Cellular Physiology

Lesson 3

Cellular Membrane Structure

CHAPTER 10 - Membrane Structure

(The Lipid Bilayer)

Molecular Biology of the Cell by B. Alberts

Prof. Marta Czernik
Experimental Embryology Laboratory
mczernik@unite.it

E-Learning

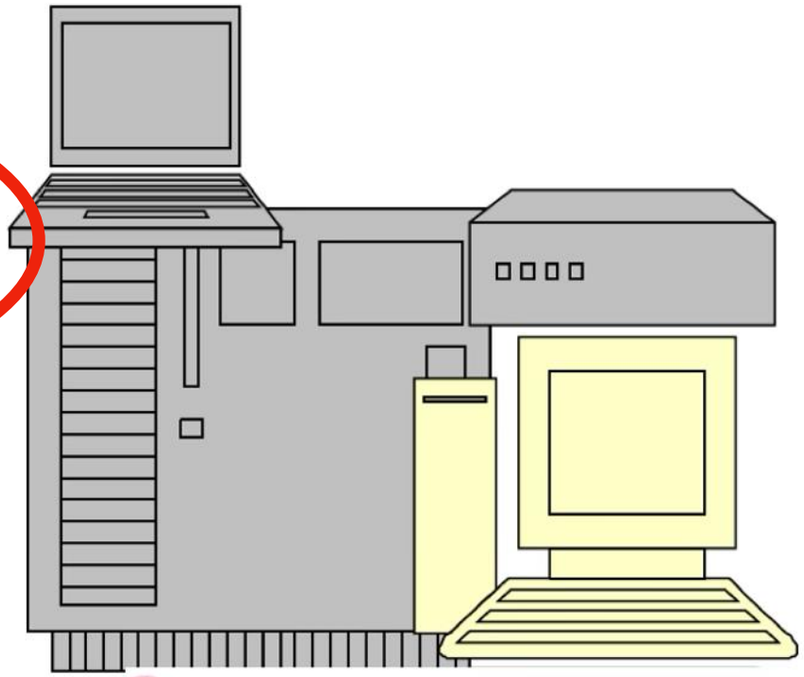
🏭 **Endoplasmic Reticulum — The Protein Factory and Transports**





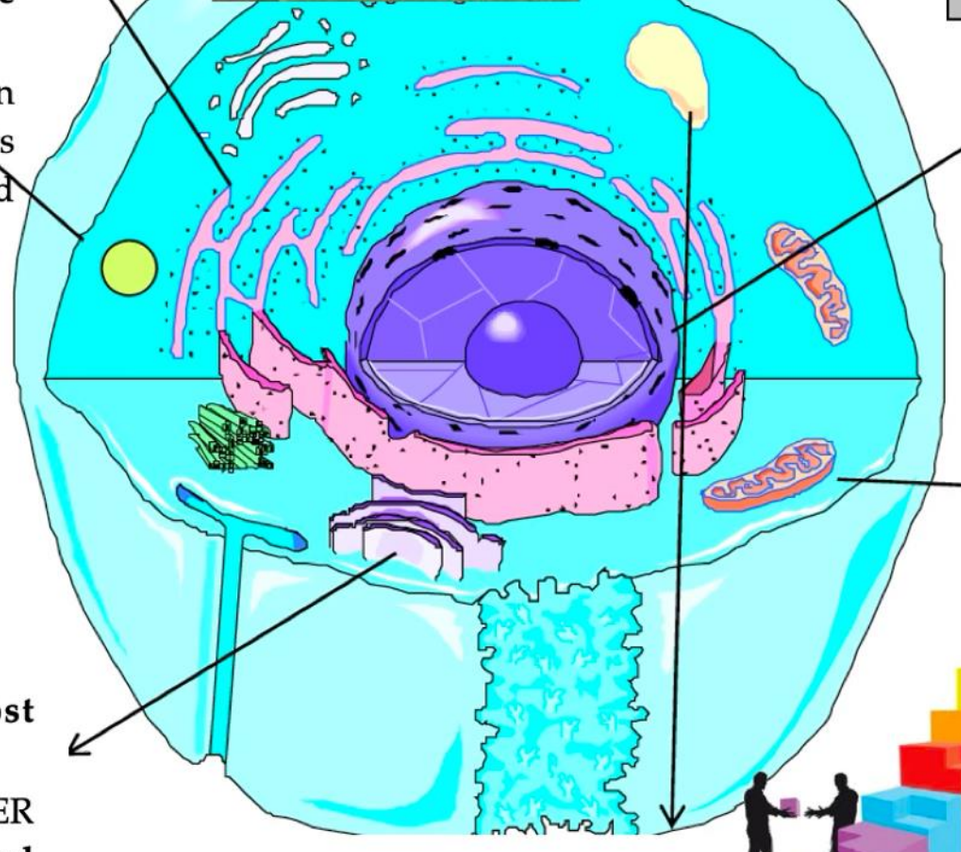
🚪 **Plasma Membrane — The City Wall & Border Control:** A selective security gate! It **decides who gets in and out**, keeping the city safe while letting in food, supplies, and information.





🗑️ **Lysosomes — The Recycling & Waste Management Center**

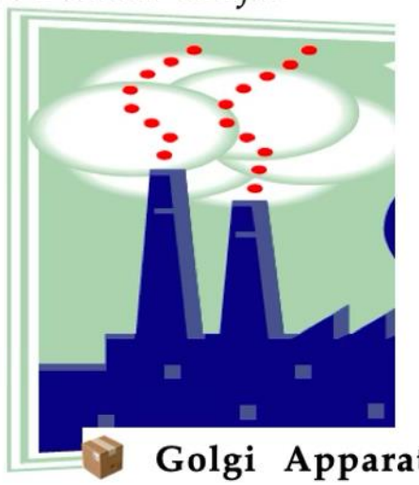
They clean up the city — breaking down trash, old materials, and unwanted guests (like bacteria). Without them, the city would be a *cellular landfill*!



🧠 **The Nucleus — City Hall (Mayor's Office)**

The boss of the whole city! It keeps the **blueprints (DNA)** safe and decides what needs to be built, fixed, or copied.

All major "city policies" come from here.



📦 **Golgi Apparatus — The Post Office / Delivery Hub**

All those proteins and lipids from the ER arrive here for **labeling, packaging, and shipping**. If a protein doesn't have a proper "address," it's going nowhere!



⚡ **Mitochondria — The Power Factory**

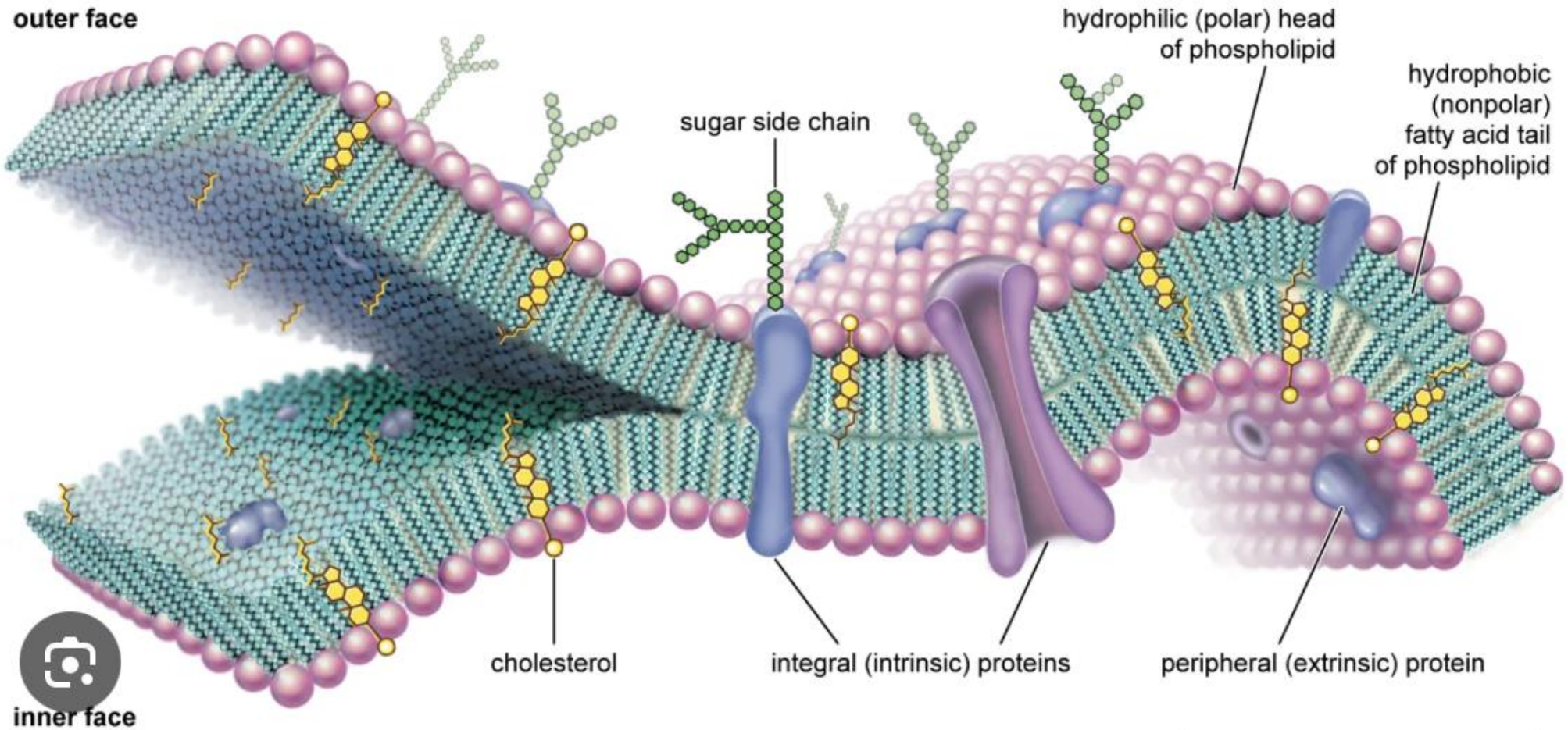
No electricity, no life! Mitochondria produce **ATP**, the city's energy currency.



🏠 **Vacuoles — The Storage Warehouses**

These are **supply depots** — storing water, food, and spare parts. In plant cells, the central vacuole is like a *giant water tank* that keeps the whole city firm and standing tall.

