Cell Biology

Unit 3 · Lesson 2 · Golgi, lysosomes and peroxisomes

The notes for Lesson 2 of Unit 3: chapters 3.3 to 3.4 of the unit book, with their figures, worked examples, exam traps and quizzes, in one file. The full unit book, with every chapter, the exam question bank and the glossary, is linked at the end.

Lesson 2 of 4 | 2 chapters | Chapters 3.3 to 3.4

About these notes

These are the notes for **Lesson 2 · Golgi, lysosomes and peroxisomes** of the University free n easy video lessons on Cell Biology Unit 3, Cell Organelles and Cytoskeleton. They are chapters 3.3 to 3.4 of the unit book, unchanged, so a page here is the same page in the full book.

3.3 Golgi apparatus and protein sorting

The Golgi apparatus is a stack of flat membrane sacs that receives proteins and lipids from the ER, finishes modifying them, and sorts them by destination, like a post office that stamps each parcel with an address. From the Golgi, cargo goes to the plasma membrane, out of the cell, or to lysosomes. Camillo Golgi saw it in nerve cells in 1898 with a silver stain. It is large in secretory cells such as goblet cells of the gut, which pour out mucus.

> You need: the ER and signal sequences from Chapter 3.2, and vesicle fusion from **Unit 2, Endocytosis and exocytosis**.

Structure: a stack with two faces

A Golgi stack has 4–8 cisternae in most animal cells, and has a direction. The **cis face** faces the ER and receives cargo; the **trans face** faces the plasma membrane and ships it out. In order from entry to exit:

- **Cis Golgi network (CGN):** a network of tubes that takes in vesicles from the ER.
- **Cis, medial and trans cisternae:** each holds a different set of enzymes, so modifications happen in sequence.

- **Trans Golgi network (TGN):** the sorting station, where cargo is packed into different carriers for different destinations.

Animal cells usually have their Golgi stacks joined into one ribbon near the nucleus and the centrosome. Plant cells have hundreds of separate stacks (sometimes called dictyosomes) scattered in the cytoplasm, which also make the pectin and hemicellulose of the cell wall.

What the Golgi does to cargo

- **Trims and rebuilds N-linked sugars** added in the ER: mannose is removed, then N-acetylglucosamine, galactose and sialic acid are added, giving "complex" oligosaccharides. Some proteins keep "high-mannose" sugars.
- **O-linked glycosylation**: sugars added to serine or threonine, as in mucins and proteoglycans.
- **Sulfation** of tyrosines and of proteoglycan sugars, in the trans Golgi network.
- **Proteolytic processing** of some precursors, such as proinsulin to insulin, which starts in the TGN and goes on in secretory granules.
- **Lipid work**: sphingomyelin and glycolipids are made here.

Moving between compartments: coated vesicles

Cargo moves in small vesicles whose coat proteins both bend the membrane and pick the cargo. Three coats matter for the exam:

- **COPII**: ER → Golgi (forward, anterograde).
- **COPI**: Golgi → ER and between cisternae (backward, retrograde). This is how escaped KDEL proteins return to the ER.
- **Clathrin** (with adaptor proteins): TGN → endosomes, and plasma membrane → endosomes in endocytosis.

A vesicle finds the right target through **Rab** GTPases that mark each compartment, and fuses using matching **SNARE** proteins: a v-SNARE on the vesicle pairs with a t-SNARE on the target membrane. How cargo crosses the stack itself is debated. The **vesicular transport model** says the cisternae stay put and vesicles carry cargo forward. The **cisternal maturation model** says each cisterna moves forward and changes its identity as COPI vesicles carry enzymes backward. Evidence now favours maturation for large cargo such as procollagen, which is too big for a normal vesicle.

