Lecture 5: Chapter 7 Nutrition and Growth

Topics

- **Microbial Nutrition**

  (Amended by Chapter 24, EM)

Microbial Nutrition

- **Nutritional requirements**
- Sources of nutrients
- Ways to get nutrients
  (Transport mechanisms)

Bacteria are composed of different elements and molecules, with water (70%) and proteins (15%) being the most abundant.

TABLE 7.2 Analysis of the Chemical Composition of an *Escherichia coli* Cell

	% Total Weight	% Dry Weight
Organic Compounds		
Proteins	15	50
Nucleic acids		
RNA	6	20
DNA	1	3
Carbohydrates	3	10
Lipids	2	Not determined
Miscellaneous	2	Not determined
Inorganic Compounds		
Water	70	
All others	1	3

	% Dry Weight
Elements	
Carbon (C)	50
Oxygen (O)	20
Nitrogen (N)	14
Hydrogen (H)	8
Phosphorus (P)	3
Sulfur (S)	1
Potassium (K)	1
Sodium (Na)	1
Calcium (Ca)	0.5
Magnesium (Mg)	0.5
Chlorine (Cl)	0.5
Iron (Fe)	0.2
Manganese (Mn), zinc (Zn), molybdenum (Mo), copper (Cu), cobalt (Co), zinc (Zn)	0.3

Table 7.2 Analysis of the chemical composition of an *E. coli* cell.

Inorganic nutrients

- Macronutrients
- Micronutrients
- Small molecules and compounds

Macronutrients

Required in **milli**molar (mM) concentrations

Nathan C. HOPKiNS CaFé is Mighty good

=> Needed for the synthesis of nucleic acids, proteins, lipids, carbohydrates ... To be assembled to plasma membrane, cell wall ….

Micronutrients

Required in **micro**molar (µM) concentrations

Mn, Cu, Zn, Mo, Ni, Se, ….

Growth factors

- Essential organic nutrients (amino acid, nitrogenous base, or vitamin that) that cannot be synthesized by the microbe, and must be supplemented if cultured.

==> Essential Amino acids, vitamins

– For example, many cells cannot synthesize all 20 amino acids so they **must** obtain them from food ("essential amino acids")

Microbial Nutrition

- Nutritional requirements
- **Sources of nutrients**
- Ways to get nutrients
  (Transport mechanisms)

Sources of nutrients

As requirements for growth and metabolism

- Carbon source
- Energy source
- Reductant (electron) source
- Inorganic nutrients (macro- and micronutrients)
- Growth factors

TABLE 7.1 Principal Inorganic Reservoirs of Elements

Element	Inorganic Environmental Reservoir
Carbon	CO_2 in air; CO_3^{2-} in rocks and sediments
Oxygen	O_2 in air, certain oxides, water
Nitrogen	N_2 in air; NO_3^-, NO_2^-, NH_4^+ in soil and water
Hydrogen	Water, H_2 gas, mineral deposits
Phosphorus	Mineral deposits (PO_4^{3-}, H_3PO_4)
Sulfur	Mineral deposits, volcanic sediments (SO_4^{2-}, H_2S, S^0)
Potassium	Mineral deposits, the ocean (KCl, K_3PO_4)
Sodium	Mineral deposits, the ocean (NaCl, NaSi)
Calcium	Mineral deposits, the ocean ($CaCO_3$, $CaCl_2$)
Magnesium	Mineral deposits, geologic sediments ($MgSO_4$)
Chloride	The ocean (NaCl, NH_4Cl)
Iron	Mineral deposits, geologic sediments ($FeSO_4$)
Manganese, molybdenum, cobalt, nickel, zinc, copper, other micronutrients	Various geologic sediments

Recycling of "bioelements"

- Bioelements – group of **macronutrients** such as carbon, nitrogen, sulfur, phosphorus, oxygen, iron, **and essential building blocks** needed by the cell

- **Biogeochemical cycles** – (re)cycling of essential bioelements (macronutrients) through biotic and abiotic environments

Environmental Microbiology
(Use of knowledge on ecology of microbes)

+ Microbial habitats - microbial communities
+ Microenvironments
  - Physical parameters change rapidly (harsh)
  - Availability and accessibility of nutrients
    - Nutrients are limited (availability)
    - Nutrients are unevenly distributed (availability)
    - Nutrients are competed for (accessibility)
  - How will changes affect growth?
    + Biogeochemical cycling of Carbon and Nitrogen
    + Biodegradation (recycling of persistant recalcitrants)
    + Aquatic and terrestrial habitats

Carbon source

Carbon - the central bioelement

- Autotroph ("self-feeders")
  - Derive carbon solely from CO_2
- Heterotroph ("mixed-feeders")
  - Derive carbon from all possible sources, including but NOT solely from CO_2
  - Usually diverse organic molecules such as sugars, proteins, lipids and their monomers

Carbon cycle

- Organic reservoir are organisms
- Recycle via carbon fixation (gas -> solid), respiration, and fermentation (solid -> gas), limestone decomposition, and methane production
- Carbon dioxide (CO_2) is main gas phase
- Methane is produced by methanogens

The carbon cycle involves the complex interaction between photosynthesis, respiration, fermentation, and limestone decomposition.

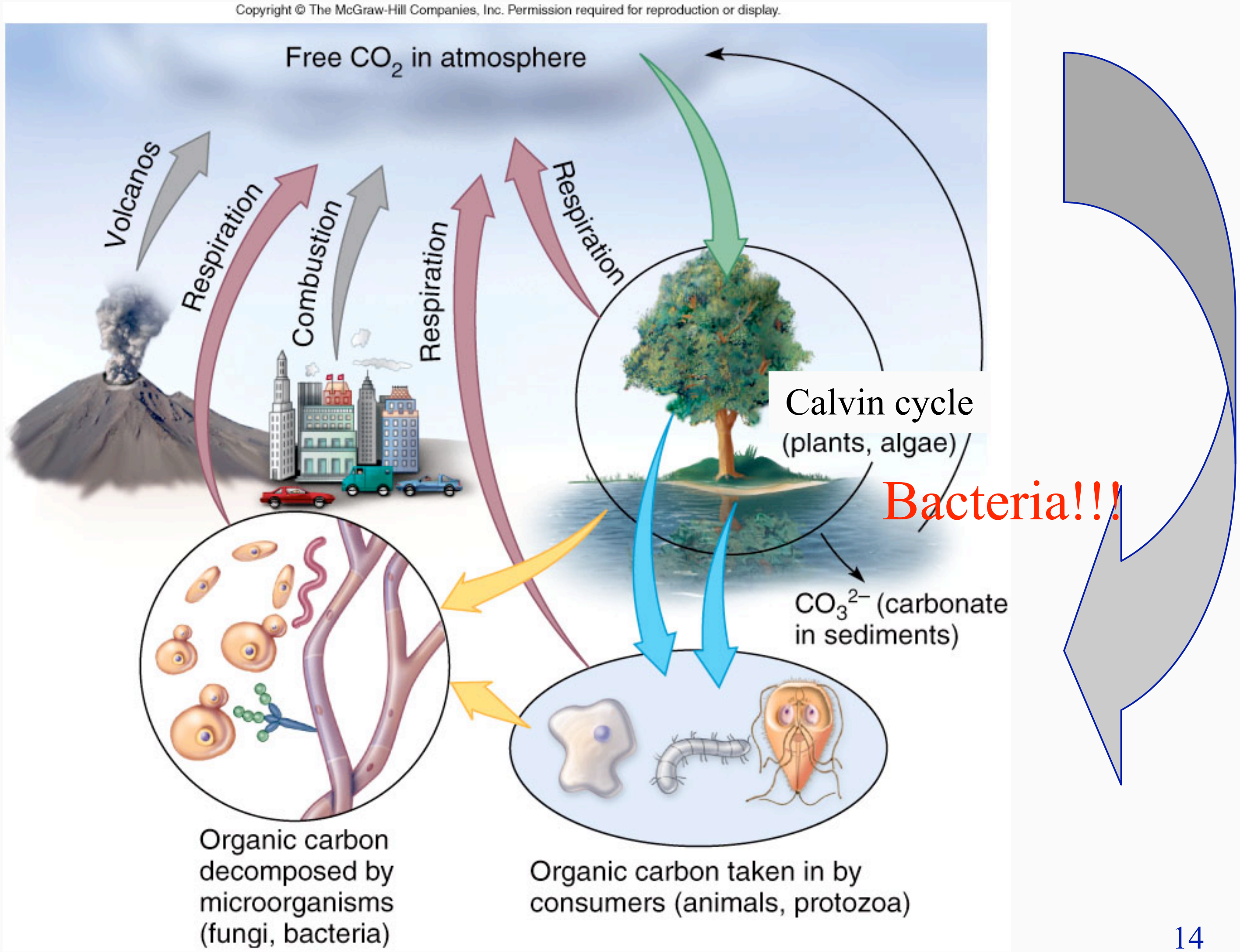


Fig. 24.6 The carbon cycle

Nitrogen Sources

- Main reservoir is N_2
- Primary nitrogen source for heterotrophs is proteins, DNA, RNA
- Some bacteria, algae, fungi and plants utilize inorganic nitrogenous nutrients
- Small number can transform N_2 into usable compounds through nitrogen fixation
- Regardless of the initial form, must be converted to NH_3 (the only form that can be directly combined with C to synthesize amino acids and other compounds)

