MICROBIOLOGY (BIOL 3702/BIOL 3702H)
LECTURE OVERVIEWS AND LEARNING OUTCOMES

This document contains Chapter Overviews and relevant Learning Outcomes for both the non-honors (BIOL 3702) and honors (BIOL 3702H) lecture sections of Microbiology as taught by Dr. Cooper at Youngstown State University. The overviews and outcomes are presented only for those chapters that will be possibly covered this semester in the course textbook (*Prescott's Microbiology*, 11th Edition, by Joanne Willey, Kathleen Sandman, and Dorothy Wood).

Chapter Overviews. The Chapter Overviews provide a broad summary of not just the material that may be covered in this course, but also those general areas that students are expected to master. Students should use the overviews to help focus their study strategies for subsequent assessment, i.e., quizzes, examinations, etc.

Learning Outcomes. The Learning Outcomes parallel six overarching microbiological concepts "deemed to be of lasting importance beyond the classroom" (*Recommended Curriculum Guidelines for Undergraduate Microbiology Education* [https://www.asm.org/Guideline/ASM-Curriculum-Guidelines-for-Undergraduate-Microb]; see also Merkel, S. 2012. The Development of Curricular Guidelines for Introductory Microbiology that Focus on Understanding. *Journal of Microbiology & Biology Education*, p. 32-38; doi:10.1128/jmbe.v13i1.363 [available via https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3577306/]). Students are strongly encouraged to use the Learning Outcomes as a guide to their foundational understanding of microbiology. Moreover, students who are able to successfully address and understand these outcomes should fare well in preparation for various means of assessment, i.e., quizzes, examinations, etc.

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Chapter 1: The Evolution of Microorganisms and Microbiology

Chapter Overview

This chapter introduces the field of microbiology and discusses the importance of microorganisms not only as causative agents of disease, but also as important contributors to food production, antibiotic manufacture, vaccine development, and environmental management. It presents a brief history of the science of microbiology and an overview of the microbial world. The origin of life and microbial evolution is put in the context of microbial phylogenies.

Learning Outcomes

After reading this chapter, students should be able to:

- Define the term *microbiology*
- Explain Carl Woese's contributions in establishing the three-domain system for classifying cellular life
- Determine the type of microbe (bacterium, fungus, etc.) when given a description of a newly discovered one
- Propose a timeline of the origin and history of microbial life and integrate supporting evidence into it

- Design a set of experiments that could be used to place a newly discovered cellular microbe on a phylogenetic tree based on small subunit (SSU) rRNA sequences
- Compare and contrast the definitions of plant and animal species, microbial species, and microbial strains
- Evaluate the importance of the contributions to microbiology made by Hooke, Leewenhoek, Pasteur, Koch, Cohn, Beijerinck, von Behring, Kitasato, Metchnikoff, and Winogradsky
- Outline a set of experiments that might be used to decide if a particular microbe is the causative agent of a disease
- Predict the difficulties that might arise when using Koch's postulates to determine if a microbe causes a disease unique to humans
- Discuss the belief held by many microbiologists that microbiology is experiencing its second golden age

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Chapter 2: Microscopy

Chapter Overview

This chapter provides a relatively detailed description of the bright-field microscope and its use. Other common types of light microscopes are also described. Following this, various procedures for the preparation and staining of specimens are introduced. The chapter continues with a description of the two major types of electron microscopes and the procedures associated with their use.

Learning Outcomes

After reading this chapter, students should be able to:

- Evaluate the parts of a light microscope in terms of their contributions to image production and use of the microscope
- Predict the relative degree of resolution based on light wavelength and numerical aperture of the lens used to examine a specimen
- Create a table that compares and contrasts the various types of light microscopes in terms of their uses, how images are created, and the quality of images produced
- Recommend a fixation process to use when the microbe is a bacterium or archaeon and when the microbe is a protist
- Plan a series of appropriate staining procedures to describe an unknown bacterium as fully as possible
- Compare what happens to Gram-positive and Gram-negative bacterial cells during each step of the Gram-staining procedure
- Create an illustration or table that compares transmission electron microscopes (TEM) to light microscopes
- Decide when it would be best to examine a microbe by TEM or scanning electron microscopy (SEM)

- Compare and contrast light microscopy and electron microscopy in terms of their uses, resolution, and the quality of the image created

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Chapter 3: Bacterial Cell Structure

Chapter Overview

This chapter provides a description of bacterial cell structure. The discussion begins with the general features of size, shape, and arrangement of bacterial cells. Then, the general features of biological membranes and the specific features of bacterial membranes are given. The cell wall is discussed with special reference to the differences between the cell walls of Gram-positive bacteria and Gram-negative bacteria, differential staining reactions, and the nature of S-layers. Important internal structures of bacteria, such as the cytoplasmic matrix, ribosomes, inclusion bodies, and the nucleoid, are described. Structures external to the cell, such as pili, fimbriae, and flagella, lead into a discussion of cell motility and chemotaxis. The chapter concludes with a description of the structure and functions of bacterial endospores.