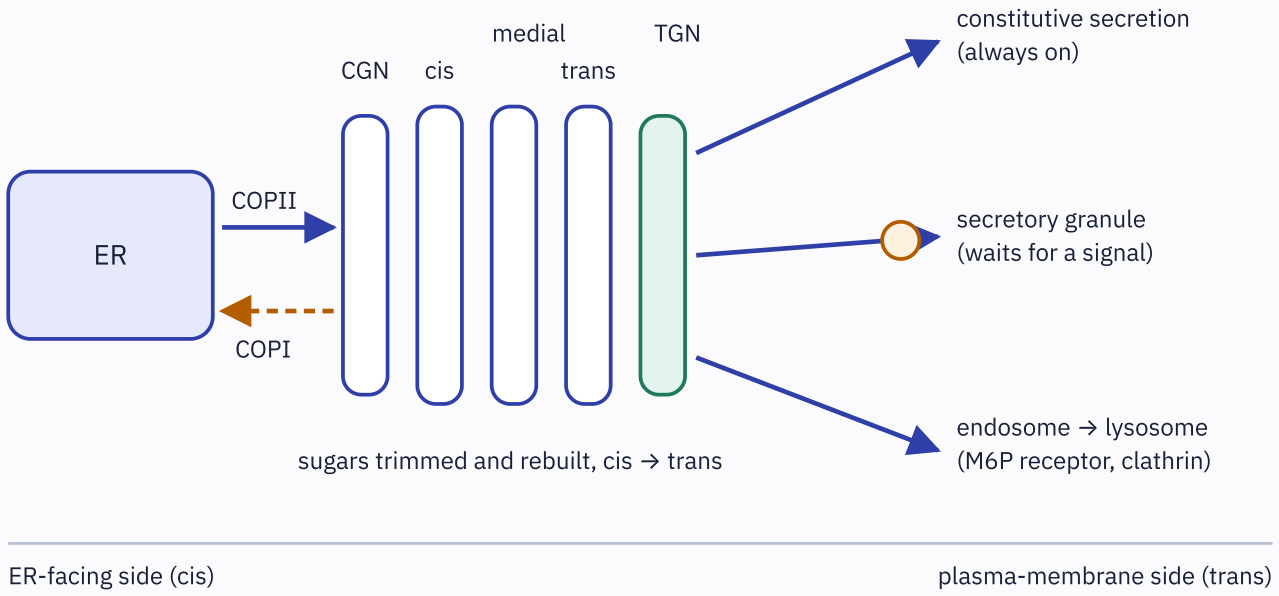


Figure 3.3.1 Cargo enters at the cis face in COPII vesicles, moves through the cisternae, and leaves the trans Golgi network by one of three routes. COPI (dashed) carries escaped ER proteins back. Notice that lysosomal enzymes are the only cargo here that needs a sugar tag to find its way.

Sorting at the TGN: three exits

1. **Constitutive secretion** is the default. A soluble protein with no sorting signal is carried in vesicles that fuse with the plasma membrane continuously. Collagen made by fibroblasts and serum albumin made by liver cells leave this way.
2. **Regulated secretion**: in specialised cells, some proteins clump together in the acidic TGN and are packed into dense **secretory granules** that wait near the plasma membrane. They fuse only on a signal, usually a rise in cytosolic Ca^{2+}. Insulin from pancreatic β cells, digestive zymogens and neurotransmitters are released this way.
3. **To lysosomes** via the **mannose-6-phosphate (M6P)** tag. In the cis Golgi, the enzyme GlcNAc-phosphotransferase recognises a 3-D **signal patch** on each lysosomal enzyme and adds GlcNAc-phosphate to its mannose. A second enzyme removes the GlcNAc, exposing M6P. In the TGN, **M6P receptors** bind the tagged enzymes and are gathered into clathrin-coated vesicles that go to endosomes. The endosome is acidic, so the enzyme falls off, its phosphate is removed, and the receptor returns to the Golgi for reuse.

Membrane proteins are sorted by short signals in their cytosolic tails, and in epithelial cells the TGN also separates proteins for the apical and the basolateral surfaces. The same material answers that heading.