Nitrogen cycle

- Nitrogen gas – most abundant component of the atmosphere
- Four steps
  - Nitrogen fixation (N_2 => NH_3=> ~NH_2)
  - Assimilation (NH_3=> ~NH_2)
  - Ammonification (~NH_2 => NH_3)
  - Nitrification (NH_3=> NO_2 => NO_3)
  - Denitrification (NO_3 => NO_2 => NO => N_2)

Nitrogen fixation

- Remove **nitrogen from the air** and convert it **into** a form **usable** by organisms
- Soil and water bacteria
  - *Azotobacter* and *Azospirillum*
  - *Clostridium*
  - Cyanobacteria (*Anabaena, Nostoc)*
- Root nodule (symbiosis)
  - *Rhizobium*
- Ammonia is the primary product

Root nodules represent a symbiotic relationship, in which rhizobia bacteria fix nitrogen for the plant legume, while the plant legume supplies the bacteria with nutrients.

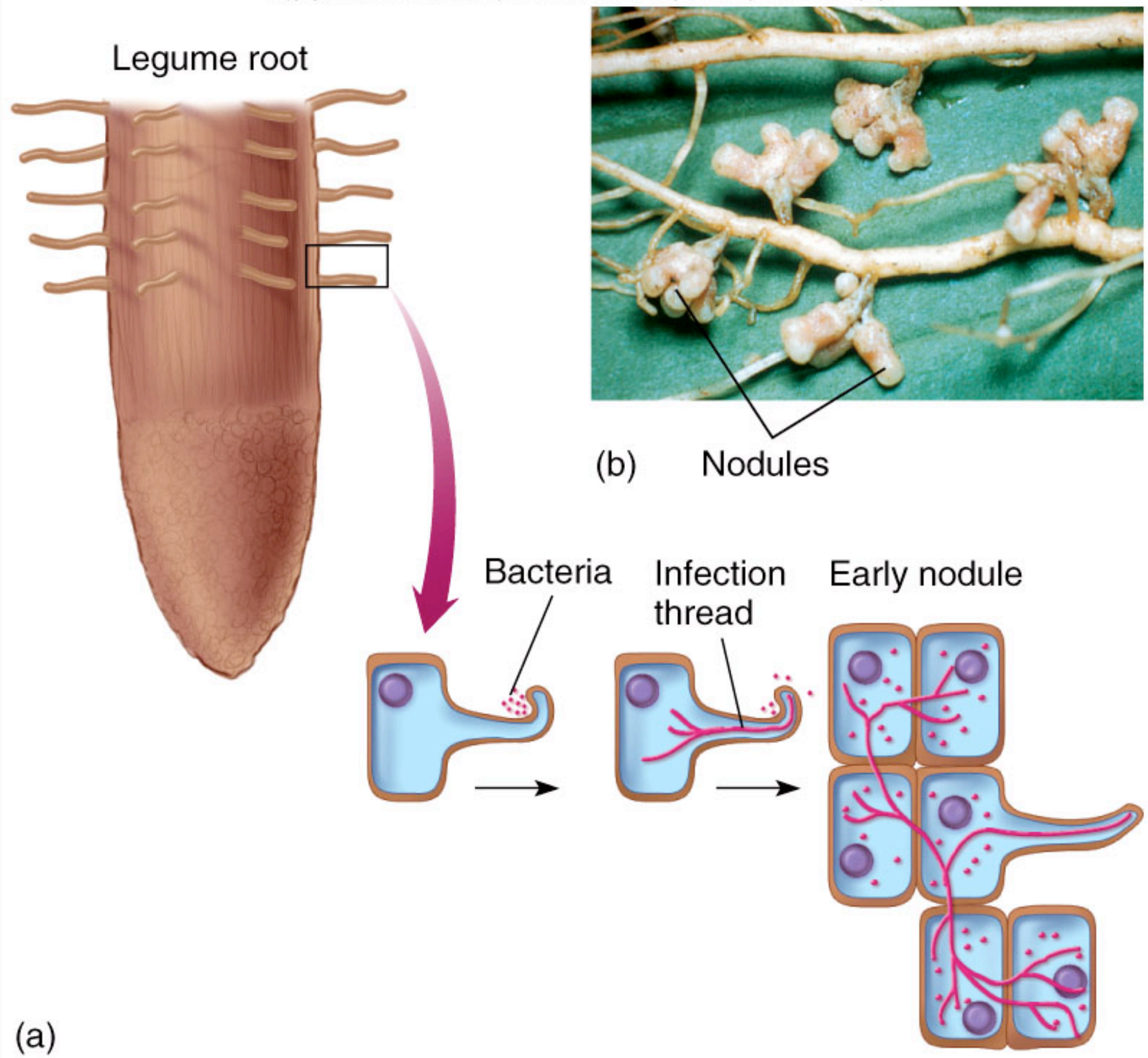


Fig. 24.9 Nitrogen fixation through symbiosis.

Plants inoculated with *Rhizobium* bacteria are healthier (ample nitrogen), than plants not inoculated (lack of nitrogen).

(a) (b)

Fig. 24.10 Inoculating legumes seeds with *Rhizobium* bacteria Increases the plant's access to nitrogen.

Ammonification

- Nitrogen containing organic matter is decomposed by soil and water bacteria
- Amino groups and ammonia are produced
- Organisms can assimilate (take up and use) the ammonia

Nitrification

- Soil and water bacteria
- Conversion of ammonia to nitrate
- Two step process
  - Ammonia (NH_4^+) to nitrite (NO_2^-)
  - Nitrite (NO_2^-) to nitrate (NO_3^-)
- Nitrate is assimilated by reduction or used as terminal electron acceptor

Denitrification

- Conversion of nitrate (NO_3^-) to nitrogen gas (N_2) or nitrous oxide (N_2O)
- Soil bacteria

Oxygen Sources

- Oxygen is a major component of organic compounds
- Also a common component of inorganic salts
- O_2 makes up 20% of the atmosphere and is dissolved in water (the oceans cover 70% of the Earth's surface)

Hydrogen Sources

- Hydrogen is a major element in all organic and several inorganic compounds
- Performs overlapping roles in the biochemistry of cells:
  - Maintaining **pH**
  - Forming **hydrogen bonds** between molecules
  - Serving as the source of **free energy** in oxidation-reduction reactions of respiration

Sedimentary cycles

- Sulfur cycle
- Phosphorus cycle
- Other cycles

Phosphorus (Phosphate) Sources

- Main inorganic source of phosphorus is phosphate (PO_4^{3-})
  - Derived from phosphoric acid
  - Found in rocks and oceanic mineral deposits
- Key component in nucleic acids
- Also found in ATP
- Phospholipids in cell membranes and coenzymes

Phosphorus cycle

- Phosphorous is part of DNA, RNA and ATP
- Inorganic phosphate is central
  - Mineral reservoir – sedimentation (rock)
- Phosphate rock is converted by sulfuric acid (*Thiobacillus* - sulfur cycle) into soluble phosphate
- Soluble PO_4^{2-} is primary source for autotrophs
- Organic PO_4^{2-} is primary source for heterotrophs
- Decomposers return organic to soluble phosphate

Sulfur Sources

- Widely distributed throughout the environment in mineral form
- Essential component of some vitamins
- Amino acids- methionine and cysteine

