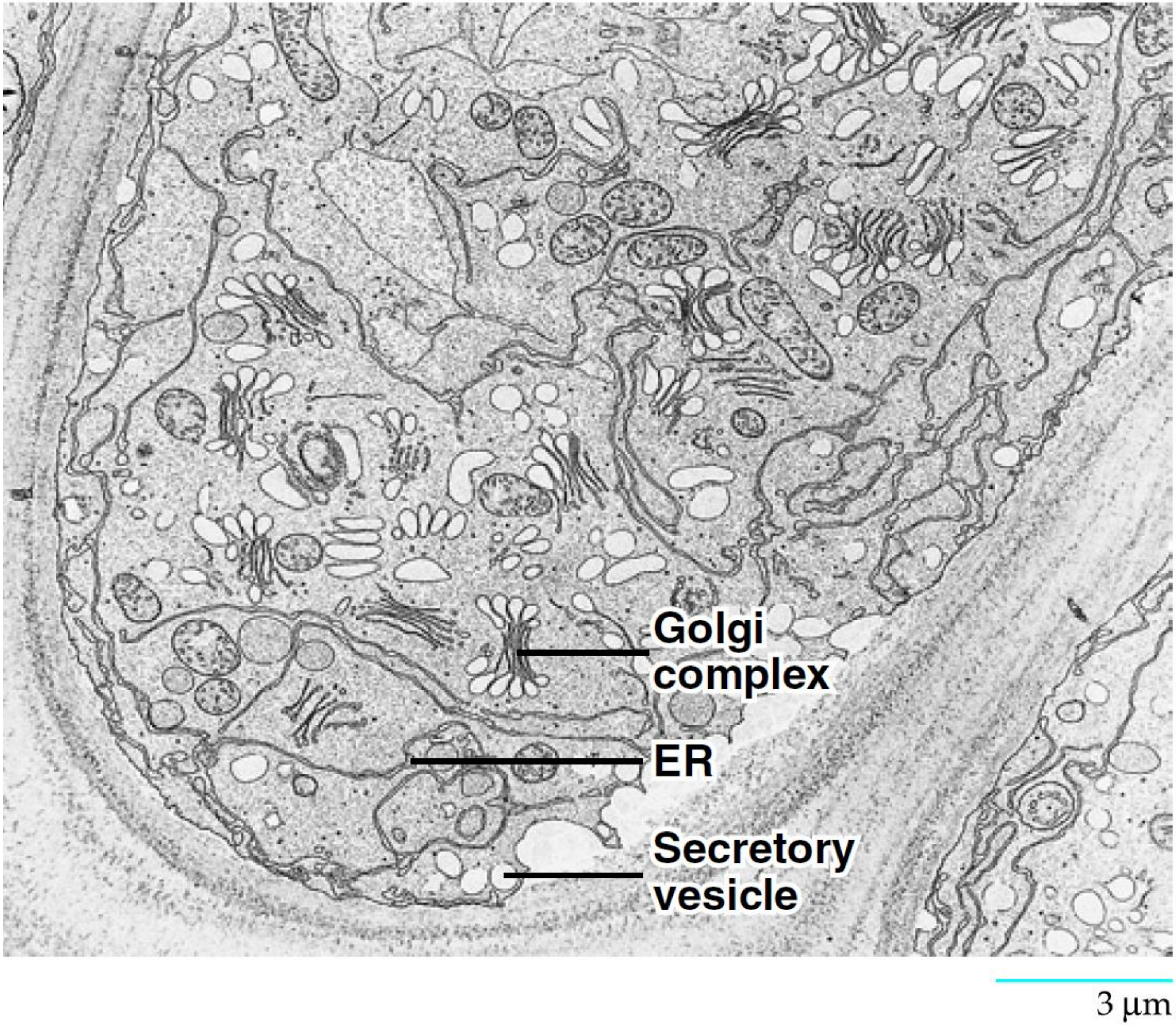
Cytoplasmic Membrane Systems

❖Under the light microscope, the cytoplasm of living cells appears relatively devoid of structure.

❖Yet, even before the beginning of the twentieth century, examination of stained sections of animal tissues hinted at the existence of an extensive membrane network within the cytoplasm.

❖It became evident from the early electron microscopic studies and the biochemical investigations that followed that the cytoplasm of eukaryotic cells was subdivided into a variety of distinct compartments bounded by membrane barriers.

❖Just as a house or restaurant is divided into specialized rooms where different activities can take place independent of one another, the cytoplasm of a cell is divided into specialized membranous compartments for analogous reasons.


Golgi complex
ER
Secretory vesicle
3 µm

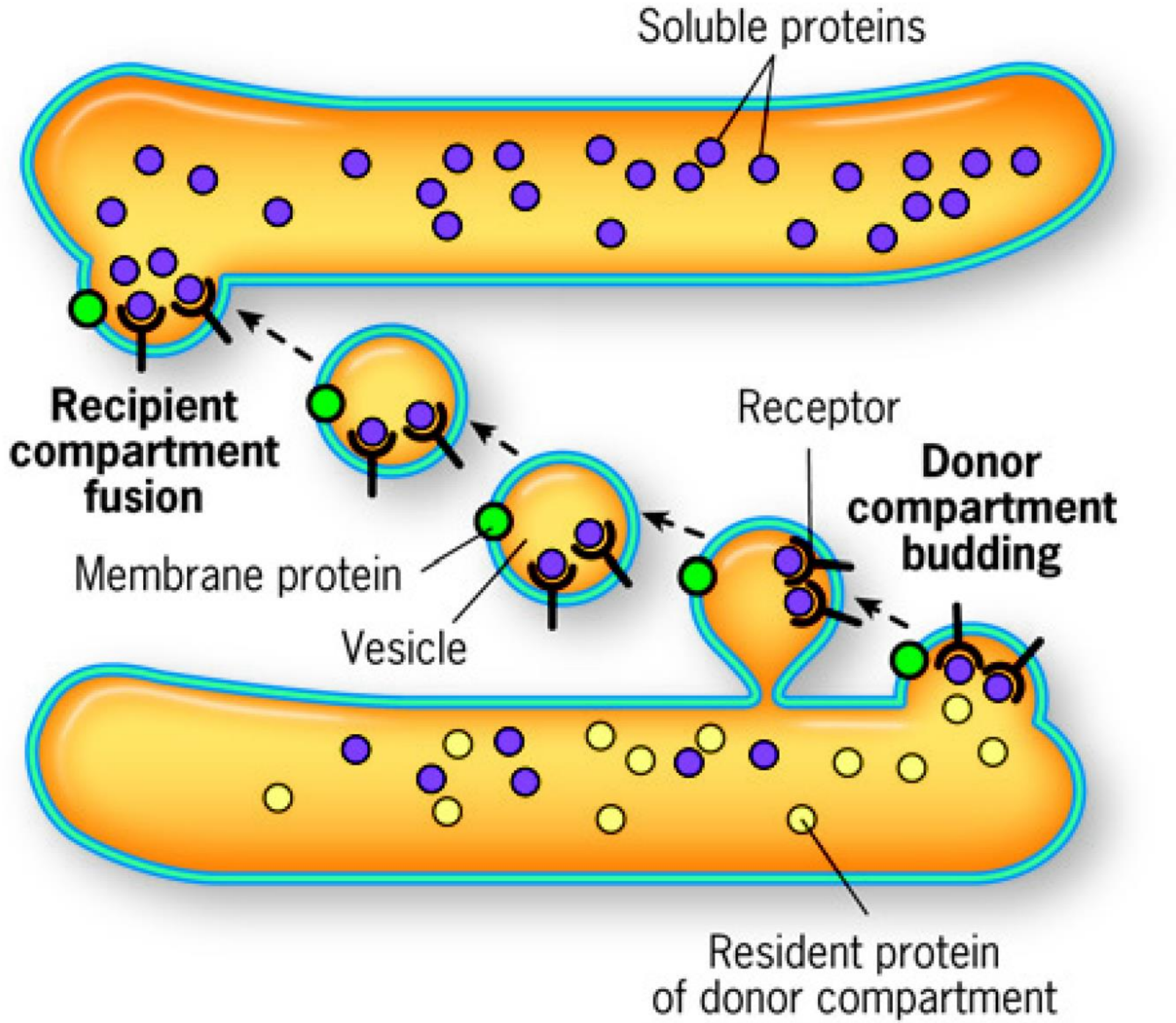
❖The organelles of the endomembrane system are part of a dynamic, integrated network in which materials are shuttled back and forth from one part of the cell to another.

