# Classification of Eukaryotes

# 5.1 The History of Eukaryotes

- First eukaryotic cells on earth approximately 2 billion years ago
- Evidence points to these eukaryotic cells evolving from prokaryotic organisms through intracellular **symbiosis**
  - Eukaryotic **organelles** originated from prokaryotic cells trapped inside of them
  - First primitive eukaryotes- probably single-celled and independent
  - Eventually formed colonies
  - Cells within colonies became specialized
  - Evolved in to multicellular organisms
- Eukaryotes have many levels of cellular complexity

## TABLE 5.1 Eukaryotic Organisms Studied in Microbiology

| Always Unicellular | May Be Unicellular or Multicellular | Always Multicellular |
|---|---|---|
| Protozoa | Fungi<br>Algae | Helminths (have unicellular egg or larval forms) |

# 5.2 Form and Function of the Eukaryotic Cell: External Structures



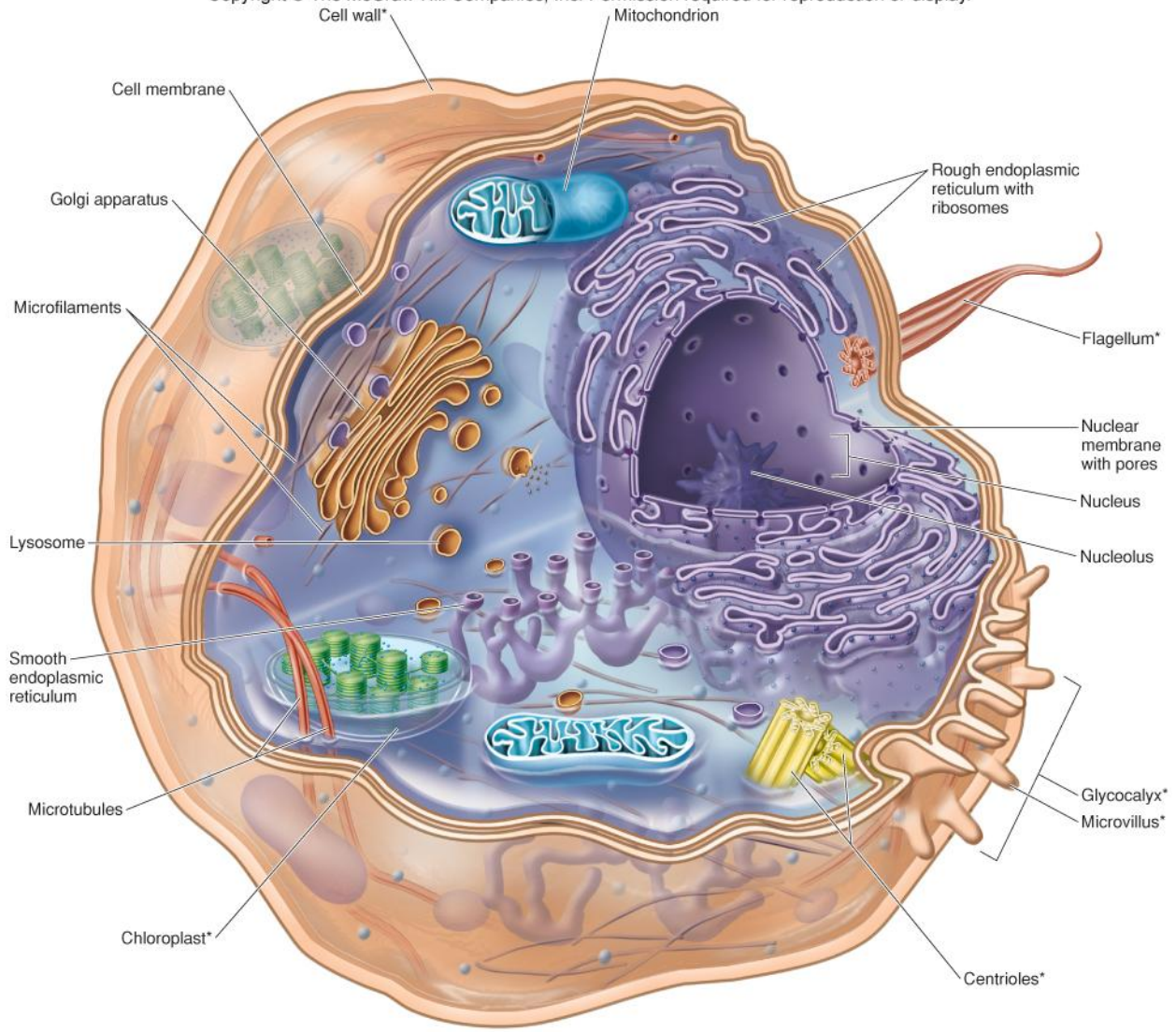
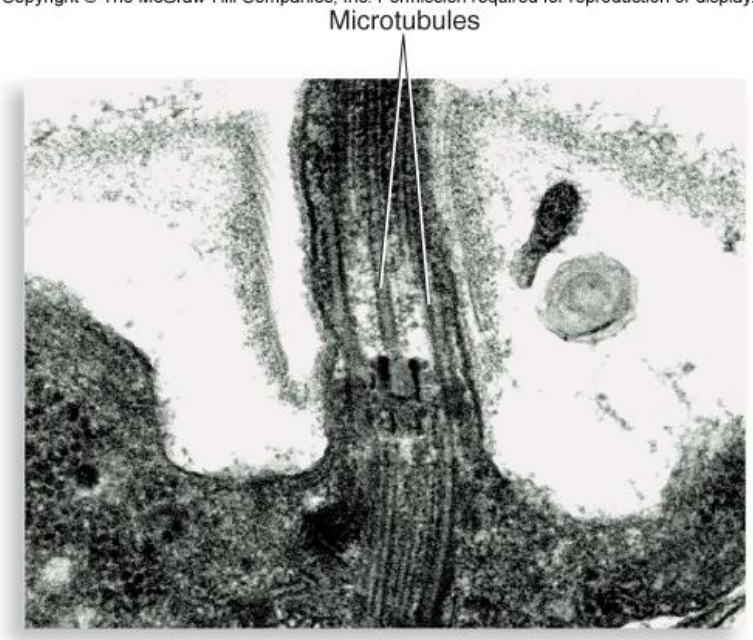



Figure 5.2

*Structure not present in all cell types

# Locomotor Appendages: Cilia and Flagella

- Eukaryotic flagella are much different from those of prokaryotes
  - 10X thicker
  - Structurally more complex
  - Covered by an extension of the cell membrane
- A single flagellum contains regularly spaced microtubules along its length
  - 9 pairs surrounding a single pair
  - The 9 + 2 arrangement

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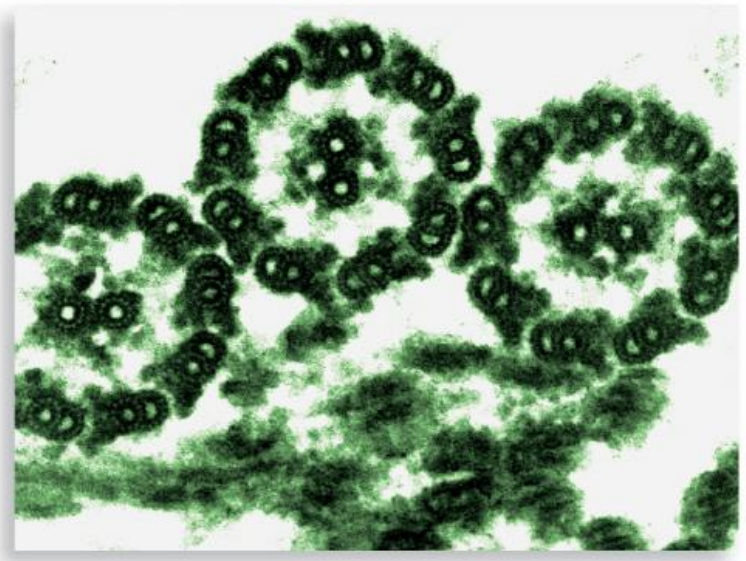


(b)



Figure 5.3

- Cilia- similar to flagella but some differences
  - Shorter
  - More numerous
  - Can also function as feeding and filtering structures

# The Glycocalyx

- Most eukaryotic cells have this outermost boundary that comes into direct contact with the environment
- Usually composed of polysaccharides
- Appears as a network of fibers, a slime layer, or a capsule
- Functions
  - Protection
  - Adhesion
  - Reception of signals
- The layer beneath the glycocalyx varies among eukaryotes
  - Fungi and most algae have a thick, rigid cell wall
  - Protozoa and animal cells do not have this cell wall

# Form and Function of the Eukaryotic Cell: Boundary Structures

- Cell Wall
  - Rigid
  - Provide support and shape
  - Different chemically from prokaryotic cell walls
  - Fungi
    - Thick, inner layer of chitin or cellulose
    - Thin outer layer of mixed glycans
  - Algae
    - Varied in chemical composition
    - May contain cellulose, pectin, mannans, and minerals

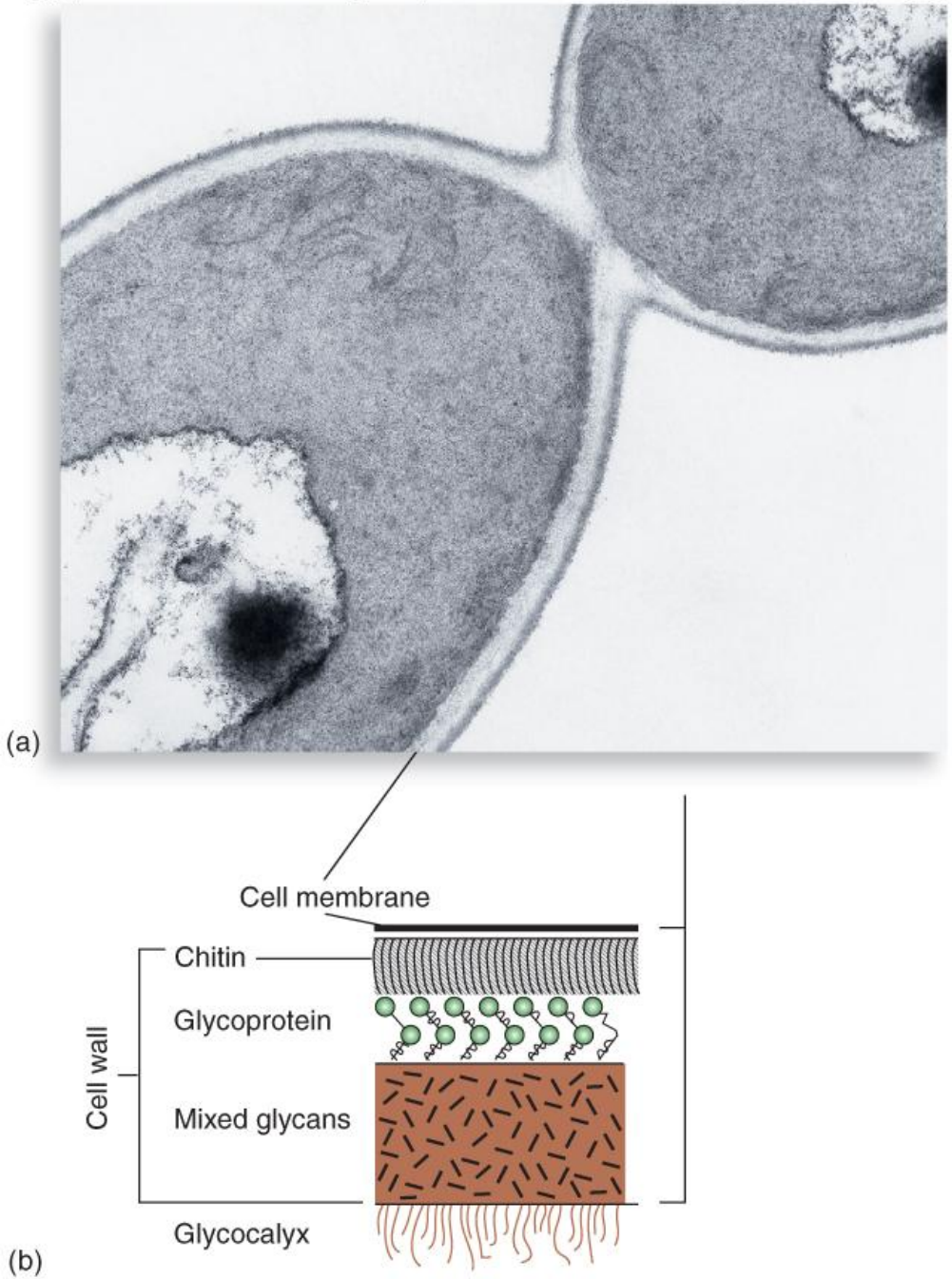





Figure 5.5

- Cytoplasmic Membrane
  - Bilayer of phospholipids with protein molecules embedded
  - Also contain sterols
    - Gives stability
    - Especially important in cells without a cell wall
  - Selectively permeable

# 5.3 Form and Function of the Eukaryotic Cell: Internal Structures

- The Nucleus: The Control Center
  - Separated from the cytoplasm by a nuclear envelope
    - Two parallel membranes separated by a narrow space
    - Perforated with nuclear pores
  - Filled with nucleoplasm
  - Contains the **nucleolus**
    - rRNA synthesis
    - Colelction area for ribosomal subunits
  - **Chromatin**
    - Comprises the **chromosomes**
      - Long, linear DNA molecules
      - Bound to **histone** proteins
      - Visible during **mitosis**