Learning Outcomes

After reading this chapter, students should be able to:

- List the characteristics originally used to describe prokaryotic cells
- Debate the "prokaryote" controversy using current evidence about bacterial cells
- Distinguish a typical bacterial cell from a typical plant or animal cell in terms of cell shapes and arrangements, size, and cell structure
- Discuss the factors that determine the size and shape of a bacterial cell
- Describe the fluid mosaic model of membrane structure and identify the types of lipids typically found in bacterial membranes
- Distinguish macroelements (macronutrients) from trace elements (micronutrients) and provide examples of each
- Provide examples of growth factors needed by some microorganisms
- Compare and contrast passive diffusion, facilitated diffusion, active transport, and group translocation, and provide examples of each
- Discuss the challenge of iron uptake and describe how bacteria overcome this difficulty
- Describe peptidoglycan structure
- Compare and contrast the cell walls of typical Gram-positive and Gram-negative bacteria
- Relate bacterial cell wall structure to the Gram-staining reaction
- List the structures found in all the layers of bacterial cell envelopes
- Identify the functions and major component molecules in cell envelope structures
- Describe the function of three types of bacterial cytoskeletal
- Compare and contrast storage inclusions and microcompartments, citing specific examples
- List the composition of bacterial ribosomes and their spatial organization within the cell
- Differentiate the structure and function of bacterial chromosomes and plasmids

- Distinguish pili (fimbriae) and flagella
- Illustrate the various patterns of flagella distribution
- Compare and contrast flagellar swimming motility, spirochete flagellar motility, and twitching and gliding motility
- State the source of energy that powers flagellar motility
- Explain why bacterial chemotaxis is referred to as a "biased random walk"
- Describe the structure of a bacterial endospore
- Explain why bacterial endospores are of particular concern to the food industry and why endospore-forming bacteria are important model organisms
- Describe in general terms the process of sporulation
- Describe those properties of endospores that are thought to contribute to its resistance to environmental stresses
- describe the three stages that transform an endospore into an active vegetative cell

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Chapter 4: Archaeal Cell Structure

Chapter Overview

This chapter focuses on archaeal cell structure and function. Many of organisms in this domain occupy extreme habitats, but by no means all of them. It is important for microbiology students to understand that because the last universal common ancestor (LUCA) is on the bacterial branch of the universal tree of life, archaea are more closely related to eukaryotes than bacteria. This chapter highlights structural features that are unique to archaea while also pointing out those that are similar to bacteria and eukaryotes.

Learning Outcomes

After reading this chapter, students should be able to:

- Describe a typical archaeal cell
- Discuss key differences between bacteria and archaea
- Draw an archaeal cell envelope and identify the component layers
- Compare and contrast archaeal and bacterial cell envelopes in terms of their structure, molecular makeup, and functions
- Compare and contrast nutrient uptake mechanisms observed in bacteria and archaea
- Compare and contrast the cytoplasm of bacterial and archaeal cells
- Discuss the organization of archaeal DNA and similarities to both bacteria and eukaryotes
- Compare and contrast bacterial and archaeal pili
- Compare and contrast bacterial and archaeal flagella in terms of their structure and function

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Chapter 5: Eukaryotic Cell Structure

Chapter Overview

This chapter focuses on eukaryotic cell structure and function. Although bacteria and archaea are immensely important in microbiology, eukaryotic microorganisms—such as fungi, algae, and protozoa—are also prominent members of many ecosystems, and some have medical significance as etiological agents of disease and as model organisms for research. The detailed discussion of eukaryotic microbial structure and function is followed by a comparison of eukaryotes and prokaryotes.

Learning Outcomes

After reading this chapter, students should be able to:

- Compare and contrast eukaryotic, bacterial, and archaeal cells in terms of their use of membranes, size, morphological diversity, and organelles
- Explain why compartmentation of the cell interior is advantageous to eukaryotic cells
- Compare and contrast the lipids found in bacteria and eukaryotes
- Identify the types of eukaryotic microbes that have cell walls and describe their composition
- Describe the functions of the cytoplasm
- Identify the three filaments that make up the cytoskeleton of eukaryotic cells and describe their functions
- Differentiate the two types of endoplasmic reticulum in terms of structure and function
- Outline the pathway of molecules through transport and secretory pathways, noting the structures involved and their roles
- List the endocytic pathways observed in mammalian cells, noting the structures involved and their role in the process, and noting those pathways that have been observed in eukaryotic microbes
- Describe the structure and function of the nucleus, chromosomes, nucleolus, and ribosomes
- Compare and contrast the chromosomes and ribosomes of bacterial, archaeal, and eukaryotic cells
- Draw a mitochondrion and identify its component parts
- Compare and contrast mitochondria and hydrogenosomes in terms of their structure and the chemical processes they carry out
- Draw a chloroplast and identify its components parts
- Differentiate between eukaryotic flagella and cilia
- Compare and contrast bacterial flagella, archaeal, and eukaryotic flagella
- Discuss the types of motility observed in eukaryotic microbes

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Chapter 6: Viruses and Other Acellular Infectious Agents

Chapter Overview

Viruses are small, acellular entities that usually possess only a single type of nucleic acid and must use the metabolic machinery of a living host in order to reproduce. Viruses have been and continue to be of tremendous importance because many human diseases have a viral etiology. The study of viruses has contributed greatly to our knowledge of molecular biology, and the blossoming field of genetic engineering is based on discoveries in the field of virology. This chapter focuses on the general properties of viruses, their structure, reproduction, infectivity, and cultivation. The discussion concludes with the features of viroids and prions.