WORKED EXAMPLE

Question (8 marks). In I-cell disease (mucolipidosis II), a child's cells show large inclusions full of undigested material, and lysosomal enzyme levels in the blood are many times normal. Explain both findings from the molecular defect. Why does adding the missing enzymes to the culture medium of the child's fibroblasts, taken from a healthy person's cells, correct the inclusions only if the enzymes carry M6P?

Solution.

1. **Defect:** the child lacks working GlcNAc-phosphotransferase, so no lysosomal enzyme gets the M6P tag in the cis Golgi.
2. **Sorting fails:** without M6P, the receptors in the TGN cannot capture the enzymes. The enzymes follow the default constitutive route and are secreted.
3. **Blood finding:** secreted enzymes reach the blood, so their blood levels are high.
4. **Inclusions:** lysosomes lack most of their hydrolases, so material taken in by endocytosis and autophagy is not broken down and piles up as inclusions (hence "inclusion cell").
5. **Rescue:** some M6P receptors also sit on the plasma membrane. Enzymes carrying M6P bind them, are taken in by clathrin-mediated endocytosis and are delivered to lysosomes, so the inclusions clear. Enzymes without M6P cannot be picked up this way.

Answer: missing M6P tag → enzymes secreted instead of sorted → high blood enzymes and empty lysosomes; rescue works through surface M6P receptors. This uptake route is also the basis of enzyme replacement therapy for some lysosomal storage diseases.

EXAM TRAPS

- COPII goes forward (ER → Golgi); COPI goes backward. A memory aid: "two goes to" the Golgi.
- The M6P tag is added in the cis Golgi but read in the trans Golgi network. Examiners ask "where" for each step.
- Constitutive secretion needs no signal; it is the default. Regulated secretion and lysosomal sorting need signals.
- Lysosomal enzymes are recognised by a 3-D signal patch, not a linear sequence like KDEL.

CHECK YOURSELF

- REMEMBER **Name the faces of the Golgi and say which one receives cargo.** 2 marks

  Cis face (receives cargo from the ER) and trans face (ships cargo out through the TGN).

- REMEMBER **Which coat protein forms vesicles at the TGN bound for endosomes?** 1 mark

  Clathrin, with adaptor proteins.

- UNDERSTAND **Distinguish constitutive and regulated secretion with one example each.** 4 marks

  Constitutive: continuous, no signal needed, in all cells; for example albumin from liver cells. Regulated: cargo stored in granules and released only on a signal such as a Ca^{2+} rise, in specialised cells; for example insulin from β cells.

- UNDERSTAND **State the two models of transport through the Golgi stack.** 3 marks

  Vesicular transport: cisternae are fixed and vesicles carry cargo forward. Cisternal maturation: cisternae move forward and mature from cis to trans while COPI vesicles return enzymes backward.

- APPLY **A drug blocks Ca^{2+} entry into pancreatic β cells. What happens to insulin secretion and to albumin secretion by the same patient's liver?** 2 marks

  Insulin release falls, because regulated secretion needs the Ca^{2+} signal. Albumin secretion carries on, because it is constitutive.

- APPLY **A lysosomal enzyme is engineered to carry KDEL at its C-terminus. Where will most of it end up?** 2 marks

  In the ER: the KDEL receptor returns it from the cis Golgi in COPI vesicles before it can reach the TGN.

- ANALYZE **Why does it make sense for the M6P receptor to release its cargo in the endosome rather than in the Golgi?** 3 marks

  Binding is pH-dependent: the receptor holds the enzyme at the near-neutral pH of the TGN and lets go at the lower pH of the endosome. That delivers the enzyme to the right place and frees the receptor to return and carry more, so few receptors serve many enzymes.