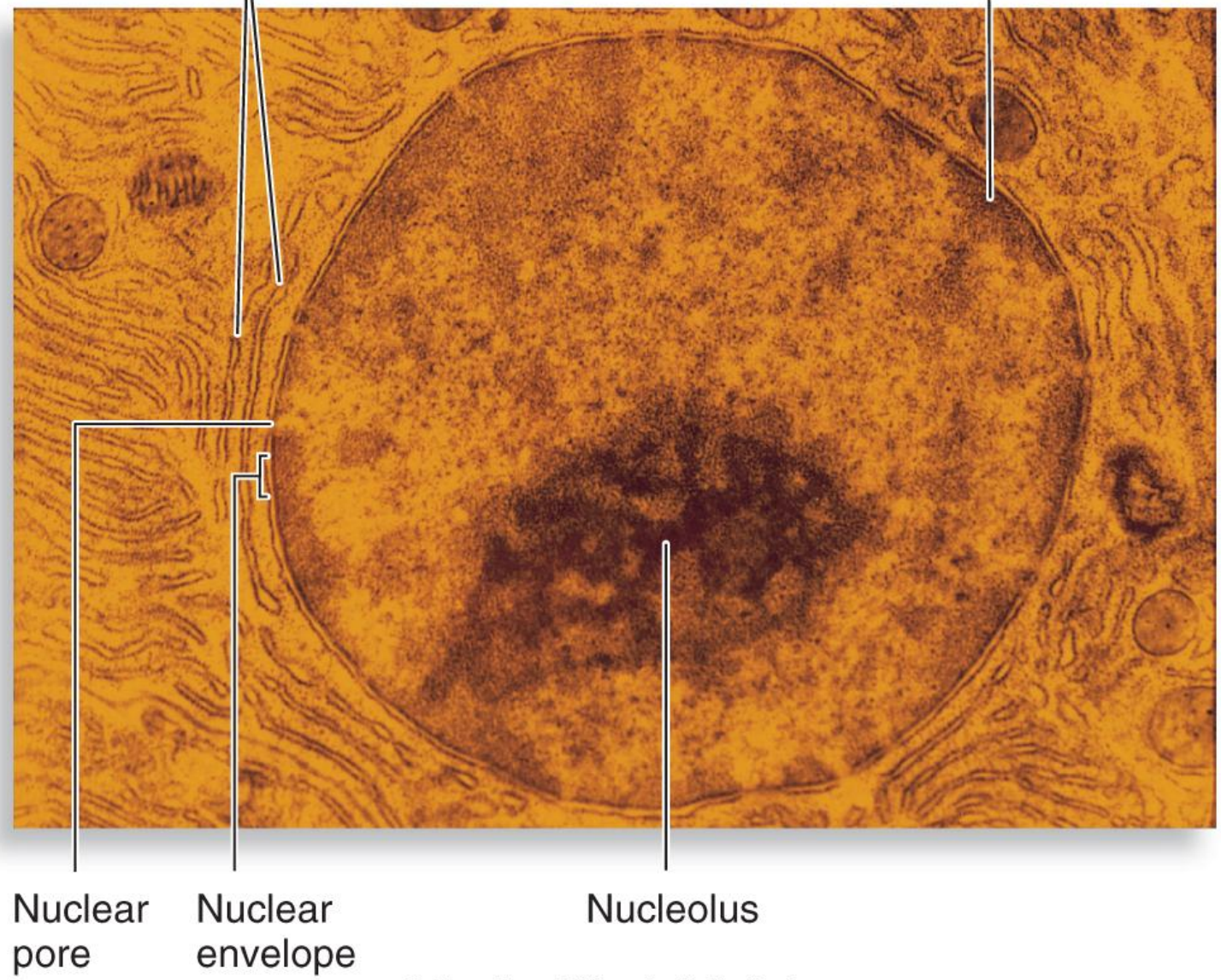
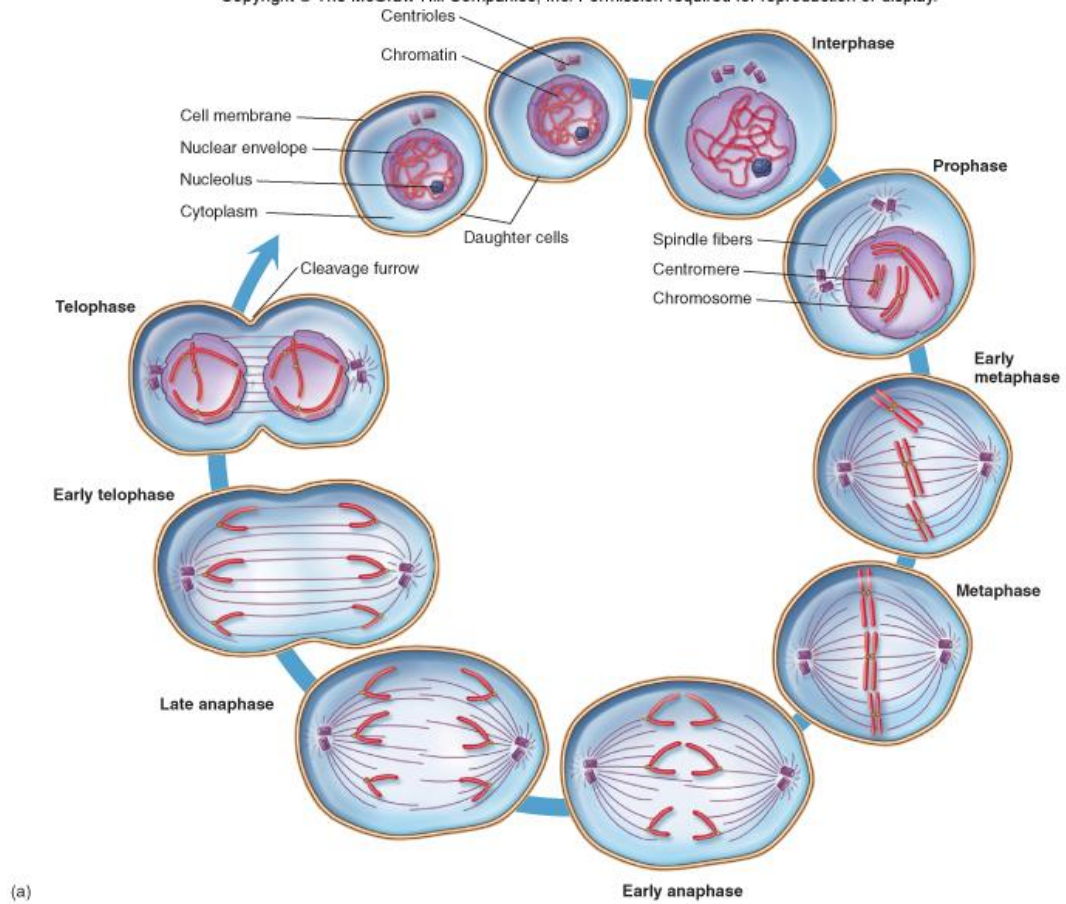



Figure 5.6



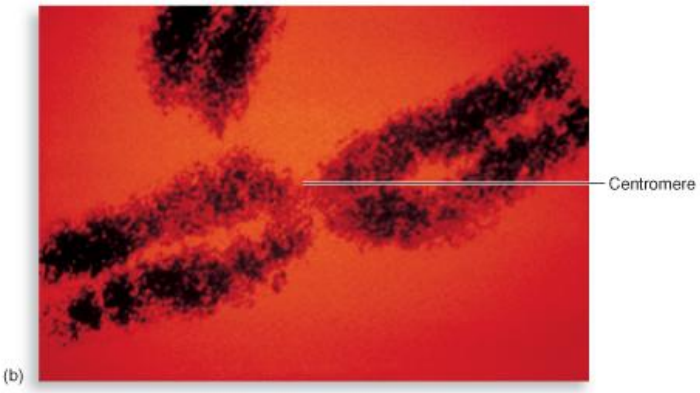






Figure 5.7

# Endoplasmic Reticulum (ER): A Passageway in the Cell

- Microscopic series of tunnels
- Used in transport and storage
- Two kinds
  - **Rough endoplasmic reticulum (RER)**
    - Originates from the outer membrane of the nuclear envelope
    - Extends through the cytoplasm
    - Spaces in the RER- cisternae- transport materials from the nucleus to the cytoplasm
    - "Rough" because of ribosomes attached to its surface
    - Proteins synthesized on the ribosomes shunted into the cavity of the RER and held for later packaging and transport

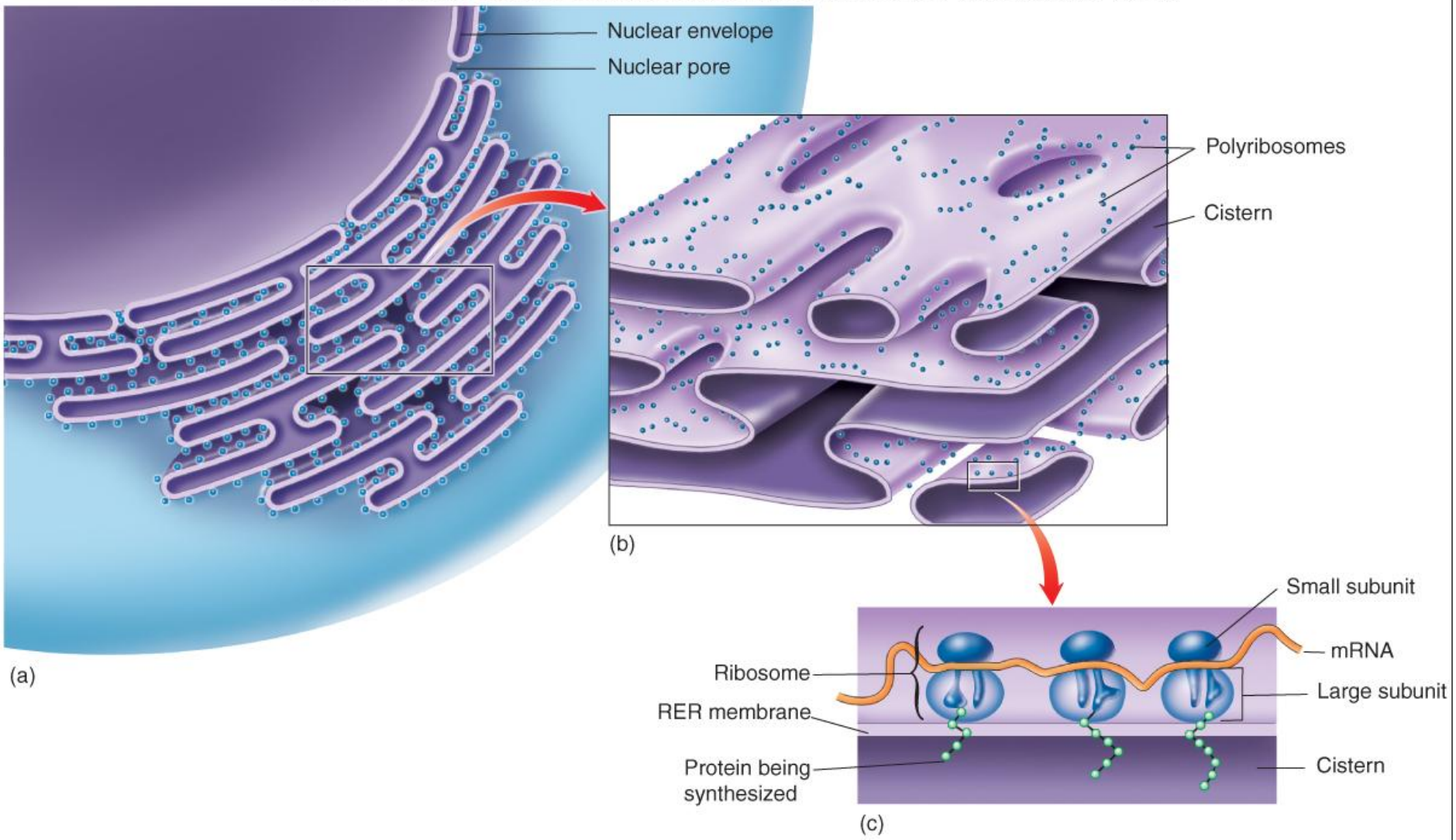



Figure 5.8

- **Smooth endoplasmic reticulum (SER)**
  - Closed tubular network
  - No ribosomes
  - Functions
    - Nutrient processing
    - Synthesis and storage of nonprotein macromolecules

# Golgi Apparatus: A Packaging Machine

- Where proteins are modified and sent to their final destinations
- A stack of cisternae
- Do not form a continuous network
- Closely associated with ER both in location and function
  - The ER buds off transitional vesicles (packets of protein) where it meets the Golgi apparatus
  - The Golgi apparatus picks up the transitional vesicles
  - The proteins are often modified by addition of polysaccharides and lipids
  - Then the apparatus pinches off condensing vesicles
    - Sent to **lysosomes**
    - Or transported outside the cell