Sulfur cycle

- Sulfur - rocks, oceans, lakes, and swamps
- Forms of sulfur
  - Hydrogen sulfide (H_2S)
  - Elemental sulfur (S)
  - Thiosulfate (S_2O_3)
  - Sulfate (SO_4)
- Cycled mostly by bacteria – *Thiobacillus*
  - Associated with phosphorus cycle
- Plants and microbes assimilate sulfate
- Animals obtain sulfur from amino acids

Other Nutrients Important in microbial Metabolism

- Potassium: protein synthesis and membrane function
- Sodium: certain types of cell transport
- Calcium: stabilizer of cell walls and endospores
- Magnesium: component of chlorophyll and stabilizer of membranes and ribosomes
- Iron: important component of cytochrome proteins
- Zinc: essential regulatory element for eukaryotic genetics, and binding factors for enzymes
- Cooper, cobalt, nickel, molybdenum, manganese, silicon, iodine, and boron: needed in small amounts by some microbes but not others (micronutrients)

Energy source

Nutritional Type

- **Phototrophs**

- **Chemo-organo-trophs**
  - **Chemo-organo-trophs**
  - **Chemo-litho-trophs**

Autotrophs and Their Energy Sources

- **Photoautotrophs**
  - Photosynthetic
  - Form the basis for most food webs
- **Chemoautotrophs**
  - Chemo**organo**autotrophs: use organic compounds for energy and inorganic compounds as a carbon source
  - Chemo**litho**autotrophs: rely totally on inorganic minerals
    - **Methanogens** (Archaea) - use hydrogen gas to produce methane and to fix carbon dioxide
    - **Nitrifying bacteria** - produce nitrite/nitrate from ammonia to fix carbon dioxide

Photo-trophs

- Derive their energy from sunlight.
  - Transform light energy into chemical energy.
- They usually get their carbon from CO_2.
- They are primary producers
  (of organic matter for heterotrophs).

- Oxygenic Phototrophs are the primary producers of oxygen
  - Ex. Algae, Cyanobacteria (also non-microbes : plants)

- Anoxygenic Phototrophs do not produce oxygen
  - Ex. Green and purple bacteria

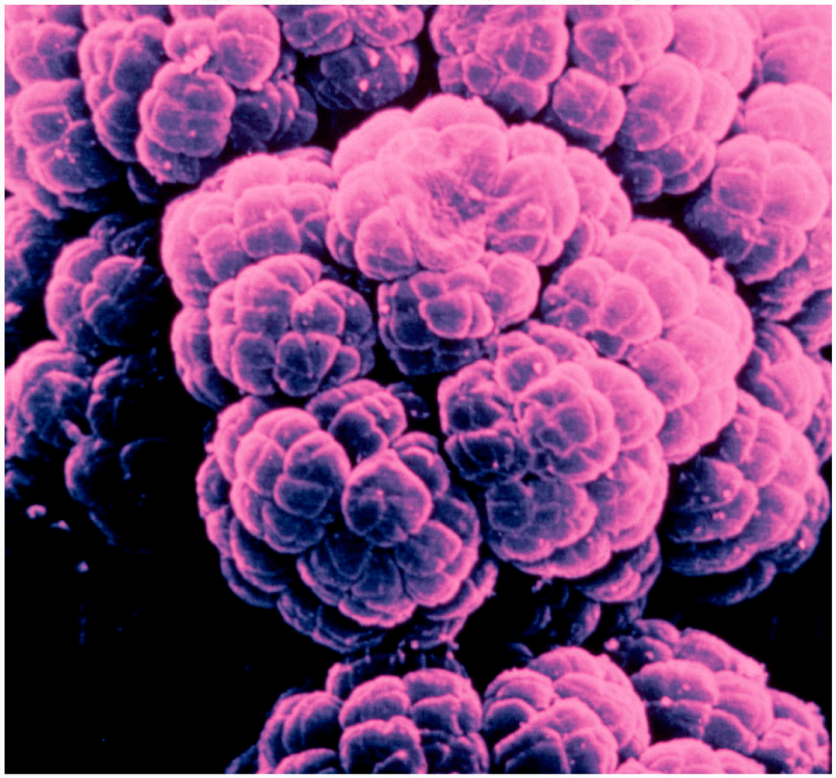
Chemo-organo-trophs

- Derive energy and electrons from bonds in organic compounds.
  - Chemoorganoheterotrophs - derive carbon from organics
    - Saprobes (saprotrophs, saprophytes)
      - decomposers of plant litter, animal matter, and dead microbes
    - Parasites
      - Need at least temporary association (on or in) with a host
  - Chemoorganoautotrophs - derive carbon solely from CO_2
    - rare

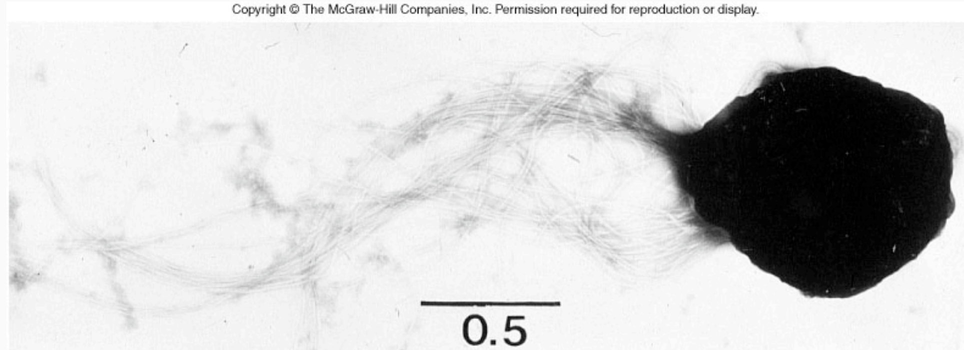
Chemo-litho-trophs

- Derive their energy and electrons only from inorganic compounds
  - Chemo-litho-autotrophs - derive carbon solely from CO_2
    - (Use neither sunlight nor organics)
  - Chemo-litho-heterotrophs - derive carbon NOT solely from CO_2
    - (can be organics or organics and CO_2)

Methanogens are an example of a chemolithoautotroph.



(a)



(b)

Energy source: Hydrogen gas - H_2

Carbon source: CO_2 (formate, acetate)

Fig. 7.1 Methane-producing archaea

Summary of the different nutritional categories based on carbon and energy source.

TABLE 7.3 Nutritional Categories of Microbes by Energy and Carbon Source

Category	Energy Source	Carbon Source	Example
Autotroph	**Nonliving environment**	**CO_2**	
Photoautotroph	Sunlight	CO_2	Photosynthetic organisms, such as algae, plants, cyanobacteria
Chemoautotroph	Simple inorganic chemicals	CO_2	Only certain bacteria, such as methanogens, deep sea vent bacteria
Heterotroph	**Other organisms or sunlight**	**Organic**	
Photoheterotroph	Sunlight	Organic	Purple and green photosynthetic bacteria
Chemoheterotroph	Metabolic conversion of the nutrients from other organisms	Organic	Protozoa, fungi, many bacteria, animals
Saprobe	Metabolizing the organic matter of dead organisms	Organic	Fungi, bacteria (decomposers)
Parasite	Utilizing the tissues, fluids of a live host	Organic	Various parasites and pathogens; can be bacteria, fungi, protozoa, animals

Table 7.3 Nutritional categories of microbes by energy and carbon source.

Important (Energy) Limitation

- **Energy is not (re)cycled**
- As energy is transferred from producer to consumer, large amounts of energy are lost in the form of heat
- Amount of energy available decreases at each successive trophic level
- Fewer individuals can be supported by remaining available energy

Organization of the Biosphere

- Biosphere
  - Terrestrial – biomes
  - Aquatic
- Ecosystem
  - Hydrosphere
  - Lithosphere
  - Atmosphere
- Communities
- Populations
- Habitats
- Niche

The different levels of organization in an ecosystem, which ranges from the biosphere to the individual organism.