BEYOND THE SYLLABUS

Golgi glycosylation decides how long a therapeutic antibody lasts in the blood and how strongly it activates immune cells, so glycoengineering of CHO cell lines (for example removing core fucose) is an industrial specialty. Enzyme replacement therapies for Gaucher and Pompe disease rely on mannose or M6P receptors for uptake. Live-cell imaging in yeast is used to watch cisternal maturation directly. Search "antibody glycoengineering afucosylation" and "enzyme replacement therapy M6P". Not for the exam.

3.4 Lysosomes, peroxisomes and vacuoles

These three organelles are the cell's digestion, oxidation and storage rooms. **Lysosomes** are acidic sacs of digestive enzymes that break down worn-out parts and material brought in from outside. **Peroxisomes** carry out oxidation reactions that make hydrogen peroxide, and destroy it safely in the same room. **Vacuoles**, large in plant and fungal cells, store water, ions and wastes and keep the plant cell firm. All three are single-membrane compartments, and lysosomes and vacuoles are close relatives: the plant vacuole does the lysosome's job too.

You need: M6P sorting from Chapter 3.3, and endocytosis from **Unit 2, Endocytosis and exocytosis**.

Lysosomes

Christian de Duve found lysosomes in the 1950s while fractionating rat liver, and later found peroxisomes too; he shared the 1974 Nobel Prize. A lysosome holds several dozen kinds of **acid hydrolases**: proteases, nucleases, lipases, glycosidases, phosphatases and sulfatases. Together they can break down every major class of large molecule.

- **Acidic inside:** a **V-type H^+-ATPase** in the membrane uses ATP to pump protons in, keeping the lumen near pH 4.5–5. The cytosol is about pH 7.2.
- **Self-protection:** the membrane proteins (such as LAMPs) are heavily glycosylated on the inside, so the enzymes cannot digest the membrane.
- **Safety catch:** the hydrolases work poorly at neutral pH. If a lysosome leaks, the enzymes do little harm in the cytosol.

Material reaches lysosomes by three routes:

1. **Endocytosis:** outside material in endocytic vesicles → early endosome → late endosome → lysosome.
2. **Phagocytosis:** large particles such as bacteria are engulfed by macrophages and neutrophils into a phagosome, which fuses with lysosomes.
3. **Autophagy:** worn-out organelles or cytosol are wrapped in a double membrane (the autophagosome), which fuses with a lysosome. Starved cells use it to recycle their own parts. Yoshinori Ohsumi won the 2016 Nobel Prize for the autophagy genes.

Older textbooks call the newly made organelle the **primary lysosome** and the one that has fused with its cargo the **secondary lysosome**; undigested remains form **residual bodies**, such as the lipofuscin pigment of ageing heart and nerve cells.

Lysosomal storage diseases are inherited loss of one hydrolase, so its substrate builds up. Three examples: **Tay–Sachs disease** (hexosaminidase A missing, GM2 ganglioside builds up in neurons), **Gaucher disease** (glucocerebrosidase), and **Pompe disease** (acid α-glucosidase, glycogen builds up in muscle). I-cell disease, where all enzymes are missorted, is in Chapter 3.3.

Peroxisomes and other microbodies

Peroxisomes are small (about 0.2–1 µm) single-membrane organelles with no DNA or ribosomes. Their key pair of enzymes:

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oxidases:  RH₂ + O₂  →  R + H₂O₂
catalase:  2 H₂O₂    →  2 H₂O + O₂
           or  H₂O₂ + R′H₂ → R′ + 2 H₂O   (peroxidative use: detoxifies phenols, etha
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Here RH_2 is an organic substrate that gives up two hydrogens. Catalase is often so abundant that it forms a crystal core visible in electron micrographs. Functions:

- **β-oxidation of very-long-chain fatty acids** (more than about 22 carbons), which mitochondria cannot handle first. The shortened chains go to mitochondria to finish.
- **Plasmalogen synthesis**, a lipid abundant in myelin.
- **Detoxification** in liver and kidney; a good share of the ethanol people drink is oxidised to acetaldehyde here.
- **Glyoxysomes** in germinating oily seeds (castor, groundnut) run the **glyoxylate cycle**, which turns stored fat into sugar. Animals lack this cycle.
- In leaves, peroxisomes take part in **photorespiration** with chloroplasts and mitochondria (see Chapter 3.7).