Learning Outcomes

After reading this chapter, students should be able to:

- Define the terms *virology, bacteriophages,* and *phages*
- List organisms that are hosts to viruses
- State the size range of virions
- Identify the parts of a virion and describe their function
- Distinguish enveloped viruses from non-enveloped viruses
- Describe the types of capsid symmetry
- Describe the five steps common to the life cycles of viruses
- Discuss the roles of receptors, capsid proteins, and envelope proteins in the life cycles of viruses
- Describe the two most common methods for virion release from a host cell
- Compare and contrast the major steps of the life cycles of virulent phages and temperate phages
- List examples of lysogenic conversion
- Differentiate among the types of viral infections of the eukaryotic cells
- Summarize the current understanding of how oncoviruses cause cancer
- List the approaches used to cultivate viruses, noting which types of viruses are cultivated by each method
- Describe three direct counting methods and two indirect counting methods used to enumerate viruses
- Outline the events that lead to the formation of a plaque in a lawn of bacterial cells
- Distinguish lethal dose from infectious dose
- Describe the structure of a viroid and discuss the practical importance of viroids
- Distinguish satellite viruses from satellite nucleic acids
- Describe prion structure and how prions are thought to replicate

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Chapter 7: Bacterial and Archaeal Growth

Chapter Overview

This chapter describes the basic nature of microbial growth. It begins with a general discussion of binary fission, the bacterial cell cycle, and proteins needed for cytokinesis. Several methods for the measurement of microbial growth are described, as are different systems for studying microbial growth. The influence of various environmental factors on the growth of microorganisms is discussed. This chapter describes the basic nutritional requirements of microorganisms. Cells must have a supply of raw materials and energy in order to construct new cellular components. It also describes the processes by which microorganisms acquire nutrients and provides information about the cultivation of microorganisms.

Learning Outcomes

After reading this chapter, students should be able to:

- Describe binary fission as observed in bacteria and archaea
- Compare binary fission with other bacterial reproductive strategies
- Summarize the three phases in a typical bacterial cell cycle
- Summarize current models for chromosome partitioning
- State the functions of cytoskeletal proteins during cytokinesis and in determining cell shape
- Compare and contrast the *Sulfolobu*s spp. cell cycle and the typical eukaryotic cell cycle
- Compare and contrast the *Sulfolobus* spp. cell cycle and a bacterial cell cycle
- Describe the five phases of a microbial growth curve observed when microbes are grown in a batch culture
- Describe three hypotheses proposed to account for the decline in cell numbers during the death phase of a growth curve
- Correlate changes in nutrient concentrations in natural environments with the five phases of a microbial growth curve
- Define the terms that describe a microbe's growth range or requirement for each of the factors that influence microbial growth
- Summarize the adaptations of extremophiles to their habitats
- Summarize the strategies used by non-extremophiles to acclimate to changes in their environment
- Describe enzymes observed in microbes that protect them against toxic O_2 products
- Discuss the mechanisms used by microbes to survive starvation
- Predict how the presence of viable but nonculturable cells in food or water systems might impact public health
- Distinguish sessile and planktonic microbial life styles
- Describe the formation of biofilms and summarize their importance in natural environments, industrial settings, and medicine
- Define quorum sensing and provide examples of cellular processes regulated by quorum sensing

- Discuss in general terms the communication that occurs between rhizobia and their plant hosts
- Describe the importance of culturing microbes to the study of microorganisms
- Distinguish defined (synthetic) media from complex media and the uses of liquid from solid growth media
- List the characteristics of agar that make it a particularly useful solidifying agent
- Compare and contrast supportive (general purpose), enriched, selective, and differential media, listing examples of each and describing how each is used
- Discuss the use of enrichment cultures in isolating microbes
- Differentiate the streak-plate, spread-plate, and pour-plate methods for isolating pure cultures
- Define the terms commonly used by microbiologists to describe colony morphology
- Evaluate direct cell counts, viable counting methods, and cell mass measurements for determining population size
- Explain why plate count results are expressed in terms of colony forming units (CFU)
- Design appropriate approaches for measuring the population size of different types of samples

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Chapter 8: Control of Microorganisms in the Environment

Chapter Overview

This chapter focuses on the control and the destruction of microorganisms by physical and chemical agents. This is a topic of great importance, because some microorganisms have deleterious effects, including food spoilage and disease. It is therefore essential to be able to kill or remove microorganisms from certain environments in order to minimize their harmful effects.

