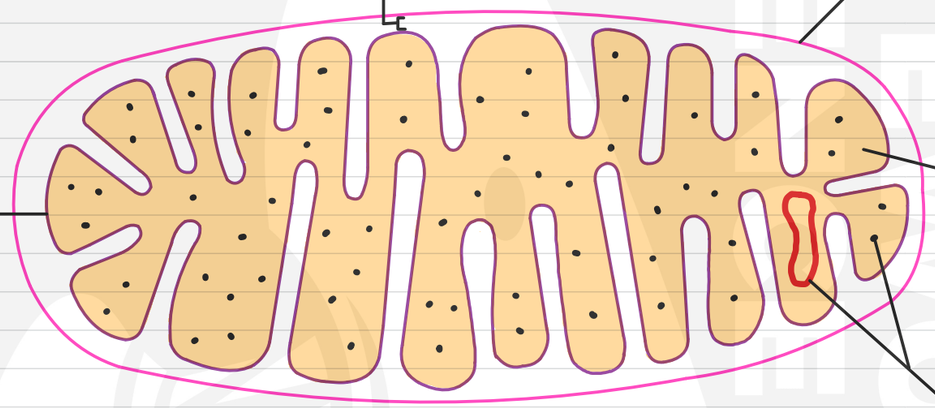
- the space and volume between the outer and inner membrane is consistent and very small. This allows rapid accumulation of protons (H^+) and the building of a gradient relative to matrix necessary for chemiosmosis

Outer mitochondrial membrane

- Separates the contents of the mitochondrion from the rest of the cell, allowing different, more ideal conditions for aerobic respiration
- Selectively permeable, allowing certain materials in and out of the mitochondrion

Inner mitochondrial membrane folded into cristae

- Inner membrane contains carriers and the transmembrane integral enzyme ATP synthase, enabling the electron transport chain and the production of ATP via chemiosmosis and oxidative phosphorylation
- Inner membrane is highly folded into invaginations called cristae. This increases the membrane surface area and thus increases the rate of ATP production



Mitochondrial matrix

- fluid inside matrix has different, optimal pH and contains a high concentration of enzymes and substrates needed for the link reaction and the Krebs cycle

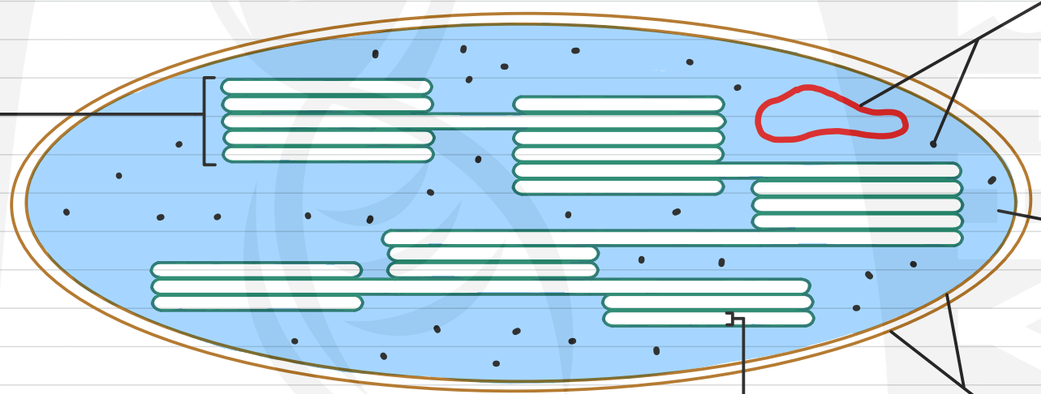
Circular, naked DNA and 70s ribosomes

- DNA allows it to replicate and make more copies of itself, independently of the rest of the cell
- DNA transcribed into mRNA and 70s ribosomes allows it to synthesize its own proteins

Chloroplast is organelle responsible for photosynthesis. Its structure has many adaptations which allow it to effectively and efficiently carry out this function:

Thylakoids arranged in grana

- Thylakoid membrane contains photosystems to absorb light as well as carriers and ATP synthase, enabling the electron transport chain and the production of ATP via chemiosmosis and reduction of NADP
- Thylakoids are stacked into grana, increasing the surface area and thus increases the amount of light absorbed as well as the rate of light-dependent reactions