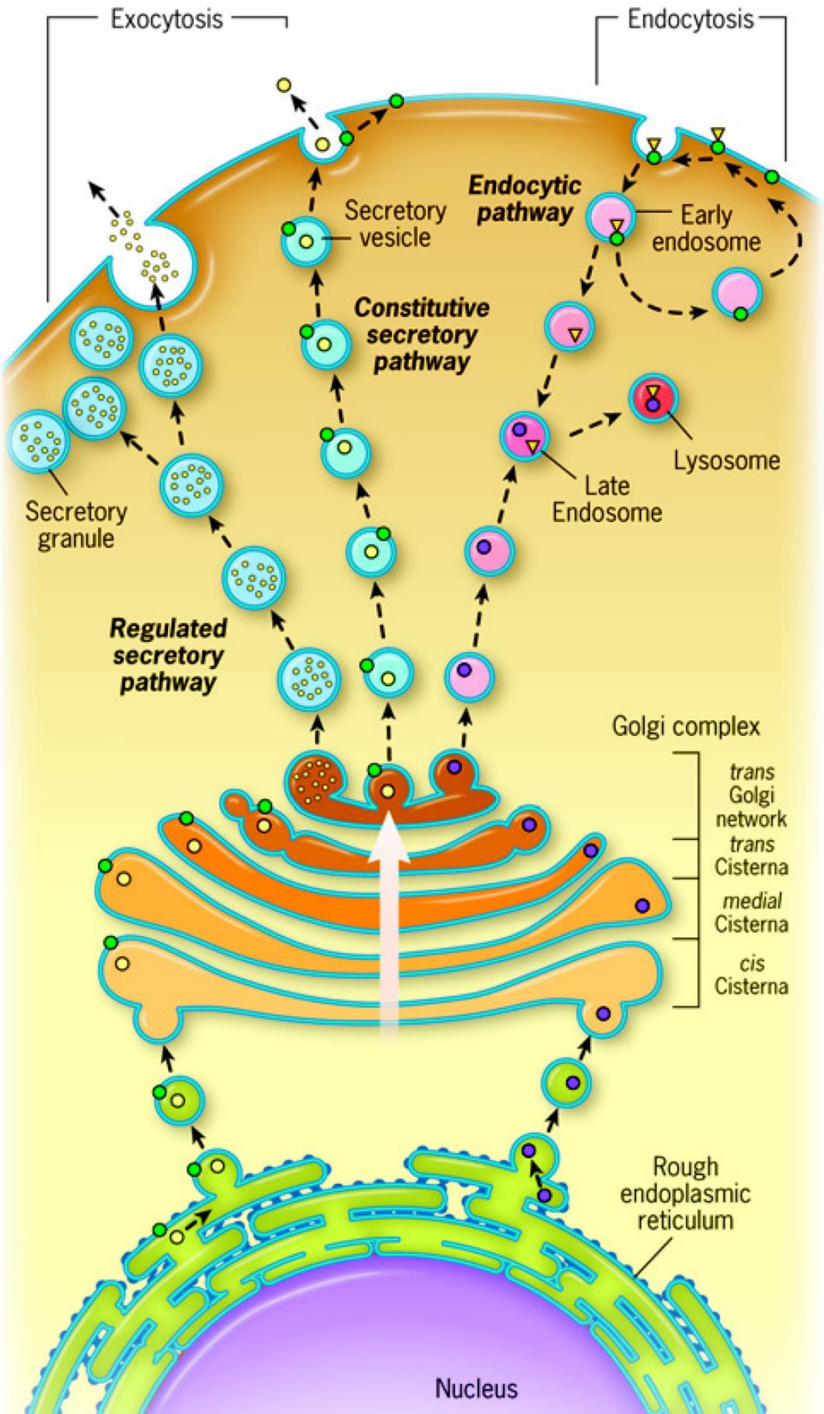
❖For the most part, materials are shuttled between organelles—from the Golgi complex to the plasma membrane, for example—in small, membrane-bounded transport vesicles that bud from a donor membrane compartment.

❖When they reach their destination, the vesicles fuse with the membrane of the acceptor compartment, which receives the vesicle's soluble cargo as well as its membranous wrapper.

❖Repeated cycles of budding and fusion shuttle a diverse array of materials along numerous pathways that traverse the cell.

- A biosynthetic pathway can be discerned in which proteins are
  - synthesized in the endoplasmic reticulum,
  - modified during passage through the Golgi complex,
  - and transported from the Golgi complex to various destinations, such as the plasma membrane, a lysosome, or the large vacuole of a plant cell.
- This route is also referred to as the secretory pathway, as many of the proteins synthesized in the endoplasmic reticulum


Soluble proteins
Recipient compartment fusion
Receptor
Donor compartment budding
Membrane protein
Vesicle
Resident protein of donor compartment



Materials follow the biosynthetic (or secretory) pathway from the endoplasmic reticulum, through the Golgi complex, and out to various locations including lysosomes, endosomes, secretory vesicles, secretory granules, vacuoles, and the plasma membrane.

