REVISION GUIDE

Rooms inside the cell, and where *two* of them came from

Compartments and their origins

A eukaryotic cell is divided by membranes into rooms with their own jobs. See why keeping reactions apart and folding membranes helps, follow a protein from the rough ER out of the cell, and find the bacteria still hiding in every mitochondrion and chloroplast.

8 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ap-biology-unit-2-compartments-and-origins

Contents

01	Keep it apart	3
02	Genes behind a wall	5
03	Folded for surface	7
04	A route out of the cell	9
05	Bubbles that carry	13
06	The cell that swallowed a bacterium	15
07	Still bacteria inside	19
08	Regions without walls	20
	Key terms	22
	Dry lab: Follow the label	23
	Check yourself	25
	Answers	26

By the end you can

- [ ] Explain how membranes and membrane-bound organelles compartmentalize a eukaryotic cell's reactions 2.9.A
- [ ] Describe the endomembrane system and the route of a secreted protein through it 2.9.A
- [ ] Explain how internal membranes minimize competing interactions and increase the surface area where reactions happen 2.9.B
- [ ] Describe the endosymbiotic origin of mitochondria and chloroplasts, and relate their functions to their free-living ancestors 2.10.A
- [ ] Compare how prokaryotic and eukaryotic cells divide up their work 2.10.A

Tick each one when you can do it without the book.

01 Keep it *apart*

2.9.A CELL COMPARTMENTALIZATION

A cell carries out thousands of reactions at once, and some would wreck each other if they met. The membranes inside a eukaryotic cell divide it into **compartments**, each with its own enzymes and conditions. This is **compartmentalization**.

A lysosome shows why. It holds enzymes that digest proteins, fats, nucleic acids and carbohydrates, in an acid interior around pH 5. Loose in the cytoplasm they would digest the cell. Kept inside membrane, they can break down a captured bacterium or a worn-out organelle, and the products go back to the cell.

Compartments also concentrate what a reaction needs. Enzymes and substrates packed into a small space meet more often, so the reaction runs faster than it would spread through the whole cell.

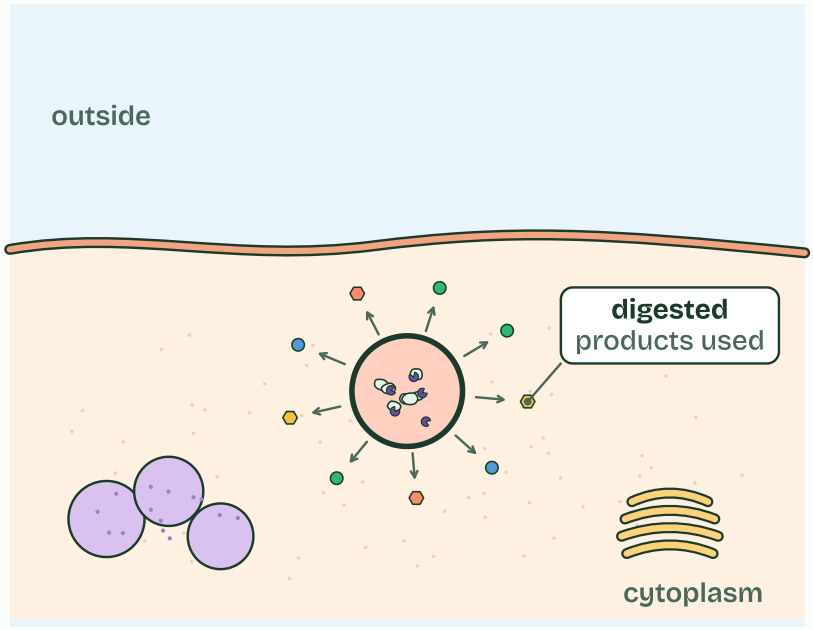
KEY POINTS

- Membranes divide a eukaryotic cell into compartments.
- Compartments keep reactions that would interfere apart.
- They hold enzymes and substrates close, so reactions run faster.

KEY TERMS

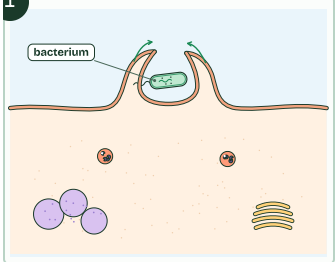
compartments
Separate regions of a cell enclosed by membranes, each with its own conditions and enzymes.

compartmentalization
The division of a cell into separate membrane-bound regions, so that different processes can run side by side without interfering.



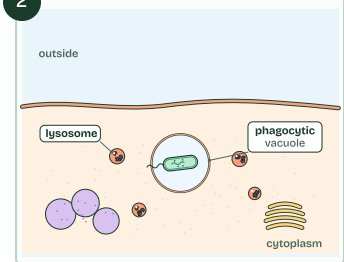
STEP BY STEP 4 STEPS

1



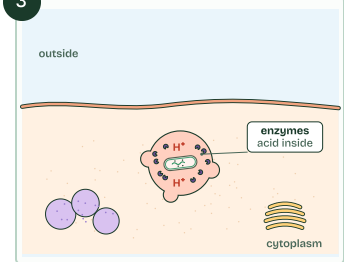
A white blood cell's membrane flows round a **bacterium**.

2



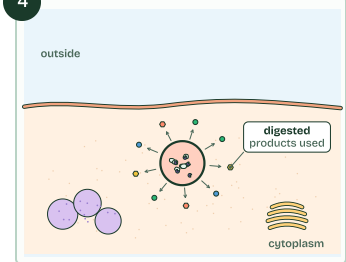
The bacterium is inside, in a **phagocytic vacuole**. Lysosomes are close by.

3



Lysosomes fuse with the vacuole, adding their enzymes in an acid compartment.

4



The bacterium is **digested**; the small molecules made are used by the cell.

WATCH OUT

Compartments are not sealed boxes. Their membranes still let some substances through, and vesicles carry material between them all the time.

PREDICT

A lysosome's enzymes work best at pH 5, and the cytoplasm is about pH 7.2. A lysosome leaks a little. What happens?

(A) The cell is digested from inside, because the enzymes work just as well in the cytoplasm as in the lysosome

(B) Little harm is done, because the enzymes work poorly at the cytoplasm's pH

(C) The cytoplasm turns acidic at once, because the lysosome's acid spreads out through the whole cell

Decide before you look. Answer on page 26.

02

2.9.A CELL COMPARTMENTALIZATION

Genes behind a *wall*

The nucleus is the largest compartment. Its double membrane, the **nuclear envelope**, keeps the DNA apart from the cytoplasm, where proteins are made. Nuclear pores let mRNA out and proteins in.

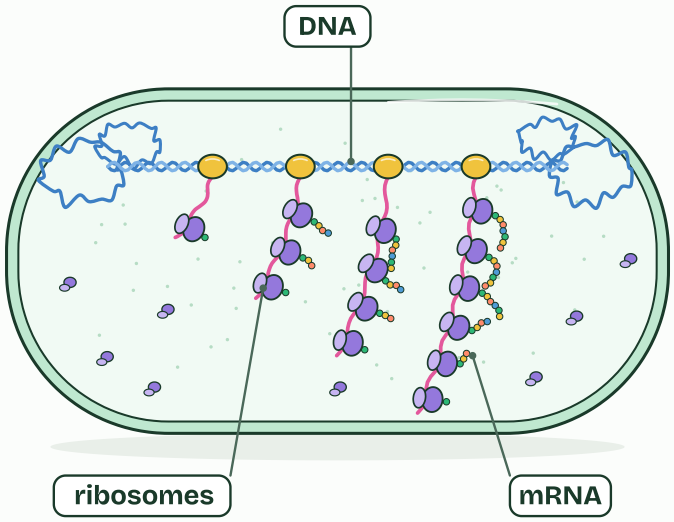
In a prokaryote, with no nucleus, ribosomes start translating an mRNA while it is still being made. In a eukaryote the mRNA is made and edited in the nucleus first, and only finished mRNA leaves for the ribosomes. Keeping the two jobs apart lets the cell check and edit its messages before any protein is made.