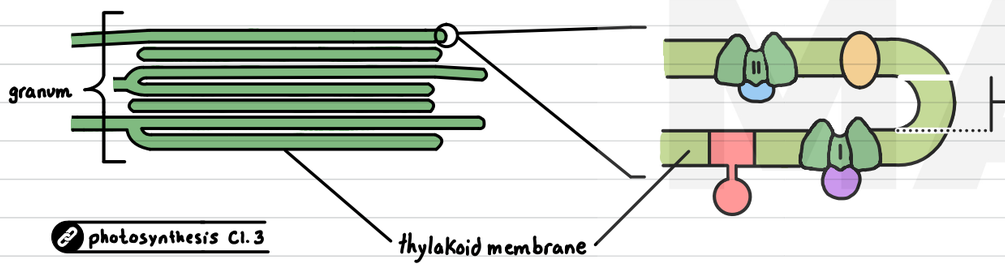


Stroma

- fluid inside stroma has different, optimal pH and contains a high concentration of enzymes and substrates needed for light-independent reactions (Calvin cycle)

Inner and outer chloroplast membranes

- the inner and outer membranes form the chloroplast envelope. This separates the contents of the chloroplast from the rest of the cell
- Selectively permeable, allowing certain materials in and out of the chloroplast (ex: triose phosphate, O_2, CO_2, H_2O)



photosynthesis Cl.3

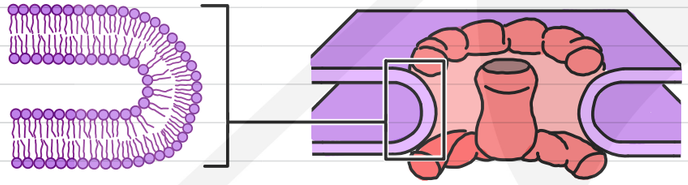
Small volume within thylakoid

- the space and volume of fluid within the thylakoid (i.e. lumen) is very small. This allows the rapid accumulation of protons (H^+) and the building of a gradient relative to the stroma necessary for chemiosmosis

HL B2.2.6—Functional benefits of the double membrane of the nucleus. B2.2.7—Structure and function of free ribosomes and of the rough endoplasmic reticulum. B2.2.8—Structure and function of the Golgi apparatus. B2.2.9—Structure and function of vesicles in cells

The double membrane of the nucleus (nuclear envelope) has a number of advantages:

✓ the inner and outer nuclear membrane are concentric and both made of a phospholipid bilayer which connect to form a pore. This is structured with numerous proteins.



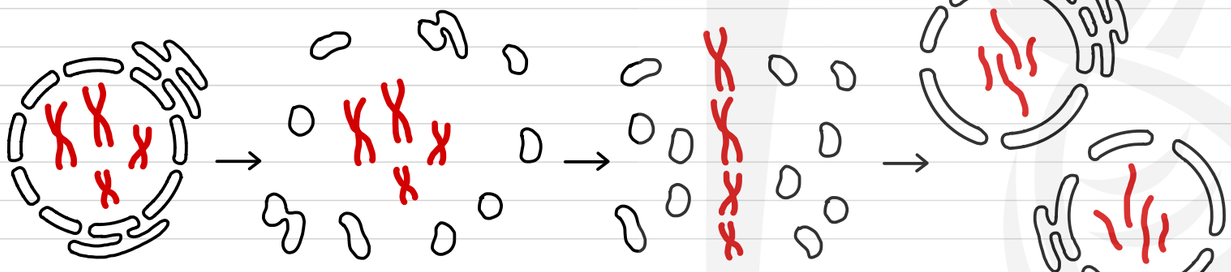
↳ nuclear pores allow selective exchange of materials between cytoplasm and nucleus. Pore complex is ~120nm across; small molecules diffuse freely while large cargo (ex: proteins, mRNA) is actively transported - far larger than ion channels

- ribosomal subunits (40s + 60s) assembled in nucleolus
- mature mRNA produced by transcription + processing
- tRNA transcribed in nucleoplasm

→ exported to cytoplasm for protein synthesis

← enzymes needed for metabolic processes (ex: RNA polymerase, helicase, ligase, etc.)
proteins needed for DNA structure (ex: histones)
transcription factors, biomolecule monomers