Cell membrane of it as a **high-tech security system**, **communication center**, and **life gate** - all packed into a structure only **5 nanometers thick!**



Pictures taken from "Encyclopædia Britannica, Inc."

When line up all the membranes from our body's cells, **they would stretch for tens of thousands of kilometers -** enough to wrap around the Earth more than once!!!!

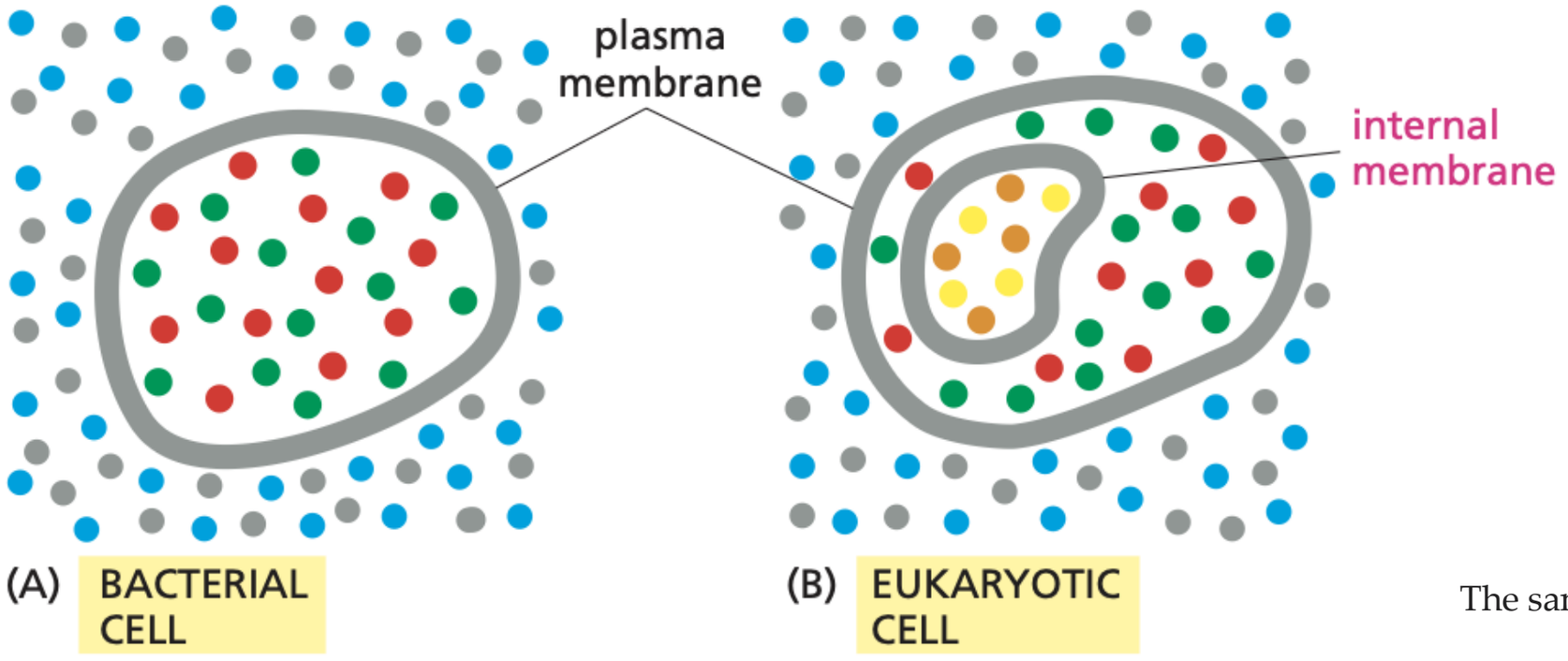
Cellular Membrane

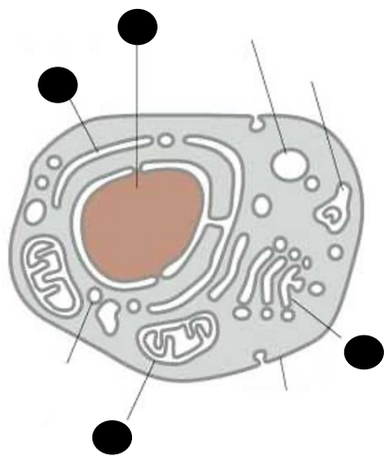
Cell is a self-reproducing system of molecules held inside a container.

That container is the **plasma membrane** - a protein-studded, fatty film so thin that it cannot be seen directly in the light microscope.

All cells use the membrane to separate and protect its components form the outside

Without membranes, there would be no cells, and thus no life.





The same principles but different resident proteins

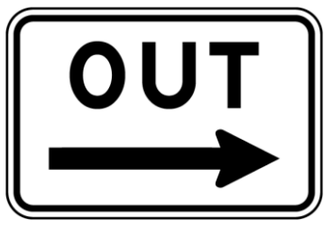
The plasma membrane is a selective barrier



Undesirable molecules, microorganisms, etc.



Metabolic products or messengers



Desirable nutrient molecules

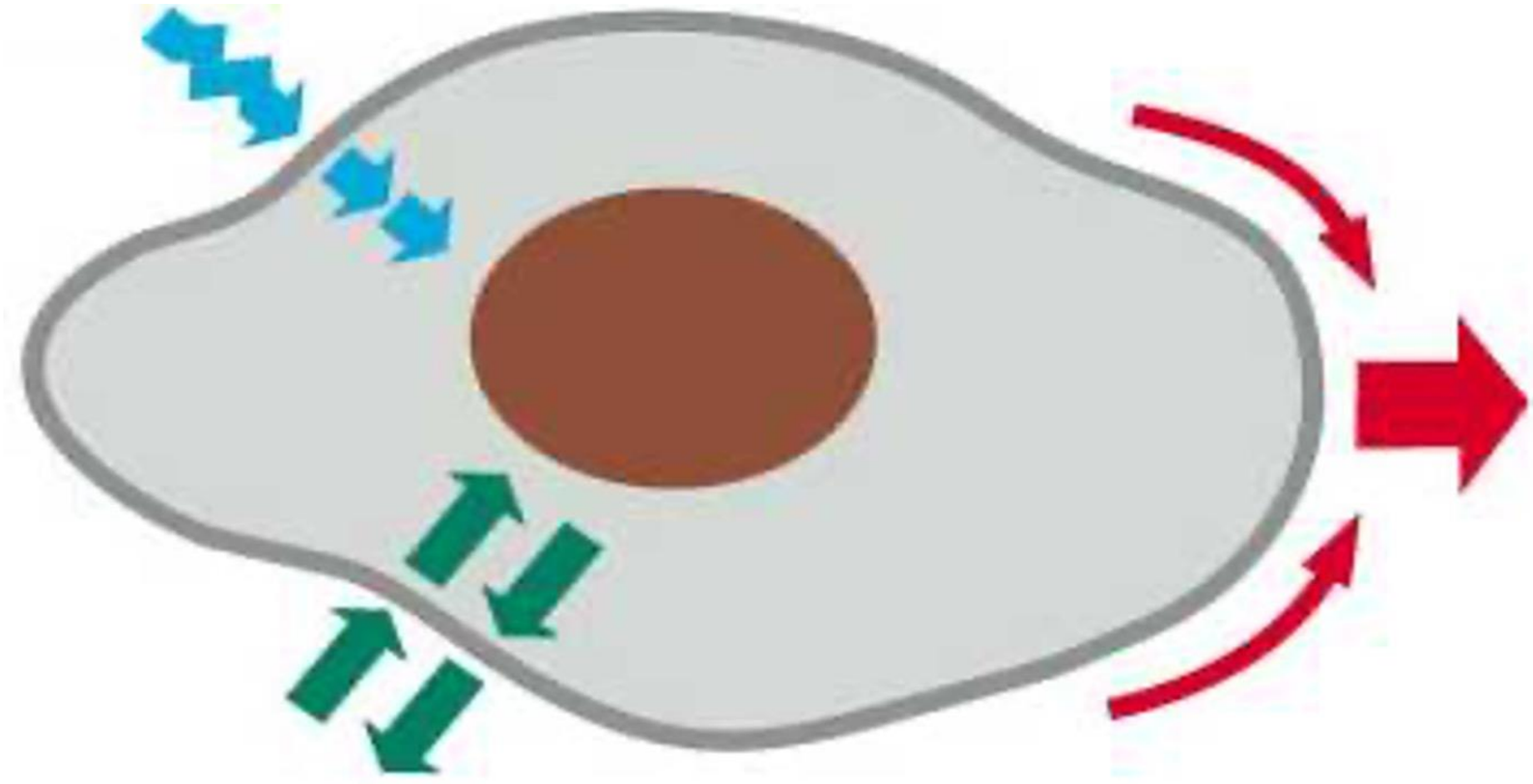
Nutrient and/or molecules



Functions of the plasma membrane

Receiving information

Cell Communication



Ability for movements and expansion

Growth and motility

Import/export small molecules

Functions of the Plasma Membrane

1. **Selective Barrier (*Security checkpoint*)**: Controls what enters and leaves the cell - allowing nutrients in, removing waste, and preventing harmful substances from entering.

2. **Communication and Signaling (*Cell's phone or Wi-Fi antenna)*:** Contains receptors that receive chemical messages (like hormones or neurotransmitters) from other cells.