Switch the figure between the two cells and follow the mRNA.

KEY POINTS

- The nuclear envelope separates DNA from the cytoplasm.
- Pores let mRNA out and proteins in.
- mRNA is edited before it reaches ribosomes, which a prokaryote cannot do.

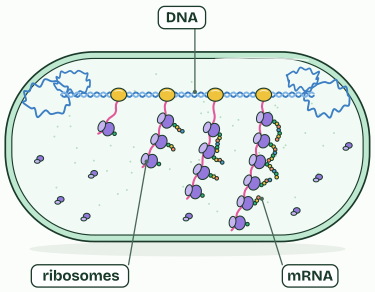
Translation starts while transcription goes on



SWITCH IT

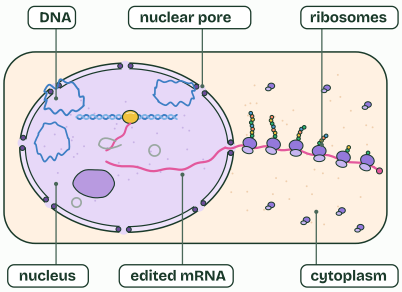
2 SETTINGS

1



Prokaryote

2



Eukaryote

WATCH OUT

Prokaryotes are not disorganized. Their DNA sits in a region, the nucleoid; it just has no membrane around it.

PREDICT

Why can a bacterium start making a protein from an mRNA before the mRNA is even finished?

(A) Its ribosomes are bigger and faster, so they can start before the whole message has been written

(B) Its DNA and ribosomes are in the same compartment, so ribosomes can reach the growing mRNA

(C) Its mRNA is edited first in the nucleoid, so the start of it is always ready to be read early

Decide before you look. Answer on page 26.

03 Folded for *surface*

2.9.B CELL COMPARTMENTALIZATION

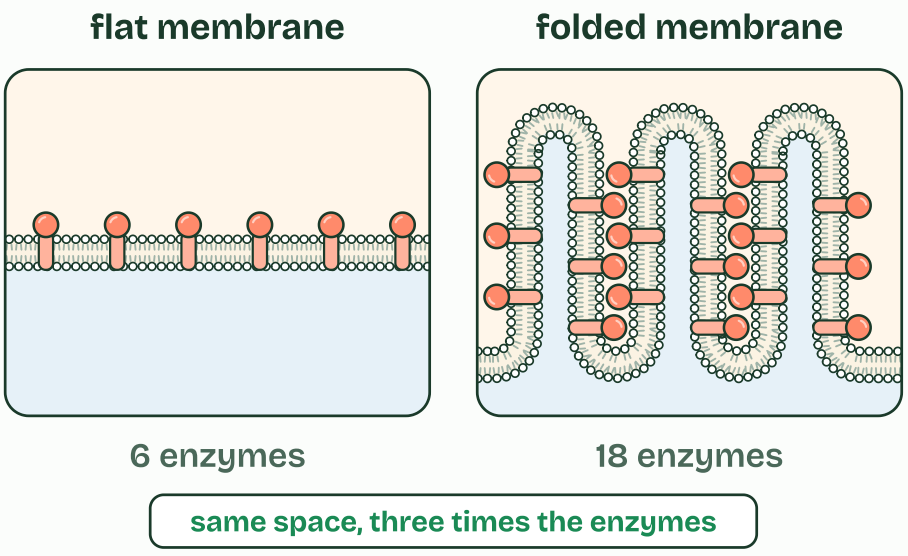
Many reactions happen on membranes, not in solution, because their enzymes are built into the membrane. Then the amount of membrane limits how fast the reaction can go. Folding a membrane packs more of it, and more enzymes, into the same space.

The inner membrane of a mitochondrion is folded into **cristae**, which carry the proteins that make most of the cell's ATP. A chloroplast is packed with stacks of **thylakoids**, whose membranes carry the pigments and proteins of the light reactions. The endoplasmic reticulum is a maze of folded membrane too, with a large surface for making proteins and lipids.

Internal membranes help in two ways: they keep competing reactions apart, and they give reactions more surface to happen on.

KEY POINTS

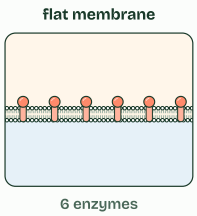
- Folded membranes give more surface for membrane enzymes.
- Cristae in mitochondria, thylakoids in chloroplasts, the ER.
- Internal membranes: fewer competing interactions, more surface.



STEP BY STEP

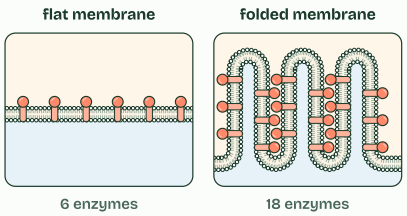
3 STEPS

1



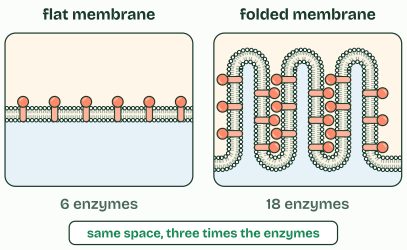
A **flat membrane** across a compartment has room for six enzymes.

2



Fold the same membrane into the **same space** and it holds three times as many.

3



More membrane, more enzymes, **more reactions at once**: cristae and thylakoids.

WATCH OUT

Folding does not make the organelle bigger. The point is more membrane in the same volume.

PREDICT

Heart muscle cells have mitochondria with many more cristae than the mitochondria of skin cells. What does this suggest?

(A) Heart cells need far less ATP, so their mitochondria fold in on themselves to take up less room

(B) Heart cells make more ATP, because more inner membrane carries more of the proteins that make it

(C) Heart cells have more DNA in their mitochondria, and the extra folds of membrane are there to store it

Decide before you look. Answer on page 26.

04 A route out of *the cell*

2.9.A CELL COMPARTMENTALIZATION

The **endomembrane system** is a set of compartments that pass membrane and cargo between them: the nuclear envelope, the endoplasmic reticulum, the Golgi complex, lysosomes, vacuoles and the plasma membrane.

A protein made for export travels through it. Ribosomes on the **rough ER** make it and thread it inside. A vesicle carries it to the **Golgi complex**, which modifies it, often adding sugars, and sorts it. Another vesicle buds off, travels to the **plasma membrane**, and fuses with it, releasing the protein outside the cell by exocytosis.

Each step happens in its own compartment, and the protein never crosses a membrane after the first. The film follows one protein the whole way.

KEY POINTS

- Endomembrane system: nuclear envelope, ER, Golgi, lysosomes, vacuoles, plasma membrane.
- Secreted protein: rough ER, vesicle, Golgi, vesicle, out.
- Vesicles carry cargo between compartments.

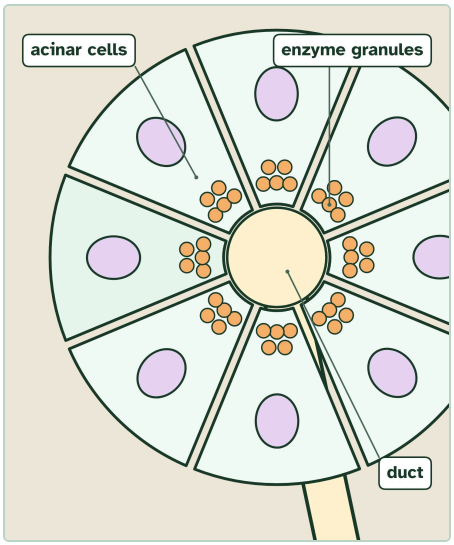
KEY TERMS

endomembrane system
The membranes of a eukaryotic cell that are linked by vesicles: the nuclear envelope, the endoplasmic reticulum, the Golgi complex, lysosomes, vacuoles and the plasma membrane.