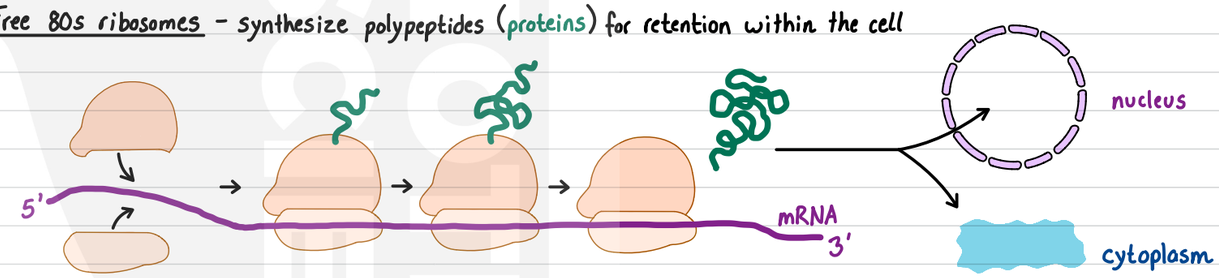
✓ Nuclear division (the division of the nucleus) occurs in both Mitosis and Meiosis. cell + nuclear division D2.1
During this process, the nucleus breaks down and reforms around the separated chromosomes. In order to do this efficiently, the nuclear membranes break into vesicles (freeing chromosomes and allowing them to associate with spindles) and migrate to each pole of the cell where they reform into new nuclei



※ only nucleus and chromosomes shown for this example of mitosis, not rest of the cell
※ the outer nuclear membrane is contiguous with the rough endoplasmic reticulum

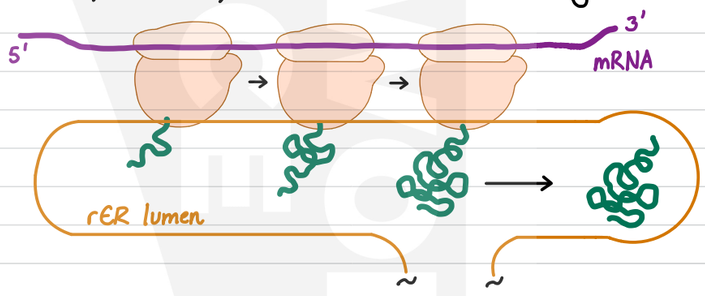
In eukaryotes, 80s ribosomes are found free in the cytoplasm or bound on the rough endoplasmic reticulum (rER)

Free 80s ribosomes - synthesize polypeptides (proteins) for retention within the cell



Ribosomes bound to rER - synthesize proteins for transport within cell or export out of cell

1 proteins synthesized by bound ribosomes on rER entering lumen

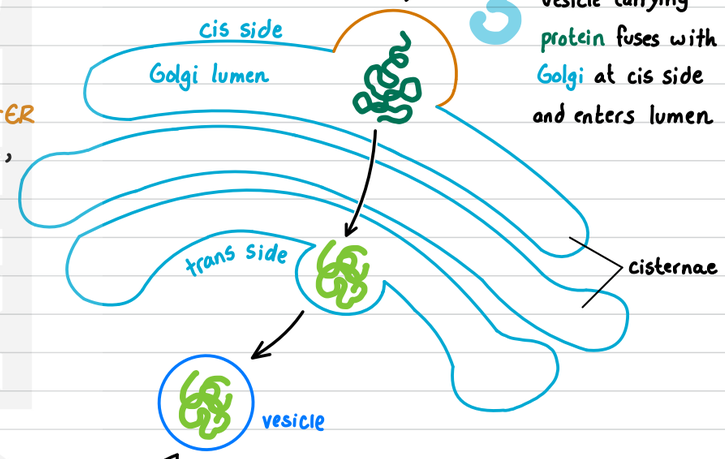


2 Proteins are packaged into vesicles which bud off and most head to Golgi

3 Vesicle carrying protein fuses with Golgi at cis side and enters lumen

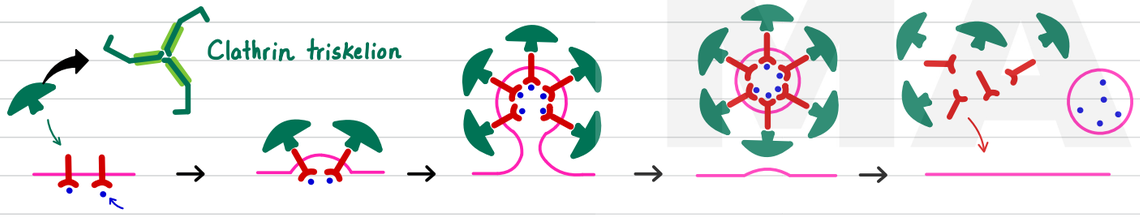
4 Golgi apparatus receives proteins from rER and as they move across its cisternae, proteins are modified by enzymes within
ex: sections can be cleaved, cross-linked or joined to other groups

protein synthesis D1.2



5 Modified protein buds off from trans side of Golgi and are sent to final destination within a secretory vesicle

Clathrin-mediated endocytosis - uses proteins to help invaginate and form a vesicle during endocytosis