Materials follow the endocytic pathway from the cell surface to the interior by way of endosomes and lysosomes, where they are generally degraded by lysosomal enzymes.

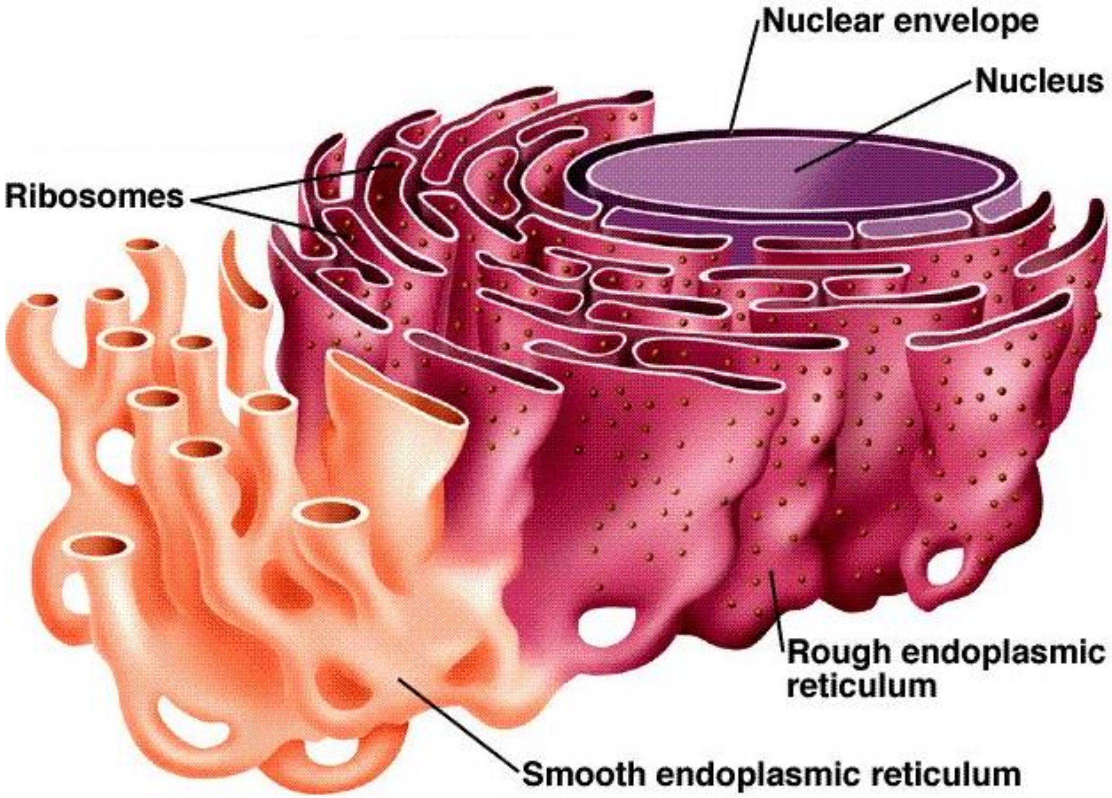
❖The endoplasmic reticulum (ER) comprises a network of membranes that penetrates much of the cytoplasm.

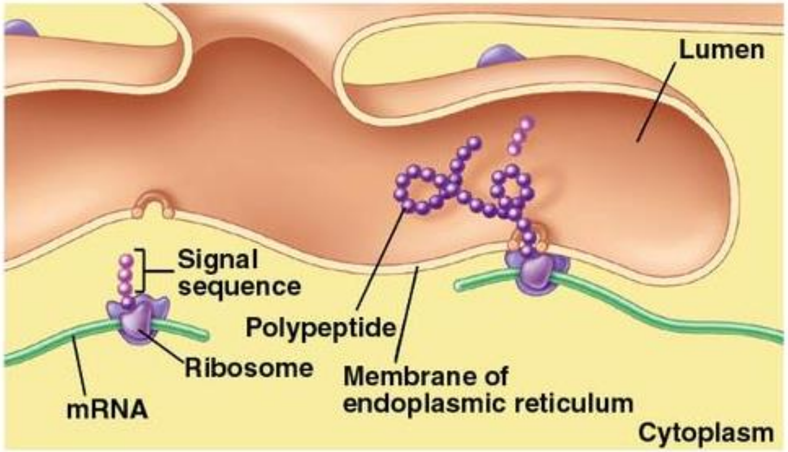
❖The ER probably evolved from invaginations of the plasma membrane.

❖Enclosed within the ER is an extensive space, or lumen, that is separated from the surrounding cytosol by the ER membrane.

❖As will be evident in the following discussion, the composition of the luminal (or cisternal) space inside the ER membranes is quite different from that of the surrounding cytosolic space.

❖Like other subcellular organelles, the ER is a highly dynamic structure undergoing continual turnover and reorganization.


Nuclear envelope
Nucleus
Ribosomes
Rough endoplasmic reticulum
Smooth endoplasmic reticulum


Lumen
Signal sequence
Polypeptide
Ribosome
mRNA
Membrane of endoplasmic reticulum
Cytoplasm