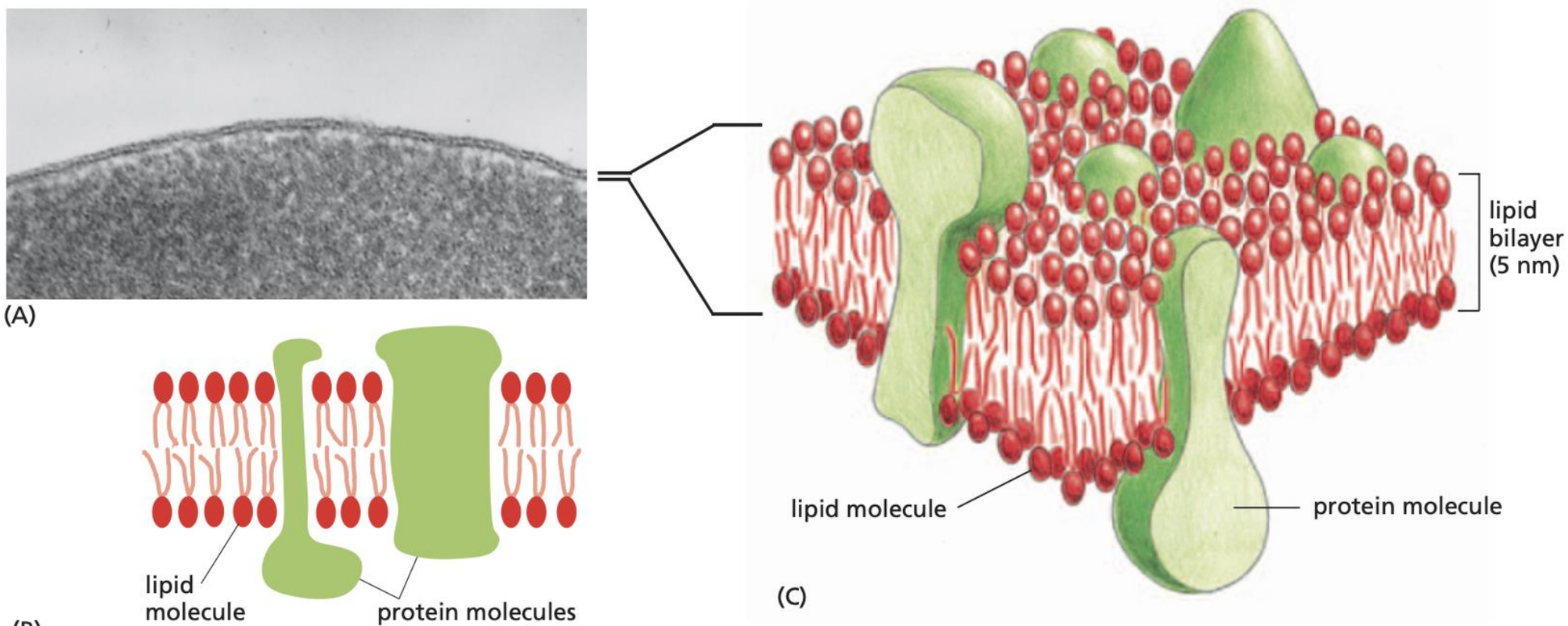
3. **Cell Recognition (*ID cards*)**: Has surface molecules that act as "ID cards," helping cells recognize each other - important for tissue organization and immune response.

4. **Structural Support and Shape**: Gives the cell its shape and anchors the cytoskeleton, helping maintain stability and flexibility.

5. **Transport Regulation**: Uses proteins to actively move ions and molecules across the membrane (e.g., Na^+/K^+ pump).

6. **Attachment and Interaction**: Helps cells stick to each other and to the extracellular matrix, forming tissues.

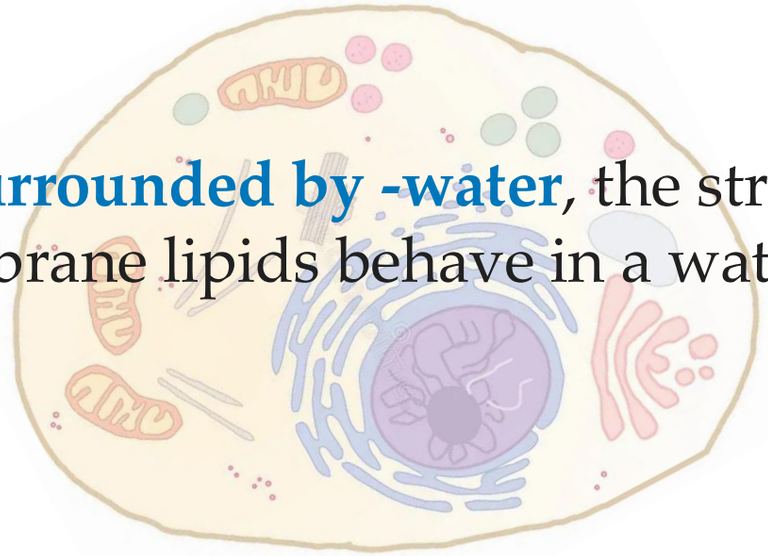
Cellular membrane



- All cellular membranes are composed of **lipids and proteins** and share a common general structure

- The lipids are arranged in two closely apposed sheets, forming a **lipid bilayer** **(serves as a permeability barrier to most water-soluble molecules**)

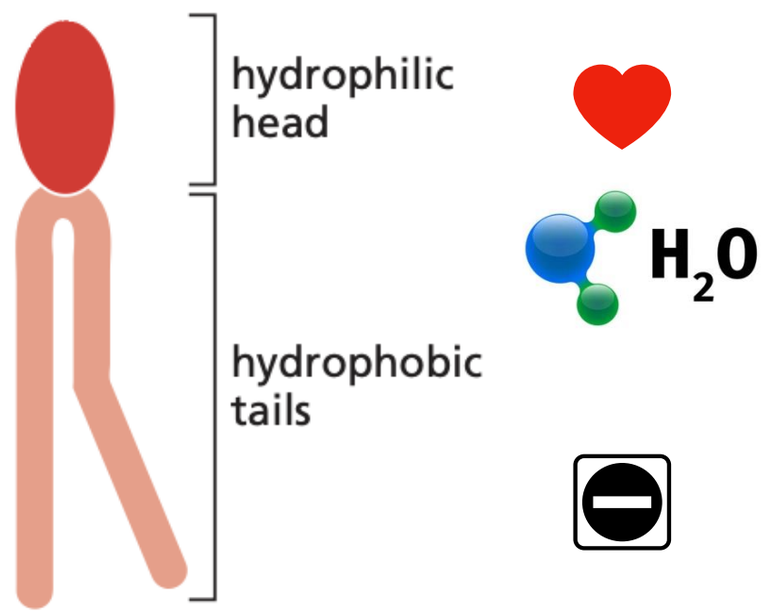
- The proteins carry out the other functions of the membrane and give different membranes their **individual characteristics.**



Cells are **filled with - and surrounded by -water**, the structure of cell membranes is determined by the way membrane lipids behave in a watery (aqueous) environment.

The lipids in cell membranes **combine two very different properties** in a single molecule:

- hydrophilic ("water-loving") head
- hydrophobic ("water-fearing") tail.



The most abundant lipids in cell membranes are the **phospholipids**, which have a phosphate-containing, **hydrophilic head** linked to a pair of **hydrophobic tails**

https://www.youtube.com/watch?v=RT61MUjogRo

Phosphatidylcholine (most common phospholipid in cell membranes), has the small molecule choline attached to a phosphate group as its hydrophilic head

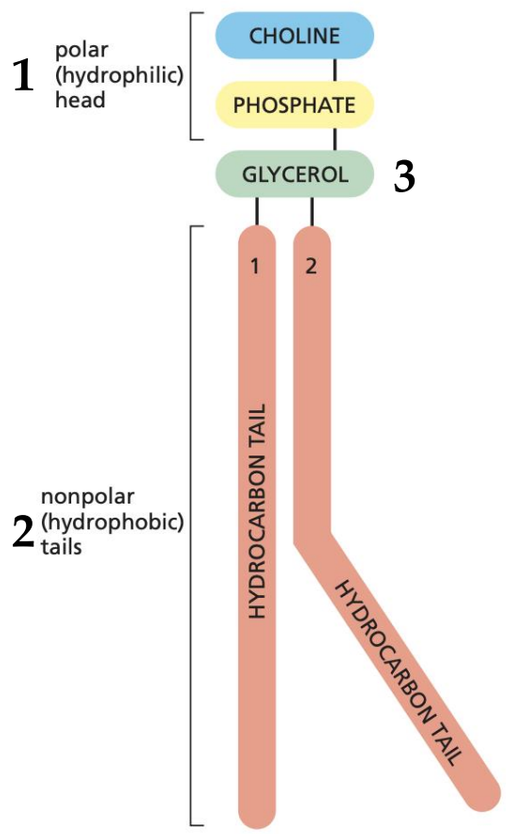
hydrophilic head, which consists of *choline* linked to a p*hosphate group;*



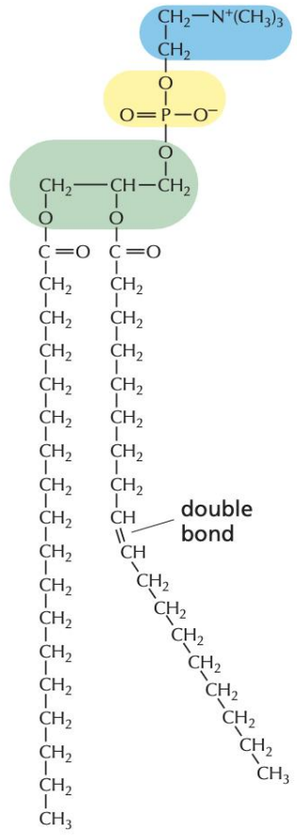
two *hydrocarbon chains*, which form the hydrophobic tails;