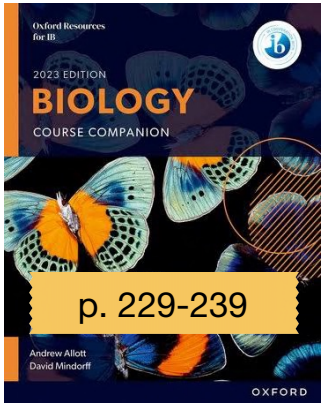


Molecules bind to specific receptors embedded on the outside of the plasma membrane. Clathrin is recruited causing the membrane to invaginate. Many clathrin proteins form a cage-like lattice around the invagination, helping it form a vesicle and bud off. Once formed, coating is removed and is reused. Vesicle transports molecules within cell

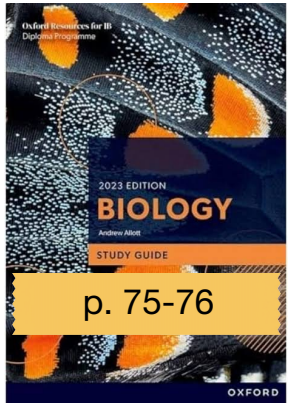
Resource Links

each resource is hyperlinked

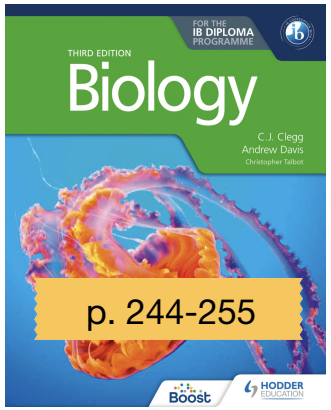
Textbooks



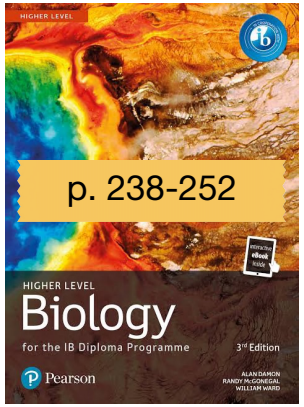
p. 229-239



p. 75-76



p. 244-255



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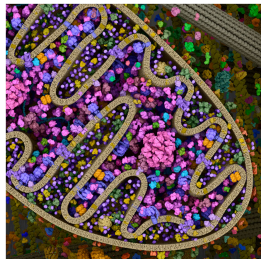
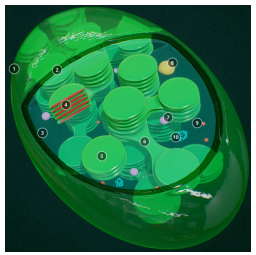
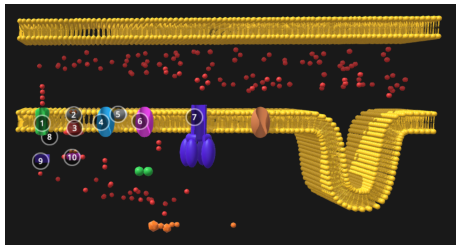
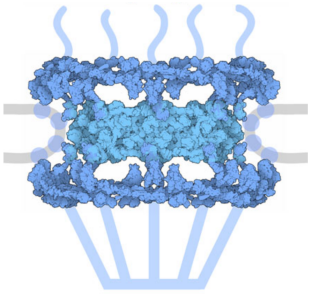
Simulators / Interactives

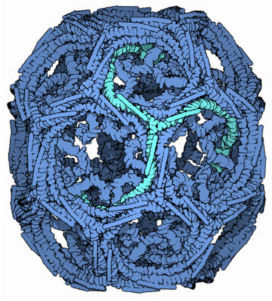

Mitochondrion

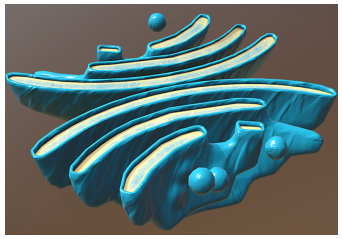

Chloroplast


Electron transport chain

3D models


Nuclear pore complex


Clathrin


Golgi apparatus

Articles

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K., & Walter, P. (2002). Fractionation of cells. Molecular Biology of the Cell - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK26936/

Frey, T. G., & Mannella, C. A. (2000). The internal structure of mitochondria. Trends in biochemical sciences, 25(7), 319–324. https://doi.org/10.1016/s0968-0004(00)01609-1

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