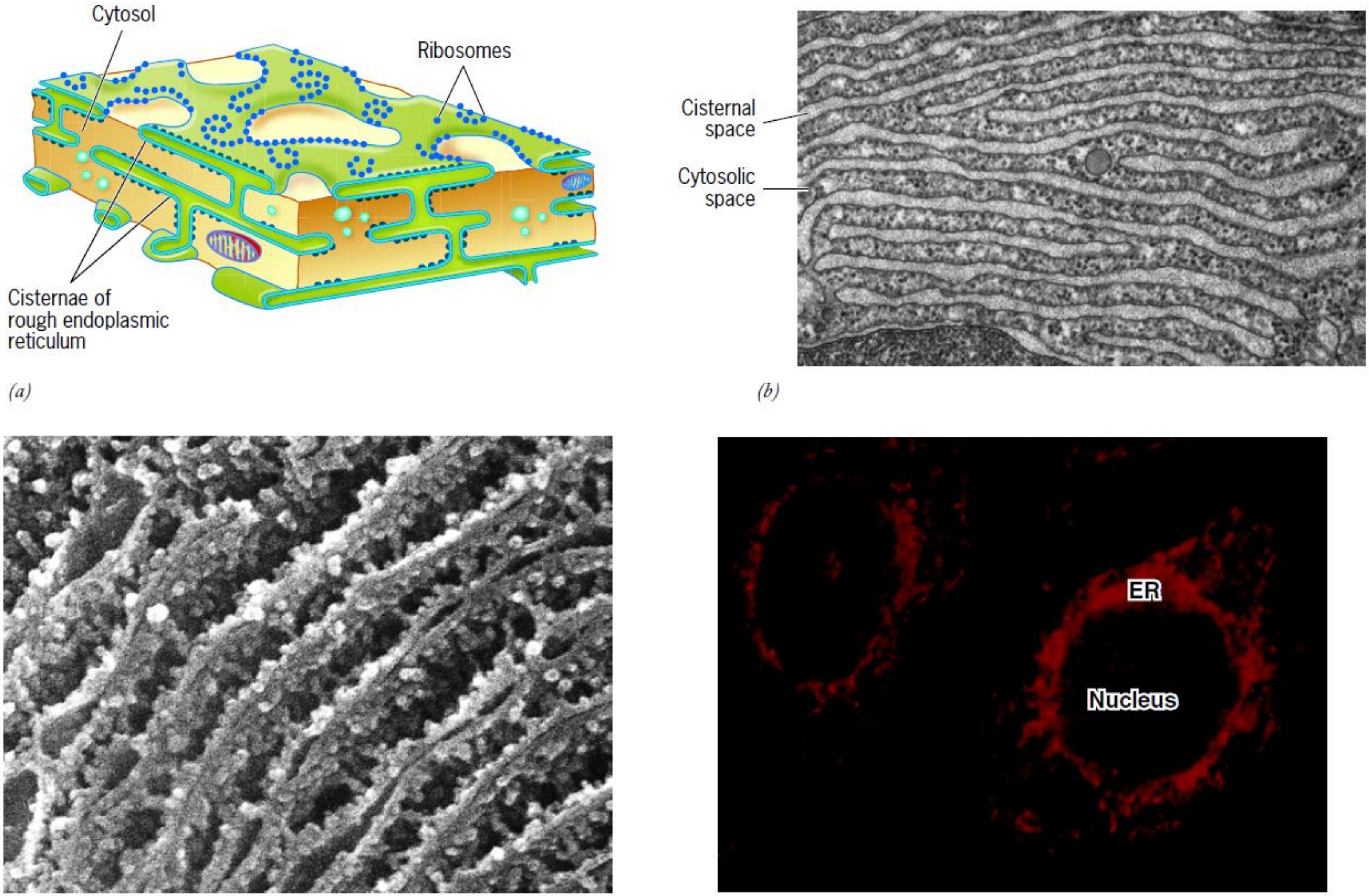
❖The endoplasmic reticulum is divided into two subcompartments, the rough endoplasmic reticulum (RER) and the smooth endoplasmic reticulum (SER).

❖The rough ER is defined by the presence of ribosomes bound to its cytosolic surface, whereas the smooth ER lacks associated ribosomes.

❖The RER is typically composed of a network of flattened sacs (cisternae).

❖The RER is continuous with the outer membrane of the nuclear envelope, which also bears ribosomes on its cytosolic surface.

❖In contrast, the membranes of the SER are highly curved and tubular, forming an interconnecting system of pipelines traversing the cytoplasm.



(a) (b)

(c) 0.3 μm (d) 10 μm

❖Fluorescently labeled proteins and lipids are capable of diffusing from one type of ER into the other, indicating that their membranes are continuous.

❖In fact, the two types of ER share many of the same proteins and engage in certain common activities, such as the synthesis of certain lipids and cholesterol.

❖At the same time, numerous proteins are found only in one or the other type of ER.

❖Different types of cells contain markedly different ratios of the two types of ER, depending on the activities of the cell.

❖For example, cells that secrete large amounts of proteins, such as the cells of the pancreas or salivary glands, have extensive regions of RER.

- The SER is extensively developed in a number of cell types, including those of skeletal muscle, kidney tubules, and steroid-producing endocrine glands .

- SER functions include:

  - Synthesis of steroid hormones in the endocrine cells of the gonad and adrenal cortex.

  - Detoxification in the liver of a wide variety of organic compounds, including barbiturates and ethanol, whose chronic use can lead to proliferation of the SER in liver cells.

  - Sequestering calcium ions within the cytoplasm of cells. The regulated release of Ca^{2+} from the SER of skeletal and cardiac muscle cells (known as the sarcoplasmic reticulum in muscle cells) triggers contraction.

❖Early investigations into the functions of the RER were carried out on cells that secrete large quantities of proteins, such as the acinar cells of the pancreas or the mucus secreting cells of the lining of the digestive tract.

❖It is evident from the drawing and micrograph that the organelles of these epithelial secretory cells are positioned in the cell in such a way as to produce a distinct polarity from one end to the other.

❖Approximately one-third of the proteins encoded by a mammalian genome are synthesized on ribosomes attached to the cytosolic surface of the RER membranes.

❖These include (a) secreted proteins, (b) integral membrane proteins, and (c) soluble proteins that reside within compartments of the endomembrane system, including the ER, Golgi complex, lysosomes, endosomes, vesicles, and plant vacuoles.

❖Other polypeptides are synthesized on “free” ribosomes, that is, on ribosomes that are not attached to the RER, and are subsequently released into the cytosol.