ANIMATION · FROM GENE TO OUTSIDE

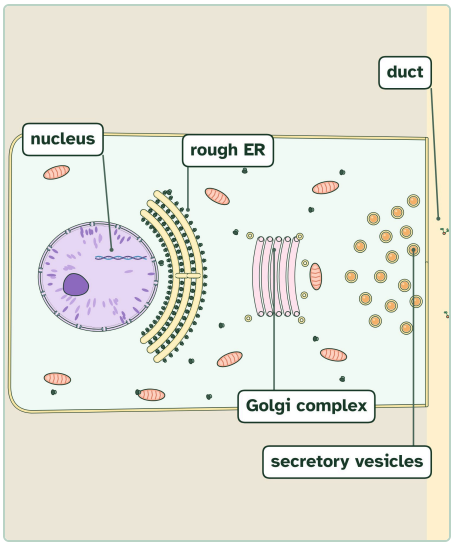
13 MOMENTS

1 A PANCREAS ACINUS



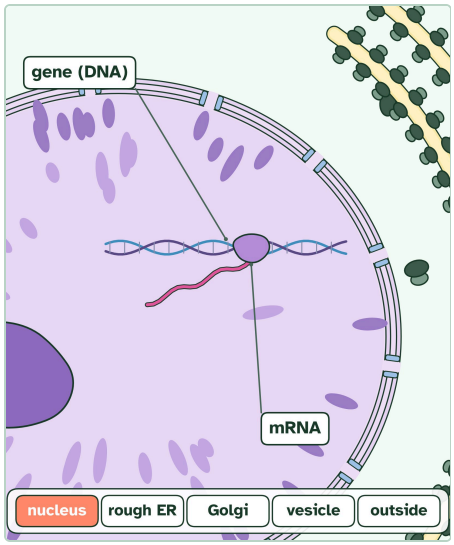
A pancreas is full of clusters of **acinar cells** round a duct. Each makes digestive enzymes and secretes them into the duct.

2 ONE ACINAR CELL



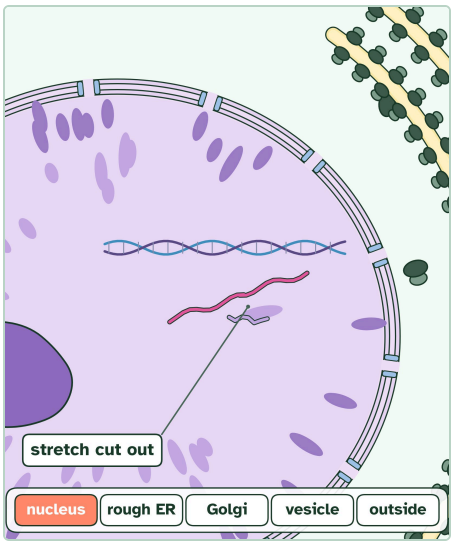
Inside one cell: the **nucleus**, sheets of **rough ER**, the **Golgi complex** and vesicles of enzyme waiting at the tip.

3 TRANSCRIPTION



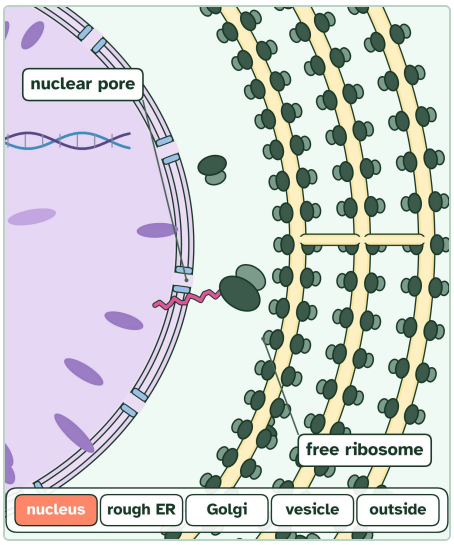
In the nucleus the gene for the enzyme is **transcribed**: an mRNA copy is made.

4 MRNA MODIFIED



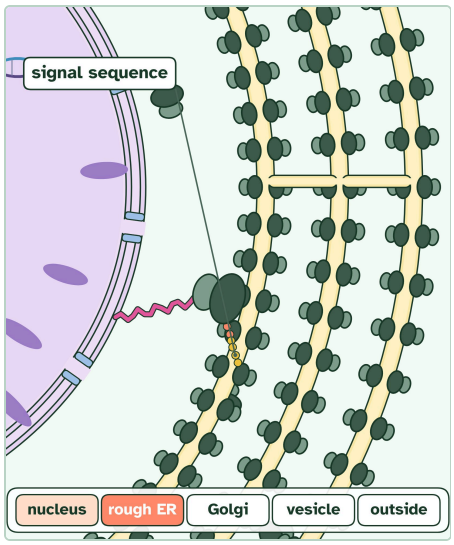
Still inside the nucleus, the mRNA is **modified**: stretches are cut out. No ribosome can reach it until this is done.

5 OUT THROUGH A PORE



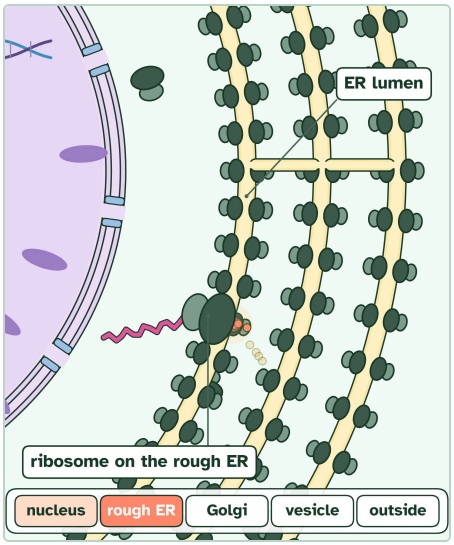
The finished mRNA leaves through a **nuclear pore**, and a free **ribosome** binds it in the cytoplasm.

6 TO THE ROUGH ER



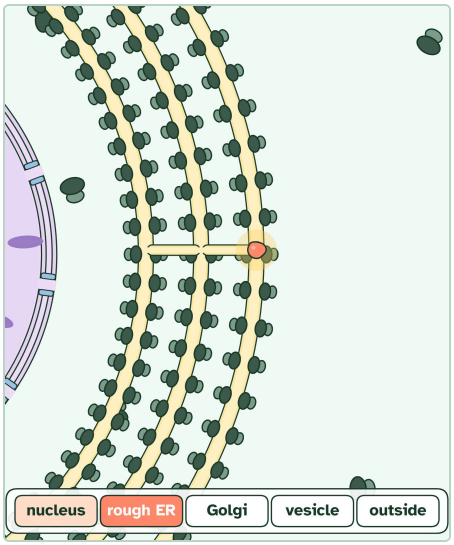
The first part of the new protein is a **signal sequence**. It leads the ribosome to the **rough ER**, where it binds.

7 INTO THE LUMEN



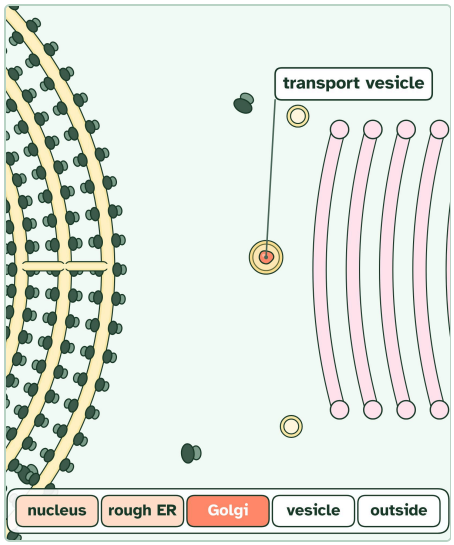
The growing chain is threaded through the membrane into the ER's **lumen**, where the signal is cut off and the protein folds.