Peroxisomal proteins are made on free ribosomes and imported **fully folded**. Most carry **PTS1**, the C-terminal tripeptide Ser–Lys–Leu (SKL). The import machine is made of proteins called

peroxins (PEX genes). Peroxisomes multiply by growing and dividing; new membrane can also come from the ER. When import fails, cells have empty peroxisome "ghosts": this is **Zellweger syndrome**, a fatal disorder of infancy.

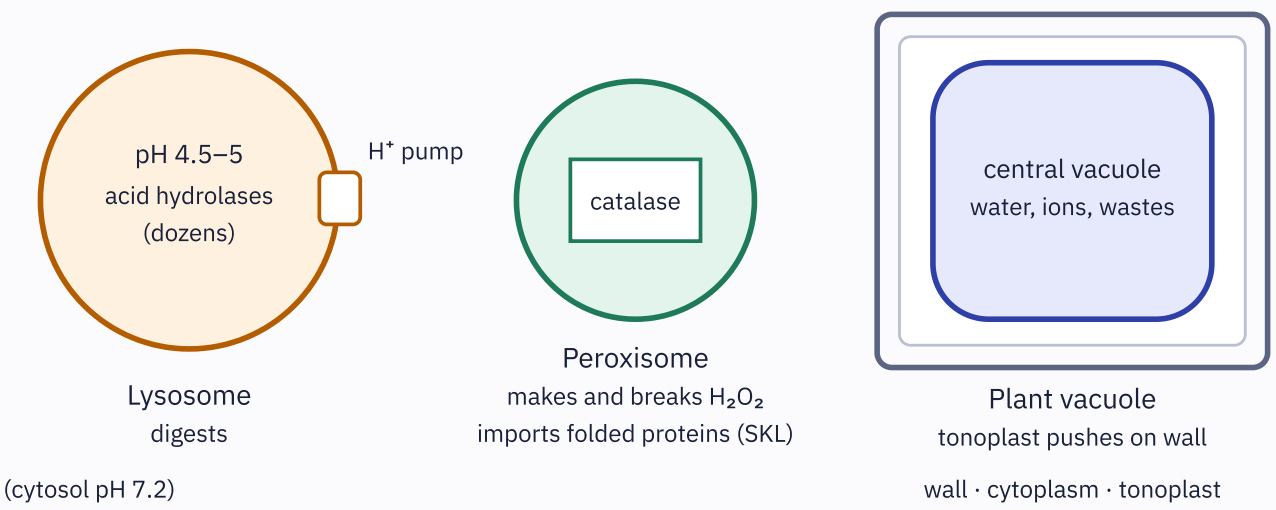


Figure 3.4.1 The three single-membrane organelles of this chapter, not to scale. The lysosome keeps its pH low with a proton pump; the peroxisome keeps catalase next to the oxidases that make H_2O_2; the plant vacuole, bounded by the tonoplast, fills most of the cell and presses the thin cytoplasm against the wall.

Vacuoles

A mature plant cell usually has one large **central vacuole** that can fill most of its volume, often up to about 90%. Its membrane is the **tonoplast**, which has its own proton pumps and transporters. The vacuole:

- takes in water by osmosis and pushes the cytoplasm against the wall; this **turgor pressure** keeps leaves and young stems firm, and its loss is why a plant wilts;
- lets the cell grow large cheaply, by adding water rather than cytoplasm;
- stores sugars, ions, pigments (anthocyanins give red and purple colours), and defensive or waste compounds such as alkaloids;
- contains acid hydrolases and acts as the plant cell's lysosome.

Freshwater protists such as *Paramecium* have **contractile vacuoles** that collect excess water and pump it out, so the cell does not burst. **Food vacuoles** in protists are phagosomes that fuse with lysosomes.