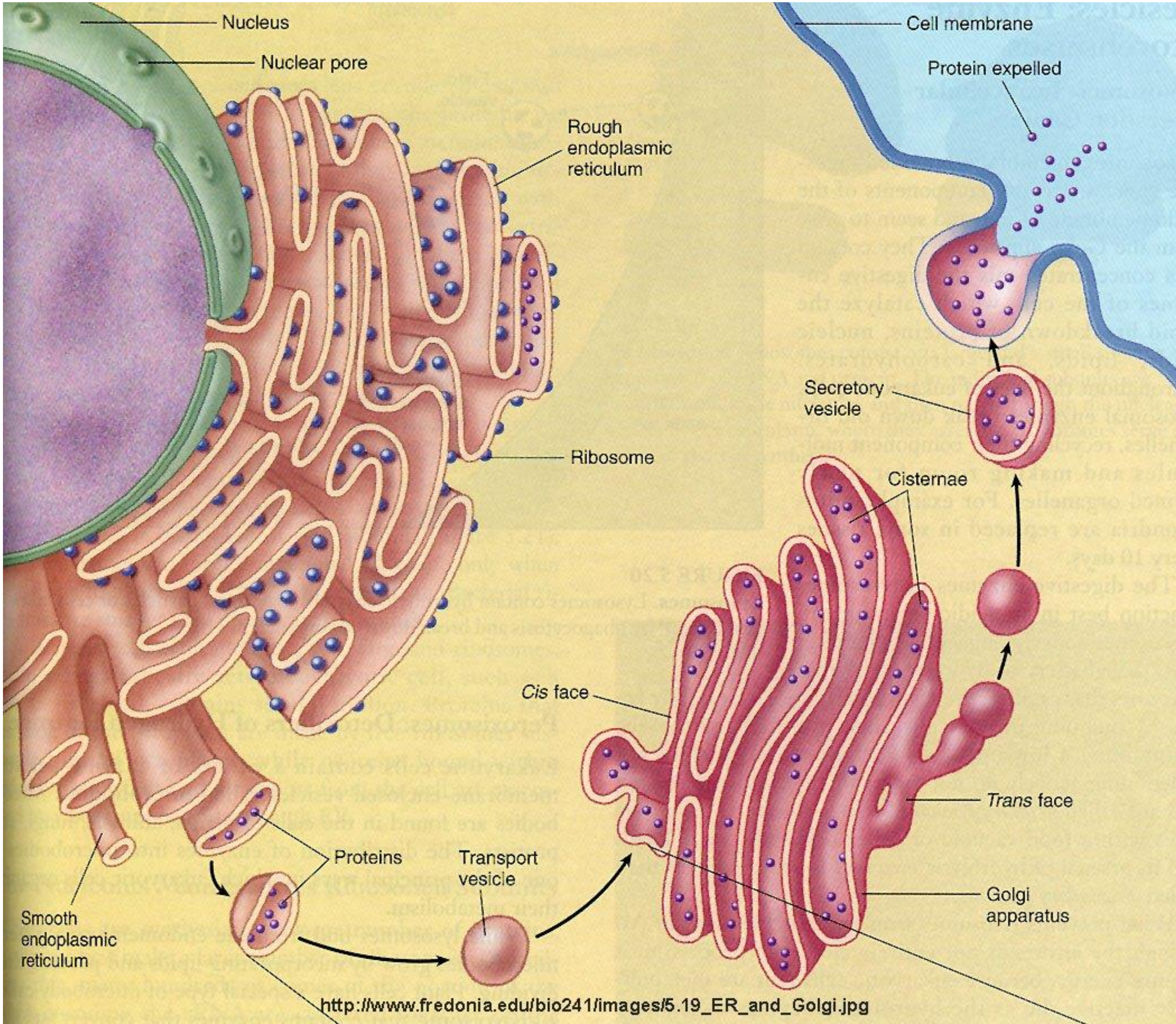
❖This class includes (a) proteins destined to remain in the cytosol (such as the enzymes of glycolysis and the proteins of the cytoskeleton), (b) peripheral proteins of the cytosolic surface of membranes (such as spectrins and ankyrins that are only weakly associated with the plasma membrane’s cytosolic surface), (c) proteins that are transported to the nucleus, and (d) proteins to be incorporated into peroxisomes, chloroplasts, and mitochondria.

❖Nearly all of the proteins produced on membrane-bound ribosomes—whether integral components of a membrane, soluble lysosomal or vacuolar enzymes, or parts of the extracellular matrix—become glycoproteins.

❖Carbohydrate groups have key roles in the function of many glycoproteins, particularly as binding sites in their interactions with other macromolecules, as occurs during many cellular processes.

❖They also aid in the proper folding and stabilization of the protein to which they are attached.

❖The sequences of sugars that comprise the oligosaccharides of glycoproteins are highly specific; if the oligosaccharides are isolated from a purified protein of a given type of cell, their sequence is consistent and predictable.