Learning Outcomes

After reading this chapter, students should be able to:

- Compare and contrast the actions of disinfection, antisepsis, chemotherapy, and sterilization
- Distinguish between cidal (killing) and static (inhibitory) agents
- Correlate antisepsis, sanitization, disinfection, and sterilization with agent effectiveness
- Explain the mechanism by which filtration removes microorganisms
- Describe the application of heat and radiation to control microorganisms
- Explain the mechanisms by which heat and radiation kill microbes
- Describe the use of and mechanism of action for phenolics, alcohols, halogens, heavy metals, quaternary ammonium chlorides, aldehydes, and oxides to control microorganisms
- Predict the effects of (1) microbial population size and composition, (2) temperature, (3) exposure time, and (4) local environmental conditions on antimicrobial agent effectiveness

- Explain various biological control methods of microbes

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Chapter 9: Antimicrobial Chemotherapy

Chapter Overview

The control or the destruction of microorganisms that reside within the bodies of humans and other animals is of tremendous importance. This chapter introduces the principles of chemotherapy and discusses the ideal characteristics for successful chemotherapeutic agents (including the concept of selectively damaging the target microorganism while minimizing damage to the host). The chapter then presents characteristics of some commonly used antibacterial, antifungal, antiviral, and antiprotozoan drugs.

Learning Outcomes

After reading this chapter, students should be able to:

- Trace the general history of antimicrobial chemotherapy
- Propose natural sources of new antimicrobial agents
- Explain the difference between a narrow and broad-spectrum drug
- Correlate drug action with cidal and static effects
- Explain how to determine the level of antibacterial drug activity using the dilution susceptibility test, the disk diffusion test, and the Etest®
- Predict antimicrobial drug levels in vivo from in vitro data
- Compare antibacterial drug mechanisms of action
- Correlate lack of microbial growth with selective toxicity
- Relate side effects of antibacterial drugs to mechanisms of action
- Explain the relative effectiveness of various antibacterial agents based on drug target
- Compare antiviral drug mechanisms of action
- Provide a rationale for combination drug therapy in the treatment of HIV
- Explain why there are far fewer antiviral agents than there are antibacterial agents
- Compare antifungal drug mechanisms of action
- Explain why there are far fewer antifungal agents than there are antibacterial agents
- Compare the mechanisms of action of antiprotozoan drugs
- Relate side effects and toxicity of antiprotozoan drugs to their mechanism of action
- Explain why there are far fewer antiprotozoan agents than there are antibacterial agents
- Report the common reasons for increasing drug resistance
- Describe common mechanisms by which antimicrobial drug resistance occurs
- Suggest strategies to overcome drug resistance

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Chapter 10: Introduction to Metabolism

Chapter Overview

This chapter discusses energy and its participation in cellular metabolic processes. In addition, the role of adenosine-5'-triphosphate (ATP) as the energy currency of cells is examined. The chapter concludes with a discussion of enzymes as biological catalysts: how they work, how they are affected by their environment, and how they are regulated.

Learning Outcomes

After reading this chapter, students should be able to:

- List the features common to all types of metabolism
- Describe the three types of work carried out by cells
- State the relationship between cellular work and energy
- Draw a simple schematic that illustrates the structure of ATP
- Describe ATP's role as a coupling agent that links exergonic and endergonic reactions
- Describe the energy cycle observed in all organisms
- Describe the metabolic functions of three nucleoside triphosphates (other than ATP)
- Describe a redox reaction, noting the role of the two half reactions and identifying the electron donor, electron acceptor, and conjugate redox pairs of the reaction
- List the molecules that are commonly found in electron transport chains (ETCs) and indicate if they transfer electrons and protons or just electrons
- Indicate the location of ETCs in bacterial, archaeal, and eukaryotic cells
- Describe the components of a biochemical pathway and how they are organized
- Describe the function and chemical makeup of enzymes
- Distinguish apoenzyme from holoenzyme and prosthetic group from coenzyme
- Draw a diagram that shows the effect of an enzyme on the activation energy of a chemical reaction
- Describe the effects of substrate concentration, pH, and temperature on enzyme activity
- Differentiate competitive and noncompetitive inhibitors of enzymes
- Compare and contrast ribozymes and enzymes
- List the three general approaches cells use to regulate metabolism
- Describe metabolic channeling and one example of how it is accomplished
- Distinguish allosteric regulation and covalent modification
- Describe the structure of an allosteric enzyme
- Explain how positive allosteric and negative allosteric effectors regulate the activity of an enzyme
- List the three chemical groups commonly used to covalently modify an enzyme and its activity
- Explain how feedback inhibition is used to control the functioning of biosynthetic pathways

- Predict which enzymes of a biochemical pathway are likely to be regulated by either allosteric control or covalent modification
- Develop a model illustrating how feedback inhibition can be used to regulate a multiply branched biosynthetic pathway

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Chapter 11: Catabolism: Energy Release and Conservation

Chapter Overview

This chapter presents an overview of energy conservation mechanisms beginning with an overview of the diversity of bacterial metabolic strategies. Chemoorganoheterotrophy is discussed first, starting with aerobic respiration, which is divided into three parts: oxidation of glucose to pyruvate, tricarboxylic acid cycle, and electron transport/oxidative phosphorylation. The text then covers anaerobic respiration followed by fermentation. The consideration of chemoorganoheterotrophic metabolism concludes with a discussion of the catabolism of lipids, proteins, and amino acids. Chemolithotrophic metabolism follows, and a discussion of the newest mechanism of energy conservation, flavin-based electron bifurcation. The chapter concludes with a discussion of the trapping of energy by phototrophy, including oxygenic and anoxygenic photosynthesis, and rhodopsin-based phototrophy.