8 TRANSPORT VESICLE



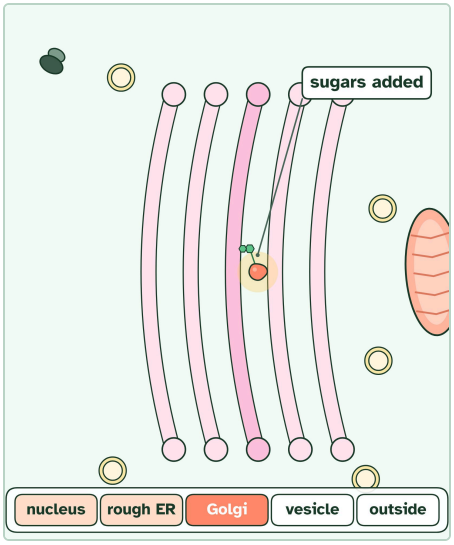
The protein moves through the lumen, and a piece of ER membrane buds off round it: a **transport vesicle**.

9 TO THE GOLGI



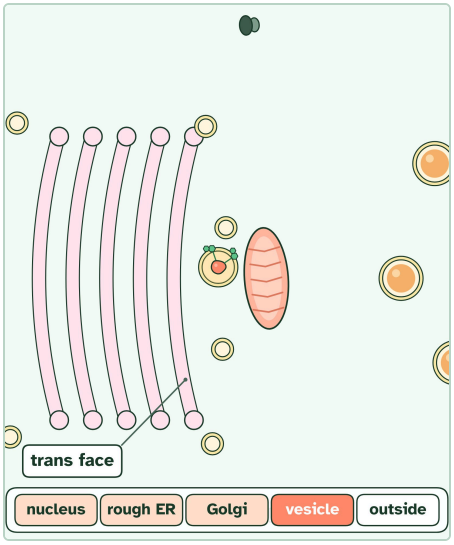
The vesicle crosses to the near face of the **Golgi complex** and fuses with it.

10 SUGARS ADDED



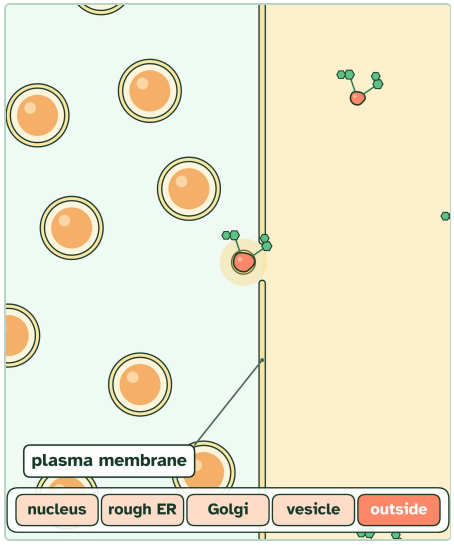
Cisterna by cisterna the protein is **modified**: here, chains of sugar are added.

11 SECRETORY VESICLE



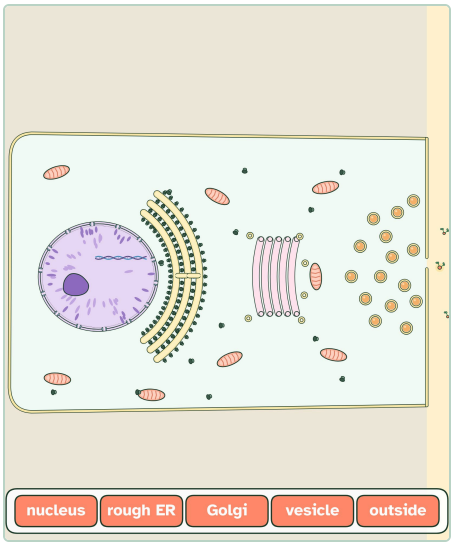
At the far face it buds off in a **secretory vesicle**, one of many waiting near the tip of the cell.

12 EXOCYTOSIS



The vesicle reaches the **plasma membrane** and fuses with it, releasing the enzyme into the duct: **exocytosis**.

13 THE WHOLE ROUTE



Nucleus, rough ER, Golgi, vesicle, out: every protein for secretion takes this route. Proteins kept in the cytosol are made by free ribosomes instead.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-2-compartments-and-origins#route

WATCH OUT

The Golgi complex does not make proteins. It receives them from the rough ER, modifies them and sends them on.

PREDICT

Cells that secrete a lot of protein, such as those making digestive enzymes, have lots of which structures?

(A) Smooth ER and large vacuoles, because the proteins are stored there before the cell can send them out

(B) Rough ER and Golgi, because those are where proteins for export are made and then processed

(C) Lysosomes and peroxisomes, because those are where proteins are broken down before they are released

Decide before you look. Answer on page 26.

2.9.A CELL COMPARTMENTALIZATION

05 Bubbles that *carry*

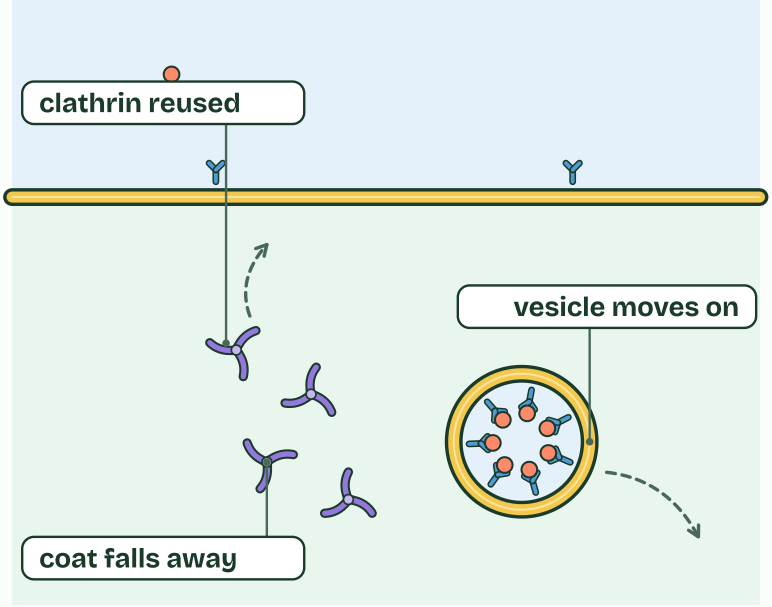
A vesicle is a small sac of membrane. It buds off one compartment with cargo inside and fuses with another, so the cargo moves without ever crossing a membrane. Vesicles link the endomembrane system, and the plasma membrane is part of it: vesicles leave it in endocytosis and join it in exocytosis.

Budding is not random. In one route, cargo binds to receptors in the membrane, and a protein called clathrin gathers on the inner face and bends it into a pit, which pinches off as a coated vesicle. Proteins on the vesicle mark where it goes.

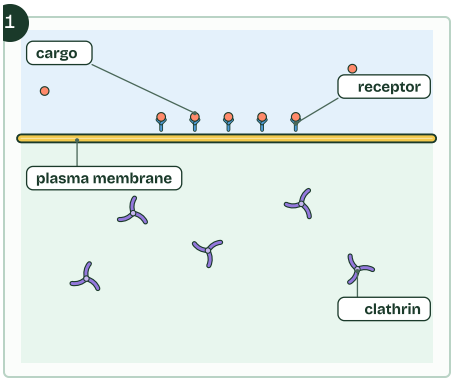
Because vesicles bud from one membrane and fuse with another, membrane itself moves through the system too: the plasma membrane is constantly taken in and added back.

KEY POINTS

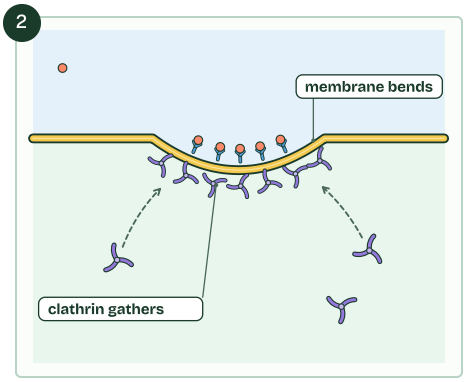
- Vesicles carry cargo between compartments without crossing a membrane.
- They bud from one membrane and fuse with another.
- Receptors and coat proteins decide what goes in and where it goes.