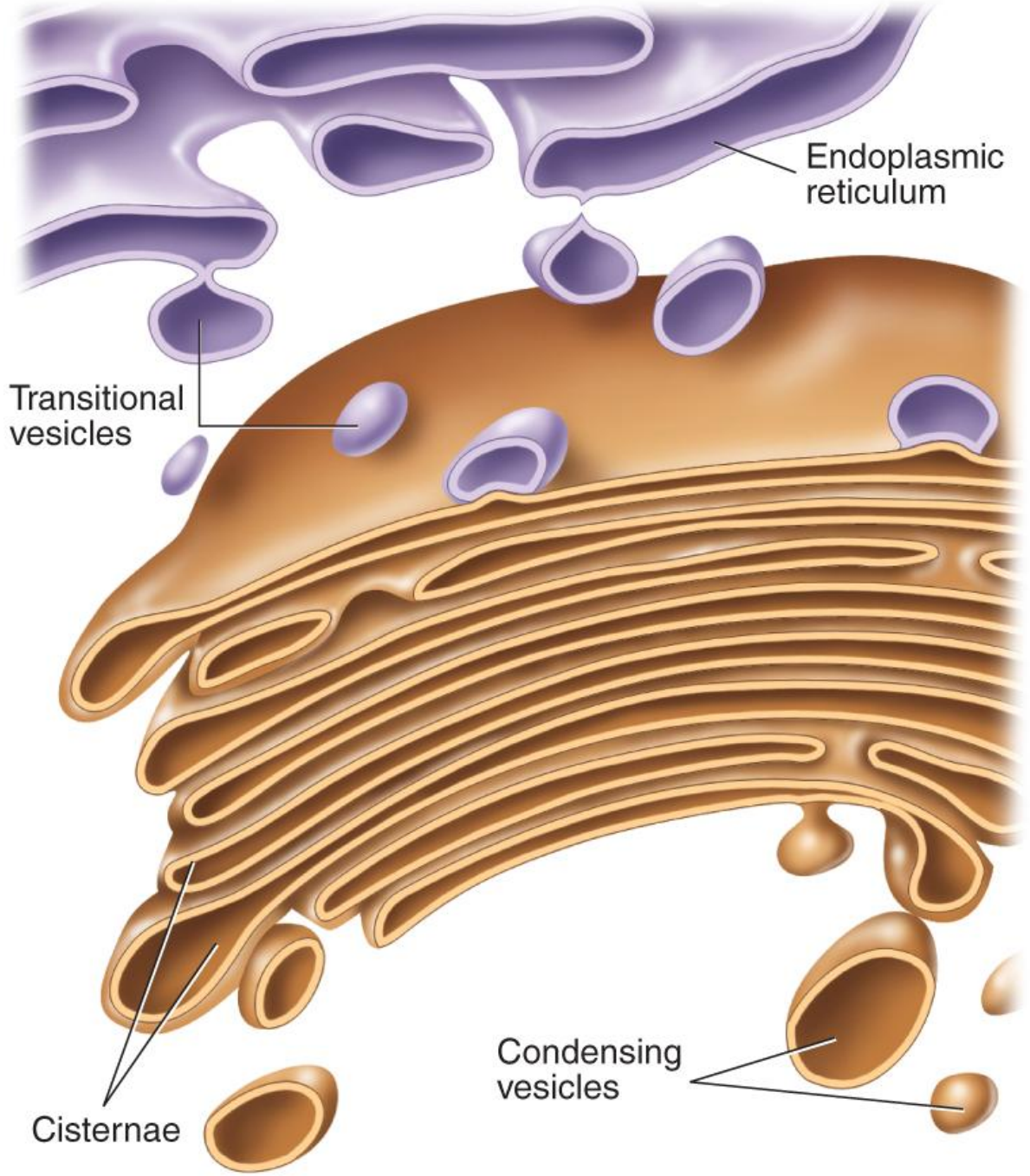



Figure 5.9

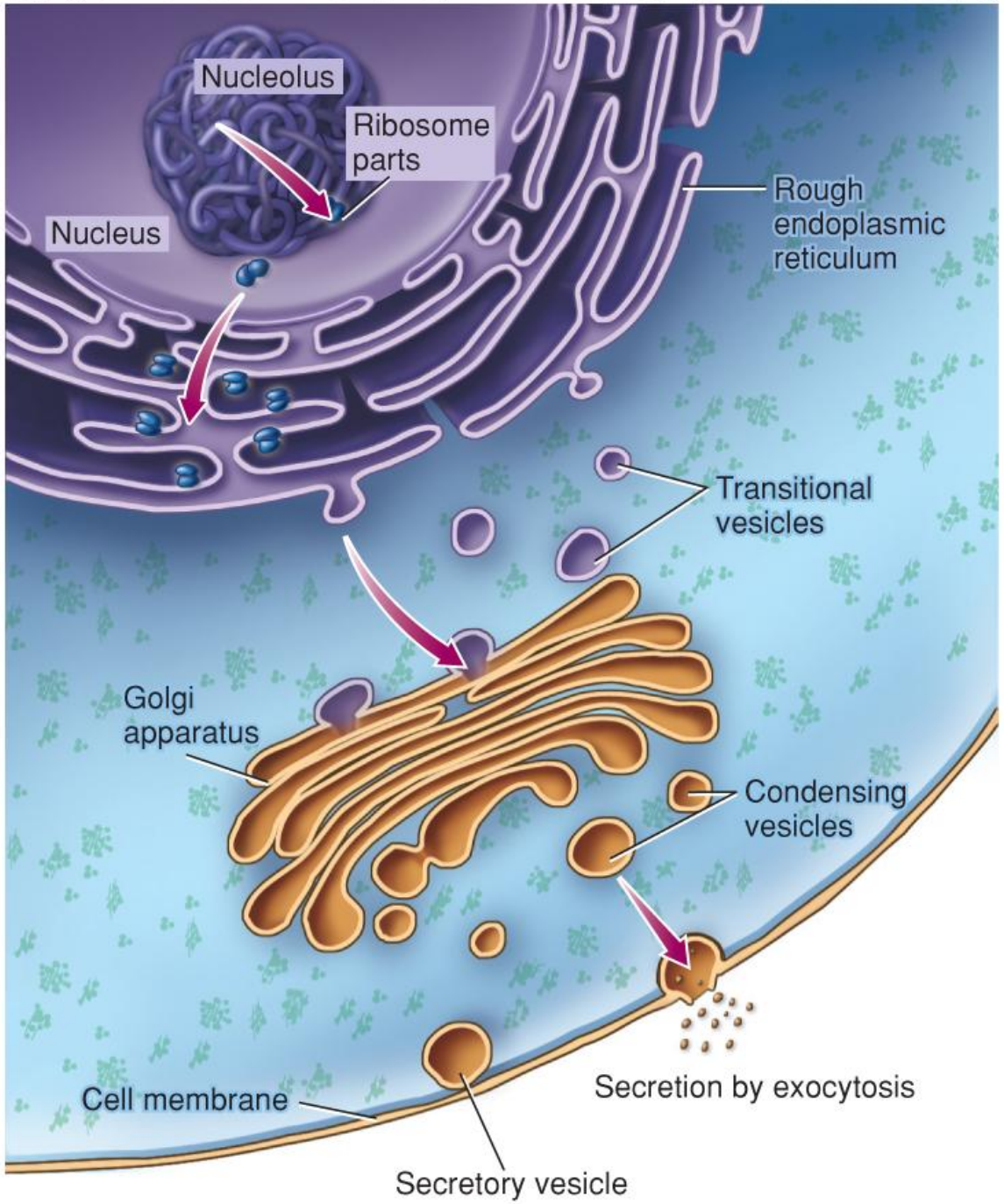



Figure 5.10

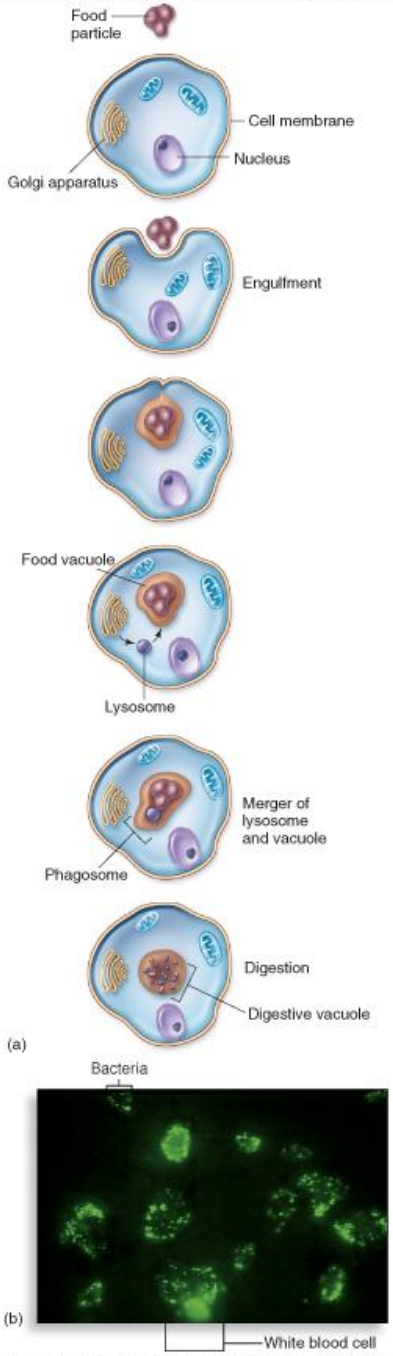
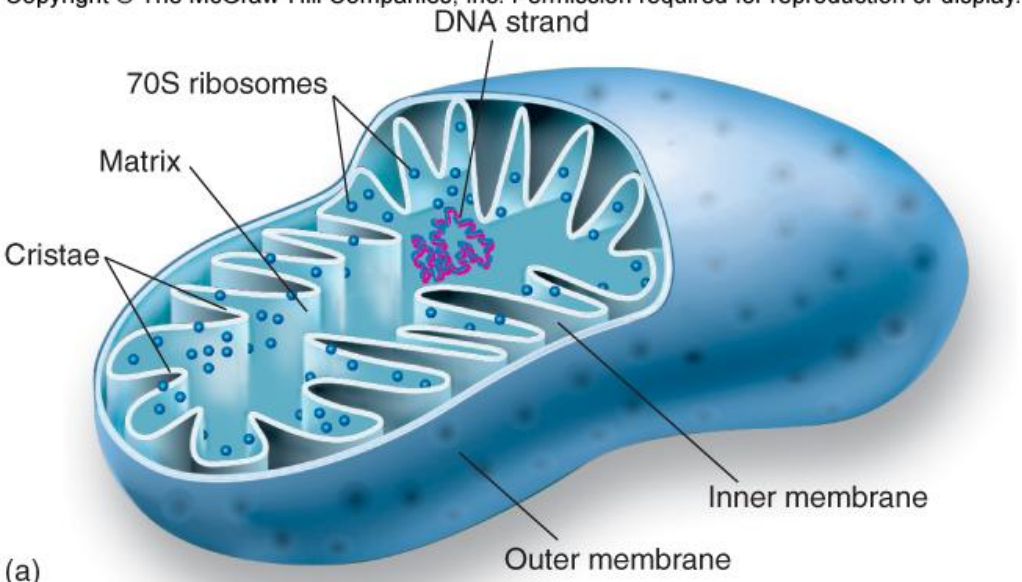



Figure 5.11

# Mitochondria: Energy Generators

- Cellular activities require a constant supply of energy
- The bulk of this energy generated by mitochondria
- Smooth, continuous outer membrane
- Inner folded membrane (folds are **cristae**)
  - Cristae hold enzymes and electron carriers of aerobic respiration
  - Spaces around cristae filled with a **matrix**
    - Ribosomes
    - DNA
    - Enzymes and other compounds involved I the metabolic cycle
- Divide independently of the cell
- Contain circular strands of DNA
- Contain prokaryotic-sized 70S ribosomes



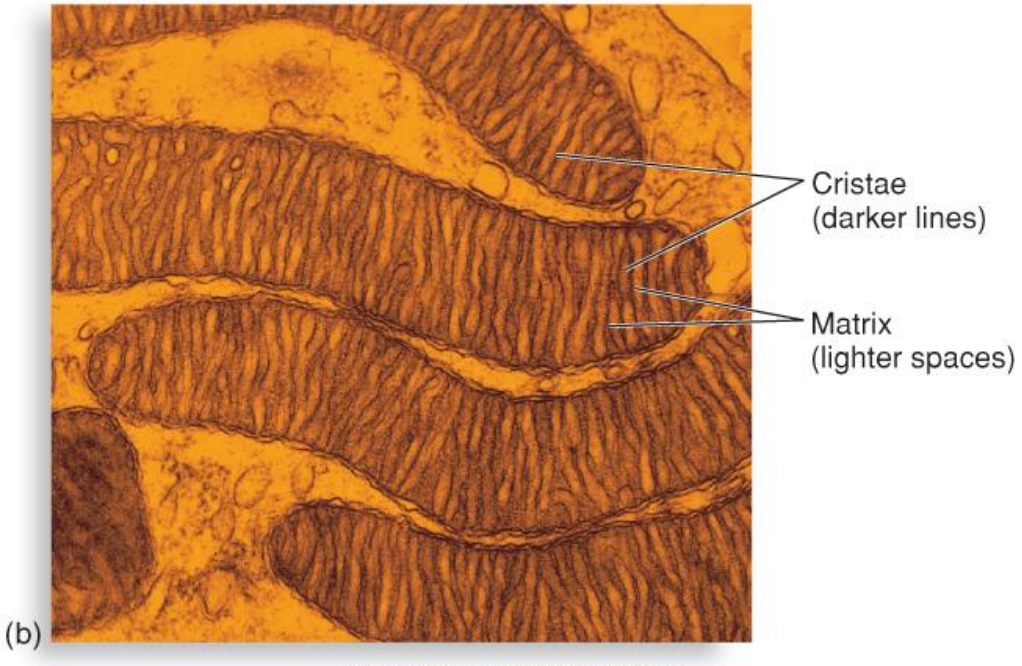






Figure 5.12

# **Chloroplasts:** Photosynthesis Machines

- Organelles found in algae and plant cells
- Convert energy of sunlight into chemical energy through photosynthesis
- Two membranes
  - Smooth outer membrane
  - Inner membrane folded in to **thylakoids**
  - Thylakoids stacked upon one another into **grana**
  - Contain chlorophyll and sometimes other pigments
- **Stroma** surrounds the thylakoids