WORKED EXAMPLE

Question (6 marks). (a) A lysosome is at pH 4.7 and the cytosol at pH 7.2. How many times higher is the H^+ concentration inside? (b) Peroxisomes in a liver sample make 0.50 µmol of H_2O_2 per minute through oxidases. If catalase removes all of it by the catalatic reaction, how much O_2 does catalase release per minute, and what is the net O_2 use of the whole oxidase–catalase pair?

Solution.

1. pH = $-\log_{10}[H^+]$, so the ratio of concentrations is 10^(pH difference). Difference = 7.2 − 4.7 = 2.5.
2. 10^2.5 = 10^2 × 10^0.5 = 100 × 3.16 ≈ 316. The lumen has about **316 times** more H^+ than the cytosol.
3. Catalase: 2 H_2O_2 → 2 H_2O + O_2. So 0.50 µmol H_2O_2 gives 0.50 ÷ 2 = **0.25 µmol O_2 per minute**.
4. The oxidases used 1 O_2 per H_2O_2 made, so 0.50 µmol O_2 per minute. Net use = 0.50 − 0.25 = **0.25 µmol O_2 per minute**.

Answer: (a) about 316-fold; (b) 0.25 µmol O_2 released, net 0.25 µmol O_2 consumed per minute. The proton gradient is held against a 316-fold difference, which is why the V-ATPase needs ATP.

EXAM TRAPS

- Lysosomal enzymes are made in the rough ER and sorted by the Golgi; peroxisomal enzymes are made on free ribosomes and imported directly. Many students say peroxisomes "bud from the Golgi"; they do not.
- Peroxisomes have no DNA, unlike mitochondria and chloroplasts.
- Do not call the vacuole membrane the plasma membrane; it is the tonoplast.
- Glyoxysomes are found in plant seeds, not in animal cells.
- "Suicide bags" is an old nickname for lysosomes; their enzymes are mostly inactive at cytosolic pH, so a single leak does not kill the cell.

CHECK YOURSELF

– REMEMBER **What is the pH inside a lysosome, and what keeps it there?** 2 marks

About 4.5–5, kept by a V-type H^+-ATPase pumping protons in.

– REMEMBER **What is the peroxisomal targeting signal PTS1?** 1 mark

The C-terminal tripeptide Ser–Lys–Leu (SKL).

– UNDERSTAND **Why are catalase and the oxidases kept in the same organelle?** 2 marks

The oxidases make H_2O_2, which is toxic; catalase next to them breaks it down at once before it can damage the rest of the cell.

– UNDERSTAND **Explain how a plant wilts in terms of the vacuole.** 3 marks

When water is short, water leaves the vacuole by osmosis, the vacuole shrinks, turgor pressure on the wall falls and the cells go limp, so leaves and stems droop.

– APPLY **A drug raises lysosomal pH from 4.8 to 6.3. By what factor does $[H^+]$ fall, and what happens to digestion?** 3 marks

10^1.5 ≈ 32-fold fall. Acid hydrolases lose most of their activity, so digestion of endocytosed and autophagic material slows. Chloroquine acts partly in this way.

– APPLY **A patient's cells cannot break down very-long-chain fatty acids, and peroxisomes look like empty membranes. Name the likely disorder and the defect.** 2 marks

Zellweger syndrome: peroxisomal protein import fails because of a PEX gene defect.

– ANALYZE **Compare lysosomes and peroxisomes on origin, enzymes and one disease each.** 4 marks

Lysosomes: from the ER–Golgi–endosome route, acid hydrolases sorted by M6P; disease, Tay–Sachs. Peroxisomes: proteins made on free ribosomes and imported folded via PTS1, organelle grows and divides; oxidases and catalase; disease, Zellweger syndrome. Both have one membrane and no DNA.