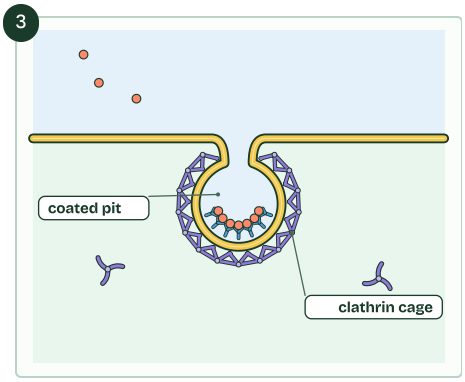
STEP BY STEP
5 STEPS



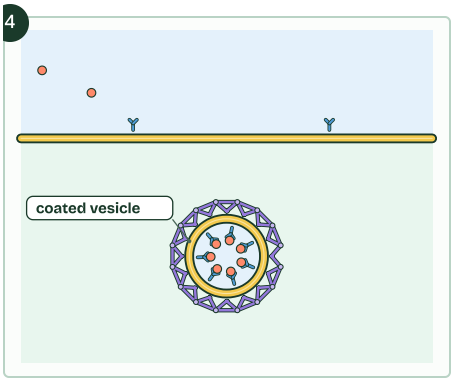
Cargo molecules outside the cell bind to **receptors** in the membrane.



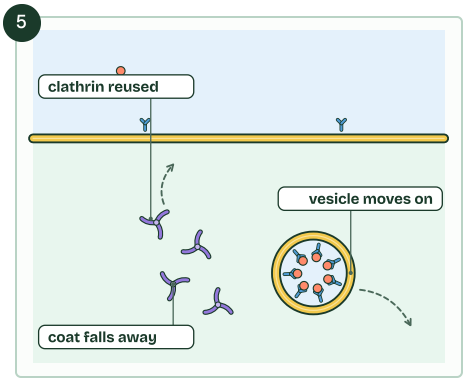
Clathrin gathers on the inner face and begins to bend the membrane.



The clathrin cage deepens it into a **coated pit**.



The pit pinches off: a **coated vesicle** with its cargo inside.



The **coat falls away** to be used again, and the vesicle moves on.

WATCH OUT

A vesicle's cargo is never in the cytoplasm. It is inside membrane the whole way.

PREDICT

A drug stops vesicles fusing with the Golgi. Where does a protein for export build up?

(A) In the Golgi complex, because the drug leaves the protein stuck there unable to move on to the plasma membrane

(B) Between the rough ER and the Golgi, in vesicles that bud from the ER but cannot fuse with the Golgi

(C) Outside the cell, because the protein can still cross out through the plasma membrane on its own

Decide before you look. Answer on page 26.

06

2.10.A ORIGINS OF CELL COMPARTMENTALIZATION

The cell that *swallowed* a bacterium

Where did compartments come from? Some formed when the plasma membrane folded inward. Two, mitochondria and chloroplasts, have a stranger history. The theory of **endosymbiosis** says they were once free-living prokaryotes.

An ancestral cell, already with a nucleus, engulfed an aerobic bacterium and did not digest it. The bacterium lived on inside, using food from its host and supplying plenty of ATP. Over many generations it became the **mitochondrion**. Later some of these cells took in a photosynthetic cyanobacterium the same way, and it became the **chloroplast**.

That is why plants and algae have both organelles, and animals and fungi only mitochondria.

KEY POINTS

- Mitochondria and chloroplasts began as free-living prokaryotes.
- An aerobic bacterium became the mitochondrion; a cyanobacterium, the chloroplast.
- Engulfed but not digested: both partners benefited.

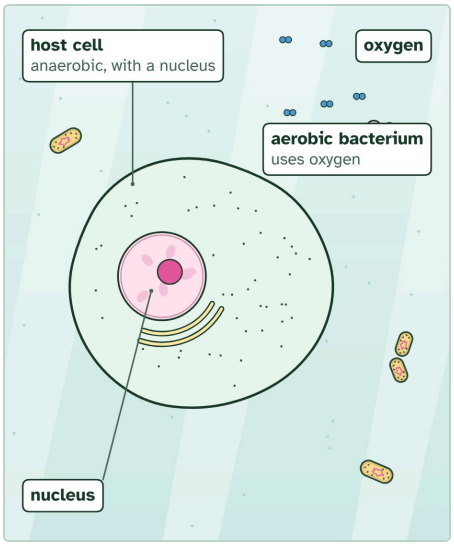
KEY TERMS

endosymbiosis
The theory that mitochondria and chloroplasts began as free-living prokaryotes that were taken into a larger cell and lived on inside it, to the benefit of both.

ANIMATION · TAKING IN A PARTNER

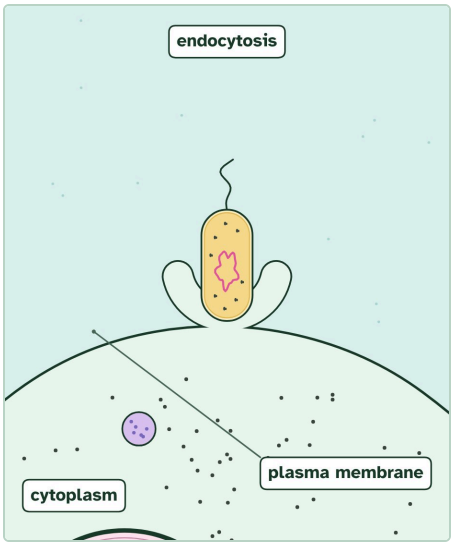
12 MOMENTS

1 THE ANCIENT SEA



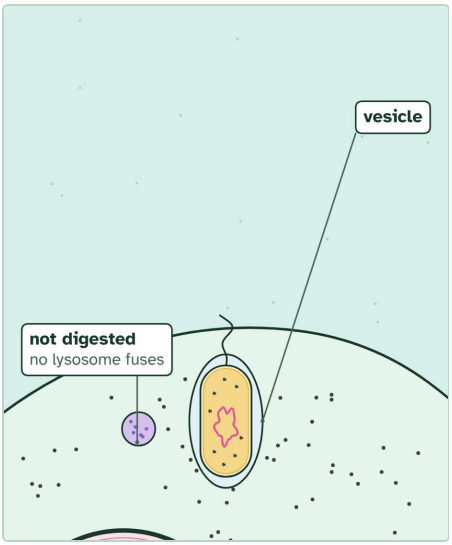
Long ago, a large **anaerobic** cell with a **nucleus** lives among small prokaryotes. Some are **aerobic bacteria**: they use oxygen to release far more energy from food.

2 ENDOCYTOSIS



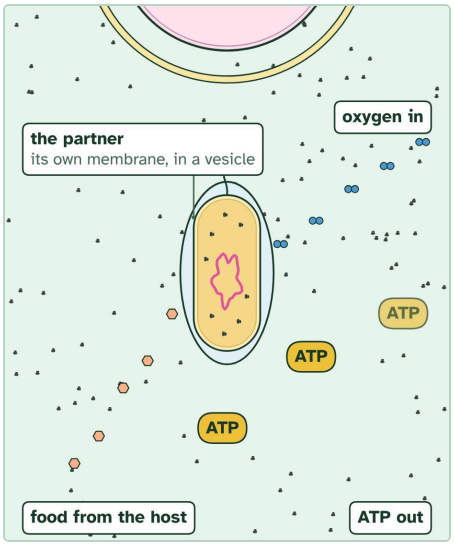
The host's plasma membrane flows round an aerobic bacterium: **endocytosis**.

3 INSIDE A VESICLE



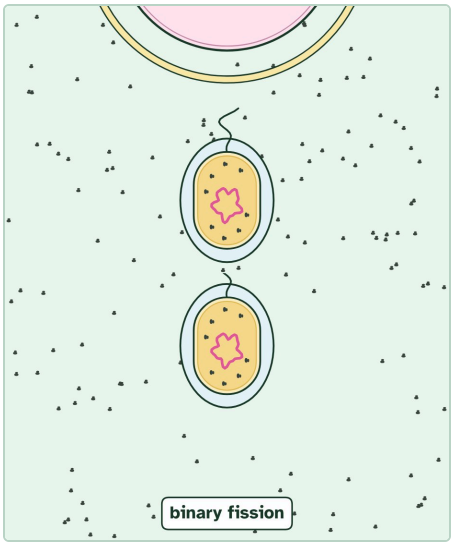
The membrane pinches off a **vesicle**. The bacterium is inside the cell, wrapped in the host's membrane, and it is **not digested**.