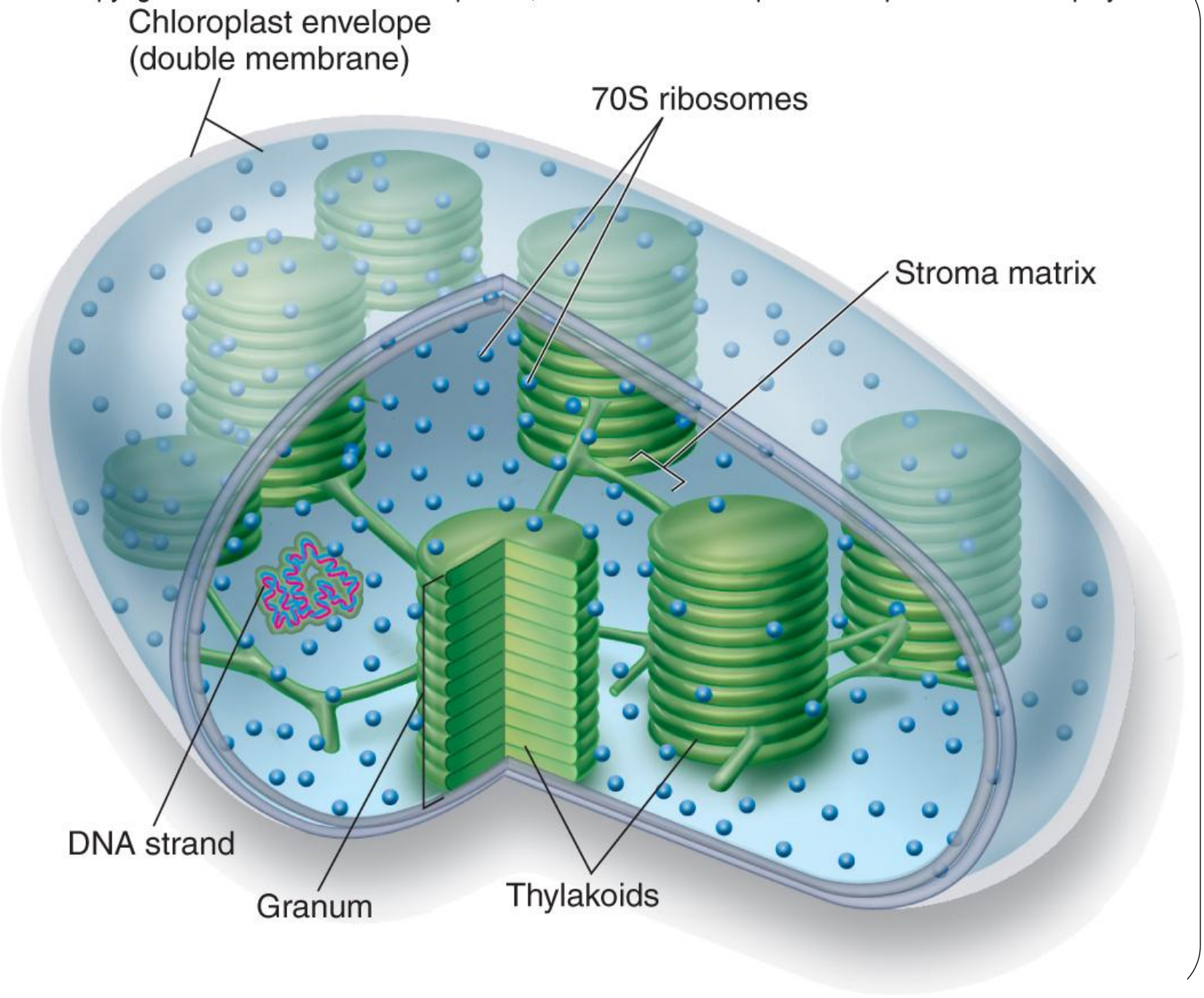



Figure 5.13

# Ribosomes: Protein Synthesizers

- Some scattered in the cytoplasm and cytoskeleton
- Others associated with RER
- Often found in chains of polyribosomes (polysomes)
- Composed of large and small subunits of ribonucleoprotein
- Larger 80S variety, composed of 60S and 40S subunits

# The Cytoskeleton: A Support Network

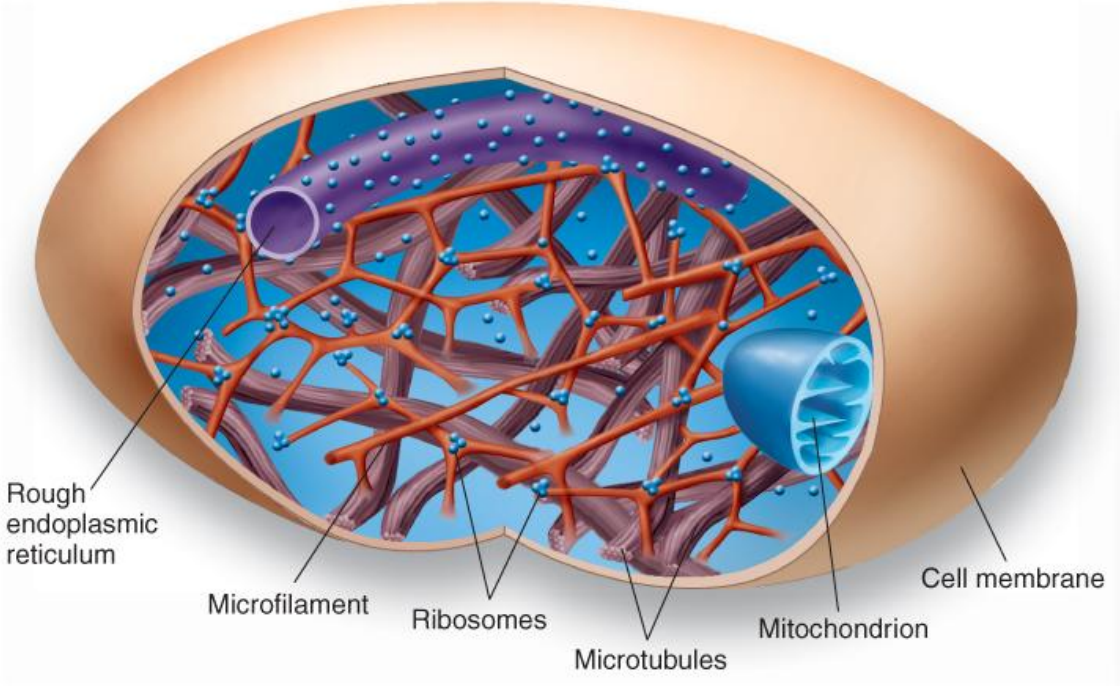
- Flexible framework of molecules criss-crossing the cytoplasm
- Several functions
  - Anchoring organelles
  - Moving RNA and vesicles
  - Permitting shape changes and movement in some cells
- Two types: Microfilaments and microtubules

# Microfilaments

- Thin protein strands
- Attach to the cell membrane
- Some responsible for movements of the cytoplasm
- Some active in amoeboid motion

# Microtubules

- Long, hollow tubes
- Maintain the shape of eukaryotic cells without walls
- Transport substances
- Responsible for the movement of cilia and flagella

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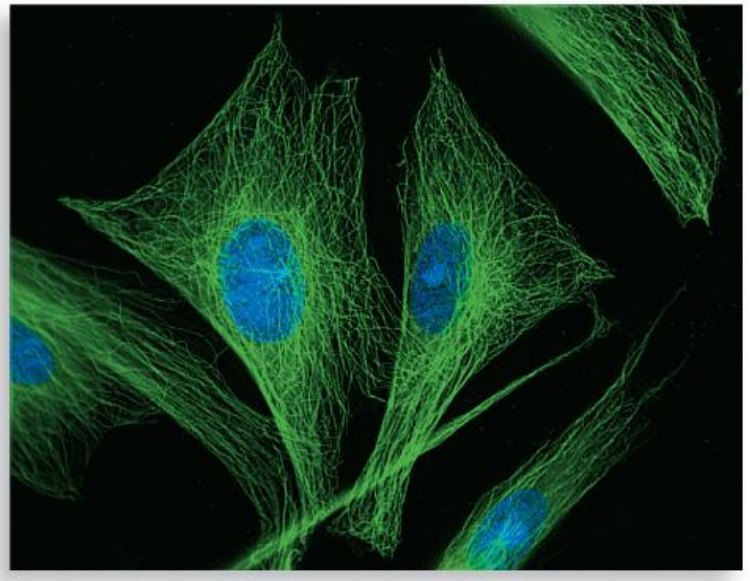


(b)



Figure 5.14

**TABLE 5.2 A General Comparison of Prokaryotic and Eukaryotic Cells and Viruses***

| Function or Structure | Characteristic | Procaryotic Cells | Eucaryotic Cells | Viruses** |
|---|---|---|---|---|
| Genetics | Nucleic acids | + | + | + |
| | Chromosomes | + | + | − |
| | True nucleus | − | + | − |
| | Nuclear envelope | − | + | − |
| Reproduction | Mitosis | − | + | − |
| | Production of sex cells | +/− | + | − |
| | Binary fission | + | + | − |
| Biosynthesis | Independent | + | + | − |
| | Golgi apparatus | − | + | − |
| | Endoplasmic reticulum | − | + | − |
| | Ribosomes | +*** | + | − |
| Respiration | Enzymes | + | + | − |
| | Mitochondria | − | + | − |
| Photosynthesis | Pigments | +/− | +/− | − |
| | Chloroplasts | − | +/− | − |
| Motility/locomotor structures | Flagella | +/−*** | +/− | − |
| | Cilia | − | +/− | − |
| Shape/protection | Membrane | + | + | +/− |
| | Cell wall | +*** | +/− | − (have capsids instead) |
| | Capsule | +/− | +/− | − |
| Complexity of function | | + | + | +/− |
| Size (in general) | | 0.5–3 μm**** | 2–100 μm | < 0.2 μm |

*+ means most members of the group exhibit this characteristic; − means most lack it; +/− means some members have it and some do not.

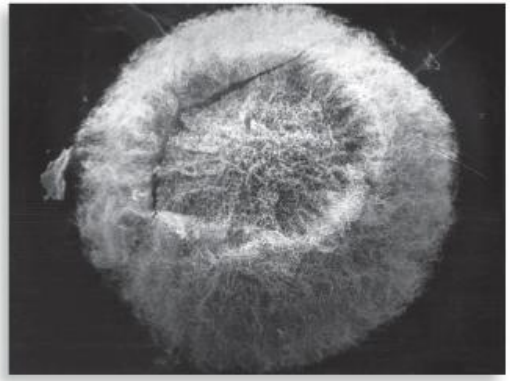
**Viruses cannot participate in metabolic or genetic activity outside their host cells.

***The prokaryotic type is functionally similar to the eukaryotic, but structurally unique.

****Much smaller and much larger bacteria exist; see Insight 4.3.

# 5.4 The Kingdom of the **Fungi**

- Myceteae
- Great variety and complexity
- Approximately 100,000 species
- Can be divided into two groups:
  - Macroscopic fungi
  - Microscopic fungi:
    - Yeasts
      - Round or oval shape
      - Unique mode of asexual reproduction
      - Some form pseudohyphae (false filaments)
    - Molds
      - Long, threadlike cells
      - Filamentous arrangement (hyphae)
    - Some are dimorphic (yeast-like and filamentous forms exist)
- Majority are unicellular or colonial



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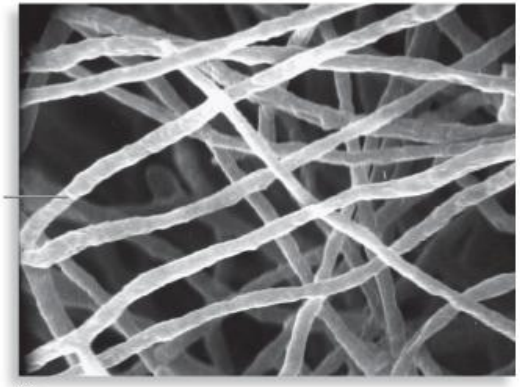