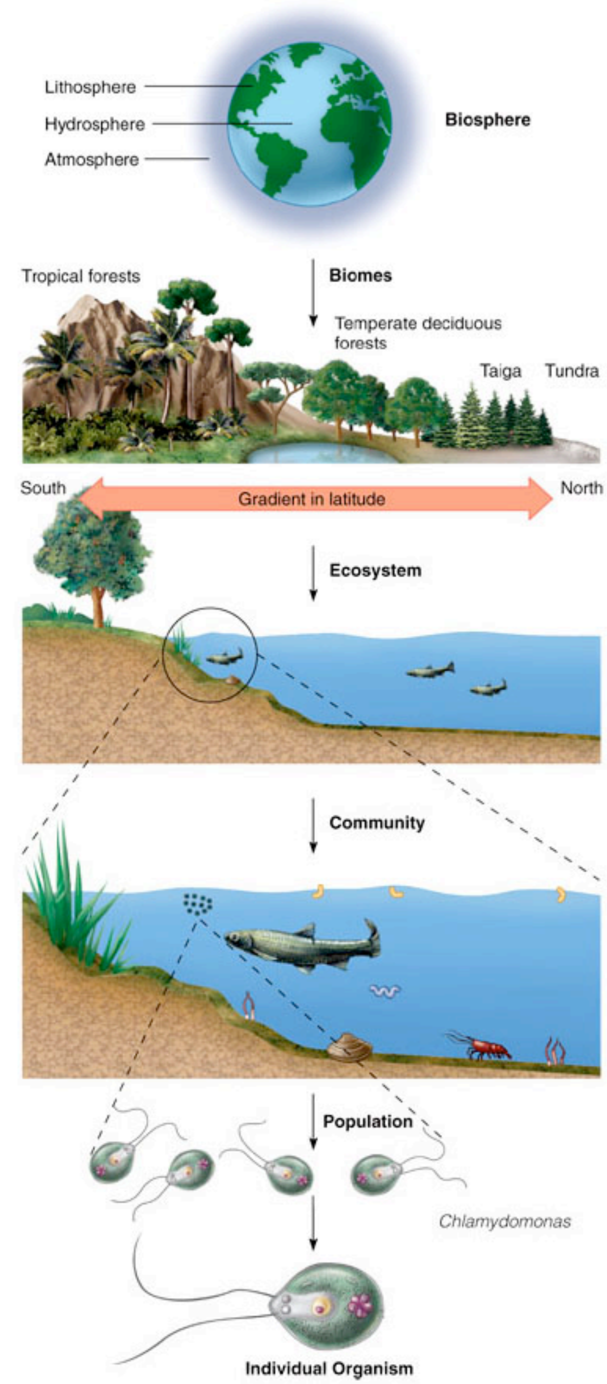


Fig. 24.2 Levels of organization in an ecosystem

Energy and nutrient flow

- Food chain
- Producers
- Consumers
- Decomposers
- Limitation
- Ecological interactions

Food chain

- Energy pyramid
  - Begins with a large amount of usable energy and ends with a smaller amount of usable energy
- Trophic (feeding) levels
  - The number of organisms that are producers, consumers and decomposers

An example of the trophic and energy pyramid.

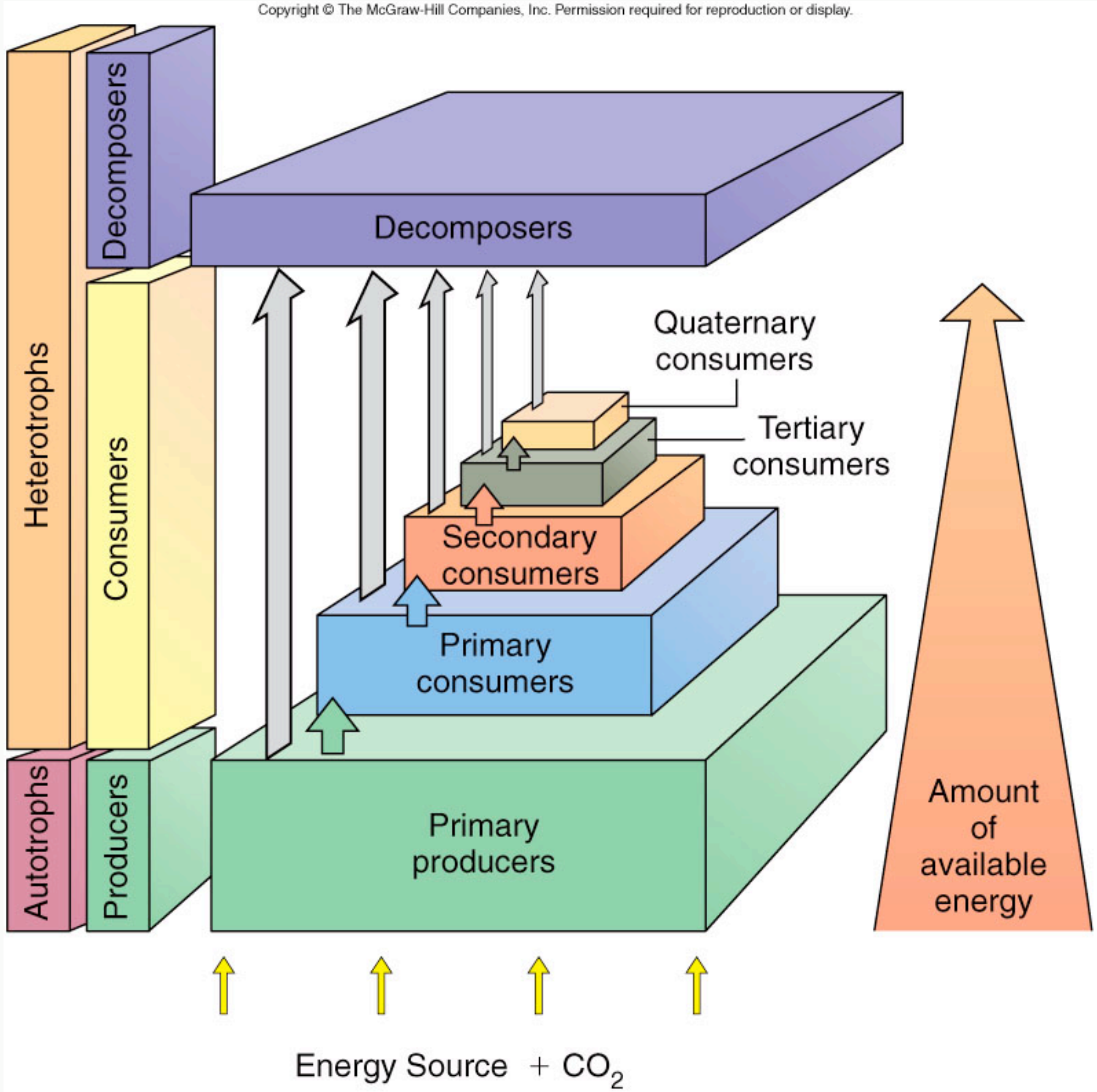


Fig. 24.3 A trophic and energy pyramid.

The roles, description of their activities, and types of microorganisms involved in the ecosystem.

TABLE 24.1 The Major Roles of Microorganisms in Ecosystems

Role	Description of Activity	Examples of Microorganisms Involved
Primary producers	Photosynthesis Chemosynthesis	Algae, cyanobacteria, sulfur bacteria Chemolithotrophic bacteria in thermal vents
Consumers	Predation	Free-living protozoa that feed on algae and bacteria; some fungi that prey upon nematodes
Decomposers	Degradation of plant and animal matter and wastes Mineralization of organic nutrients	Soil saprobes (primarily bacteria and fungi) that degrade cellulose, lignin, and other complex macromolecules Soil bacteria that reduce organic compounds to inorganic compounds such as CO_2 and minerals
Cycling agents for biogeochemical cycles	Recycling compounds containing carbon, nitrogen, phosphorus, sulfur	Specialized bacteria that transform elements into different chemical compounds to keep them cycling from the biotic to the abiotic and back to the biotic phases of the biosphere
Parasites	Living and feeding on hosts	Viruses, bacteria, protozoa, fungi, and worms that play a role in population control

Table 24.1 The major roles of microorganisms in ecosystems.

Producer

- Fundamental energy source
- Drives the trophic pyramid
- Autotrophs - produce organic carbon compounds by fixing inorganic carbon
- Photosynthetic organisms
  - Cyanobacteria
  - Algae (and Plants)

- Lithotrophs (oxidize reduced inorganics)

Consumers

- Feed on other living organisms
- Obtain energy from organic substrate bonds (break bonds = release energy)
  - Ex. Animals, protozoa, some bacteria and fungi
  - Function at several levels
    - Primary, secondary, tertiary and quaternary consumers

A simple example of the different levels of a consumer.