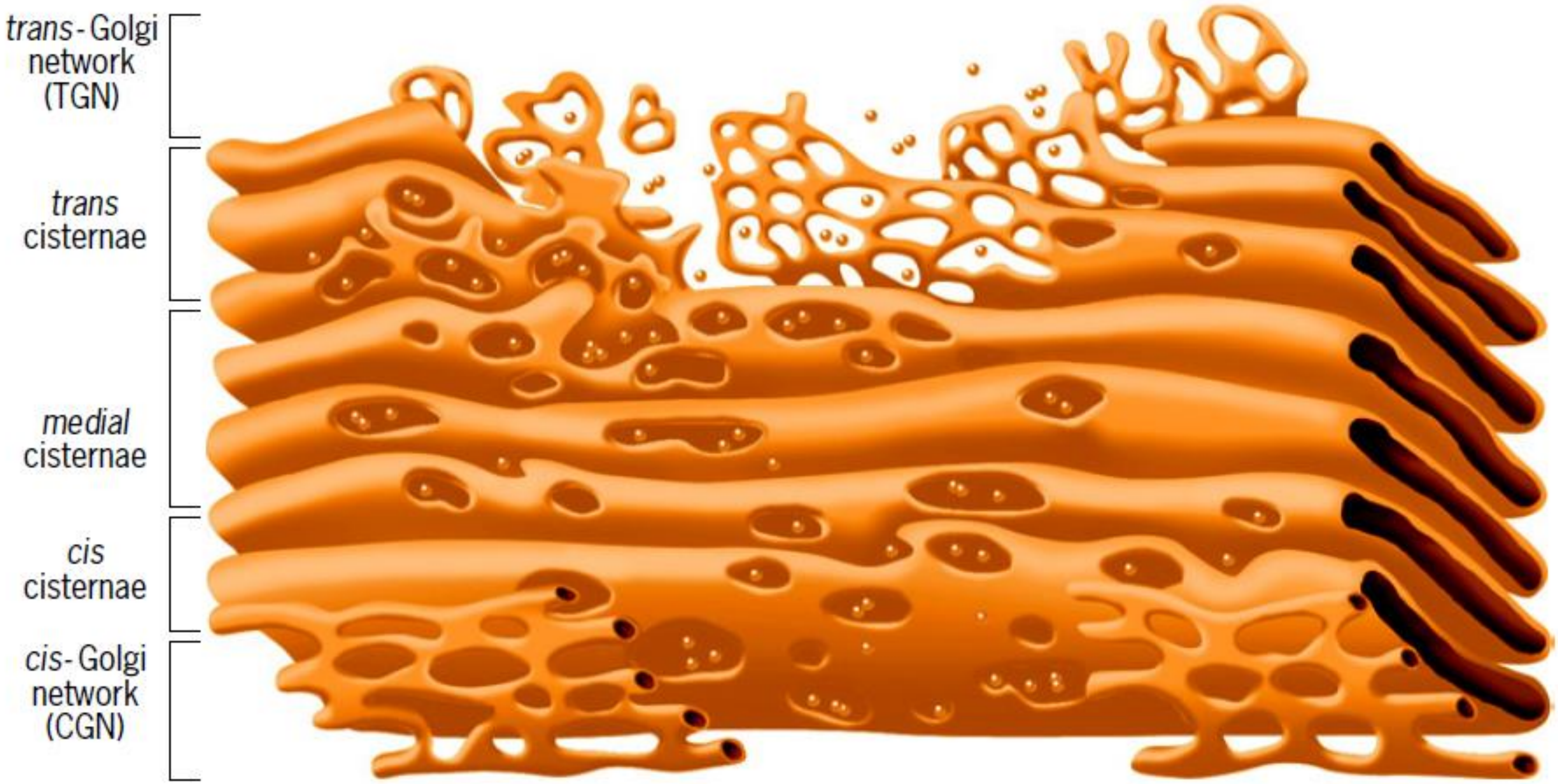

Nucleus
Nuclear pore
Rough endoplasmic reticulum
Ribosome
Cell membrane
Protein expelled
Secretory vesicle
Cisternae
Cis face
Trans face
Golgi apparatus
Proteins
Transport vesicle
Smooth endoplasmic reticulum
http://www.fredonia.edu/bio241/images/5.19_ER_and_Golgi.jpg

❖In the latter years of the nineteenth century, an Italian biologist, Camillo Golgi, was inventing new types of staining procedures that might reveal the organization of nerve cells within the central nervous system.

❖In 1898, Golgi applied a metallic stain to nerve cells from the cerebellum and discovered a darkly stained reticular network located near the cell nucleus.

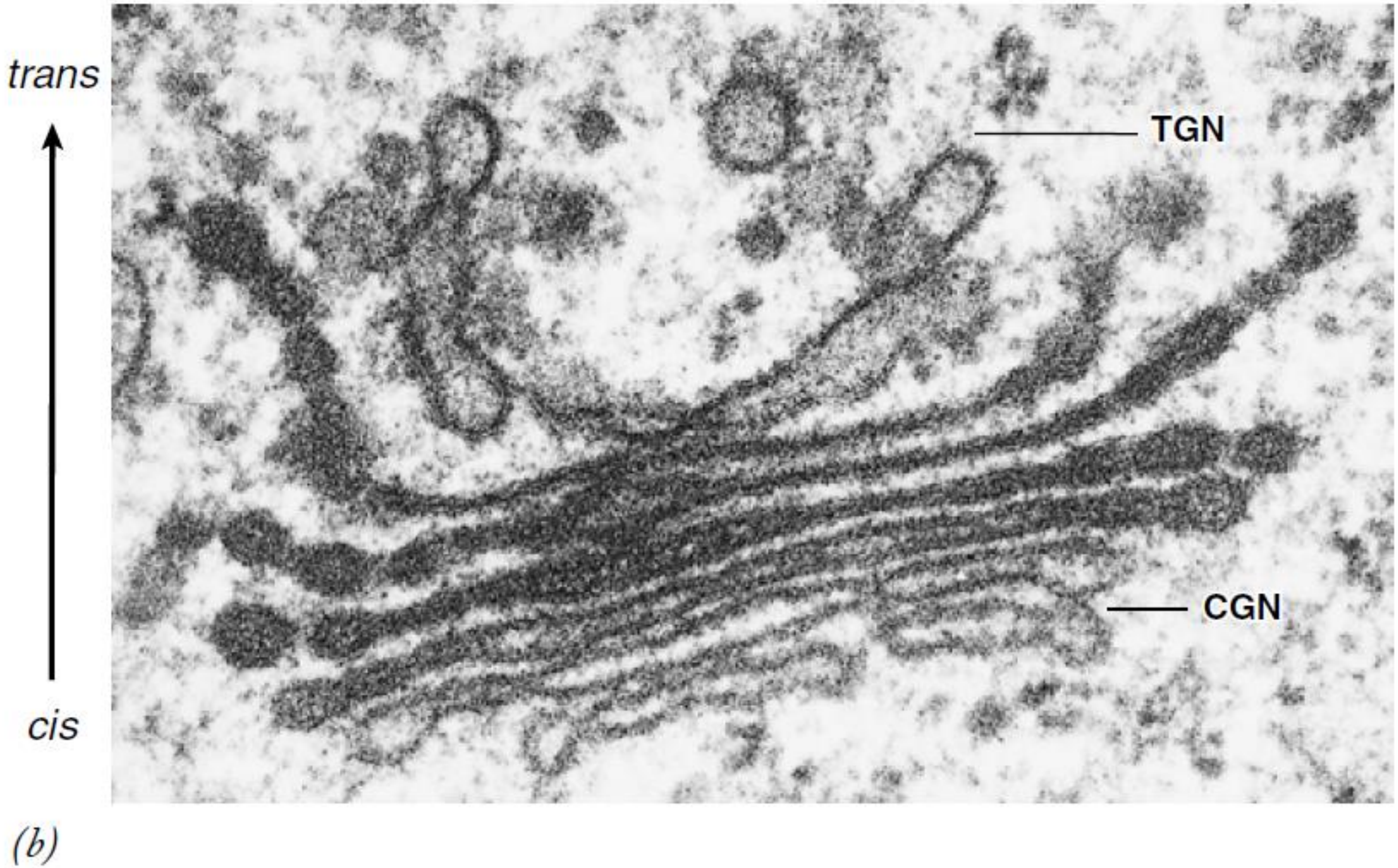
❖This network, which was later identified in other cell types and named the Golgi complex, helped earn its discoverer the Nobel Prize in 1906.

❖The Golgi complex has a characteristic morphology consisting primarily of flattened, disc-like, membranous cisternae with dilated rims and associated vesicles and tubules



trans-Golgi network (TGN)
trans cisternae
medial cisternae
cis cisternae
cis-Golgi network (CGN)

(a)