4 PARTNERS



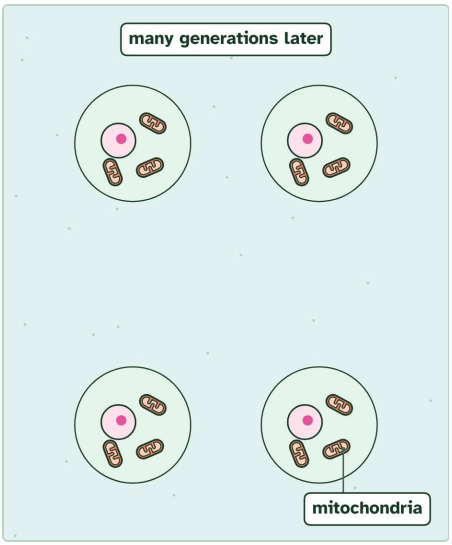
A **partnership**: the host supplies food, and the bacterium uses **oxygen** to make far more **ATP** than the host could alone.

5 BINARY FISSION



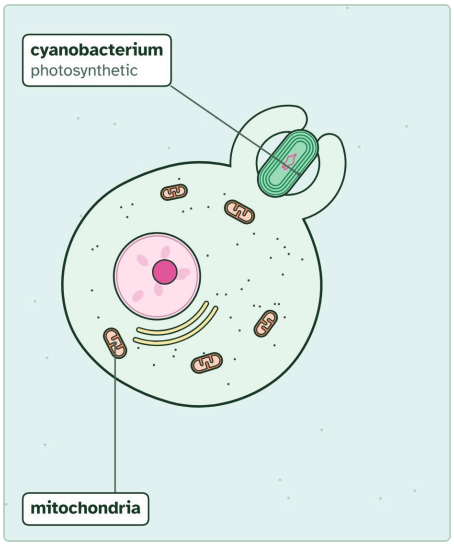
Inside its host the bacterium still **divides in two**, by binary fission.

6 MITOCHONDRION



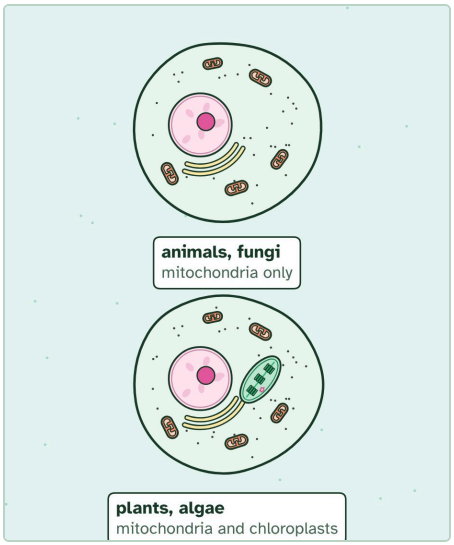
Each time the host divides, both daughters inherit partners. Over **many generations** neither can live without the other: the bacterium has become the **mitochondrion**.

7 A CYANOBACTERIUM



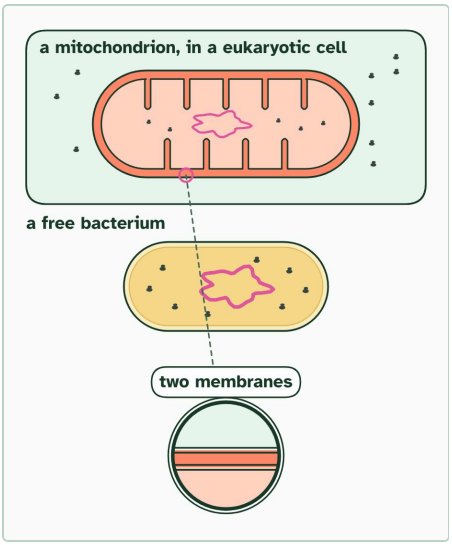
Later, **some** of these cells take in a **cyanobacterium**, which photosynthesizes, in the same way.

8 CHLOROPLAST



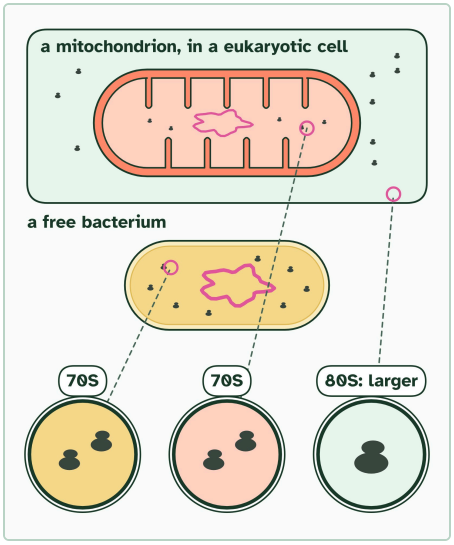
It becomes the **chloroplast**. So plants and algae have both organelles, while animals and fungi have only mitochondria.

9 TWO MEMBRANES



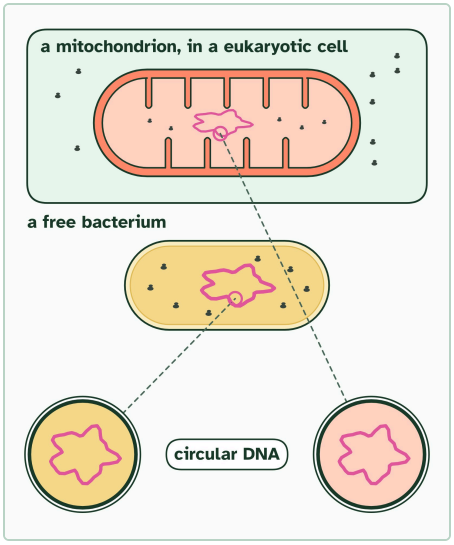
The evidence: a mitochondrion still looks like a bacterium. It has **two membranes**, the outer one from the vesicle it was taken in by.

10 ITS OWN RIBOSOMES



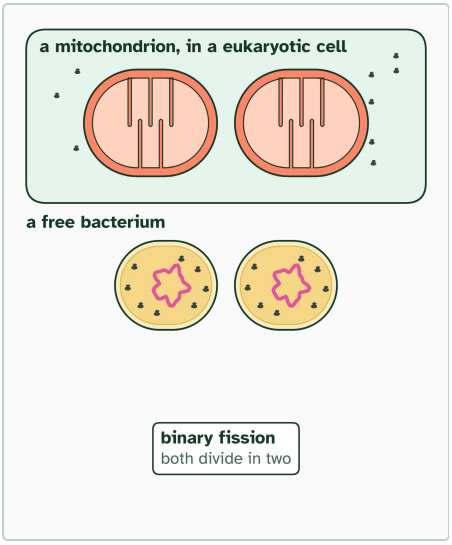
Its own ribosomes, small like a prokaryote's (70S), not the larger 80S ribosomes of the cytoplasm around it.

11 CIRCULAR DNA



Its own **naked, circular DNA**, like a bacterium's, not the linear chromosomes of the nucleus.

12 DIVIDES IN TWO



And it can only **divide in two**, as a bacterium does: a cell cannot make one from scratch. Chloroplasts show all the same evidence.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-2-compartments-and-origins#endosymbiosis

WATCH OUT

Endosymbiosis does not explain the nucleus or the ER. It is about mitochondria and chloroplasts.

PREDICT

If a cell lost all its mitochondria, could it make new ones from its own nuclear genes and membranes?