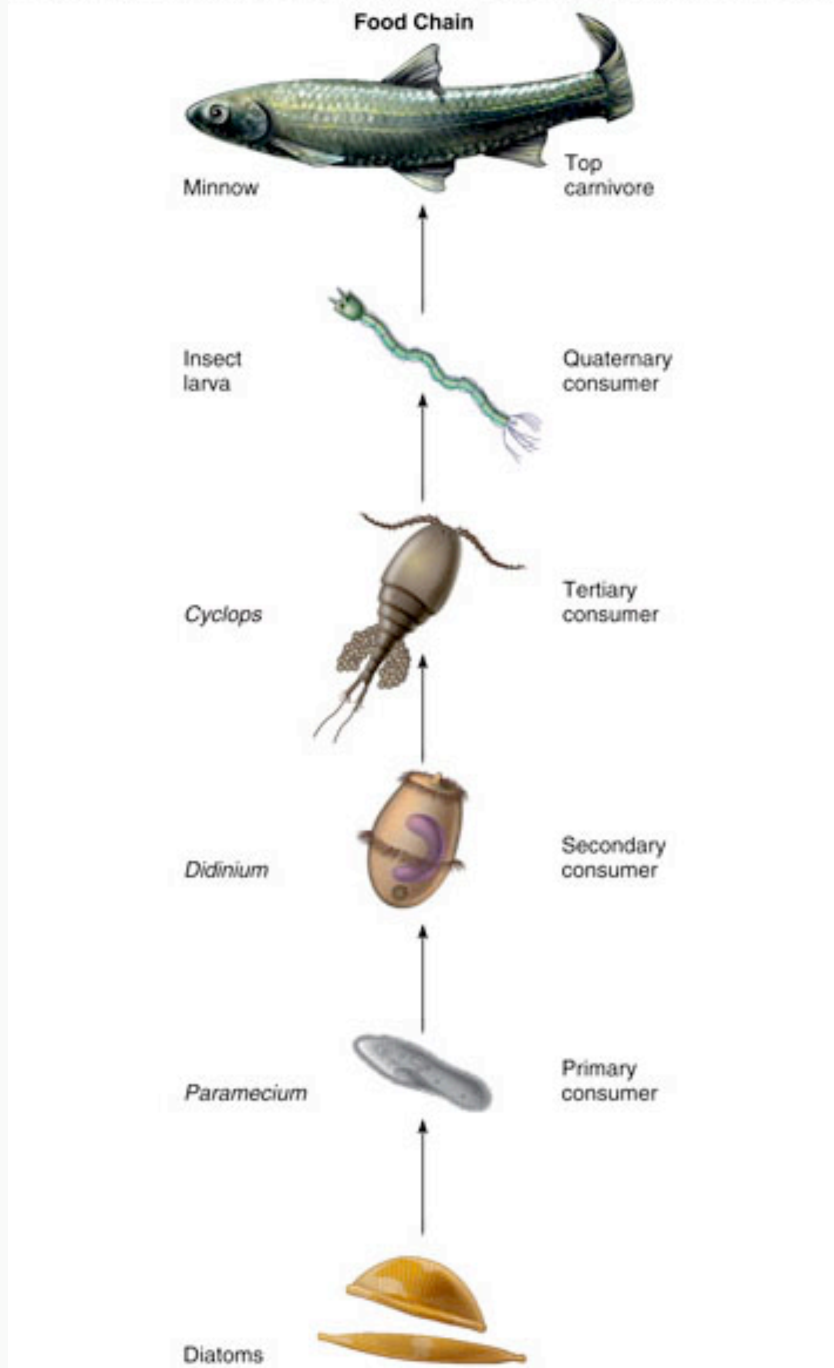


Fig. 24.4 Food **chain**

Decomposer

- Saprobes - inhabit all levels of the food pyramid
- Primarily bacteria
- Reduce organic matter into **inorganic minerals and gases**
- **Mineralization** - cycled decomposed material back into the ecosystem and global biogeochemical cycles

Trophic patterns can be complex, as many producers and composers are involved.

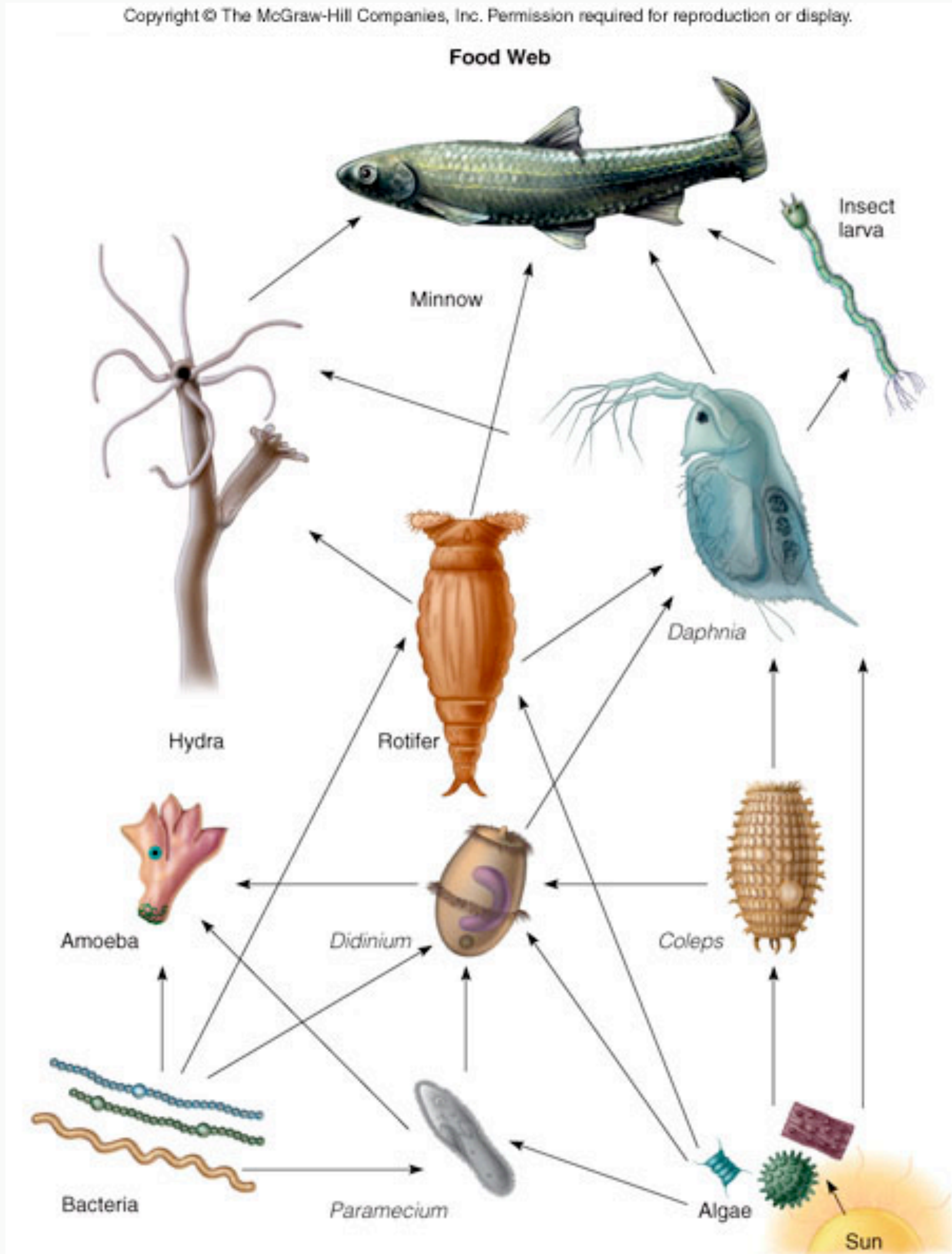


Fig. 24.5 Food **web**

Ecological interactions

- Symbiosis (“living together”)
  - Commensalism ("eating at the same table”)
  - Co-metabolism (“simultaneous metabolism of 2 compounds”)
  - Syntrophy (“eating together”)
  - Synergism (“working together”)
  - Parasitism (”one benefits on the expense of another one”)
- Antagonism (“working against one another”)
  - Competition (“striving against one another”)
  - Predator (“hunting and killing prey”)
  - Scavengers (“consuming dead material, cleaning up”)

Microbial Nutrition

- Nutritional requirements
- Sources of nutrients
- **Ways to get nutrients (Transport mechanisms)**

Transport mechanisms

- Passive transport
  - Diffusion
    - Osmosis
  - Facilitated Diffusion
    - Carriers, Channels
- Active transport
- Endocytosis

Representation of a saprobe (saprotroph) and its mode of action.