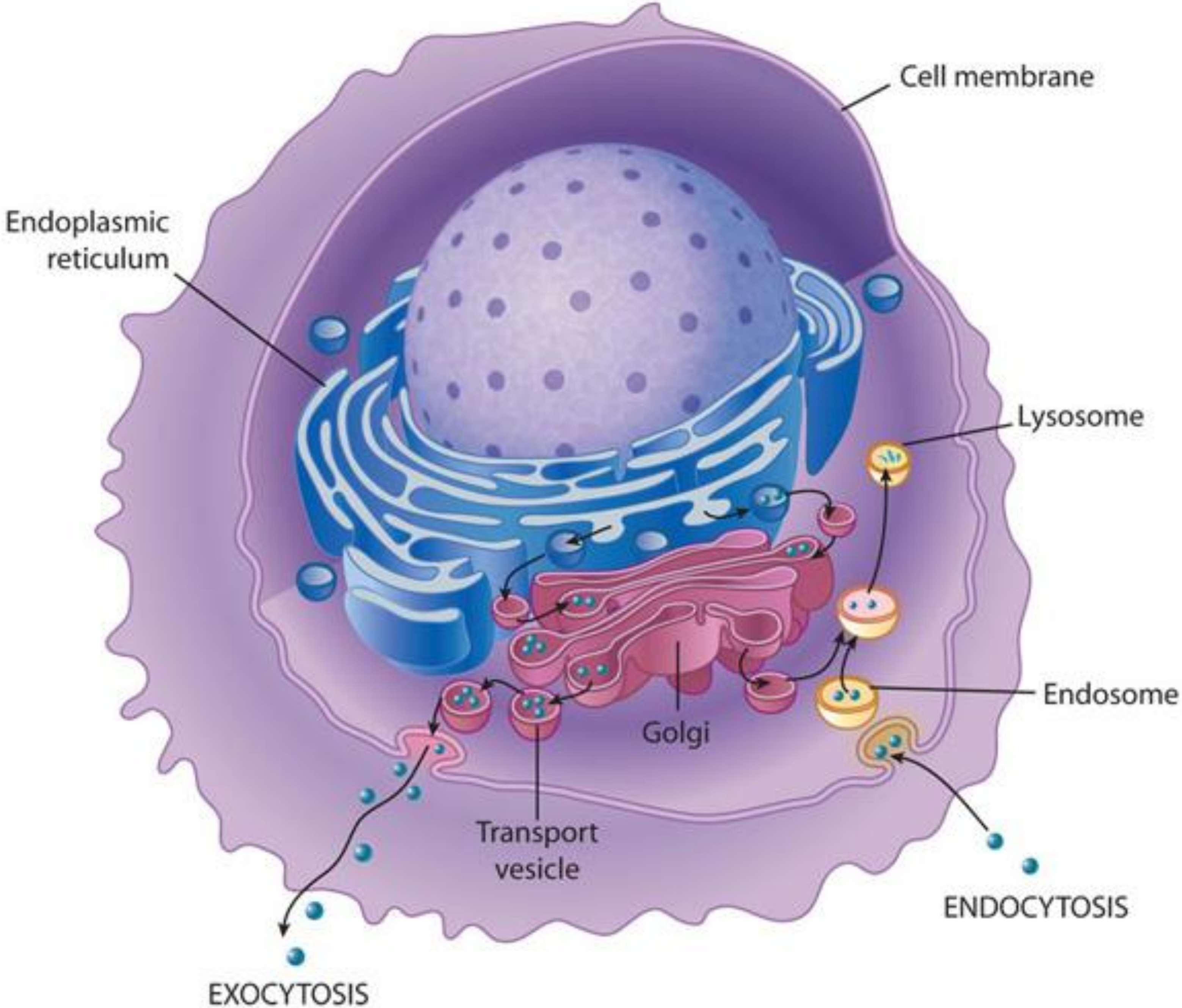

trans
cis
TGN
CGN
(b)

❖Differences in composition of the membrane compartments from the cis to the trans face reflect the fact that the Golgi complex is primarily a “processing plant.”

❖Newly synthesized membrane proteins, as well as secretory and lysosomal proteins, leave the ER and enter the Golgi complex at its cis face and then pass across the stack to the trans face.

❖As they progress along the stack, proteins that were originally synthesized in the rough ER are sequentially modified in specific ways. In the best-studied Golgi activity, a protein’s carbohydrates are modified by a series of stepwise enzymatic reactions.

❖The Golgi complex plays a key role in the assembly of the carbohydrate component of glycoproteins and glycolipids.


Cell membrane
Endoplasmic reticulum
Lysosome
Endosome
Golgi
Transport vesicle
EXOCYTOSIS
ENDOCYTOSIS

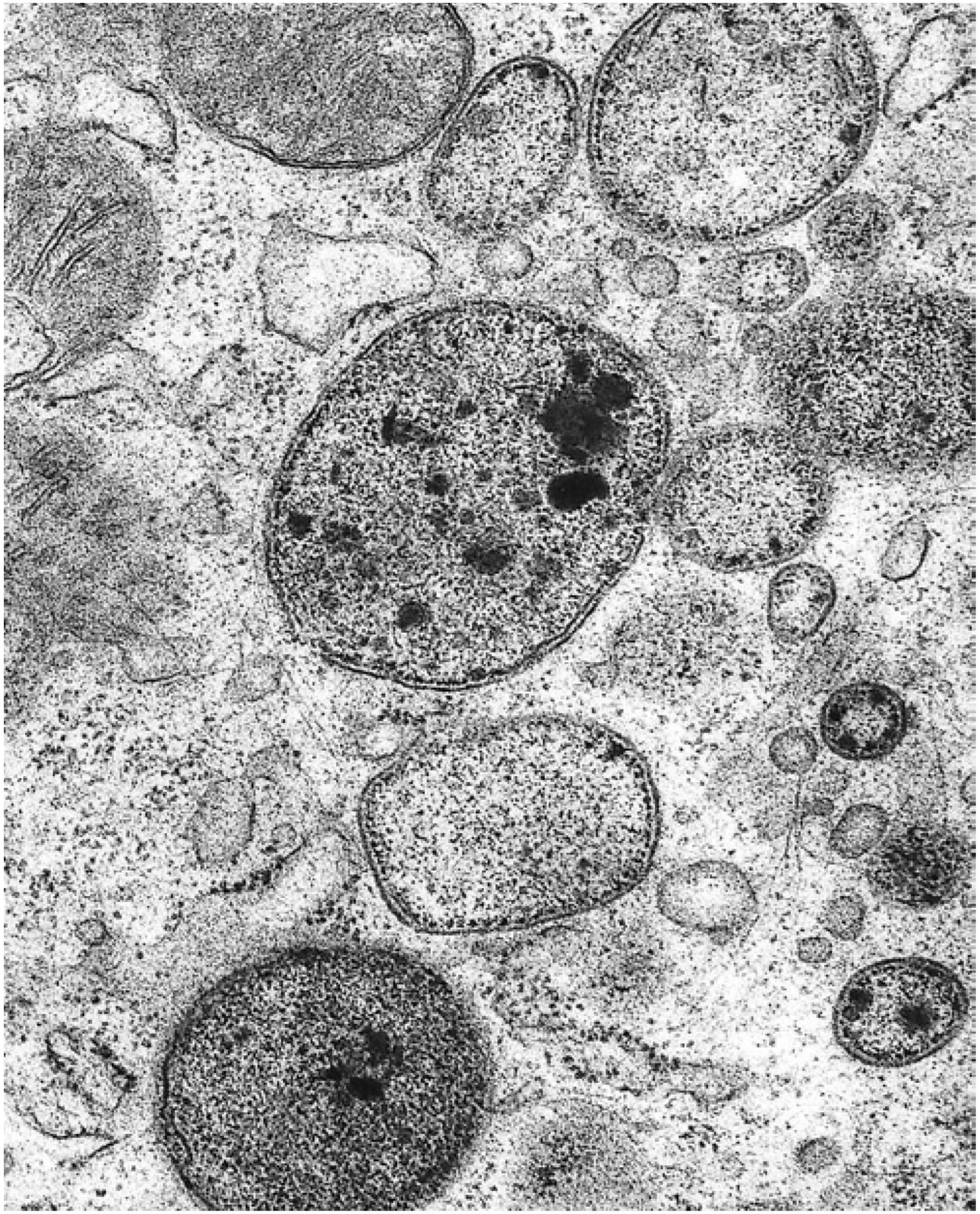
❖Lysosomes are an animal cell's digestive organelles.