(A) Yes, because the instructions for every organelle are held in the DNA of the nucleus

(B) No, because new mitochondria only ever form when an existing one divides

(C) Yes, as long as the cell still has its endoplasmic reticulum to build the membranes

Decide before you look. Answer on page 26.

07

2.10.A ORIGINS OF CELL COMPARTMENTALIZATION

Still *bacteria* inside

Mitochondria and chloroplasts still look and behave like their free-living relatives. Each has **two membranes**: the inner one its own, the outer one from the vesicle it was engulfed in. Each has its own **circular DNA**, like a bacterium's, and its own **ribosomes**, small like a prokaryote's. Each makes new copies only by **dividing in two**, as bacteria do.

Their jobs match too. The mitochondrion carries out aerobic respiration, as its bacterial ancestor did, on an inner membrane that matches the bacterium's plasma membrane. The chloroplast photosynthesizes on thylakoids, as cyanobacteria still do.

A theory is strong when it explains many separate observations at once, and this one does.

KEY POINTS

- Two membranes, circular DNA, small ribosomes, division in two.
- The mitochondrion respires as aerobic bacteria do.
- The chloroplast photosynthesizes on thylakoids, as cyanobacteria do.

WATCH OUT

Mitochondria cannot live on their own today. Over time most of their genes moved to the nucleus, so they now depend on the cell.

PREDICT

Some antibiotics stop bacterial ribosomes working and leave the patient's cytoplasm ribosomes alone. In high doses, which organelle's proteins can they also affect?

(A) The rough ER, because its ribosomes make most of the proteins that cells send out of themselves

(B) The mitochondria, because their own ribosomes are like a bacterium's

(C) The nucleus, because its envelope is a double membrane built like a bacterium's

Decide before you look. Answer on page 26.

08

2.10.A ORIGINS OF CELL COMPARTMENTALIZATION

Regions without *walls*

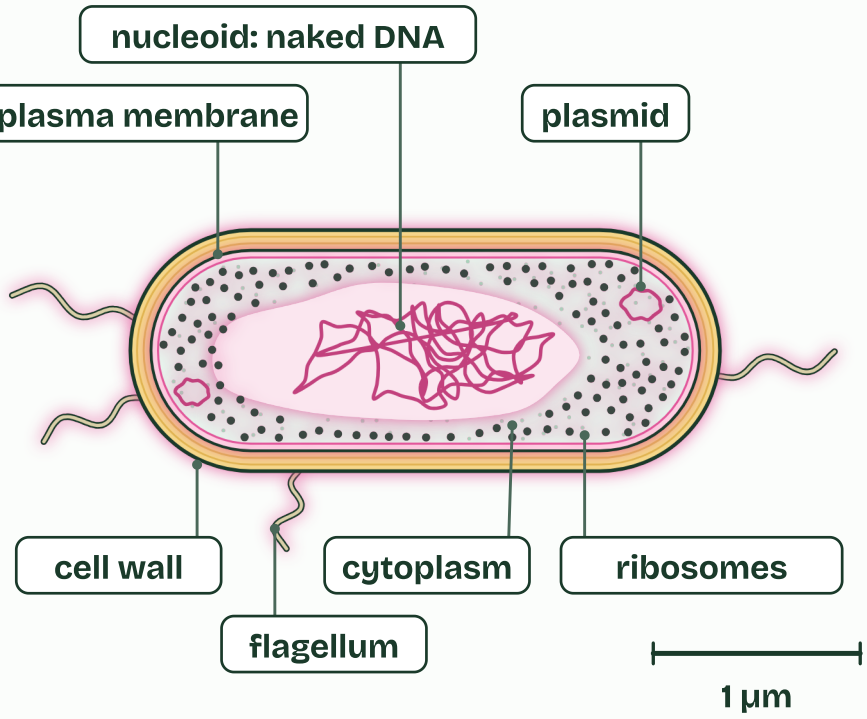
Prokaryotes generally have no membrane-bound organelles, but they are not just bags of chemicals. They have internal regions with their own jobs. The DNA sits in the **nucleoid**. Ribosomes cluster where proteins are made. Some have folds of plasma membrane for respiration, and cyanobacteria have thylakoid membranes for photosynthesis, the same structures their descendants keep in chloroplasts.

Eukaryotes go much further: internal membranes partition the whole cell into specialized compartments. That difference is one reason eukaryotic cells can be so much larger.

So both kinds of cell divide up their work. A prokaryote does it by region; a eukaryote, by membrane.

KEY POINTS

- Prokaryotes: no membrane-bound organelles, but specialized regions.
- The nucleoid, ribosomes, and in some, internal membranes.
- Eukaryotes partition the cell with internal membranes.



Flagellum A long protein whip that spins to drive the cell along. Bacillus has many; not every bacterium has one.

Plasma membrane A phospholipid bilayer just inside the wall. It controls what enters and leaves the cytoplasm.

Cell wall A thick layer of peptidoglycan outside the membrane. It keeps the cell's shape and stops it bursting when water comes in.

Cytoplasm Mostly water, with enzymes, ribosomes and the DNA in it. Most of the cell's metabolism happens here.

Nucleoid The region where the DNA is: one loop of naked DNA, not wound round histones, with no membrane round it.

Ribosomes Smaller than the ribosomes of a eukaryote, but built the same way, of rRNA and protein. They make the cell's proteins.

Plasmid A small extra loop of DNA, found in many bacteria but not all. Plasmids can carry genes such as antibiotic resistance, and can pass from cell to cell.

WATCH OUT

A nucleoid is not a nucleus. It is a region where the DNA gathers, with no membrane around it.

PREDICT

Cyanobacteria have stacks of internal thylakoid membranes, yet they are still prokaryotes. Why?

(A) Because thylakoids are made of protein, not membrane, so they do not count as a compartment

(B) Because they still have no nucleus or other membrane-bound organelles like mitochondria

(C) Because their thylakoids are found only outside the cell, attached to the cell wall

Decide before you look. Answer on page 26.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

compartmentalization 01
The division of a cell into separate membrane-bound regions, so that different processes can run side by side without interfering.

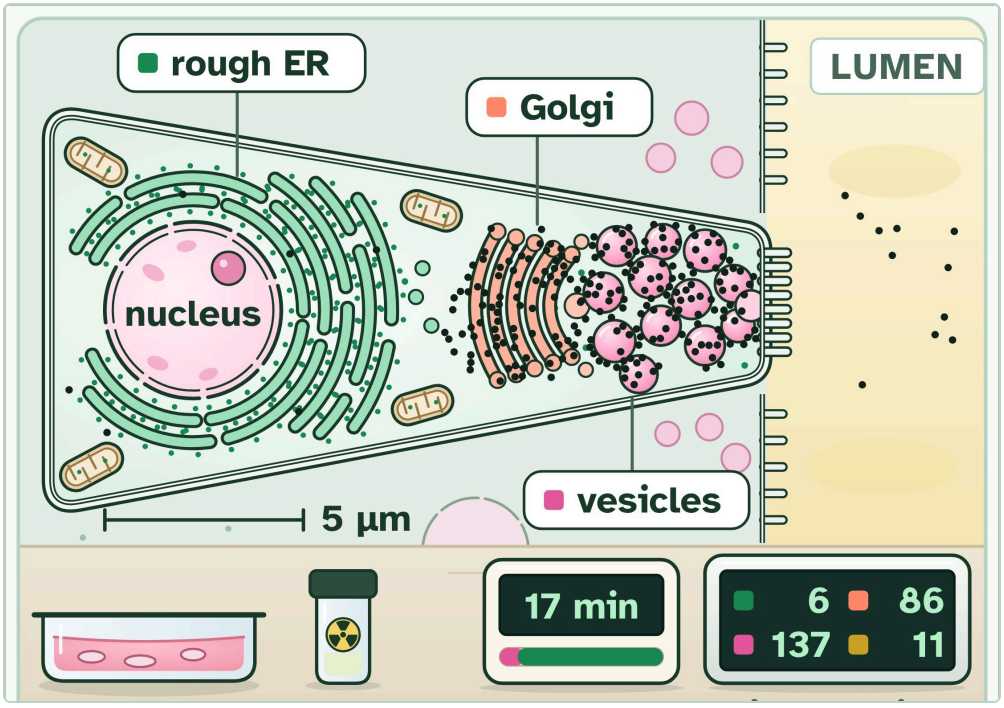
compartments 01
Separate regions of a cell enclosed by membranes, each with its own conditions and enzymes.

endomembrane system 04
The membranes of a eukaryotic cell that are linked by vesicles: the nuclear envelope, the endoplasmic reticulum, the Golgi complex, lysosomes, vacuoles and the plasma membrane.

endosymbiosis 06
The theory that mitochondria and chloroplasts began as free-living prokaryotes that were taken into a larger cell and lived on inside it, to the benefit of both.