Learning Outcomes

After reading this chapter, students should be able to:

- State the carbon, energy, and electron sources of photolithotrophs, photoorganoheterotrophs, chemolithoautotrophs, chemolithoheterotrophs, and chemoorganoheterotrophs
- Describe the products of the fueling reactions
- Discuss the metabolic flexibility of microorganisms
- List the three types of chemoorganotrophic metabolisms
- List the pathways of major importance to chemoorganotrophs and explain their importance
- Propose an explanation that accounts for the existence of amphibolic pathways
- Describe in general terms what happens to a molecule of glucose during aerobic respiration
- List the end products made during aerobic respiration
- Identify the process that generates the most ATP during aerobic respiration
- List the three major pathways that catabolize glucose to pyruvate
- Describe substrate-level phosphorylation
- Diagram the major changes made to glucose as it is catabolized by the Embden-Meyerhof, Entner-Doudoroff, and pentose phosphate pathways
- Identify those reactions the Embden-Meyerhof, Entner-Doudoroff, and pentose phosphate pathways that consume ATP, produce ATP and NAD(P)H, generate precursor metabolites, or are redox reactions

- Calculate the yields of ATP and NAD(P)H by the Embden-Meyerhof, Entner-Doudoroff, and pentose phosphate pathways
- Summarize the function of the Embden-Meyerhof, Entner-Doudoroff, and pentose-phosphate pathways
- State the alternate names for the tricarboxylic acid (TCA) cycle
- Diagram the major changes made to pyruvate as it is catabolized by the TCA cycle
- Identify those reactions of the TCA cycle that produce ATP (or GTP) and NAD(P)H, generate precursor metabolites, or are redox reactions
- Calculate the yields of GTP, NAD(P)H, and $FADH_2$ by the TCA cycle.
- Summarize the function of the TCA cycle
- Diagram the connections between the various glycolytic pathways and the TCA cycle
- Locate the TCA cycle enzymes in bacterial, archaeal, and eukaryotic cells
- Compare and contrast the mitochondrial electron transport chain (ETC) and bacterial ETCs
- Describe the chemiosmotic hypothesis
- Explain how ATP synthase uses proton motive force (PMF) to generate ATP
- Draw a simple diagram that shows the connections between the glycolytic pathways, TCA cycle, ETC, and ATP synthesis
- List the ways the PMF is used by bacterial cells in addition to ATP synthesis
- Calculate the maximum possible ATP yields when glucose is completely catabolized to six molecules of CO_2 during aerobic respiration
- Compare and contrast aerobic respiration and anaerobic respiration using glucose as a carbon source
- List examples of terminal electron acceptors used during anaerobic respiration
- Explain why the use of nitrate (NO_3^-) as a terminal electron acceptor is dissimilatory nitrate reduction
- Explain why less energy is conserved during anaerobic respiration, as compared to aerobic respiration
- Discuss three examples of the importance of anaerobic respiration
- Compare and contrast the importance of oxidative phosphorylation and substrate level phosphorylation in aerobic respiration, anaerobic respiration, and fermentation
- List the pathways that may function during fermentation if glucose is the organism's carbon and energy source
- List some of the common fermentation pathways and their products and examples of their importance
- Compare the use of ATP synthase during respiration and fermentation
- Differentiate the catabolism of disaccharides and polysaccharides by hydrolysis from their catabolism by phosphorolysis

- Discuss the fate of the fatty acid and glycerol components of triglycerides when triglycerides are catabolized
- State the name of the enzymes responsible for hydrolyzing proteins into amino acids
- Distinguish deamination from transamination and explain how the two are related
- Draw a simple diagram that illustrates how the pathways used to catabolize reduced organic molecules other than glucose connect to the glycolytic pathways and the TCA cycle
- Describe in general terms the fueling reactions of chemolithotrophs
- List the molecules commonly used as energy sources and electron donors by chemolithotrophs
- Discuss the use of electron transport chains and oxidative phosphorylation by chemolithotrophs
- Predict the relative amount of energy released for each of the commonly used energy sources of chemolithotrophs, as compared to energy released during aerobic and anaerobic respiration of glucose
- Differentiate nitrification from denitrification
- List three examples of important chemolithotrophic processes
- Explain why electron bifurcation is a fundamental mechanism of energy conservation that differs from ATP hydrolysis or proton motive force
- Describe in general terms the fueling reactions of phototrophs
- Differentiate phototrophy from photosynthesis
- Describe the light and dark reactions that occur during photosynthesis
- Summarize the structure and function of the light-absorbing pigments used by oxygenic and anoxygenic phototrophs
- Explain why oxidative phosphorylation and photophosphorylation by chlorophyll-based phototrophs differ primarily in the energy source driving the process
- Distinguish cyclic photophosphorylation from noncyclic photophosphorylation
- Compare and contrast oxygenic photosynthesis, anoxygenic phototrophy, and rhodopsin-based phototrophy