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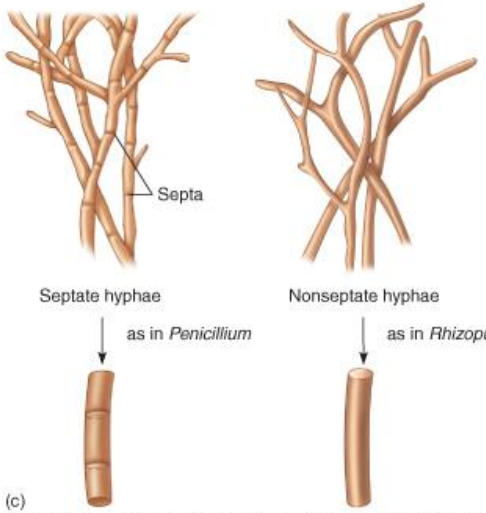
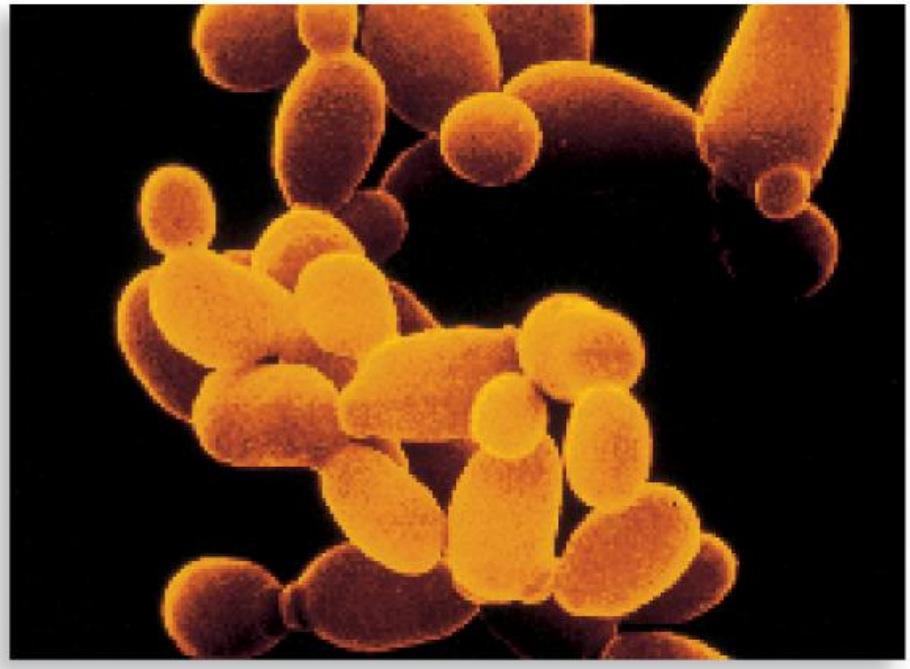



(c)



Figure 5.15



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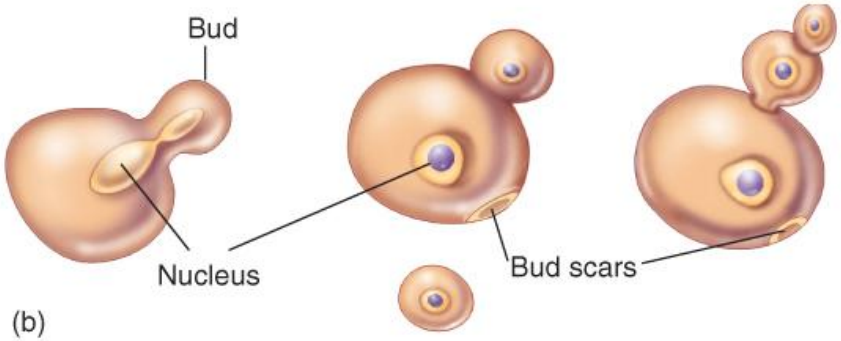


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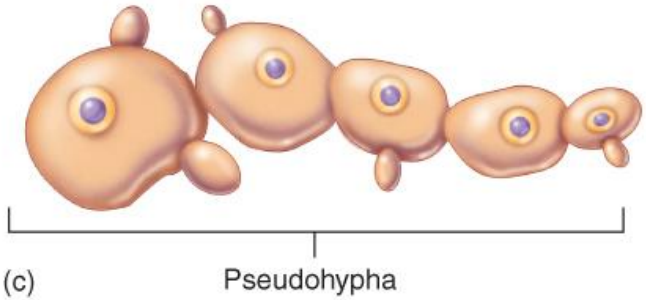


(c) Pseudohypha



Figure 5.16

# Fungal Nutrition

- Heterotrophic
- Acquire nutrients from **substrates**
- Most fungi are **saprobes**
- Can also be **parasites**
- General method of obtaining nutrition
  - Penetrates the substrate
  - Secretes enzymes
  - Breaks down the enzymes into small molecules
  - Absorbs the molecules
- Can absorb a wide variety of substrates
- Large medical and agricultural importance

(a)

(b)

Figure 5.17

# Organization of Microscopic Fungi

- Most grow in loose associations or colonies
- Yeasts- soft, uniform texture and appearance
- Filamentous fungal colonies- cottony, hairy, or velvety textures
- **Mycelium**- the woven, intertwining mass of hyphae that makes up the body or colony of a mold
- Unique organizational features of hyphae
  - **Septa**- divide the hyphae into segments (most fungi have septate hyphae)
  - Nonseptate hyphae- one long, continuous, multinucleate cell
- Functions of hyphae
  - Vegetative hyphae (mycelia)- visible mass of growth on the substrate surface; penetrates the substrate to digest and absorb nutrients
  - Reproductive (fertile) hyphae- from vegetative hyphae; responsible for the production of **spores**

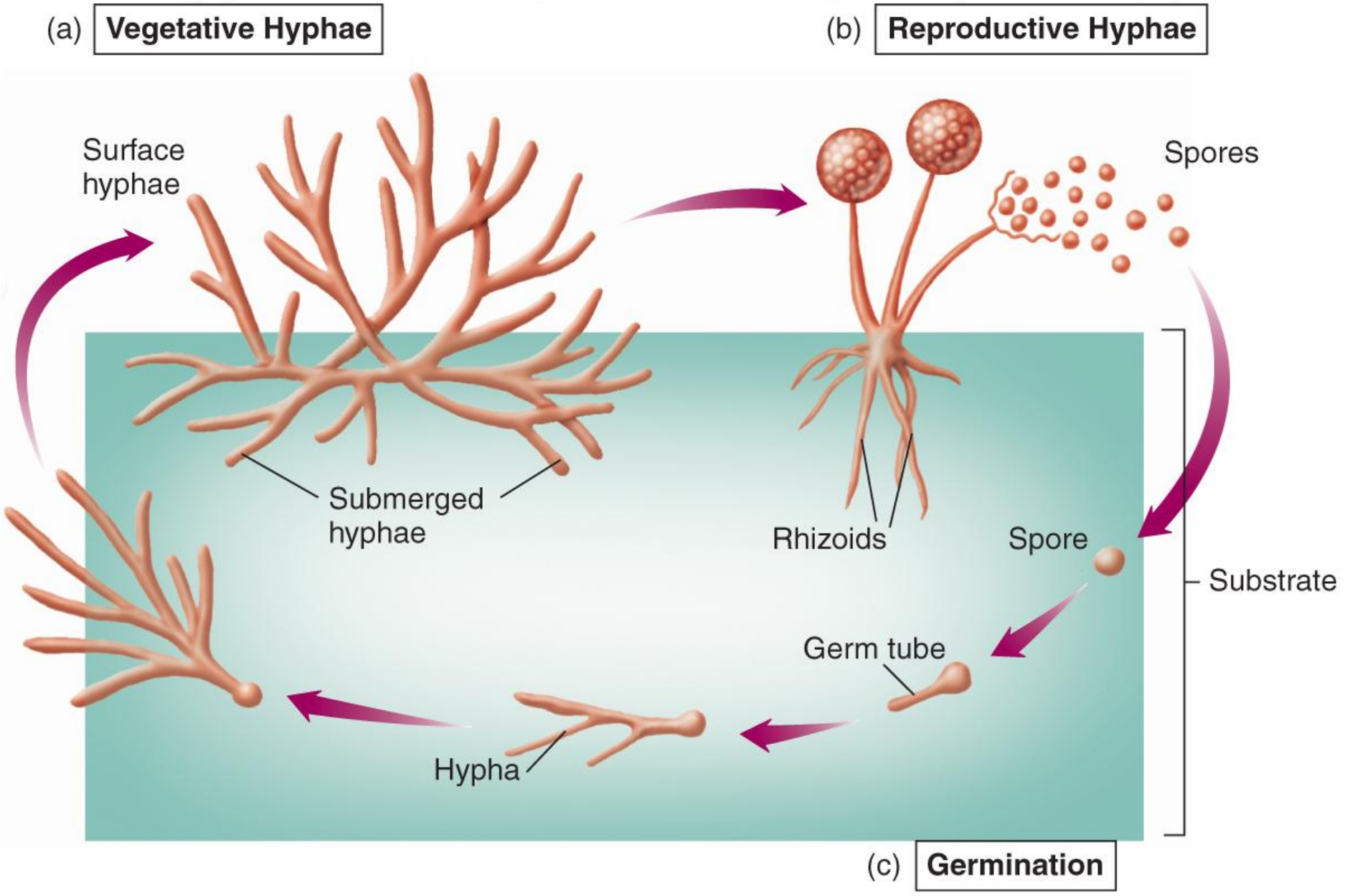



Figure 5.18

# Reproductive Strategies and Spore Formation

- Most can propagate by growth of hyphae or fragmentation
- Primary reproductive mode- the production of spores
- Function of spores
  - Multiplication
  - Survival
  - Producing genetic variation
  - Dissemination
- Large diversity in spores among the fungi
  - General grouping of spores- asexual and sexual

# Asexual Spores

- **Sporangiospores**
  - Formed by successive cleavages within the **sporangium**
  - Sporangium attached to the sporangiophore
  - Released when the sporangium ruptures
- **Conidiospores**
  - Aka **conidia**
  - Free spores
  - Develop either by pinching off the tip of fertile hypha or by segmentation of a vegetative hypha

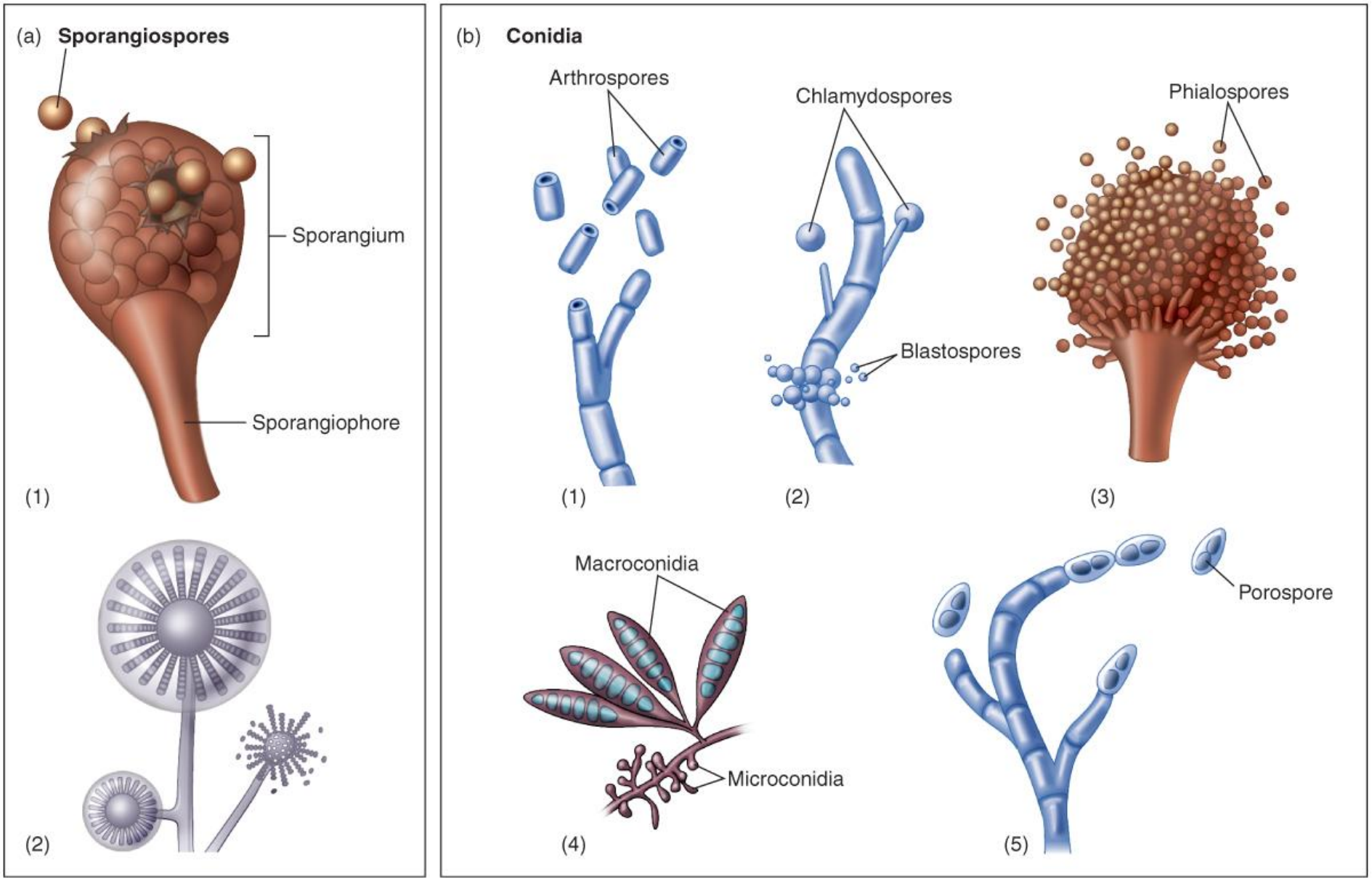



Figure 5.19

# Sexual Spores

- Increases genetic variation
- Majority of fungi produce sexual spores at some point

# Fungal Identification and Cultivation

- Medical specimens
  - Isolated on special types of media
  - Observed macroscopically and microscopically
- Usually use sexual spore-forming structures and spores
- Other characteristics that contribute to identification
  - Hyphal type
  - Colony texture and pigmentation
  - Physiological characteristics
  - Genetic makeup

# The Roles of Fungi in Nature and Industry

- Nearly all fungi are free-living and don't need a host
- Human infection by pathogenic fungi usually occurs through accidental contact
- Humans are generally resistant to fungal infection, except for two main types
  - Primary pathogens
  - Opportunistic pathogens
- Mycoses vary in the way the agent enters the body and the degree of tissue involvement