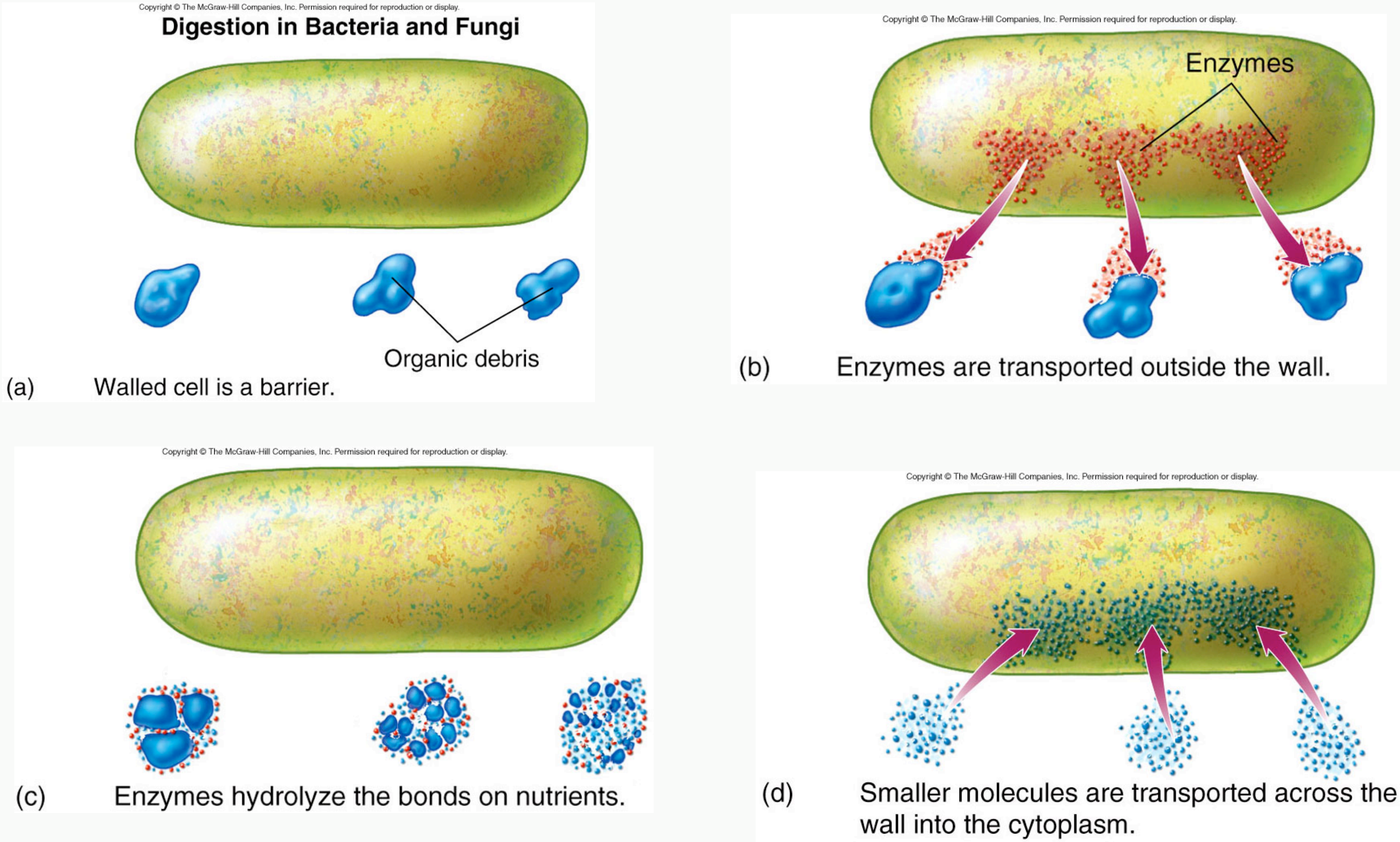


Fig. 7.2 Extracellular digestion in a saprobe with a cell wall.

Diffusion

- Net movement of molecules from a high concentrated area to a low concentrated area
- No energy is expended (passive)
- *Concentration difference* and *permeability* affect movement of solute (molecule in solution)

A cube of sugar will diffuse from a concentrated area into a more dilute region, until an equilibrium is reached.

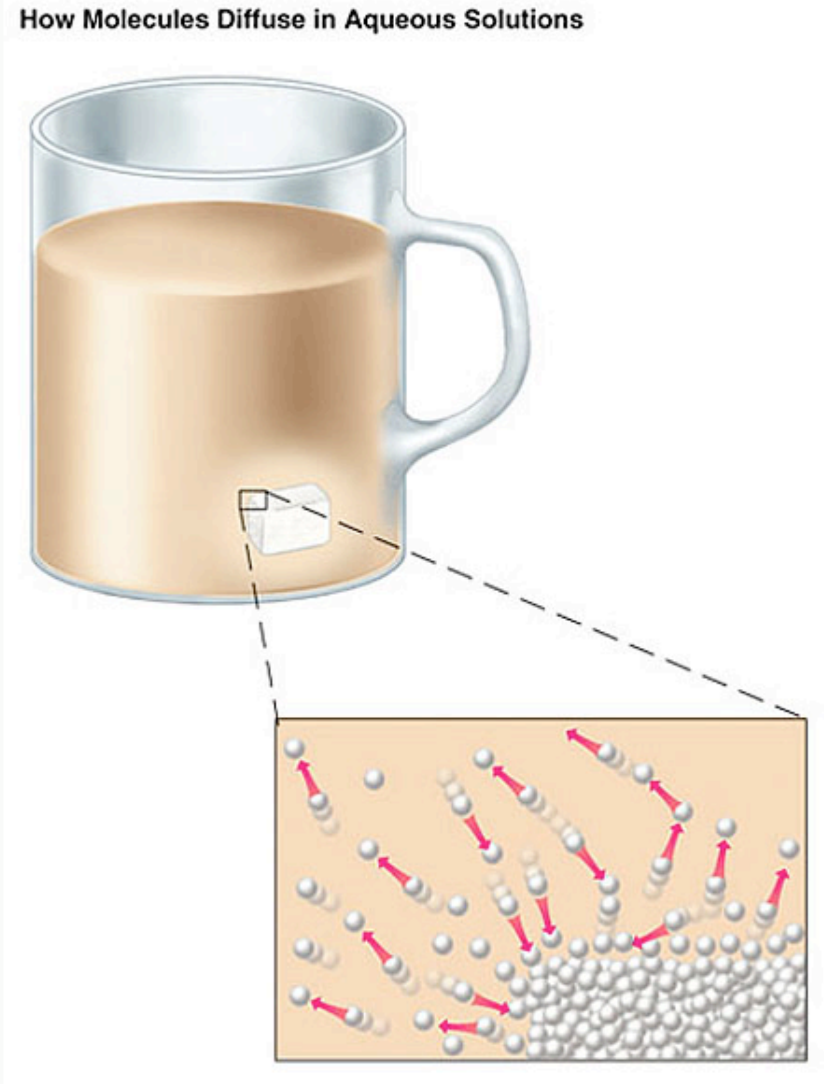


Fig. 7.5 Diffusion of molecules in aqueous solutions

Osmosis

- Diffusion of water through a permeable but selective membrane

- Water moves toward the area with higher solute concentrations

Osmotic Relationships

- The osmotic relationship between cells and their environment is determined by the relative concentrations of the solutions on either side of the cell membrane
- **Isotonic:** The environment is equal in solute concentration to the cell's internal environment
  - No net change in cell volume
  - Generally the most stable environment for cells
- **Hypotonic:** The solute concentration of the external environment is lower than that of the cell's internal environment
  - Net direction of osmosis is from the hypotonic solution into the cell
  - Cells without cell walls swell and can burst
- **Hypertonic**: The environment has a higher solute concentration than the cytoplasm
  - Will force water to diffuse out of a cell
  - Said to have high osmotic pressure

Representation of the osmosis process.