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Chapter 12: Anabolism: The Use of Energy in Biosynthesis

Chapter Overview

This chapter presents an overview of anabolism starting with the fixation of carbon dioxide. It then focuses on the synthesis of carbohydrates and peptidoglycan; the assimilation of phosphorus, sulfur, and nitrogen; and the synthesis of amino acids, purines and pyrimidines, and lipids.

Learning Outcomes

After reading this chapter, students should be able to:

- Describe in general terms the steps organisms use to convert a carbon source and inorganic molecules to cells
- Discuss the principles that govern biosynthesis
- List the central metabolic pathways, noting which precursor metabolites are generated by each pathway
- Draw a simple diagram that lists all the precursor metabolites and illustrates how they are used in biosynthesis
- List the pathways used by microbes to fix CO_2, noting the types of organisms (eukaryotes, bacteria, archaea) that use each pathway
- Describe in general terms the three phases of the Calvin-Benson cycle
- Identify the steps of the Calvin-Benson cycle that consume ATP and NADPH
- Compare and contrast gluconeogenesis and the Embden-Meyerhof pathway
- Describe the role of ATP and UTP in the synthesis of monosaccharides (other than glucose) and polysaccharides
- Outline the major steps in peptidoglycan synthesis
- Evaluate the effectiveness of targeting antibiotics to peptidoglycan synthesis
- Discuss the three mechanisms microorganisms use to assimilate inorganic nitrogen and the role of transaminases in them
- Describe the two methods microbes use to assimilate sulfur
- Differentiate assimilatory nitrate reduction from dissimilatory nitrate reduction and assimilatory sulfate reduction from dissimilatory sulfate reduction
- Evaluate the efficiency of using branched pathways for synthesizing amino acids
- List the major anaplerotic reactions and explain their importance
- Describe the two pathways for porphyrin synthesis and identify the types of organisms that use each
- Identify which nitrogenous bases are purines and which are pyrimidines.
- Draw a simple diagram that illustrates the chemical moieties found in nucleosides and nucleotides
- Discuss in general terms how phosphorous is assimilated
- Compare and contrast purine and pyrimidine biosynthesis
- Discuss the methods used to convert ribonucleotides to deoxyribonucleotides

- Describe the role of acetyl-CoA, acyl carrier protein (ACP), and fatty acid synthase in fatty acid synthesis
- Distinguish saturated fatty acids from unsaturated fatty acids
- Describe the roles of dihydroxyacetone phosphate and fatty acids in the synthesis of triacylglycerol
- Describe the roles of diacylglycerol and CTP in the synthesis of phospholipids
- Summarize lipopolysaccharide synthesis
- Describe the Lpt pathway
- Compare sterol synthesis to archaeal isoprenoid lipid synthesis

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Chapter 16: Mechanisms of Genetic Variation

Chapter Overview

This chapter begins with a discussion of mutation and genetic variation and includes molecular mechanisms of mutation and repair. A general discussion of bacterial recombination, plasmids, and transposable elements follows, with examination of the acquisition of genetic information by conjugation, transformation, and transduction. The chapter concludes with a discussion of the mechanisms of antibiotic resistance and the role of horizontal gene transfer in the spread of these traits among bacteria.

Learning Outcomes

After reading this chapter, students should be able to:

- Distinguish spontaneous from induced mutations, and list the most common ways each arises
- Summarize how base analogues, DNA-modifying agents, and intercalating agents cause mutations
- Discuss the possible effects of mutations
- Differentiate mutant detection from mutant selection
- Design an experiment to isolate mutant bacteria that are auxotrophic for a specific amino acid
- Propose an experiment to isolate revertants of an amino acid auxotroph and predict the types of mutations that might lead to the revertant phenotype
- Distinguish vertical gene transfer from horizontal gene transfer
- Summarize the four possible outcomes of horizontal gene transfer
- Compare and contrast homologous recombination and site-specific recombination
- Differentiate insertion sequences from transposons
- Distinguish simple transposition from replicative transposition
- Defend this statement “Transposable elements are important factors in the evolution of bacteria and archaea.”
- Identify the type of plasmids that are important creators of genetic variation