Dry lab: *Follow the label*

Give pancreas cells a short pulse of radioactive amino acid, chase it with unlabeled, and count the silver grains over each part of the cell. Find the route a protein takes out, and block a step to see where it piles up.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. biologybybradford.com/guides/ap-biology-unit-2-compartments-and-origins#lab

Your question

Which route does a protein made for export take through the cell, and in what order? Predict first: where will most of the label be 7 minutes after the pulse?

What you can change

The chase time, from 0 to 117 minutes, and a drug added after the pulse that blocks either the exit from the ER or exocytosis. Each dish is one fixed cell, counted fresh, so two dishes at one time are two repeats.

What to record

The percentage of the 240 silver grains over the rough ER, the Golgi, the vesicles and outside the cell for each dish. Graph each part against chase time. The counts are modeled on the shape of Jamieson and Palade's results, with real sampling scatter.

Find out

- **Follow the label.** With no drug, run every chase time from 0 to 117 minutes. Where is most of the label at each?
- **Order the stops.** Graph it. Which part of the cell peaks first, which next, and which last? What does the order tell you about the route?
- **Block a step.** Predict, then run Block ER exit at 37 minutes. Do the same with Block exocytosis at 117 minutes. Where does the label pile up each time?
- **Repeats.** Run each chase time at least twice. How much do two dishes at the same time differ?

Record

- For each dish: the drug, the chase time and the percentage of grains over the rough ER, Golgi, vesicles and outside the cell.
- A graph of the percentage in each part against chase time, one line per part.
- The chase time at which each part holds the most label.
- For each drug, where the label built up, and which step that shows was blocked.

Your question Which route does a protein made for export take through the cell, and in what order? Predict first: where will most of the label be 7 minutes after the pulse?**What you can change**The chase time, from 0 to 117 minutes, and a drug added after the pulse that blocks either the exit from the ER or exocytosis. Each dish is one fixed cell, counted fresh, so two dishes at one time are two repeats.**What to record**The percentage of the 240 silver grains over the rough ER, the Golgi, the vesicles and outside the cell for each dish. Graph each part against chase time. The counts are modeled on the shape of Jamieson and Palade's results, with real sampling scatter.

Back to the cell

Use your results to explain how the cell's membrane-bound compartments work together to make a protein and send it out of the cell.

QUESTIONS ON THE LAB

QUESTION 1

Why is the chase done with the same amino acid, unlabeled, rather than just stopping the experiment?

(A) The unlabeled amino acid washes the radioactive protein out of the cells before they are fixed

(B) The cells go on making protein, but none of it is labeled, so only the first batch is followed

(C) The unlabeled amino acid speeds up the cell, so the labeled protein moves through it faster

Answer on page 27.

QUESTION 2

The Golgi holds the most label at about 7 minutes and the vesicles at about 37. What does this show?

(A) Proteins go to the vesicles first, then back to the Golgi, which sends them on to the rough ER

(B) The Golgi and the vesicles make their own proteins, the Golgi much faster than the vesicles do

(C) Proteins pass through the Golgi before they reach the vesicles, on their way out of the cell

Answer on page 27.

QUESTION 3

With Block exocytosis, nearly all the label at 117 minutes is in the vesicles. What does that suggest the drug does?

(A) It stops the rough ER making protein, so the label never gets as far as the Golgi complex

(B) It stops vesicles fusing with the plasma membrane, so they fill up but cannot release the protein

(C) It breaks down the protein once it is outside the cell, so no label is found out there

Answer on page 27.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on 2.9, 2.10 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?program=ap&units=U2&ced=2.9,2.10&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 A lysosome's enzymes work best at pH 5, and the cytoplasm is about pH 7.2. A lysosome leaks a little. What happens?

B **Little harm is done, because the enzymes work poorly at the cytoplasm's pH**

A small leak does little damage because the enzymes need acid conditions. The compartment does two jobs: it keeps the enzymes apart and gives them the pH they need.

02 Why can a bacterium start making a protein from an mRNA before the mRNA is even finished?

B **Its DNA and ribosomes are in the same compartment, so ribosomes can reach the growing mRNA**

With no nuclear envelope, there is nothing between the DNA and the ribosomes. In a eukaryote the envelope keeps them apart, so transcription and translation happen in turn, in two places.

03 Heart muscle cells have mitochondria with many more cristae than the mitochondria of skin cells. What does this suggest?

B **Heart cells make more ATP, because more inner membrane carries more of the proteins that make it**

The ATP-making proteins sit in the inner membrane. More cristae, more membrane, more of those proteins: a heart that never rests needs a steady, large supply of ATP.

04 Cells that secrete a lot of protein, such as those making digestive enzymes, have lots of which structures?

B **Rough ER and Golgi, because those are where proteins for export are made and then processed**

Proteins for export are made by ribosomes on the rough ER and processed in the Golgi. Pancreas cells that make digestive enzymes are packed with both.

05 A drug stops vesicles fusing with the Golgi. Where does a protein for export build up?

B **Between the rough ER and the Golgi, in vesicles that bud from the ER but cannot fuse with the Golgi**

The vesicles still bud from the ER, but they cannot deliver their cargo. The dry lab shows the same logic: block a step, and the label piles up just before it.

06 If a cell lost all its mitochondria, could it make new ones from its own nuclear genes and membranes?

B **No, because new mitochondria only ever form when an existing one divides**

Mitochondria arise only from other mitochondria, which grow and split as a bacterium does, and part of what they need is coded in their own DNA. That is one of the strongest clues that they were once bacteria.

07 Some antibiotics stop bacterial ribosomes working and leave the patient's cytoplasm ribosomes alone. In high doses, which organelle's proteins can they also affect?

B **The mitochondria, because their own ribosomes are like a bacterium's**

Mitochondrial ribosomes resemble bacterial ones, so drugs that target bacterial ribosomes can slow protein synthesis inside mitochondria too. It is a side effect, and more evidence for endosymbiosis.

08 Cyanobacteria have stacks of internal thylakoid membranes, yet they are still prokaryotes. Why?

B **Because they still have no nucleus or other membrane-bound organelles like mitochondria**

What makes a eukaryote is a nucleus and membrane-bound organelles. Internal folds of membrane, like thylakoids, are found in some prokaryotes too.

QUESTIONS ON THE DRY LAB

Q1 Why is the chase done with the same amino acid, unlabeled, rather than just stopping the experiment?

B **The cells go on making protein, but none of it is labeled, so only the first batch is followed**

Flooding the cells with unlabeled amino acid means any protein made after the pulse carries no label. The labeled batch moves on through the cell like a marked parcel, and its position at each time shows the route.

Q2 The Golgi holds the most label at about 7 minutes and the vesicles at about 37. What does this show?

C **Proteins pass through the Golgi before they reach the vesicles, on their way out of the cell**

The label arrives in each part in turn, so the parts are stops on one route: rough ER, then Golgi, then vesicles, then outside. Each peak comes after the one before it.

Q3 With Block exocytosis, nearly all the label at 117 minutes is in the vesicles. What does that suggest the drug does?

B **It stops vesicles fusing with the plasma membrane, so they fill up but cannot release the protein**

The protein still gets through the ER and Golgi into vesicles, so those steps work. It stops at the last step: vesicles cannot fuse with the membrane, so the label builds up in them.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.