## TABLE 5.3 Major Fungal Infections of Humans

| Degree of Tissue Involvement and Area Affected | Name of Infection | Name of Causative Fungus |
|---|---|---|
| **Superficial (not deeply invasive)** | | |
| Outer epidermis | Tinea versicolor | *Malassezia furfur* |
| Epidermis, hair, and dermis can be attacked. | Dermatophytosis, also called tinea or ringworm of the scalp, body, feet (athlete's foot), toenails | *Microsporum*, *Trichophyton*, and *Epidermophyton* |
| Mucous membranes, skin, nails | Candidiasis, or yeast infection | *Candida albicans* |
| **Systemic (deep; organism enters lungs; can invade other organs)** | | |
| Lung | Coccidioidomycosis (San Joaquin Valley fever) | *Coccidioides immitis* |
| | North American blastomycosis (Chicago disease) | *Blastomyces dermatitidis* |
| | Histoplasmosis (Ohio Valley fever) | *Histoplasma capsulatum* |
| | Cryptococcosis (torulosis) | *Cryptococcus neoformans* |
| Lung, skin | Paracoccidioidomycosis (South American blastomycosis) | *Paracoccidioides brasiliensis* |

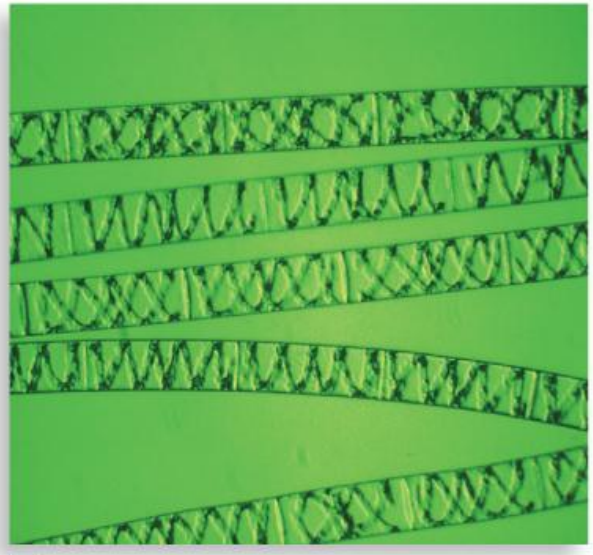
- Not only involved in infections
  - Allergies
  - Poisoning
  - Agricultural damage
- Benefits of fungi
  - Decomposing organic matter and returning essential minerals to the soil
  - Mycorrhizae increase the ability of plant roots to absorb water and nutrients
  - Production of
    - Antibiotics
    - Alcohol
    - Organic acids
    - Vitamins
  - Food flavorings

# 5.5 The Protists

- Traditionally contains the algae and protozoa
- Two major taxonomic categories
  - Subkingdom Algae
  - Subkingdom Protozoa
- Any unicellular or colonial organism that lacks true tissues

# The **Algae**: Photosynthetic protists

- Vary in length from a few micrometers to 100 meters
- Unicellular, colonial, and filamentous forms
- Larger forms can possess tissues and simple organs
- Exhibit all eukaryotic organelles
- Chloroplasts contain chlorophyll as well as other pigments
- One of the main components of **plankton**
- Rarely infectious
- Primary medical threat: shellfish exposed to red tide



(a)

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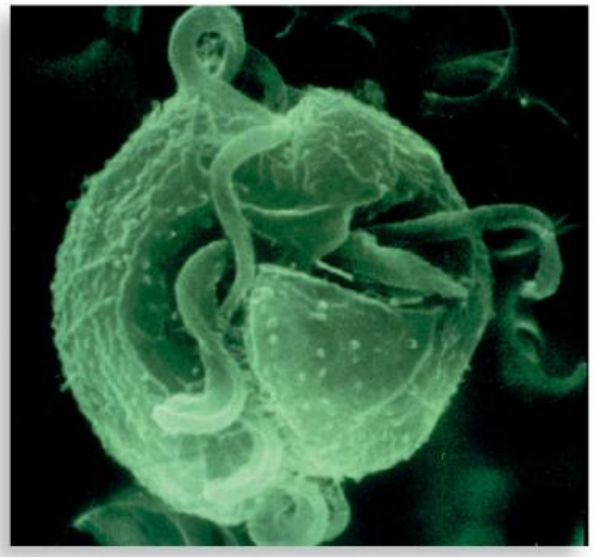


(c)



Figure 5.21

# Biology of the Protozoa

- About 65,000 species
- Most are harmless, free-living inhabitants of water and soil
- Few are parasites

# Protozoan Form and Function

- Most are single cells
- Contain major eukaryotic organelles except chloroplasts
- Cytoplasm usually divided
  - **Ectoplasm**: clear outer layer involved in locomotion, feeding, and protection
  - Endoplasm: granular inner region housing the nucleus, mitochondria, and food and contractile vacuoles
- Some ciliates and flagellates have organelles working like a primitive nervous system
- No cell wall- so some flexibility
- Cell shape can remain constant or can change constantly (amoebas)
- Size between 3 to 300 μm

# Nutritional and Habitat Range

- Heterotrophic
- Usually require their food in a complex organic form
- Free-living species scavenge or graze
- Some have special feeding structures such as oral grooves; some absorb food directly through the cell membrane
- Parasitic species live on the fluids of their host; or can actively feed on tissues
- Predominant habitats
  - Fresh and marine water
  - Soil
  - Plants
  - Animals
- Many can convert to a resistant, dormant stage called a cyst

# Styles of Locomotion

- All but the Apicomplexa are motile by means of **pseudopods**, **flagella**, or **cilia**
- Some unusual species move by gliding or twisting
- Pseudopods
  - Amoeboid motion
  - Can serve as feeding structures
- Flagella
  - From one to several
  - Some attached along the length of the cell by the undulating membrane
- Cilia
  - Mostly distributed over the entire surface of the cell
  - Form characteristic patterns

# Life Cycles and Reproduction



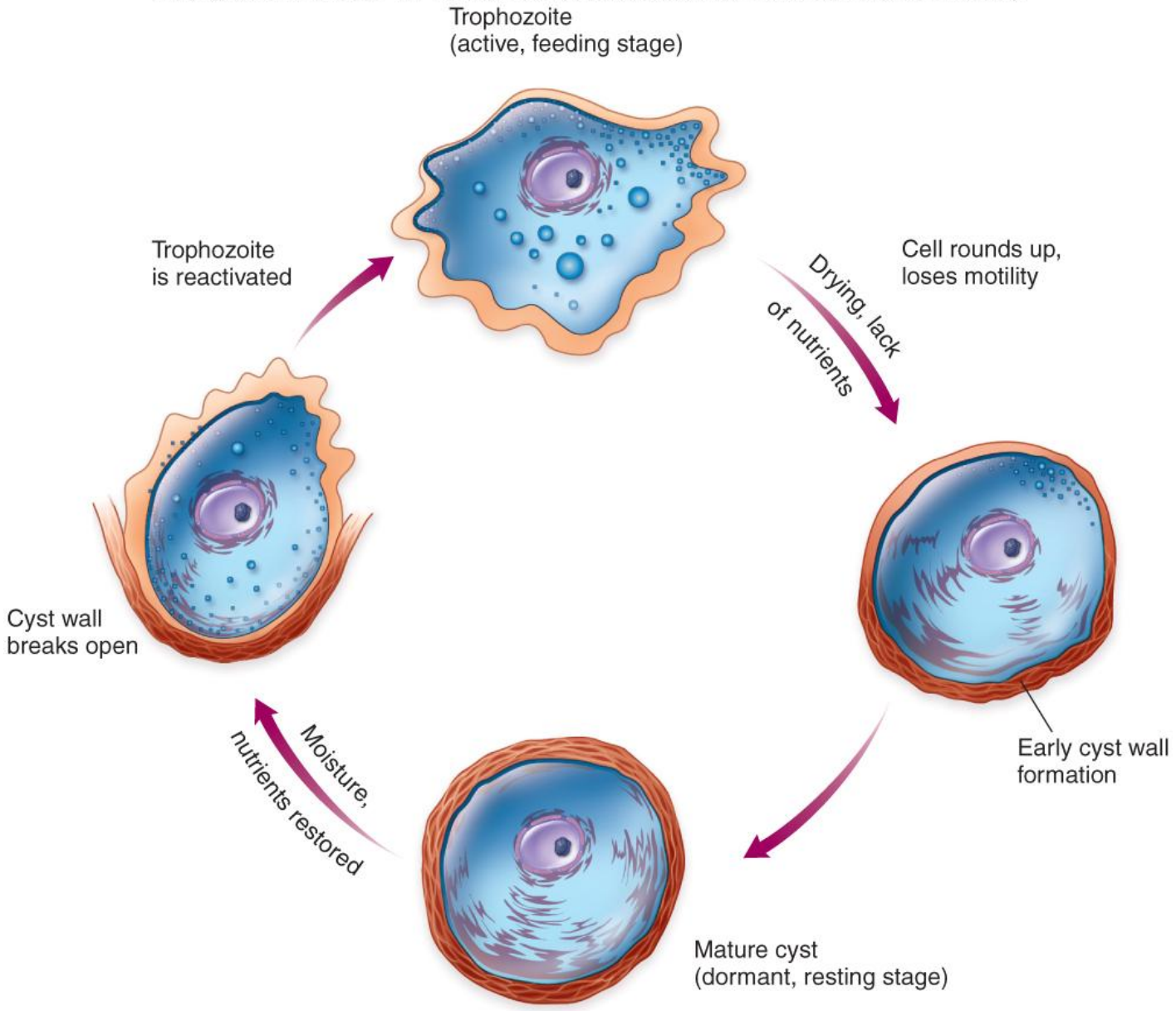



Figure 5.22

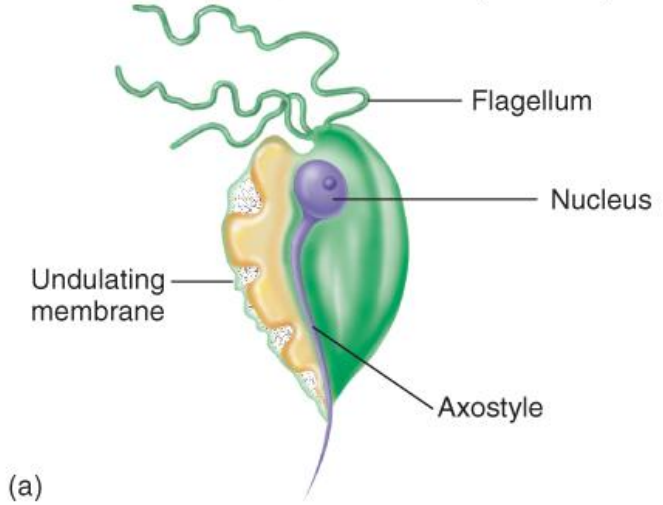
- Vary from simple to complex
- Some exist only in **trophozoite** stage
- Others alternate between trophozoite and **cyst**
- Life cycle of a parasitic protozoan determines the mode of transmission to hosts
- All reproduce by asexual methods
  - Usually mitotic cell division
  - Some by multiple fission
- Sexual reproduction occurs during the life cycle of most protozoa
  - Ciliates participate in **conjugation**

# Classification of Selected Medically Important Protozoa

- Four groups
- Based on:
  - Method of motility
  - Mode of reproduction
  - Stages in the lifecycle

# **Mastigophora** (Flagellated)

- Motility primarily by flagella
- Single nucleus
- Sexual reproduction by syngamy
- Division by longitudinal fission
- Parasitic forms tend to lack mitochondria and Golgi apparatus
- Most form cysts and are free-living
- Most are solitary
- Examples
  - *Trypanosoma*
  - *Leishmania*
  - *Giardia*
  - *Trichomonas*




(a)

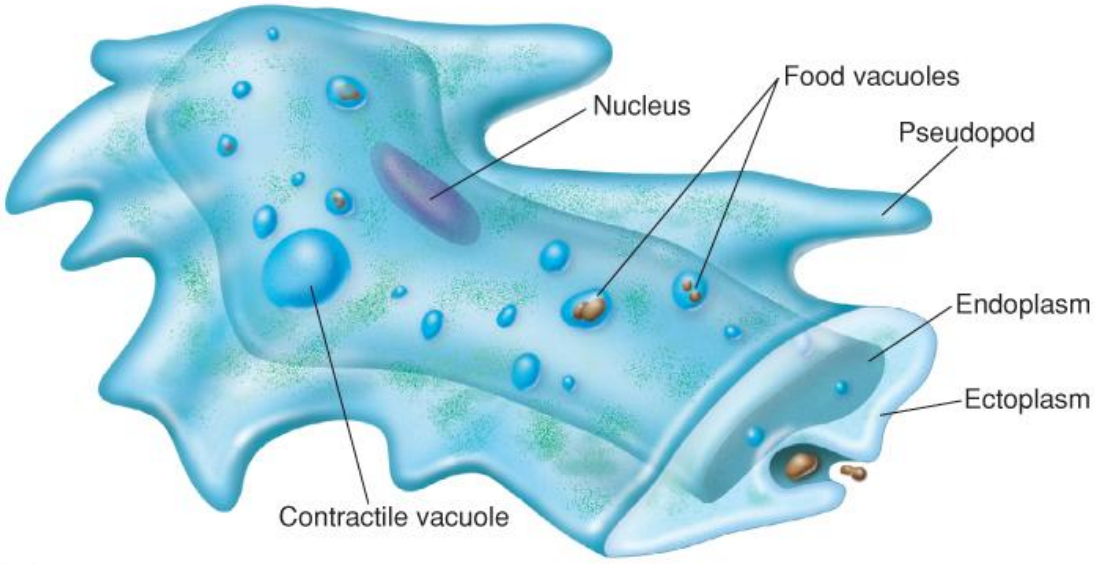
(b)