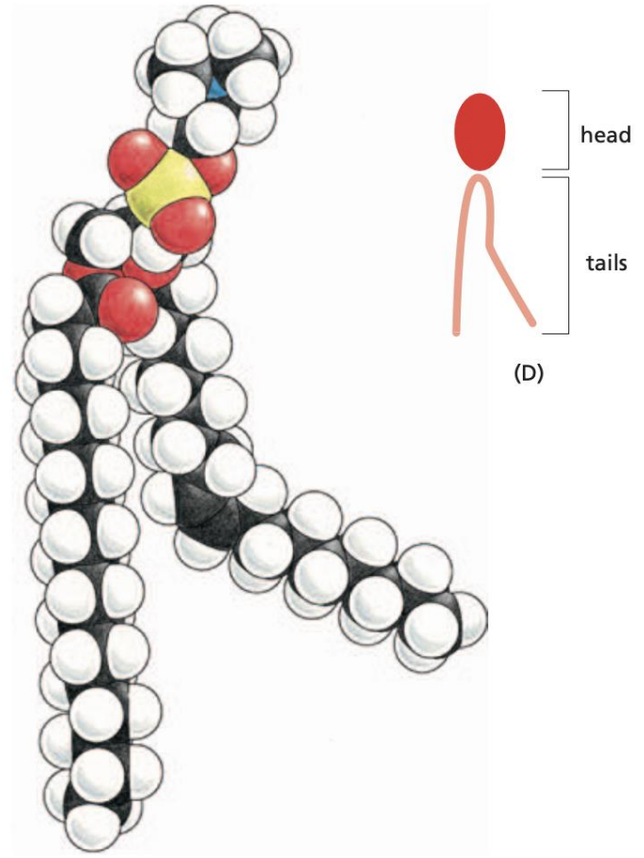
schematically



chemical formula



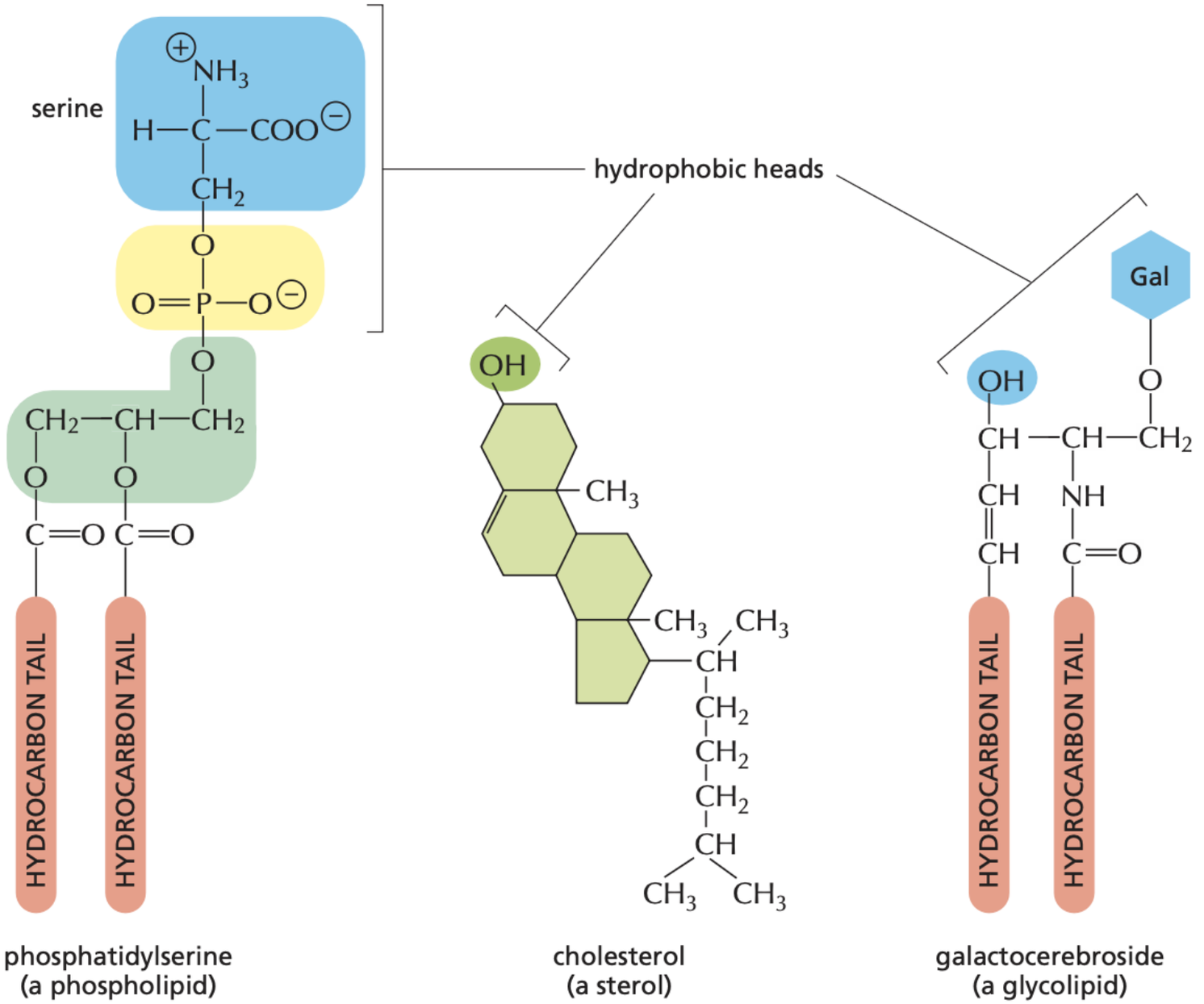
space-filing model



Each of the **hydrophobic tails is a *fatty acid*** [a hydrocarbon chain with a -COOH (carboxyl) group at one end] which has been attached to glycerol via this group.

A **kink in one of the hydrocarbon chains** occurs where there is a double bond between two carbon atoms.

Other types of Membrane lipids



phosphatidylserine
(a phospholipid)

cholesterol
(a sterol)

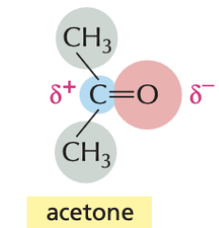
galactocerebroside
(a glycolipid)

Glycolipid -
Have a sugar as part of hydrophilic head

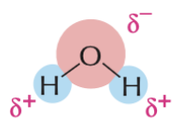
Molecules with both hydrophilic and hydrophobic parts are termed **amphipathic.**

Hydrophilic ("water-loving") molecules dissolve easily in water (attract water molecules) because they have charged or polar groups that can form hydrogen bonds or electrostatic interactions with water.

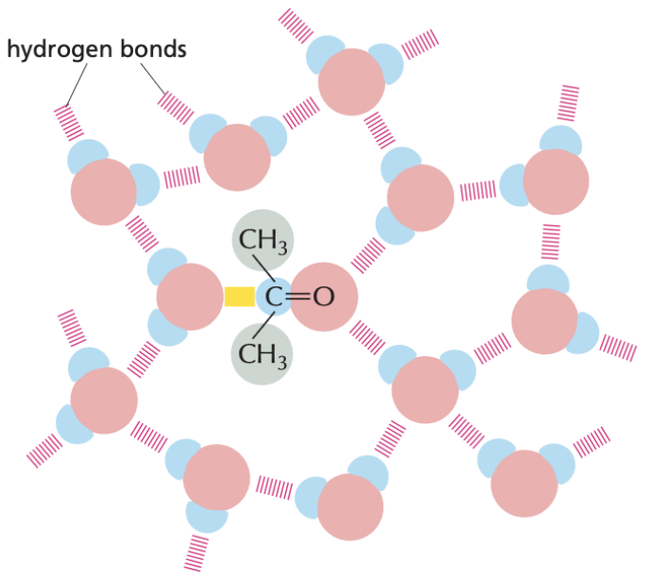
Polar atoms



acetone



water



acetone in water

Hydrophilic molecules are like **people who love being in the rain.**

They **mix well with water** because they have parts (charged or polar groups) that can **form friendships** - or, scientifically speaking, **hydrogen bonds** and **electrostatic interactions** - with water molecules.

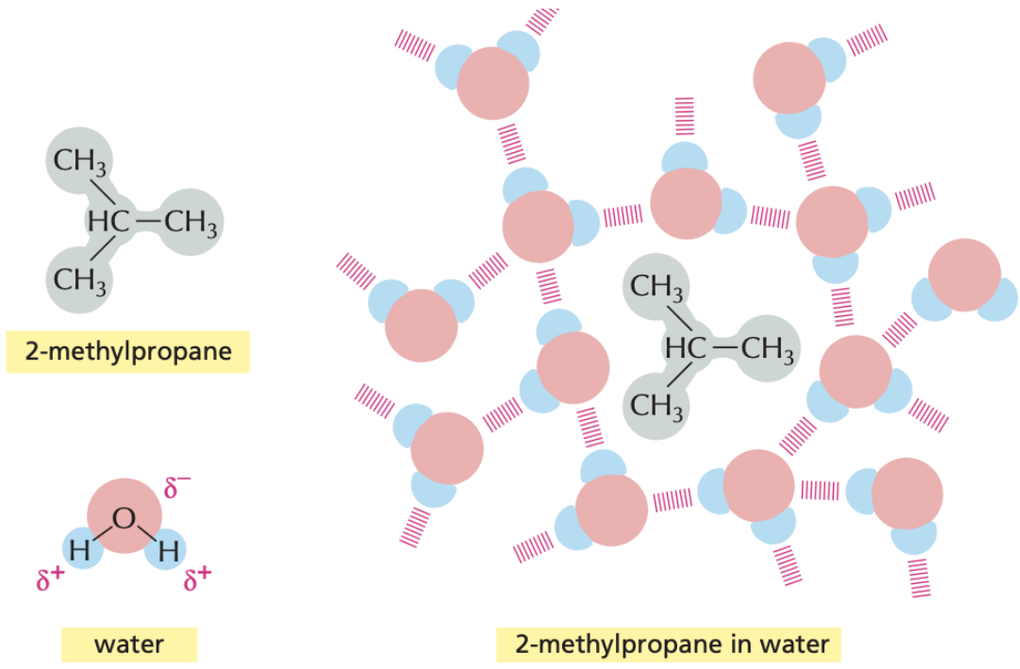
So when you put them in water, they don't hide or clump together.



- Water molecules are attracted to sugar molecules.
- They surround the sugar molecules and help separate them from one another.
- As a result, the sugar spreads throughout the water.

This happens because sugar has special chemical groups **called polar groups**, which can form weak attractions with water called **hydrogen bonds.**

Hydrophobic ("water-fearing") molecules are mostly uncharged and non-polar, so they can't make these interactions. Water molecules around them become more ordered, which costs energy. To reduce this cost, hydrophobic molecules stick together and form droplets - like fats and oils do in water.



Hydrophobic molecules are like **people who hate getting wet in the rain** - they try to stay away from water at all costs!