- Describe the features of the F factor that allow it to (1) transfer itself to a new host cell and (2) integrate into a host cell's chromosome
- Outline the events that occur when an F^+ cell encounters an F^- cell
- Distinguish F^+, Hfr, and F′ cells from each other
- Explain how Hfr cells arise
- Outline the events that occur when an Hfr cell encounters an F^- cell
- Describe the factors that contribute to a bacterium being naturally transformation competent
- Predict the outcomes of transformation using a DNA fragment versus using a plasmid
- Design an experiment to transform bacteria that are not naturally competent with a plasmid that carries genes encoding ampicillin resistance and the protein that generates green fluorescence
- Differentiate generalized transduction from specialized transduction
- Correlate a phage's life cycle to its capacity to mediate generalized or specialized transduction
- Distinguish between conjugation, transformation, and transduction
- Describe an R plasmid and its associated genetic elements
- Distinguish integrative conjugative elements, transposons, and conjugative plasmids
- Describe how genetic elements mobilize portions of chromosomes

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Chapter 19: Microbial Taxonomy and the Evolution of Diversity

Chapter Overview

Microorganisms are tremendously diverse in size, shape, physiology, and lifestyle. This chapter introduces the general principles of microbial taxonomy and presents an overview of the current classification scheme accepted by most microbiologists. The chapter then pivots to a discussion of the species concept as applied to asexual microorganisms and covers principles of evolution that drive diversity. It concludes with an introduction to *Bergey's Manual of Systemic Bacteriology*.

Learning Outcomes

After reading this chapter, students should be able to:

- Explain the utility of taxonomy and systematics
- Illustrate the differences between phenetic and genotypic classification
- Outline the general scheme of taxonomic hierarchy
- Explain how the binomial system of Linnaeus is used in microbial taxonomy
- Describe the approaches commonly used to determine taxonomic classification
- Assess the impact molecular methods have had on the field of microbial taxonomy and phylogeny

- Compare and contrast nucleotide sequencing and non-sequencing-based molecular approaches used in microbial taxonomy and phylogeny
- Paraphrase the rationale underpinning the construction of phylogenetic trees
- Compare and contrast rooted and unrooted trees
- Outline the general considerations used in building a phylogenetic tree
- Characterize the challenges horizontal gene transfer introduces in the study of microbial evolution
- Diagram the endosymbiotic theory of the origin of mitochondria and chloroplasts
- Compare and contrast the two theories that address the origin of the nucleus
- Explain why the concept of a microbial species is difficult to define
- List the "gold standard" taxonomic methods currently applied to species designation
- Explain the importance of adaptive mutations in giving rise to new ecotypes
- Describe the foundation of and the importance of *Bergey's Manual of Systemic Bacteriology*

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Chapter 27: Microbial Interactions

Chapter Overview

This chapter focuses on the relationships microorganisms have with other organisms and each other. The chapter begins with a discussion of symbiotic relationships, and examples of each type of relationship are presented. These include microbe-insect mutualisms, dinoflaggellate-coral endosymbiosis, hydrothermal vents, and mammalian rumens as cooperative interactions. The attine ant and its fungal gardens are described in detail as an example of amensalism, and several examples of parasitism and competition are included.

Learning Outcomes

After reading this chapter, students should be able to:

- Compare and contrast different types of microbial interactions, including mutualism, cooperation, commensalism, amensalism, predation, parasitism, and competition
- Distinguish mutualism and cooperation
- Explain how metabolic relationships can cement mutualistic relationships
- Relate coral bleaching to a symbiotic relationship
- Describe the relationship between microbes and complex organisms, as illustrated in the tube worm and the mammalian rumen
- Distinguish commensalism and amensalism
- Provide specific examples of each of these types of interactions
- Distinguish predation, parasitism and competition
- Provide examples of predation, parasitism and competition involving microbes

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Chapter 32: Innate Host Resistance

Chapter Overview

Humans resist parasitic relationships by employing both innate and adaptive immune mechanisms. The innate resistance mechanisms are explored in this chapter. Physical barriers of innate resistance are discussed for several tissues and organs. The details of innate immunity are presented, including complement activation, cytokines, and acute phase proteins. There is a discussion of immunity and the cells and organs involved in human immune responses. The mechanisms of cellular immunity are presented and inflammation detailed.

Learning Outcomes

After reading this chapter, students should be able to:

- Define the term *immunity*
- Define the term *antigen*
- In general terms, differentiate the role of the innate and adaptive immune system
- identify the barriers that help prevent microbial invasion of the host
- Explain how the physical and mechanical barriers function to prevent microbial invasion of the host
- Relate host anatomy and secretions to the success of innate resistance strategies
- Discuss host mediators that have antimicrobial actions
- Describe in general terms the activation of the host complement system and its three outcomes
- List the three categories of cytokines and discuss their major functions
- Describe the function of acute-phase proteins
- Recognize the different types of leukocytes involved with innate resistance
- Outline the leukocyte response to microbial invasion to include the function of the different types of leukocytes and mechanisms of killing infected cells or invading pathogens
- Differentiate between primary and secondary lymphoid organs and tissues in terms of structure and function
- Explain the role of the spleen in host defense
- Explain the methods by which pathogens are recognized by phagocytes
- Compare and contrast the processes of autophagy and phagocytosis
- Correlate the biochemical activities within the phagolysosome with pathogen destruction
- Outline the sequence of innate host responses that result in inflammation
- Distinguish acute and chronic inflammation in terms of the host responses involved

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Chapter 33: Adaptive Immunity

Chapter Overview

This chapter focuses on adaptive immunity, a complex process involving interactions of the antigens of a pathogen with antigen-receptors and antibodies of a host. These interactions trigger a series of events that either destroy the pathogen or render it harmless. Most of the chapter is devoted to discussions of the cells and molecules of the adaptive immune system. During the discussion, the various connections between these cells and molecules are drawn and linked to other types of immune responses. The chapter continues with a discussion of the ways these responses protect higher animals against viral and bacterial pathogens. It concludes with a discussion of hypersensitivities (allergies), autoimmune diseases, and immunodeficiencies.