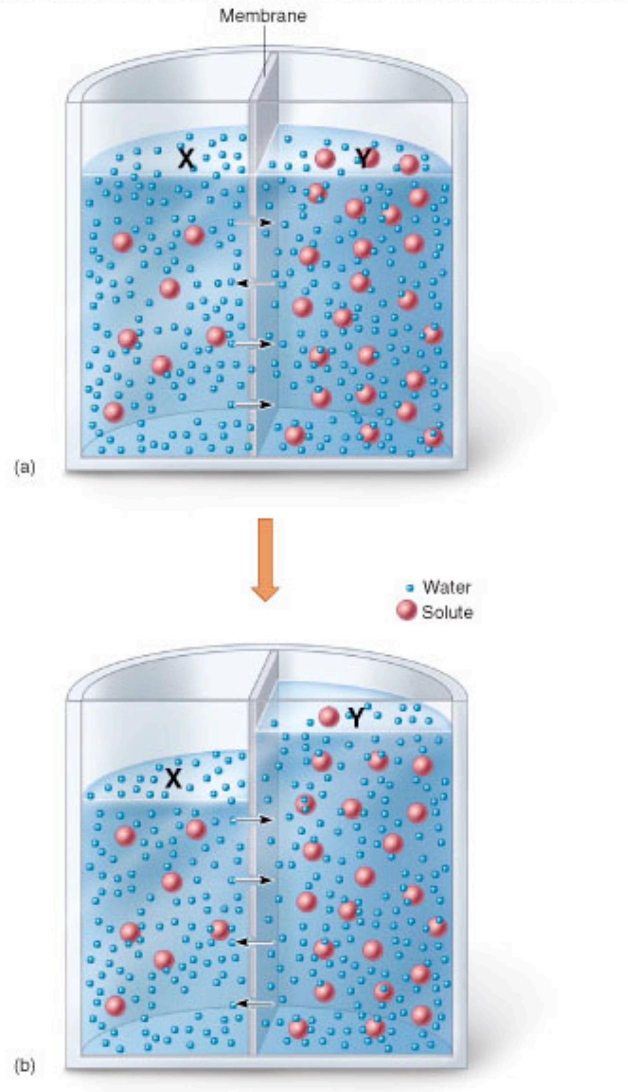


Fig. 7.3 Osmosis, the diffusion of water through a selectively permeable membrane

Adaptations to Osmotic Variations in the Environment

- Example: fresh pond water- hypotonic conditions
  - Bacteria: cell wall protects them from bursting
  - Amoeba: a water (or contractile) vacuole that moves excess water out of the cell
- Example: high-salt environment- hypertonic conditions
  - Halobacteria living in the Great Salt Lake absorb salt to make their cells isotonic with the environment

Cells with- and without cell walls, and their responses to different osmotic conditions (isotonic, hypotonic, hypertonic).

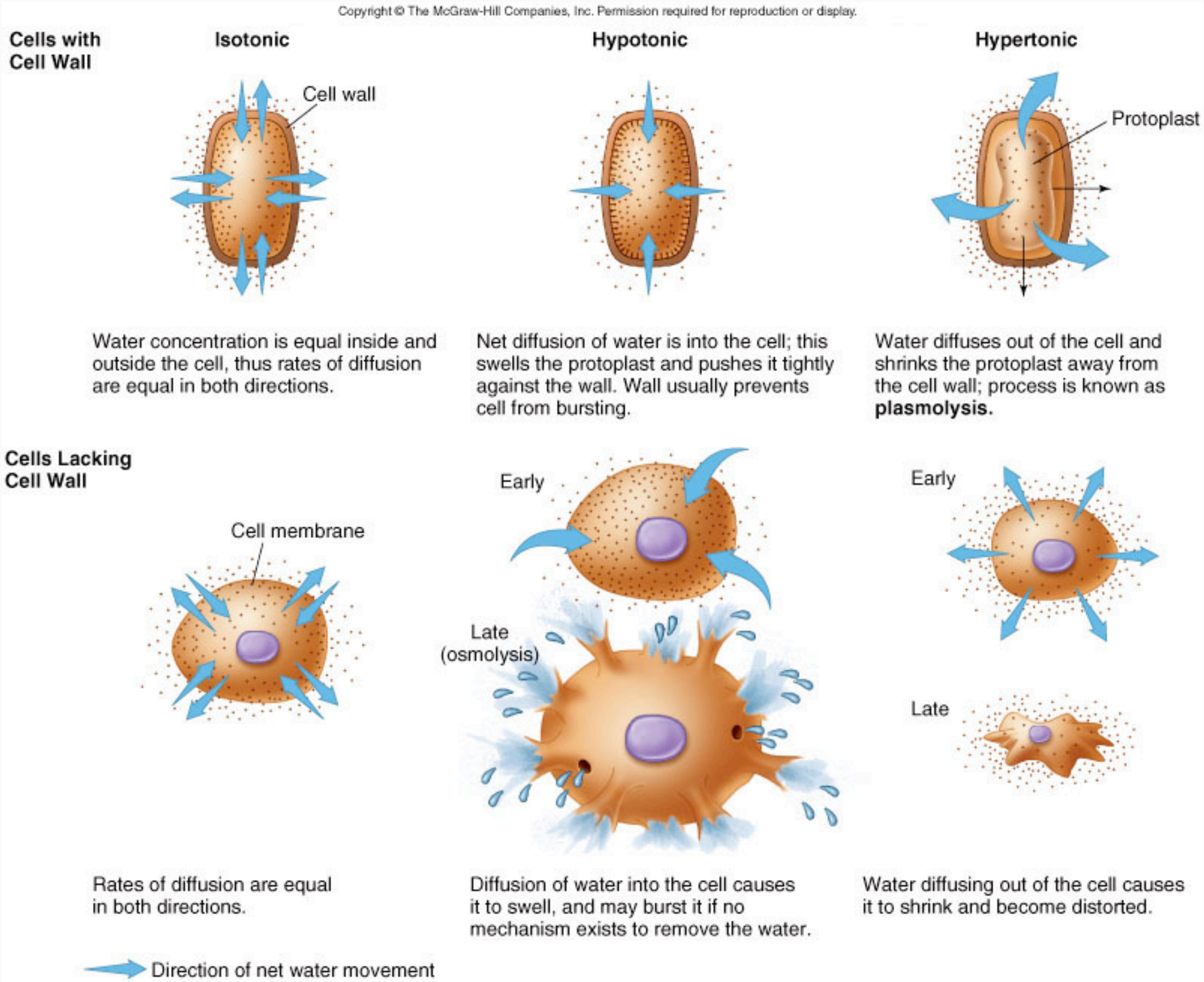


Fig. 7.4 Cell responses to solutions of differing osmotic content.

Facilitated diffusion

- Transport of polar molecules and ions across the membrane
- No energy is expended (passive)
- Channel and carrier proteins facilitate the binding and transport
  - Specificity
  - Saturation
  - Competition

Representation of the facilitated diffusion process.