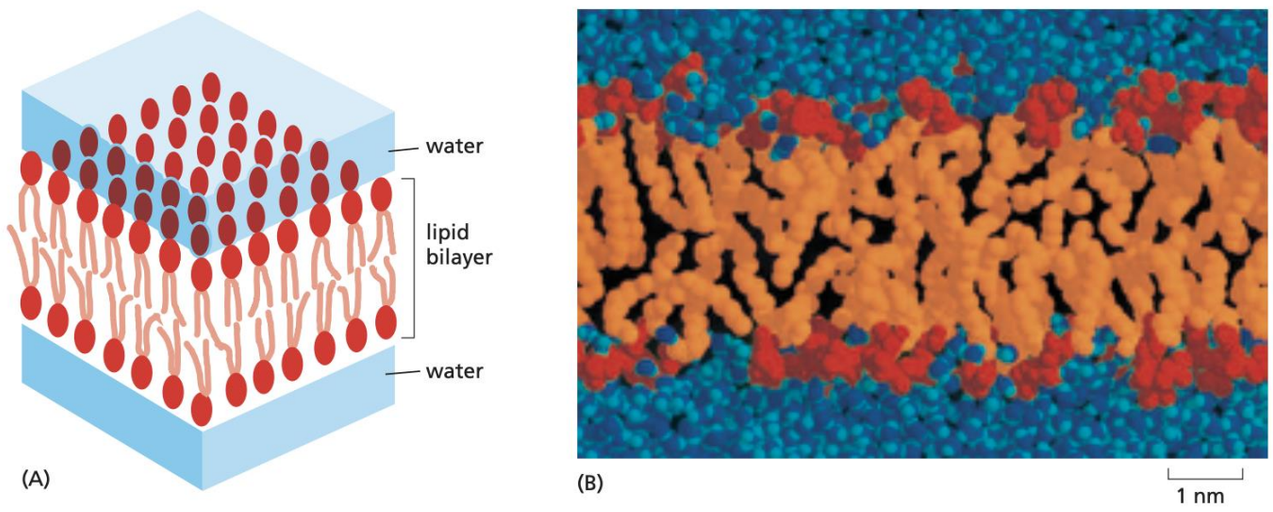
They are **uncharged and non-polar**, which means they can't form "friendships" (hydrogen bonds) with water molecules. Because of that, water doesn't mix with them easily.

That's why **oil and water don't mix** - oil molecules huddle together and form droplets, just like people squeezing under one umbrella during a storm!

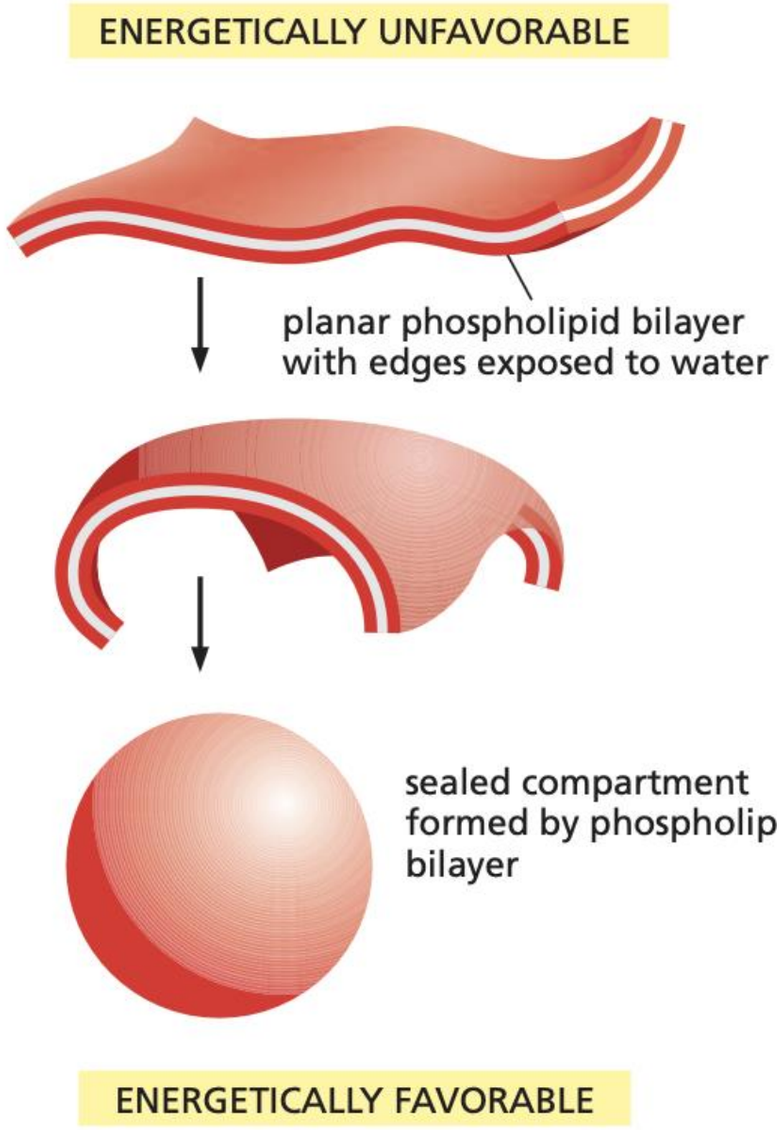
Amphipathic molecules, such as phospholipids, are subject to **two conflicting forces**: the hydrophilic head is attracted to water, while the hydrophobic tails shun water and seek to aggregate with other hydrophobic molecules.

This conflict is beautifully resolved by the formulation of a LIPID BILAYER

The hydrophilic heads face water on both surfaces of the bilayer; but the hydrophobic tails are all shielded from the water, as they lie next to one another in the interior, like the filling in a sandwich



Amphipatic phospholipids form a bilayer in water



Phospholipid bilayers spontaneously close in on themselves to form sealed compartments.

The closed structure is stable because it avoids the exposure of the hydrophobic hydrocarbon tails to water, which would be energetically unfavourable.

https://en.khanacademy.org/science/ap-biology/cell-structure-and-function/plasma-membranes/v/fluid-mosaic-model-of-cell-membranes

The Lipid Bilayer is a Flexible two-dimensional Fluid

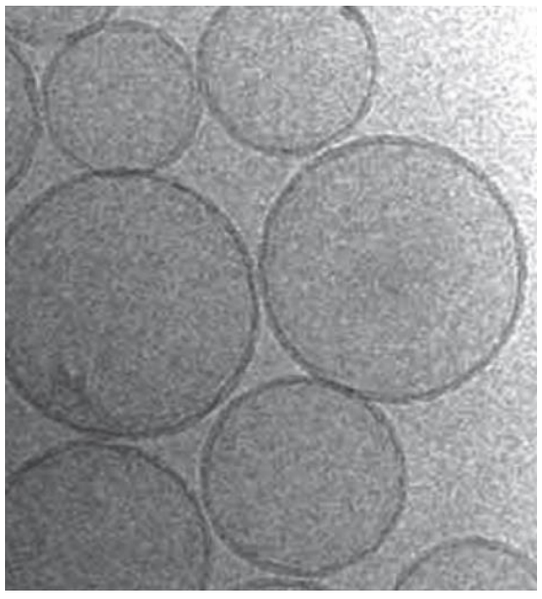
Water inside and outside of the membrane keeps lipids trapped in the bilayer but they like to changing place with one another and move freely inside (like people in the crowned place).

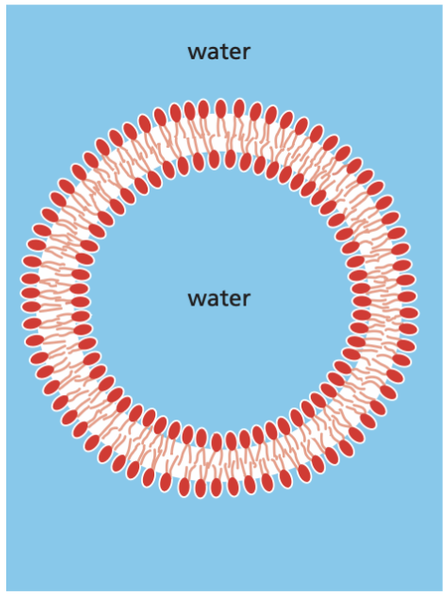
That fluidity is essential for membrane function.

The lipid bilayer is also flexible - able to bend (important for membrane function)

The fluidity of the lipid bilayer can be study using synthetic lipid bilayers

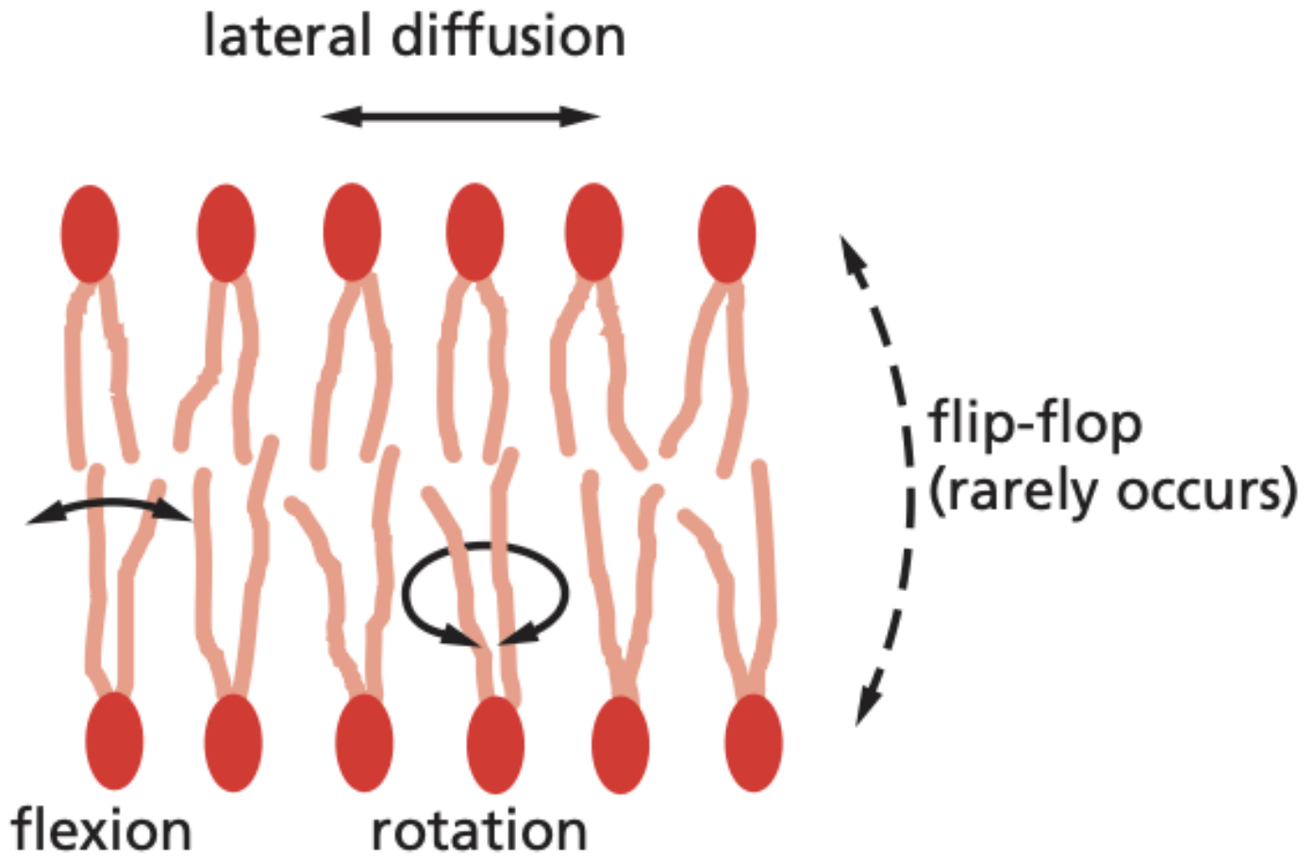
Pure phospholipids can form closed, spherical liposomes.