❖A typical lysosome contains at least 50 different hydrolytic enzymes produced in the rough ER and targeted to these organelles.

❖Taken together, lysosomal enzymes can hydrolyze virtually every type of biological macromolecule.

❖The enzymes of a lysosome share an important property: all have their optimal activity at an acid pH and thus are acid hydrolases.

❖Lysosomal membranes also contain a variety of highly glycosylated integral proteins whose carbohydrate chains are thought to form a protective lining that shields the membrane from attack by the enclosed enzymes.



0.3 µm

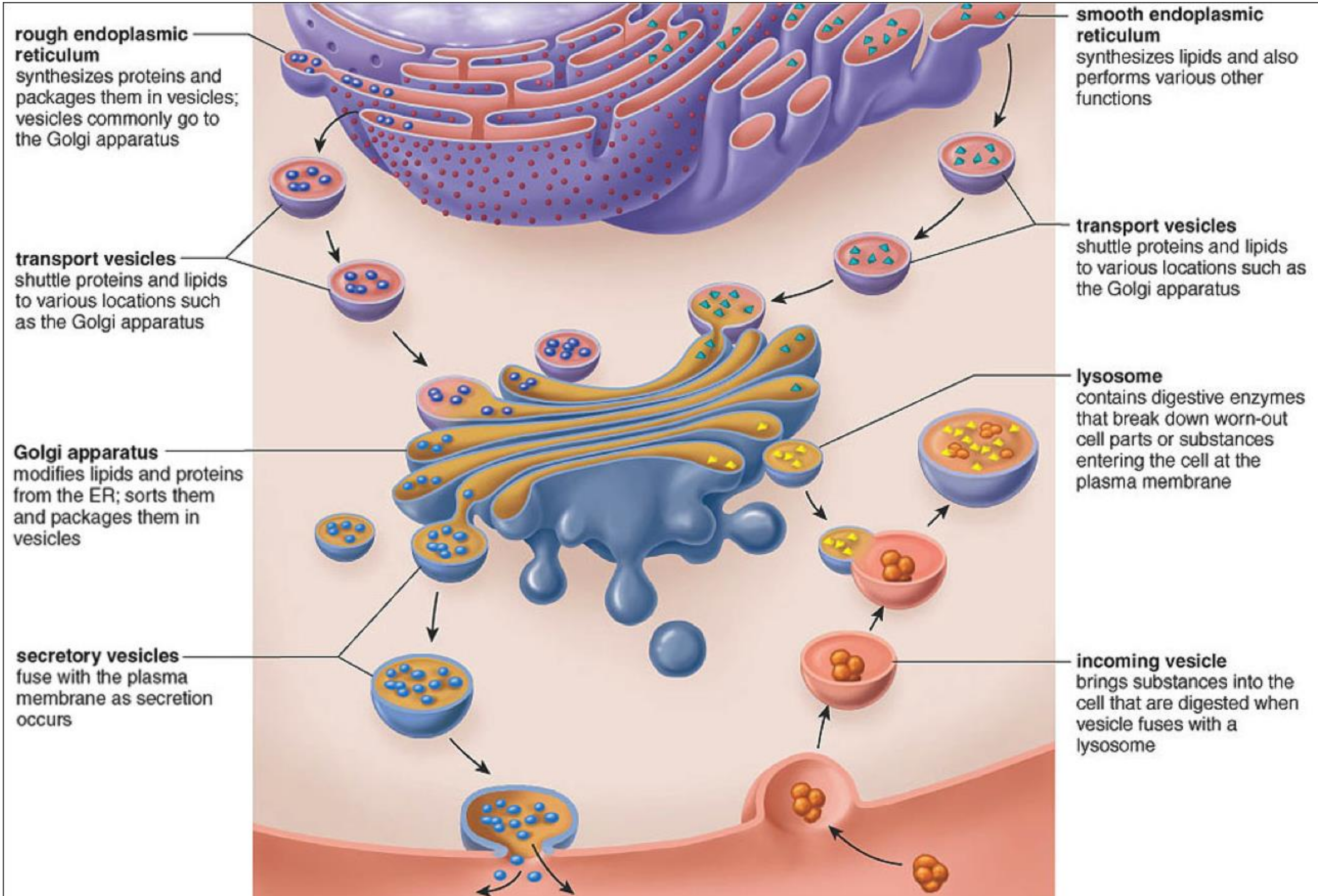
- The presence within a cell of what is, in essence, a bag of destructive enzymes suggests a number of possible functions.

- The best studied role of lysosomes is the breakdown of materials brought into the cell from the extracellular environment.

- In mammals, phagocytic cells, such as macrophages and neutrophils, function as scavengers that ingest debris and potentially dangerous microorganisms.

- Ingested bacteria are generally inactivated by the low pH of the lysosome and then digested enzymatically.

- Peptides produced by this digestive process are "posted" on the cell surface where they alert the immune system to the presence of a foreign agent.


rough endoplasmic reticulum
synthesizes proteins and packages them in vesicles; vesicles commonly go to the Golgi apparatus
smooth endoplasmic reticulum
synthesizes lipids and also performs various other functions
transport vesicles
shuttle proteins and lipids to various locations such as the Golgi apparatus
transport vesicles
shuttle proteins and lipids to various locations such as the Golgi apparatus
lysosome
contains digestive enzymes that break down worn-out cell parts or substances entering the cell at the plasma membrane
Golgi apparatus
modifies lipids and proteins from the ER; sorts them and packages them in vesicles
secretory vesicles
fuse with the plasma membrane as secretion occurs
incoming vesicle
brings substances into the cell that are digested when vesicle fuses with a lysosome