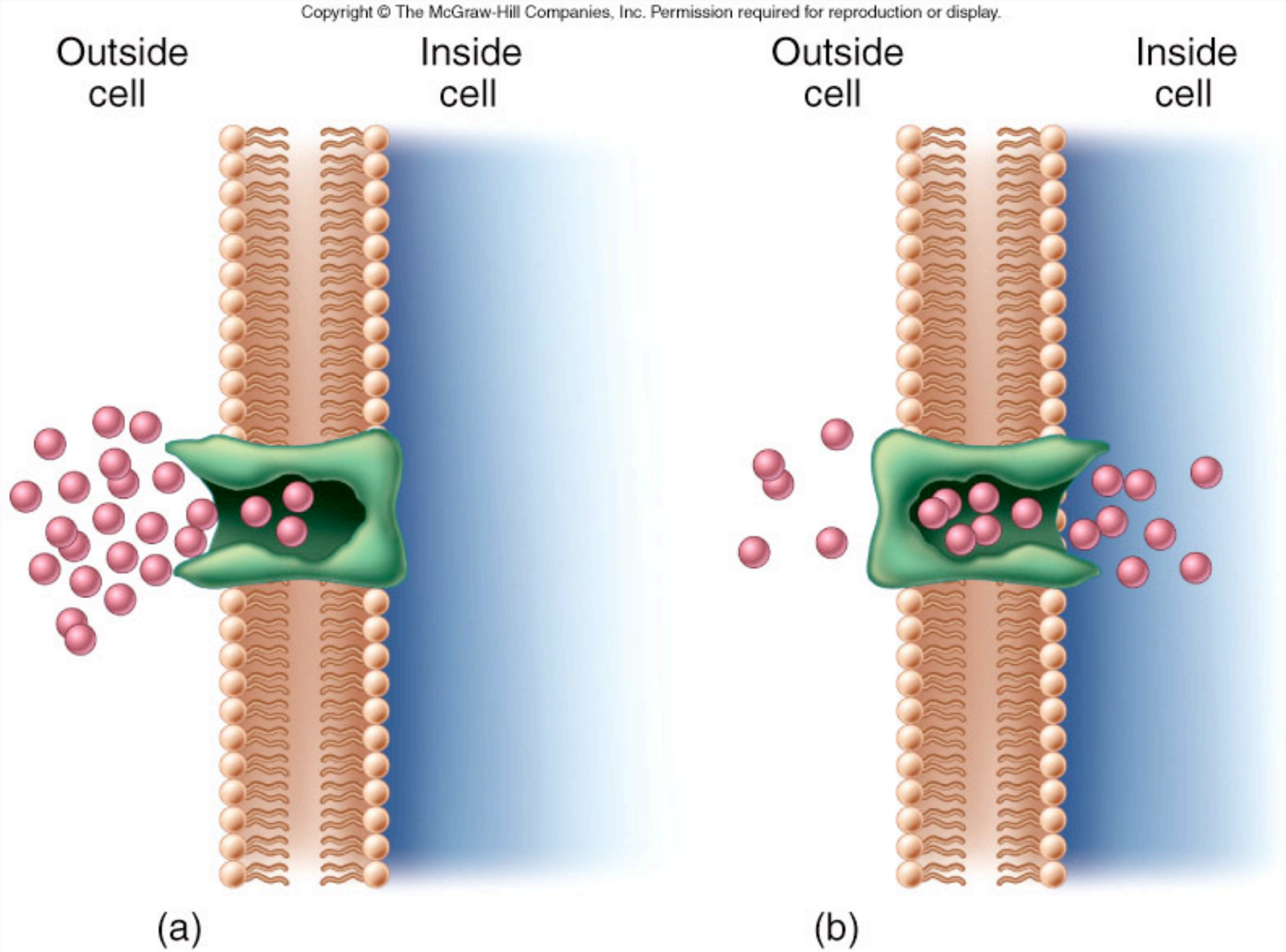


Fig. 7.6 Facilitated diffusion

Active transport

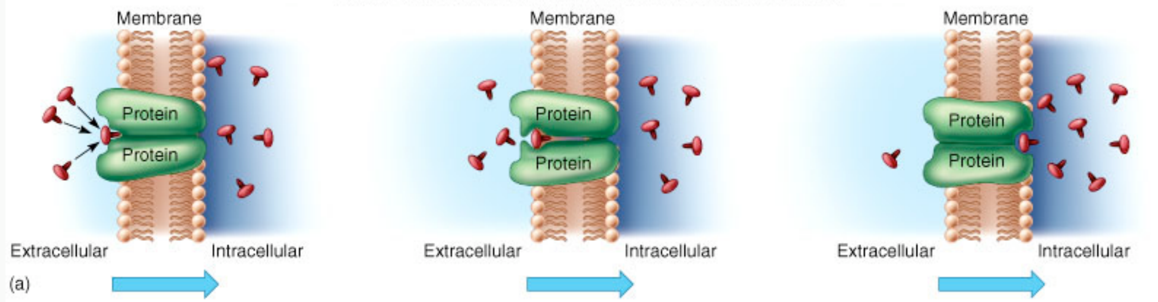
- Transport of molecules requires use of energy (active)
- Outcome is movement uphill a gradient

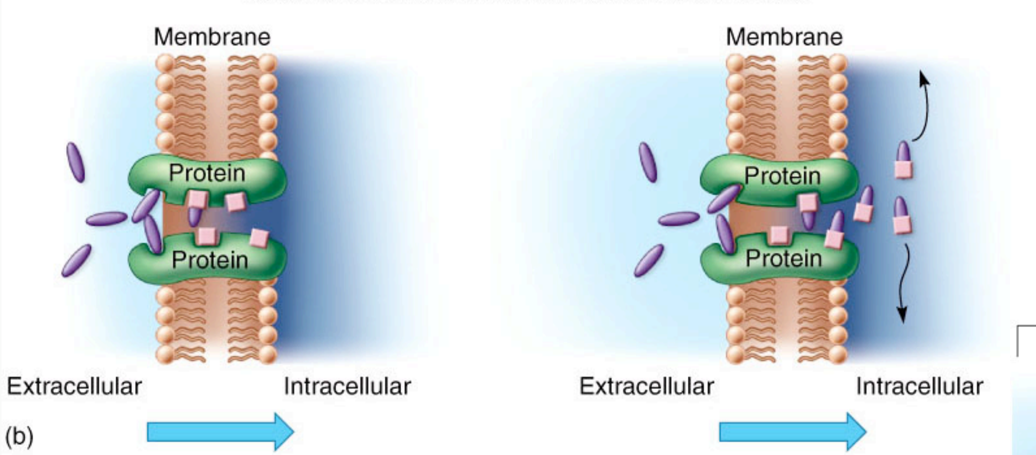
- Ex. Permeases and protein pumps transport sugars, amino acids, organic acids, phosphates and metal ions.
- Ex. Group translocation transports and modifies specific sugars

Endocytosis

- Substances are taken, but are not transported through the membrane.
- Requires energy (active)
- Common for eukaryotes
- Ex. Phagocytosis, pinocytosis

Example of the permease, group translocation, and endocytosis processes.





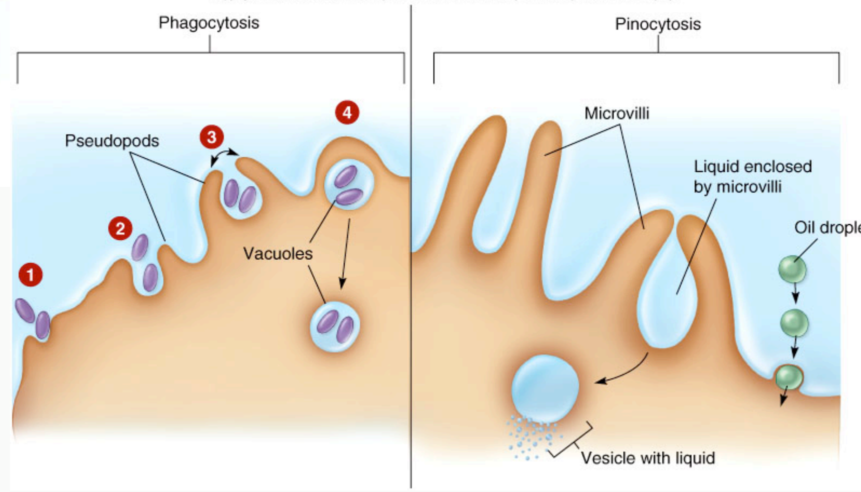


Fig. 7.7 Active transport

Summary of the transport processes in cells.

TABLE 7.4 Summary of Transport Processes in Cells

General Process	Nature of Transport	Examples	Description	Qualities
Passive	Energy expenditure is not required. Substances exist in a gradient and move from areas of higher concentration toward areas of lower concentration in the gradient.	Diffusion	A fundamental property of atoms and molecules that exist in a state of random motion	Nonspecific Brownian movement
		Facilitated diffusion	Molecule binds to a receptor in membrane and is carried across to other side	Molecule specific; transports both ways
Active	Energy expenditure is required. Molecules need not exist in a gradient. Rate of transport is increased. Transport may occur against a concentration gradient.	Carrier-mediated active transport	Atoms or molecules are pumped into or out of the cell by specialized receptors. Driven by ATP or the proton motive force	Transports simple sugars, amino acids, inorganic ions (Na^+, K^+)
		Group translocation	Molecule is moved across membrane and simultaneously converted to a metabolically useful substance.	Alternate system for transporting nutrients (sugars, amino acids)
		Bulk transport	Mass transport of large particles, cells, and liquids by engulfment and vesicle formation	Includes endocytosis, phagocytosis, pinocytosis

Table 7.4 Summary of transport processes in cells