Synthetic bilayers (liposomes) show the same behavior.

Lipids rarely “flip-flop” from one side to the other without proteins, but they move sideways, rotate, and bend their tails very quickly (a lipid can diffuse across the length of a bacterial cell in about a second)



The FLUIDITY of a Lipid Bilayer

- Membrane fluidity is important for its function and depends of its composition

- the closer and more regular the packing of the tails, the more viscous and less (lower) fluid the bilayer will be.

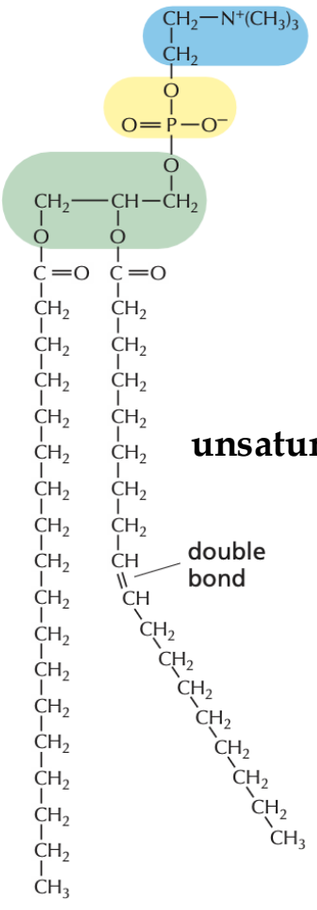
- Length and the number of double bonds the hydrocarbon tails contain affect how tightly they pack in the bilayer.

- A shorter chain length reduces the tendency of the hydrocarbon tails to interact with one another - increases the fluidity of the bilayer.

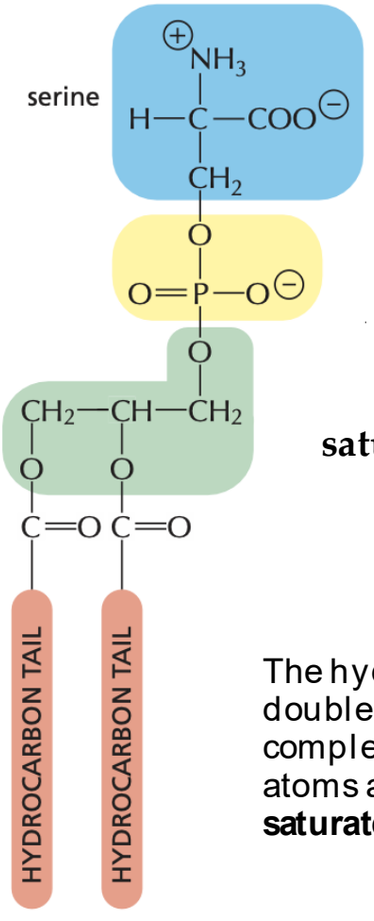
https://www.youtube.com/watch?v=UYg4Owdm3cA

A hydrocarbon chain with a double bond has fewer hydrogens, so it is called **unsaturated**. A chain with no double bonds has the maximum number of hydrogens and is **saturated**.

The chain that harbors a double bond does not contain the maximum number of hydrogen atoms that could, in principle, be attached to its carbon backbone; it is thus said to be unsaturated with respect to hydrogen.



unsaturated



saturated

The hydrocarbon tail with no double bonds has a full complement of hydrogen atoms and is said to be **saturated**

Each double bond creates a kink in the tail, making it harder for the lipids to pack tightly. As a result, membranes with more **unsaturated tails are more fluid.**

Bacteria and yeast can change the length and saturation of their membrane lipids to keep the membrane equally fluid at different temperatures.

At high temperatures they make lipids with longer tails and fewer double bonds, which makes the membrane less fluid.

Plants naturally produce unsaturated (more fluid, liquid at RT) oils.

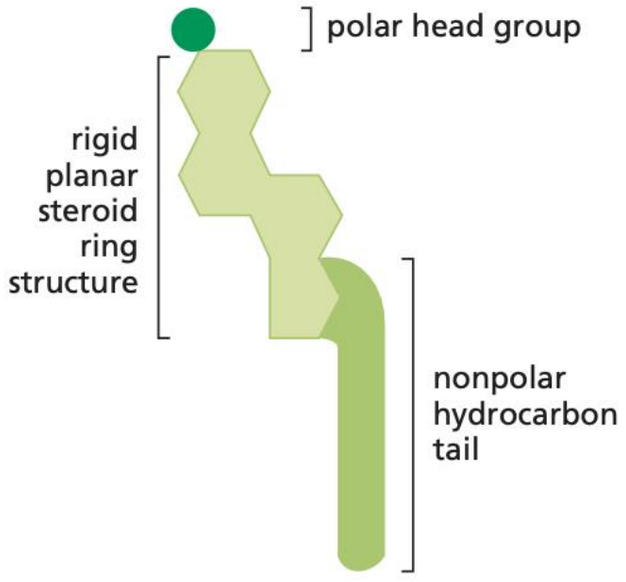
Animal fats (butter, lard) are mostly saturated and solid at room temperature (RT).

Margarine is made by adding hydrogen to vegetable oils to remove double bonds, turning them into more solid, butter-like fats at RT.

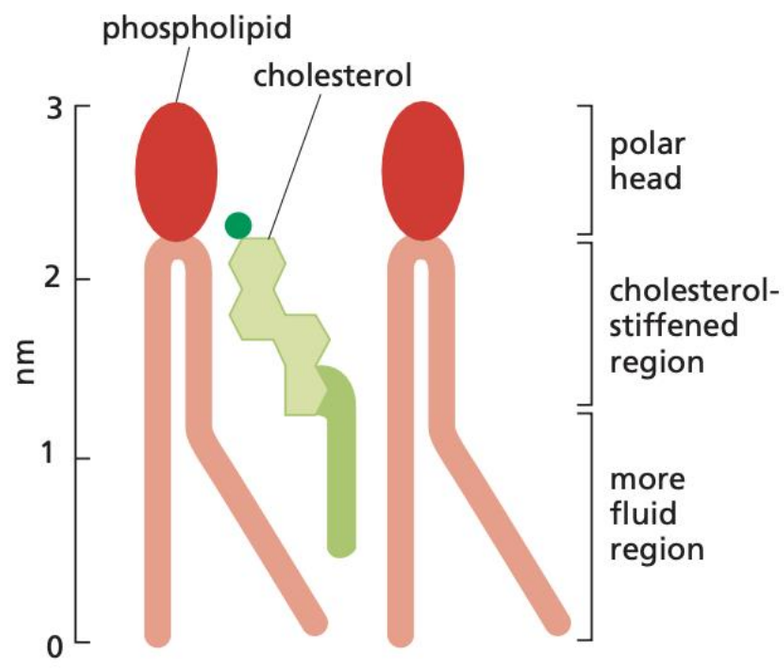
How to increase Membrane Fluidity

In animal cells, cholesterol is used to modulate membrane fluidity – it fills the gaps between the nodes of unsaturated chains.

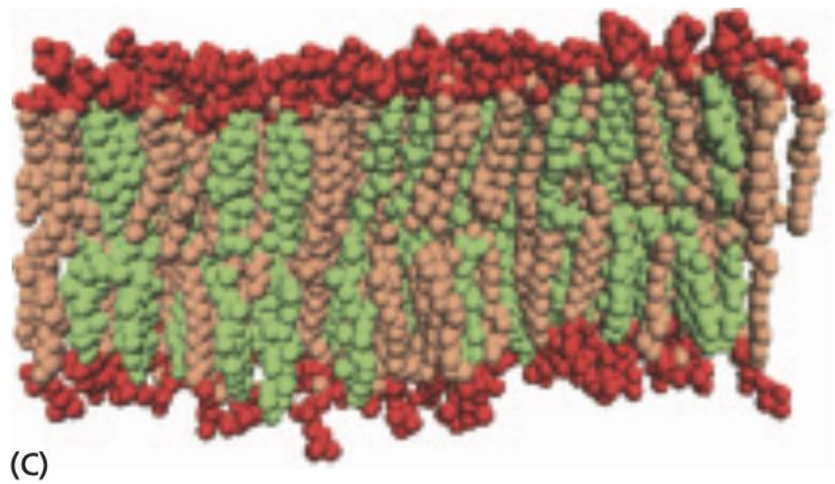
Particularly used in the plasma membrane - tight packing - lower fluidity/permeability.



The shape of a cholesterol molecule



Cholesterol fits into the gaps between phospholipid molecules in a lipid bilayer



Space-filling model of the bilayer, with cholesterol molecules

Why does the membrane need to be fluid?

- It allows rapid lateral diffusion of membrane proteins in the bilayer and promotes their interactions (important for cellular communication/signalling).

- It facilitates the distribution of lipids and membrane proteins from the insertion site to other regions of the cell.

- It allows membranes to fuse and mix molecules.

If the membrane is fluid…	The cell can…
Proteins move sideways	Organize signaling and other activities
Membrane bends	Change shape
Membranes rearrange and fuse	Perform endocytosis and exocytosis
Lipids adjust their packing	Maintain proper membrane function

If biological membrane were not fluid, it is hard to imagine how cells could live, grow and reproduce.

Where the membrane Assembly Begins?