BEYOND THE SYLLABUS

Autophagy is a major drug target: boosting it may clear toxic protein clumps in Parkinson's and Alzheimer's disease, while blocking it may starve some tumours. Enzyme replacement and gene therapies are approved or in trials for several lysosomal storage diseases. Engineered yeast peroxisomes are being used as compartments for metabolic engineering, keeping toxic pathway intermediates away from the cytosol. Search "autophagy neurodegeneration" and "peroxisome compartmentalization metabolic engineering". Not for the exam.

Key terms of this lesson

TERM	MEANING OR FORMULA	CHAPTER
COPII / COPI / clathrin	ER→Golgi / Golgi→ER / TGN and plasma membrane→endosomes	3.3
Mannose-6-phosphate	tag added in cis Golgi, read by M6P receptor in TGN; sends enzymes to lysosomes	3.3
Lysosome pH	4.5–5, kept by V-type H^+-ATPase; [H^+] ratio = 10^(ΔpH)	3.4
Catalase	2 H_2O_2 → 2 H_2O + O_2; PTS1 = C-terminal SKL	3.4

Glossary (terms used in this lesson)

Acid hydrolase Digestive enzyme of the lysosome that works best at low pH.

Catalase Peroxisomal enzyme that breaks H_2O_2 into water and oxygen.

Centrosome Two centrioles with pericentriolar material; the main microtubule-organising centre of animal cells.

Cisterna A flattened membrane sac of the ER or Golgi.

Mannose-6-phosphate Sugar tag that targets enzymes from the Golgi to lysosomes.

Tonoplast Membrane around the plant vacuole.

Trans Golgi network Exit face of the Golgi where cargo is sorted to its destinations.

The full unit book

Every chapter of Unit 3, the unit summary, the exam question bank with model answers and the full glossary: Cell Biology · Unit 3 · Cell Organelles and Cytoskeleton (one file, works offline).

Sources and further reading

Standard textbooks

- Bruce Alberts and others, *Molecular Biology of the Cell* (W. W. Norton / Garland Science): chapters on intracellular compartments and protein sorting, intracellular membrane traffic, energy conversion in mitochondria and chloroplasts, and the cytoskeleton. (from memory; check)
- Harvey Lodish and others, *Molecular Cell Biology* (W. H. Freeman / Macmillan). (from memory; check)
- Geoffrey M. Cooper, *The Cell: A Molecular Approach* (Sinauer / Oxford University Press). (from memory; check)
- Gerald Karp, *Cell and Molecular Biology: Concepts and Experiments* (Wiley). (from memory; check)
- P. S. Verma and V. K. Agarwal, *Cell Biology, Genetics, Molecular Biology, Evolution and Ecology* (S. Chand), widely prescribed in Indian universities. (from memory; check)

Open resources

- OpenStax, *Biology 2e*, Chapter 4 "Cell Structure", section 4.3 "Eukaryotic Cells" and 4.4 "The Endomembrane System and Proteins" (CC BY 4.0): an open textbook covering the organelles of this unit at an introductory level. Reached through the course pages below; section titles from memory; check.
- Penn State DuBois, Biology 110 course pages built on OpenStax *Biology 2e*: psu.pb.unizin.org/biol110/part/cell-structure/
- City Tech OpenLab, Biology 1101 Course Hub, Lecture 11 "The Eukaryotic Cell", with readings and slides: openlab.citytech.cuny.edu/bio1101coursehub/?p=3597

Numbers in this book (pore size limit, ribosome protein counts, mtDNA size, filament diameters, motor step sizes) are standard textbook values written from memory; check them against your prescribed book. Worked-example inputs such as step rates and translation speeds are given in the question and are for practice.

Syllabus: the University free n easy universal syllabus, built from top universities' syllabi.

Built for the University free n easy YouTube channel from the universal syllabus of Cell Biology (Oct 2026). Written with top universities' syllabi and standard textbooks; check a formula against your prescribed book before an exam, and report mistakes on the channel.