Learning Outcomes

After reading this chapter, students should be able to:

- Contrast host innate resistance with adaptive immunity
- Define the two branches of adaptive immunity by their cell types and general function
- Predict the types of molecules that can serve as antigens
- Describe the relationship between haptens and antigens
- Compare and contrast methods by which immunity occurs by natural and artificial means
- Distinguish between the active and passive forms of natural and artificial immunity
- Compare the processes by which MHC class I and class II receptors recognize foreignness
- Identify cells that function as antigen-presenting cells (APCs)
- Discuss the difference between T-cell development and T-cell activation
- Contrast the biological functions of T-cell subsets
- Describe T-cell receptor structure and function
- Diagram antigen presentation within MHC receptors interacting with the appropriate T-cell type
- Compare and contrast the activities of T_H1, T_H2, T_H17, Treg cells, and CTLs
- Describe the B-cell receptor structure and function
- Diagram the steps required for a B cell to become an APC
- Compare T-cell-dependent and T-cell-independent B-cell activation in terms of mechanism and outcome
- Compare and contrast the structure and function of the five classes of antibody
- Explain how primary and secondary antibody responses differ
- Explain the consequences of antibody binding of antigen
- Assess the effectiveness of antigen removal by antibody
- Predict which antigens will be most susceptible to antibody action
- Explain the differences between hypersensitivity, autoimmunity, tissue rejection, and immunodeficiency

- Explain the immunologic basis for donated tissue rejection
- Predict the impact of immunosuppression or immunodeficiency has on the host

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Chapter 34: The Microbe-Human Ecosystem

Chapter Overview

This chapter focuses on the relationship between humans and their microbiome. It begins with the establishment of the microbiome in a newborn and how the gut community matures. Current approaches to investigating the gut microbiome are presented, along with an extensive discussion of dietary influences. The chapter concludes with a discussion of microbiome manipulation.

Learning Outcomes

After reading this chapter, students should be able to:

- Define the word *microbiome*
- Explain why humans are considered holobionts
- Discuss the role of bifidobacteria in the infant microbiome
- Describe the different environmental niches on/in the human body and what microbes generally exist in these areas
- Predict the environmental host conditions that favor the association of acidophilic, anaerobic, lactic acid fermenting, and halophilic bacteria
- Discuss the factors that help mediate microbial diversity in and on the human body
- Explain the contribution the gut microbiome makes to human metabolism
- Analyze the importance of germ-free mice to our understanding of the human microbiome
- Differentiate between direct and indirect mechanisms responsible for colonization resistance
- List three specific reasons the immune system depends on the microbiome to maintain homeostasis
- Compare and contrast three routes by which gut microbes communicate with the central nervous system (CNS)
- Describe metabolic syndrome and the metabolic endotoxemia hypothesis
- Discuss the microbial link between a diet rich in red meat and atherosclerosis
- Discuss in broad terms the relationship between the microbiome and cancer
- Describe how a product is classified as a probiotic
- Predict uses of probiotics in the prevention of illness

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Chapter 35: Infection and Pathogenicity

Chapter Overview

This chapter focuses on infection and pathogenicity. The development of a disease state is a dynamic process that is dependent on the virulence of the pathogen and the resistance of the host. This dynamic process is illustrated in the discussions of viral and bacterial pathogenesis. Modes of transmission and development of diseased states are presented. The chapter includes a discussion of mechanisms used by viruses and bacteria to evade host defenses.

Learning Outcomes

After reading this chapter, students should be able to:

- Differentiate between pathogenicity and virulence
- Compare opportunistic, extracellular, and intracellular pathogens and discuss their requirements for survival
- Relate the infectious disease process to time, identifying events associated with each stage of the process
- Summarize the infectious process
- List and describe the means by which microorgansims access human cells and tissues to cause disease
- Correlate initial microbial numbers and replication rates to infection and lethality
- Compare the molecular mechanisms by which microorganisms adhere to and invade human cells and tissues
- Compare and contrast competition between microbial species with competition between microbial and human cells
- Describe features that allow microorganisms to overcome host resistance and immunity
- Discuss strategies microorganisms have evolved to exploit human cells and tissues as resources for their survival
- Differentiate between the characteristics of microbes in a biofilm and their planktonic counterparts
- Predict the microbial virulence factors and host cell responses that result in host damage
- Discuss the origin and nature of pathogenicity islands
- Illustrate the mechanisms by which microbial toxins impact human cells