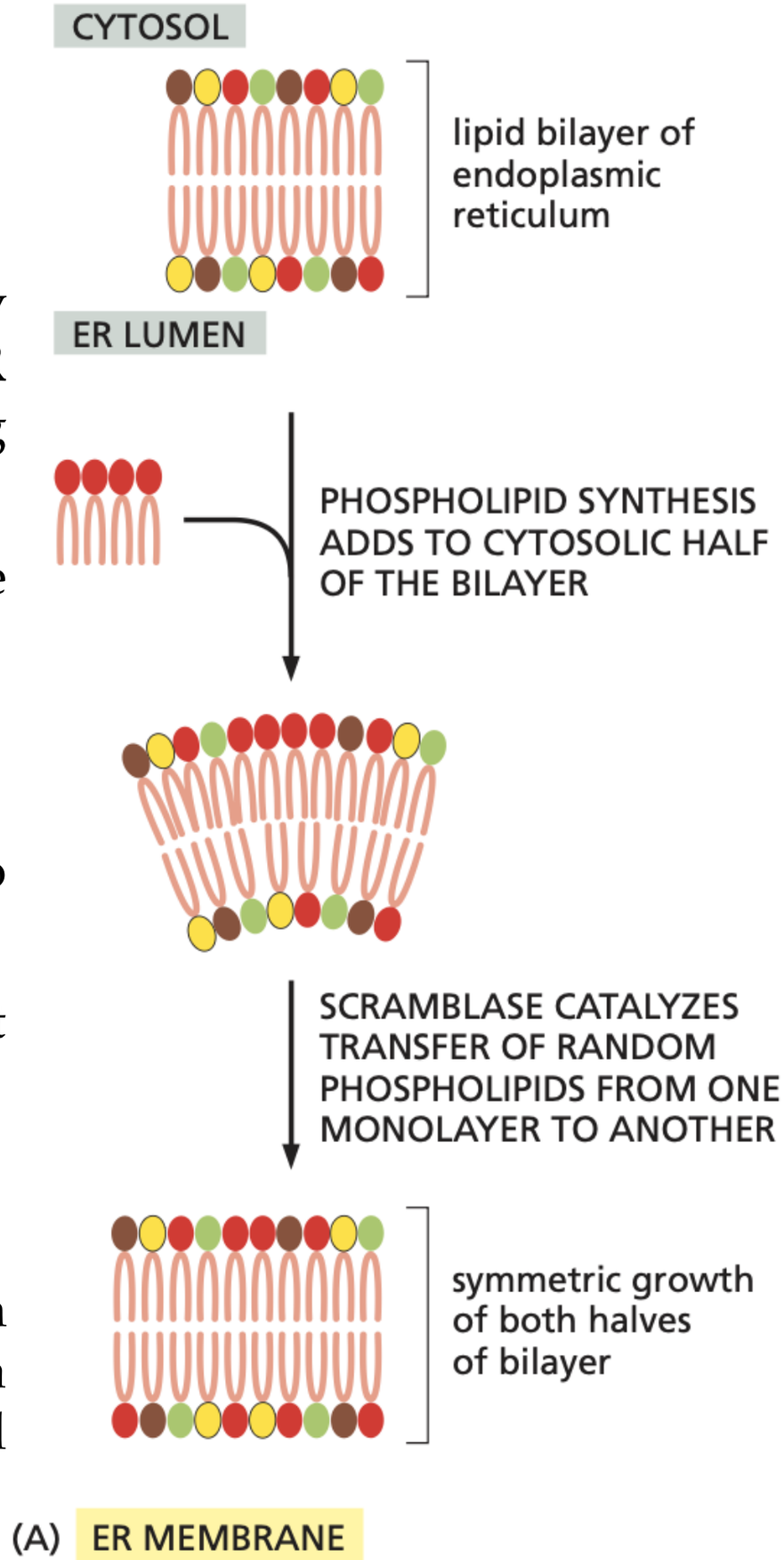
In eukaryotic cells, new **phospholipids** are made by enzymes bound on the **cytosolic surface of the ER** membrane, using **free fatty acids** as substrate, as building blocks.

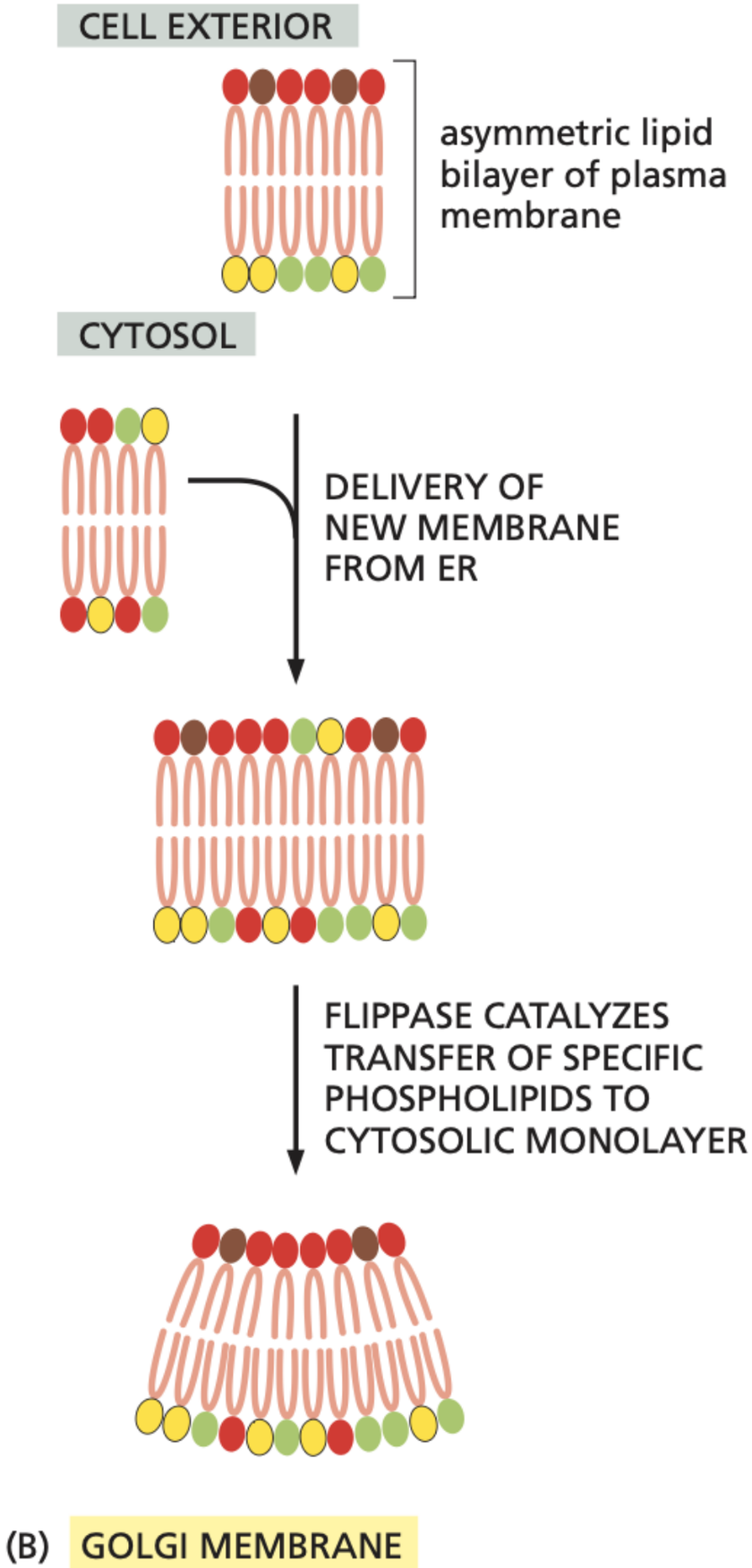
Initially, the phospholipids are added only to one half of the bilayer.

Enzymes called **scramblases** then move phospholipids to the other side, so the bilayer grows evenly.

Some of the new **membrane stays in the ER**, while the rest is packaged into **small vesicles**.

These vesicles travel to the **Golgi apparatus**, and from there, more vesicles carry membrane to the plasma membrane and other cell compartments, ensuring the cell has enough membrane in the right places.



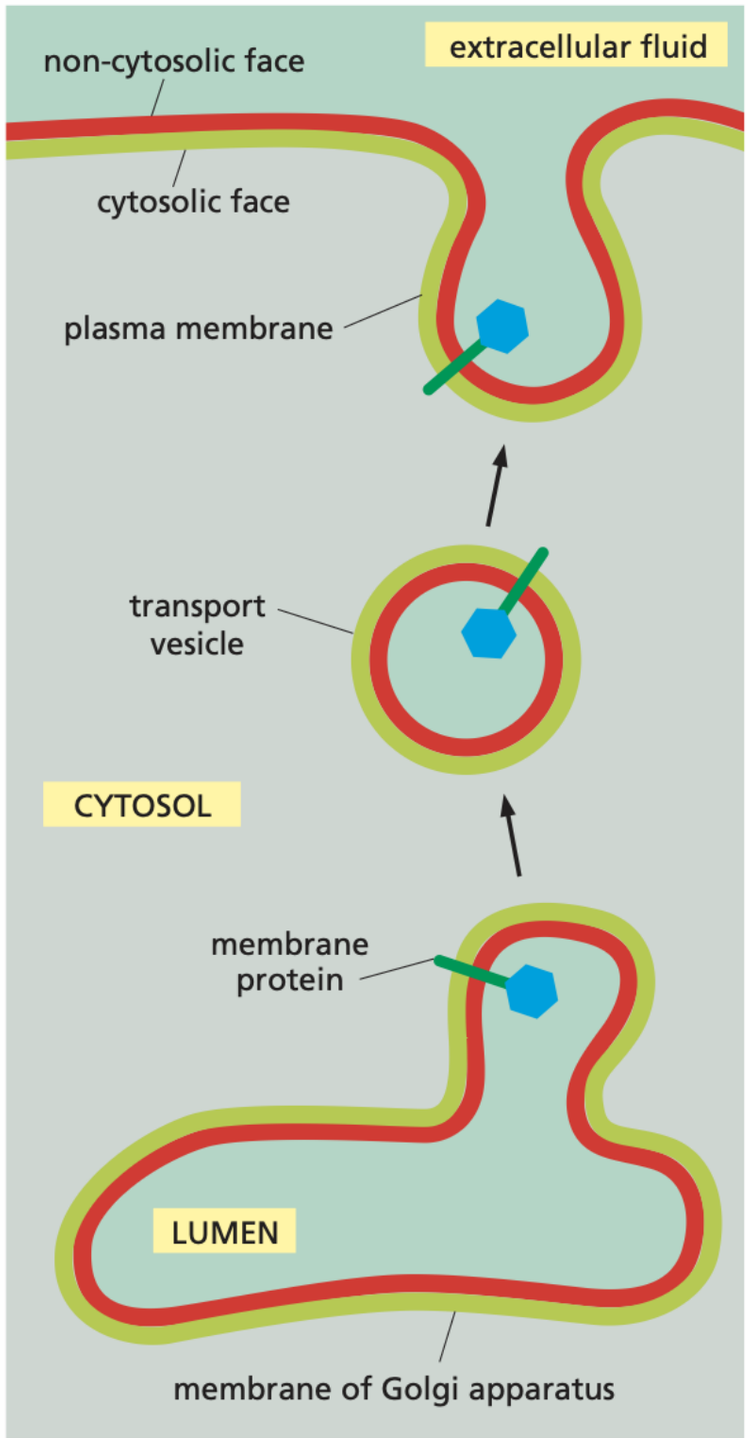


When membranes leave the ER and are incorporated in the Golgi, they encounter enzymes called **flippases**, which selectively remove "phospholipids light green" and "yellow" from the noncytosolic monolayer and flip them to the cytosolic side.