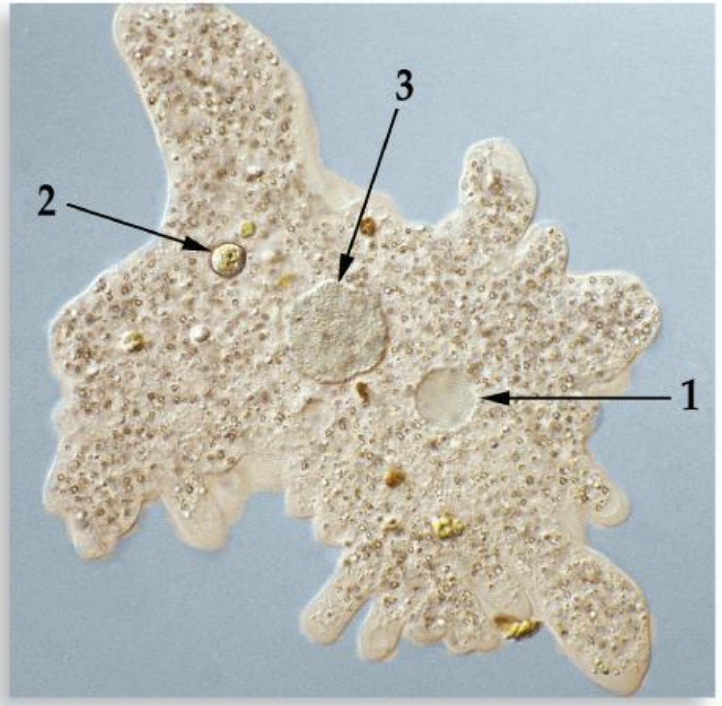
Figure 5.23

# **Sarcodina** (Amoebas)

- Pseudopods
- Some have flagellated reproductive states
- Asexual reproduction by fission
- Two groups have an external shell
- Mostly uninucleate
- Usually encyst
- Most free-living
- Examples
  - *Entamoeba*
  - Foraminifera
  - Radiolarians




(a)




(b)



Figure 5.24

# **Ciliophora** (Ciliated)

- Trophozoites mobile by cilia
- Some have cilia in tufts for feeding and attachment
- Most develop cysts
- Both macronuclei and micronuclei
- Division by transverse fission
- Most have definite mouth and feeding organelle
- Show relatively advanced behavior
- Majority are free-living and harmless

(a)

(b)



Figure 5.25

# **Apicomplexa** (Sporozoa)

- Most not motile except male gametes
- Complex life cycles
- Produce **sporozoites** following sexual reproduction
- Important in transmission of infections
- Most form oocysts
- Entire group is parasitic
- Examples
  - *Plasmodium*
  - *Toxoplasma gondii*

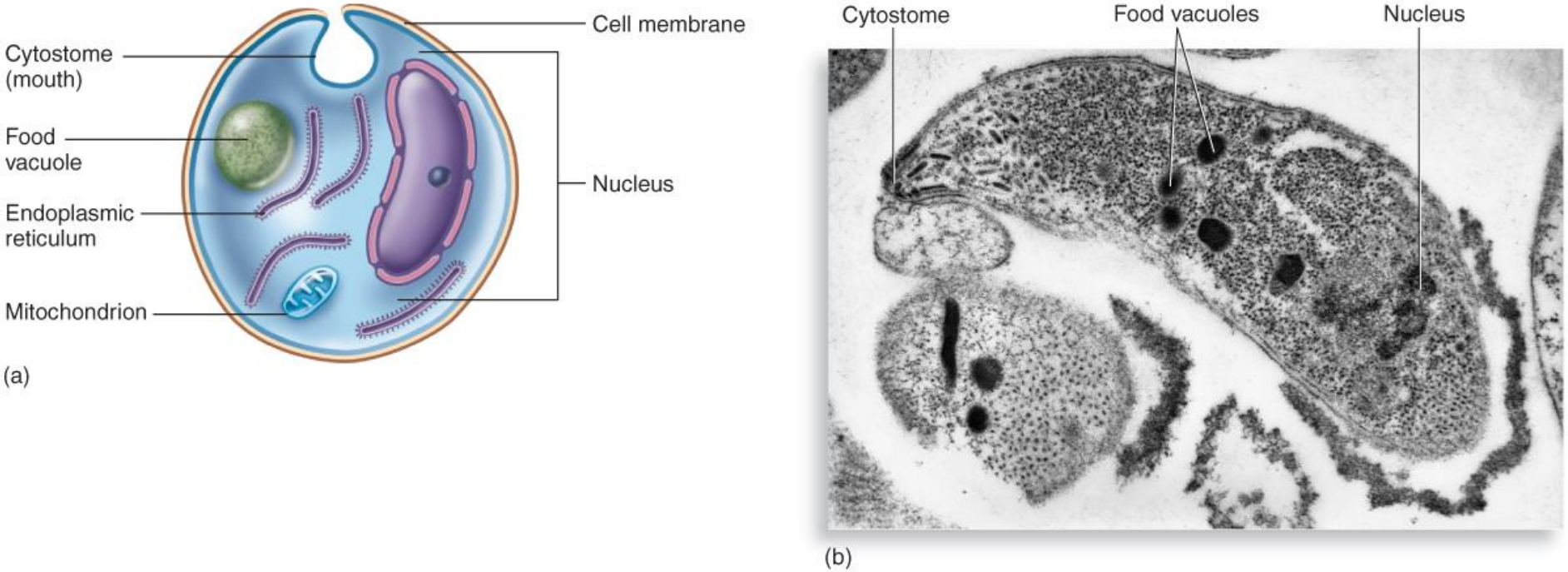





Figure 5.26

# Protozoan Identification and Cultivation

- Shape and size of cell
- Type, number, and distribution of locomotor structures
- Presence of special organelles or cysts
- Number of nuclei
- Can be cultivated on artificial media or in laboratory animals

# Important Protozoan Pathogens



**TABLE 5.4 Major Pathogenic Protozoa, Infections, and Primary Sources**

| Protozoan/Disease | Reservoir/Source |
|---|---|
| **Amoeboid Protozoa** | |
| Amoebiasis: *Entamoeba histolytica* | Human/water and food |
| Brain infection: *Naegleria, Acanthamoeba* | Free-living in water |
| **Ciliated Protozoa** | |
| Balantidiosis: *Balantidium coli* | Zoonotic in pigs |
| **Flagellated Protozoa** | |
| Giardiasis: *Giardia lamblia* | Zoonotic/water and food |
| Trichomoniasis: *T. hominis, T. vaginalis* | Human |
| Hemoflagellates | |
| Trypanosomiasis: *Trypanosoma brucei, T. cruzi* | Zoonotic/ vector-borne |
| Leishmaniasis: *Leishmania donovani, L. tropica, L. brasiliensis* | Zoonotic/ vector-borne |
| **Apicomplexan Protozoa** | |
| Malaria: *Plasmodium vivax, P. falciparum, P. malariae* | Human/vector-borne |
| Toxoplasmosis: *Toxoplasma gondii* | Zoonotic/vector-borne |
| Cryptosporidiosis: *Cryptosporidium* | Free-living/water, food |
| Cyclosporiasis: *Cyclospora cayetanensis* | Water/fresh produce |

# Pathogenic Flagellates: Trypanosomes

- Genus *Trypanosoma*
- *T. brucei* causes sleeping sickness
- *T. cruzi* causes Chagas disease

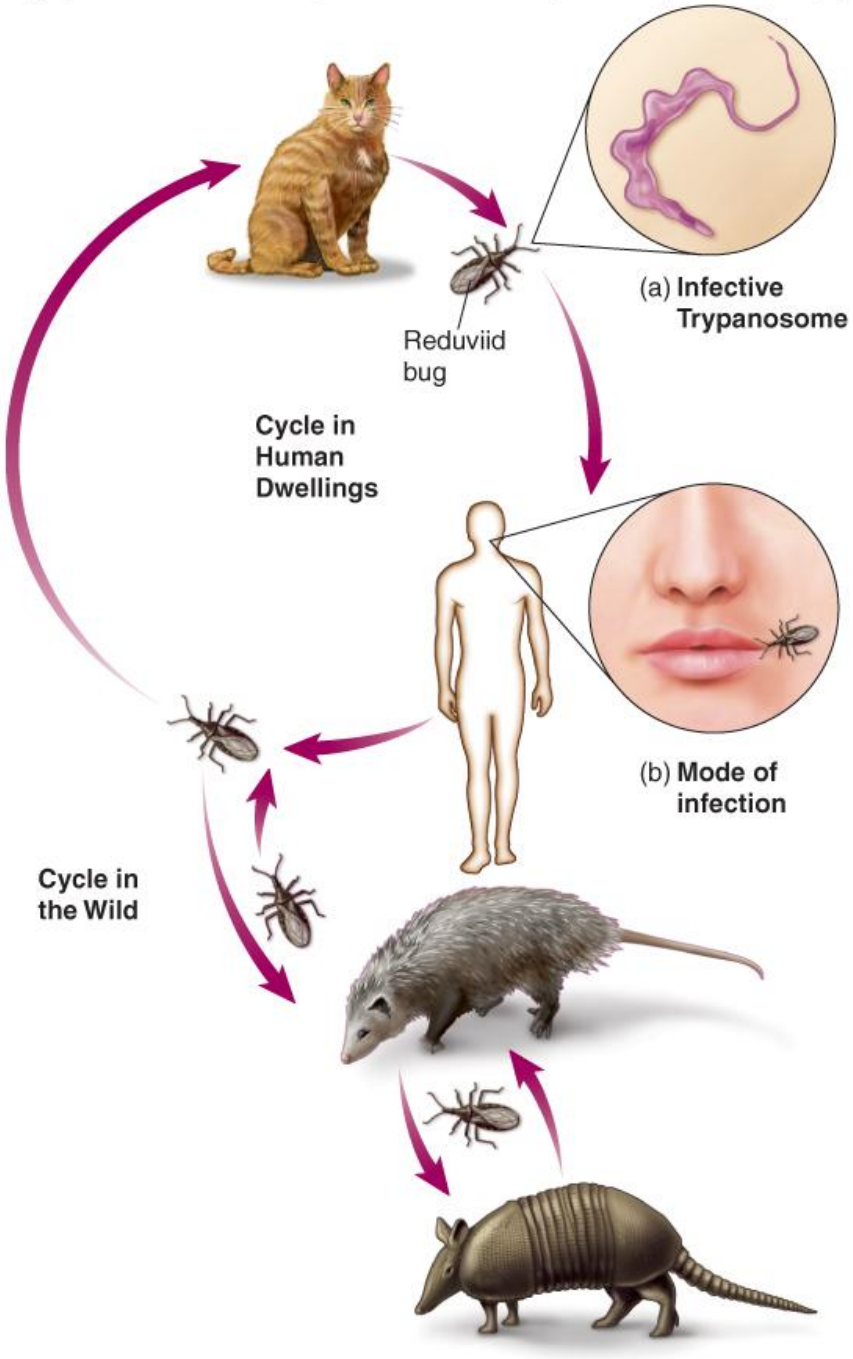



Figure 5.27

# Infective Amoebas: *Entamoeba*

- Amoebiasis caused by *Entamoeba histolytica*
- Fourth most common protozoan infection in the world
- Aka amoebic dysentery

