Chapter 5 – Microbial Nutrition

Common Requirements

- Macroelements
  - Required in significant amounts, the lack of which can limit growth
  - C, O, H, N, S, P: components of proteins, carbohydrates, lipids, and nucleic acids
  - K, Ca, Mg, Fe: as ions, play important roles in microbial physiology
- Microelements (trace elements)
  - Required in minute amounts
  - Usually not a growth limiting factor due to their ubiquitous nature
  - Mn, Zn, Co Mo, Ni, and Cu
- Some microbes have special requirements that reflect their morphology or environment, e.g., diatoms need silicon as in silicic acid

C, H, and O Requirements

- Organic compounds serve microbes as a source for
  - The required elements of C, H, and O
  - Energy
  - Electrons for oxidation-reduction reactions or biosynthetic processes
- Not all carbon sources, however, provide energy or hydrogen, e.g., carbon dioxide (CO_2)
- Autotrophs use CO_2 as their carbon source, but this molecule does not provide H or energy
  - Many autotrophs use sunlight for energy via photosynthesis
  - Some autotrophs oxidize inorganic molecules to derive electrons and energy
- Heterotrophs use preformed organic matter as a carbon source, which can also generate electrons and energy
- Remarkably, microbes are extraordinarily flexible with regard to their carbon sources
  - Some will utilize a diverse array of carbon sources, including waxes, rubber, etc.
  - Other microbes are restricted in their carbon sources, e.g., methanogens metabolize only single carbon molecules
  - Still others will digest relatively complex molecules, e.g., pesticides, oil, etc.

Microbial Nutritional Types

- Microbes can be grouped into nutritional classes based upon their sources of: [see Table 5.1]
  - Carbon
    - Autotrophs - carbon dioxide
    - Heterotrophs - reduced, preformed organic molecules
  - Energy
    - Phototrophs - light
    - Chemotrophs - oxidation of chemical compounds (either organic or inorganic)
  - Electrons
    - Lithotrophs - reduced inorganic substances
    - Organotrophs - organic compounds
- Based upon these classes, most microbes can be divided into four different nutritional types: [Table 5.2]
  - Photolithotrophic autotrophy
  - Photoorganotrophic heterotrophy
  - Chemolithotrophic autotrophy
  - Chemoorganotrophic heterotrophy
- Some microbes (mixotrophs) alter their metabolic patterns in response to particular environment, e.g., purple nonsulfur bacteria
  - Absence of oxygen - function as photoorganotrophic heterotrophs
  - Normal oxygen levels - function as chemotrophs
  - Low oxygen levels - photosynthesis and oxidative metabolism is present

N, P, and S Requirements

- Requirements of N, P, and S
  - May be acquired from organic molecules
  - Usually provided by inorganic sources
- Nitrogen - needed for amino acids, purines, pyrimidines, etc.
  - Some microbes reduce NO_3 to NH_3
  - Some microbes assimilate atmospheric nitrogen (N_2)
- Phosphorous - needed for nucleic acids, nucleotides, cofactors, etc.
  - Almost all microbes use inorganic phosphate as a source of phosphorous
  - Some microbes utilize organophosphates

- Sulfur - needed for certain amino acids and vitamins
  - ∗ Most microbes reduce SO_4 to sulfur
  - ∗ Some reduce the amino acids cysteine or methionine to acquire sulfur

Growth Factors

- Growth factors are organic compounds that are essential cellular components that cannot be made by a microbe
- Three types of growth factor:
  - ∗ Amino acids
  - ∗ Purines and pyrimidines
  - ∗ Vitamins - small organic compounds that make up all or part of enzyme cofactors