This transfer leaves "phospholipids red and brown" concentrated in the noncytosolic monolayer.

The resulting curvature of the membrane may actually help drive subsequent vesicle budding.

Membranes retain their orientation during transfer between cell compartments.

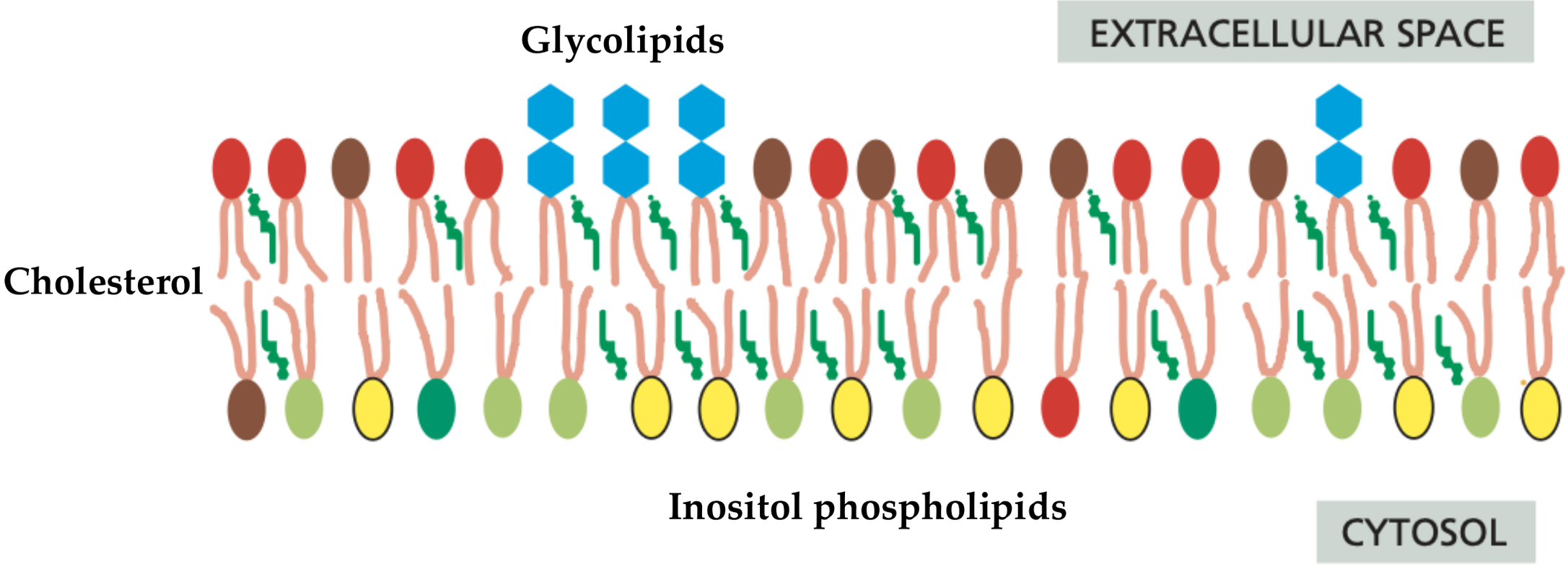


Membranes are transported by a process of vesicle budding and fusing.

Orientations of both the membrane lipids and proteins are preserved during the process.

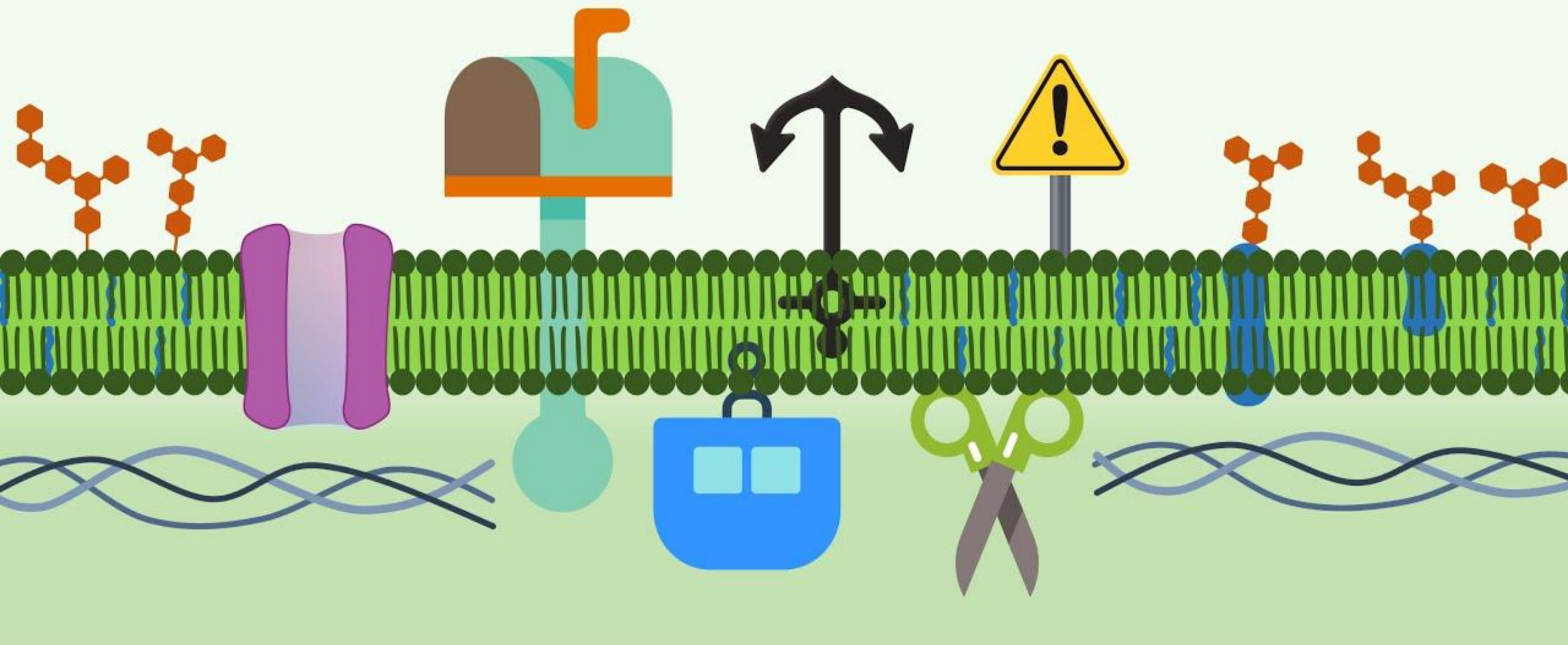
Lipid bilayer asymmetry

Glycolipids are found mainly in the plasma membrane and only on the **outer (non-cytosolic) side**. Their sugar groups face outward and form part of the protective carbohydrate coat around animal cells.
These sugars are added in the Golgi apparatus to lipids on the outer half of the bilayer, and glycolipids stay there because there are no enzymes to flip them to the inner side.



Term	Meaning
Cell membrane	Specialized structure that surrounds the cell and its internal environment; controls movement of substances into/out of cell
Hydrophobic	Molecule that repels water ("water-fearing")
Hydrophilic	Molecule that is attracted to water ("water-loving")
Amphipathic	Molecule that contains both a hydrophobic and a hydrophilic end
Phospholipid	Amphipathic lipid made of glycerol, two fatty acid tails, and a phosphate group
Phospholipid bilayer	A biological membrane involving two layers of phospholipids with their tails pointing inward
Semipermeable membrane	Membrane that allows certain substances to pass through

Cell Membrane



https://www.youtube.com/watch?v=SsFqmYATM3k

Any Questions?

It's a skin and a city wall at once: The membrane is only about 5 nm thick — 1/20,000 of a human hair - yet it protects the cell and controls all traffic in and out.

Our cells are constantly recycling it: Every few minutes vesicles from inside the cell fuse with the plasma membrane and other bits pinch off. In a day a cell can recycle an amount of membrane equal to its entire surface area many times.

It's a living "sea" of lipids: Lipids and many proteins drift sideways like boats in a 2-D ocean; a single lipid can travel the length of a bacterial cell in about a second.

It's decorated like a candy apple: Sugars attached to proteins and lipids form a carbohydrate "coat" that protects the cell and helps it stick to neighbours - and is unique to each cell type, a bit like a barcode.

Cholesterol is its shock absorber: Cholesterol molecules slot between lipids and keep the membrane from becoming too stiff when cold or too leaky when hot.

It can self-heal: Small tears in the bilayer close spontaneously because exposing its edges to water costs energy.

Our brain uses most of it: Neurons have huge membrane surfaces because of their long processes; membrane turnover is massive in the nervous system.

Many viruses steal bits of the host cell membrane to make their own outer coat ("envelope") when they bud out of the cell.

https://app.jove.com/science-education/v/11659/asymmetric-lipid-bilayer