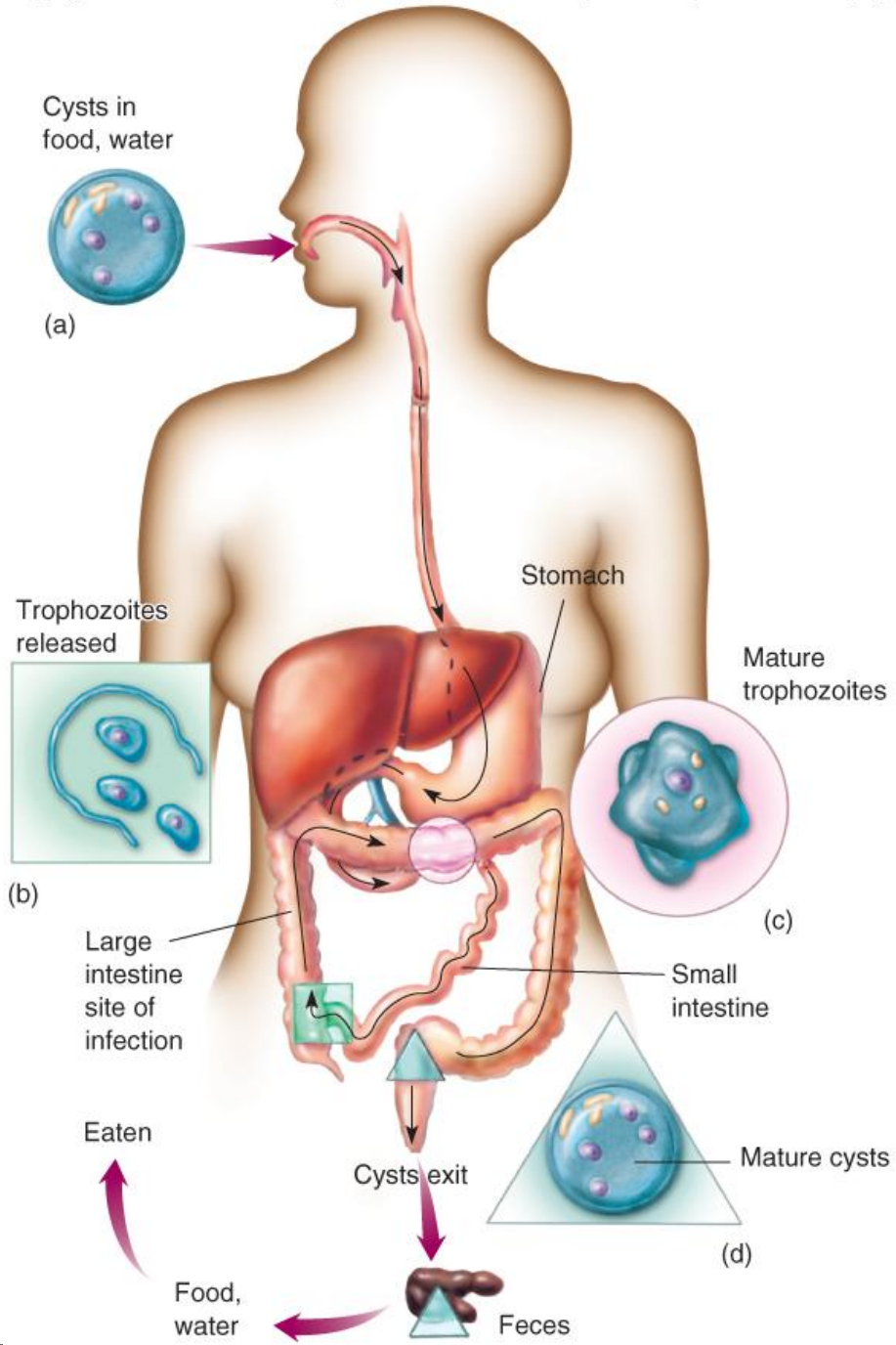


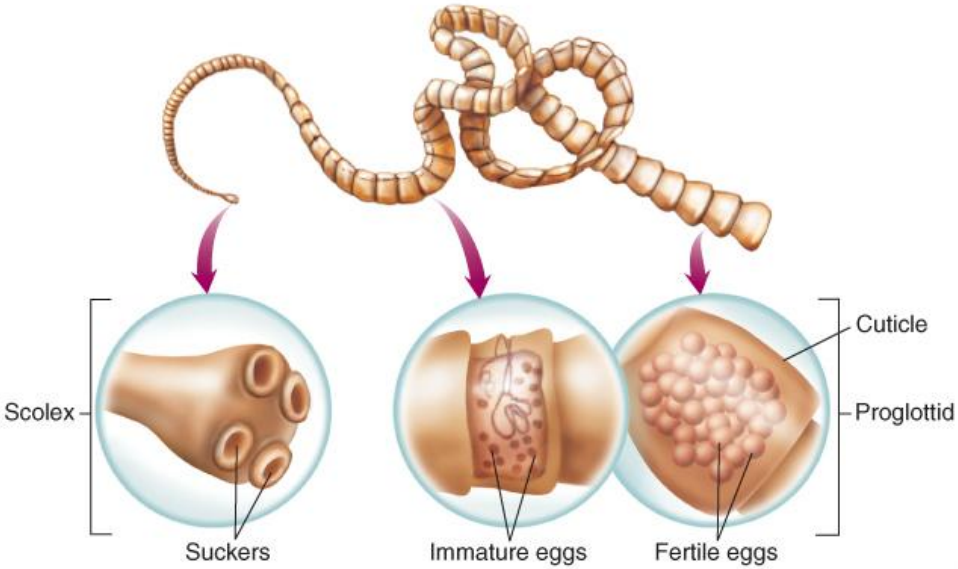

Figure 5.28

# 5.6 The Parasitic Helminths

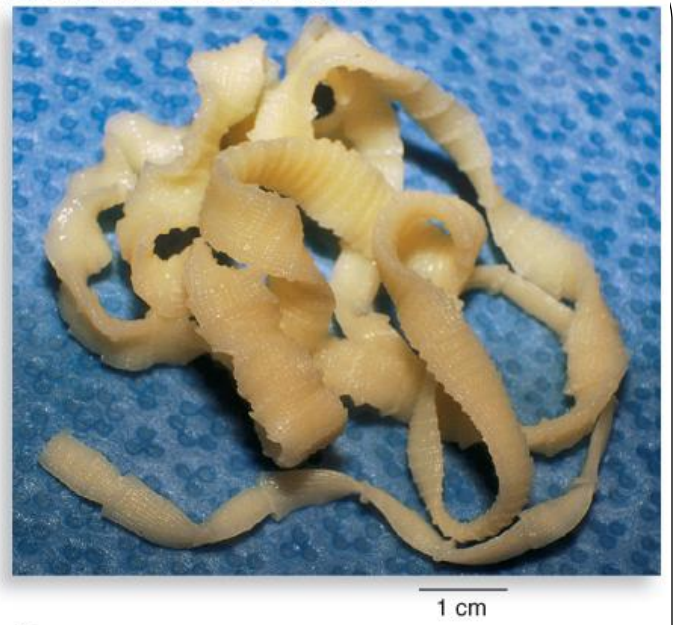
- Tapeworms, flukes, and roundworms
- Adults large enough to be seen with the naked eye
- From 1 mm to 25 m in length
- Microscope is necessary to identify eggs and larvae
- Two major groups: Flatworms and Roundworms

# Flatworms

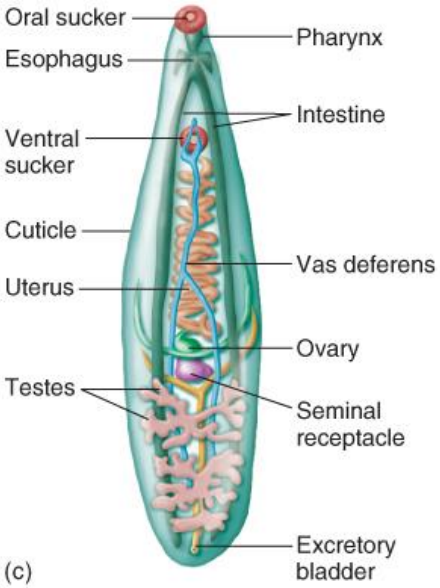
- Phylum Platyhelminthes
- Thin
- Often segmented
- Subdivisions
  - **Cestodes** (tapeworms)
  - **Trematodes** (flukes)




(a)




(b)




(c)


(d)



Figure 5.29

# Roundworms

- Phylum Aschelminthes
- Aka **nematodes**
- Elongate
- Cylindrical
- Unsegmented

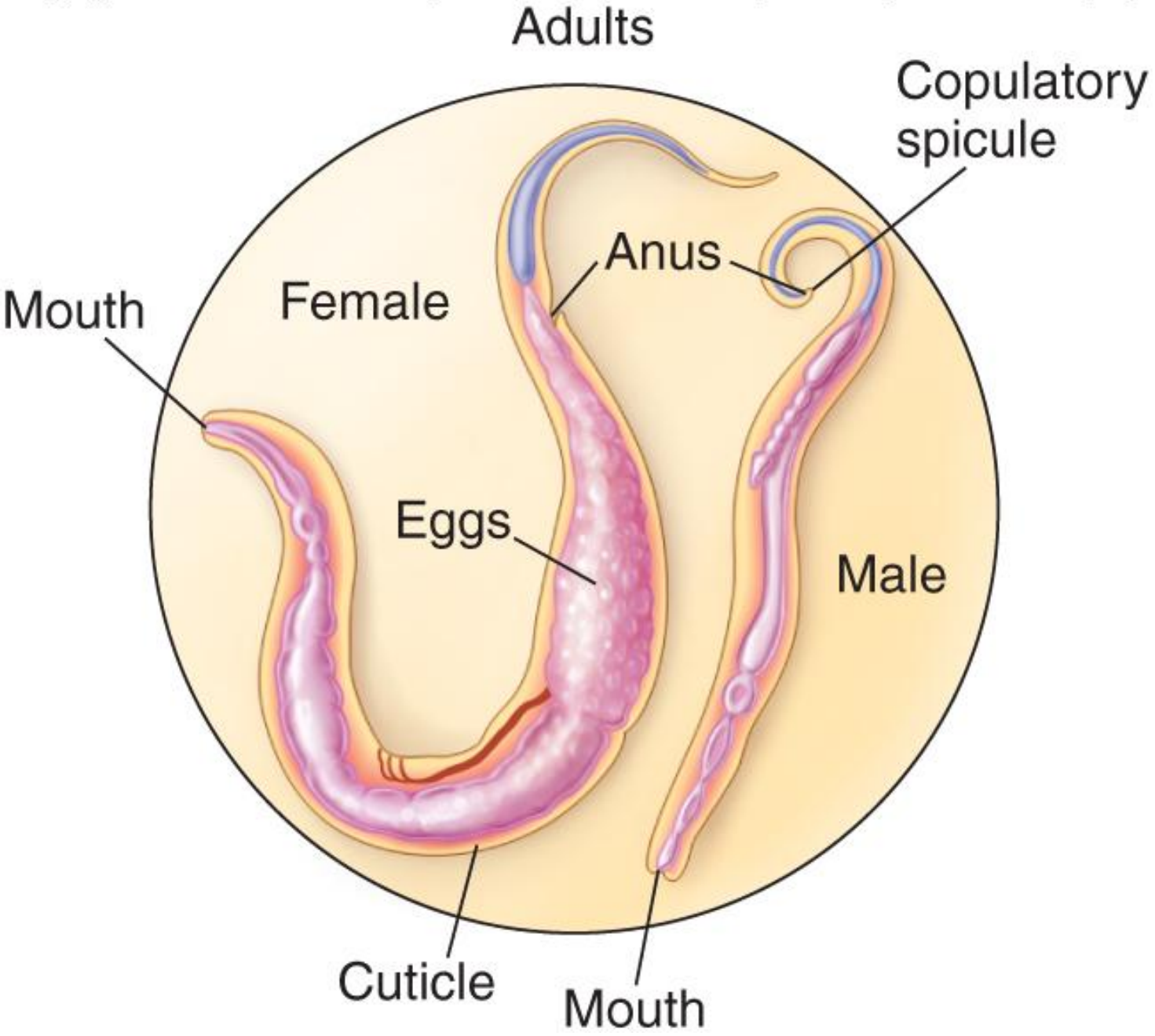



Figure 5.30

# General Worm Morphology

- Most developed organs are those of the reproductive tract
- Some degree of reduction in digestive, excretory, nervous, and muscular systems
- Most have thick cuticles for protection and mouth glands for breaking down the host's tissue

# Life Cycles and Reproduction

- Fertilized egg (embryo), larval, and adult stages
- In most, adults derive nutrients and reproduce sexually in a host's body
  - Nematodes- separate sexes
  - Trematodes- separate sexes or **hermaphroditic**
- Must complete the life cycle by transmitting an infective form to the body of another host
  - Larval development- intermediate (secondary) host
  - Adulthood and mating- **definitive (final) host**

**TABLE 5.5** Examples of Helminths and Their Modes of Transmission

| Classification | Common Name of Disease or Worm | Life Cycle Requirement | Spread to Humans By |
|---|---|---|---|
| **Roundworms** | | | |
| **Nematodes** | | | |
| Intestinal Nematodes | | | Ingestion |
| Infective in egg (embryo) stage | | | |
| *Ascaris lumbricoides* | Ascariasis | Humans | Fecal pollution of soil with eggs |
| *Enterobius vermicularis* | Pinworm | Humans | Close contact |
| Infective in larval stage | | | |
| *Trichinella spiralis* | Trichina worm | Pigs, wild mammals | Consumption of meat containing larvae |
| Tissue Nematodes | | | Burrowing of larva into tissue |
| *Onchocerca volvulus* | River blindness | Humans, black flies | Fly bite |
| *Dracunculus medinensis* | Guinea worm | Humans and *Cyclops* (an aquatic invertebrate) | Ingestion of water containing *Cyclops* |
| **Flatworms** | | | |
| **Trematodes** | | | |
| *Schistosoma japonicum* | Blood fluke | Humans and snails | Ingestion of fresh water containing larval stage |
| **Cestodes** | | | |
| *T. solium* | Pork tapeworm | Humans, swine | Consumption of undercooked or raw pork |
| *Diphyllobothrium latum* | Fish tapeworm | Humans, fish | Consumption of undercooked or raw fish |

# A Helminth Cycle: The Pinworm

- Person swallows microscopic eggs
  - Picked up from another infected person by direct contact
  - Or by touching articles an infected person has touched
- Eggs hatch in the intestine
- Release larvae that mature in to adult worms (about 1 month)
- Male and female worms mate
- Female migrates out of the anus to deposit eggs
  - Causes intense itchiness
  - Relieved by scratching
  - Scratching contaminates the fingers which transfer the eggs
- Eggs spread to others or the original host reinfects him or herself

# Helminth Classification and Identification

- Shape
- Size
- Degree of development of various organs
- Presence of hooks, suckers, or other special structures
- Mode of reproduction
- Kinds of hosts
- Appearance of eggs and larvae

# Distribution and Importance of Parasitic Worms

- About 50 species parasitize humans
- Distributed in all areas of the world
- Yearly estimate of worldwide infections- in the billions

# SUMMARY

- History of Eukaryotic cell
- Fungi
- Algae
- Protozoa
- Helminths