Uptake of Nutrients

- Nutrient use requires the uptake of particular nutrients
- Mechanisms for the uptake of nutrients must be:
  - ∗ Specific
  - ∗ Able to transport substances against a concentration gradient
  - ∗ Able to pass nutrients through a selectively permeable membrane
- Several basic mechanisms include:
  - ∗ Facilitated diffusion
  - ∗ Active transport
  - ∗ Group translocation (procaryotes only)
  - ∗ Siderophores for iron uptake
  - ∗ Endocytosis (eucaryotes only; Chapter 4)
- Facilitated diffusion
  - ∗ Passive diffusion - molecules move freely from an area of high concentration to an area of low concentration due to random thermal energy
  - ∗ Facilitated diffusion differs in that the rate of diffusion is increased by using carrier molecules (permeases) embedded in the plasma membrane
  - ∗ Each permease is specific for the particular molecule being transported
  - ∗ Rate of diffusion increases as the concentration gradient increases, but the process can become “saturated”, i.e., at a certain concentration all of the permeases are bound with transport molecules
  - ∗ No energy input required

  - ∗ Process is reversible, i.e., if concentration is higher in the cell, molecules will move out into the environment
  - ∗ More important in eucaryotes than in procaryotes
- ◆ Active transport
  - ∗ Energy dependent process whereby molecules are moved against a concentration gradient into the cell
  - ∗ Resembles facilitated diffusion in that it requires a membrane-bound carrier protein specific for the molecule to be transported
  - ∗ Can also be saturated at high solute concentrations
  - ∗ Requires the input of energy (e.g., ATP)
  - ∗ ABC transporters (*A*TP-*b*inding *c*assette) [see Chapter 4] are a type of active transport system found in both procaryotes and eucaryotes
    - ● Two hydrophobic domains form a pore through the plasma membrane
    - ● Two nucleotide-binding domains hydrolyze ATP to drive the uptake of molecules
    - ● In bacteria, special substrate binding proteins found in the periplasmic space (Gram negative) or attached to the external side of the plasma membrane (Gram positive) help the molecule to be transported interact with the membrane cassette proteins
    - ● Gram-negative bacteria have developed specialized mechanisms to help the transport molecule cross the outer membrane
    - ● ABC transporters are important mechanisms of drug resistance in eucaryotes by pumping out drugs as they enter the cell
  - ∗ Symport/antiport transporter systems
    - ● Bacteria use these systems involving proton gradients to drive the uptake of molecules
      - ❖ Symport involves the cotransport of two substances in the same direction
      - ❖ Antiport involves the movement of substances in opposite directions
    - ● Commonly, the proton gradient or the binding of the cotransported molecule causes a change in shape of the transport protein, thereby moving the molecule into the cell
    - ● Eucaryotes also use symport systems, but use ATP as the energy source instead of protons
- ◆ Group Translocations
  - ∗ Energy dependent system whereby molecules are chemically altered while being transported into the cell
  - ∗ Used by procaryotes, not eucaryotes
  - ∗ Best example - phosphoenolpyruvate: sugar transferase system (PTS)

- Iron uptake
  - Iron uptake is problematic given the insolubility of the Fe^{3+} ion (usually in the form of hydroxides)
  - Microbes (procaryotes and eucaryotes) overcome this difficulty by secreting special high-affinity, iron-binding molecules termed siderophores
  - Two general types of siderophores
    - Hydroxamates (e.g., ferrichrome)
    - Phenolates-catecholates (e.g, enterobactin)
  - Microbes have developed specialized transport systems for siderophores
  - Once transported in, molecule releases the iron ion which is reduced to its ferrous form (Fe^{2+})
  - Siderophore is recycled

Culture Media

- To study microbes, a system of growing and maintaining microbes in the laboratory is essential
- Culture media must contain the essential components necessary for microbial growth as well as be useful in the identification and characterization of microorganisms
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  - Synthetic (defined) - all the components of a medium are known and well defined, e.g., glucose-salts broth

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  - Complex - one or more of the components are comprised of a chemically unknown substance, e.g., tryptic soy broth
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  - ∗ Some enriched media can be both selective and differential, e.g., MacConkey's agar