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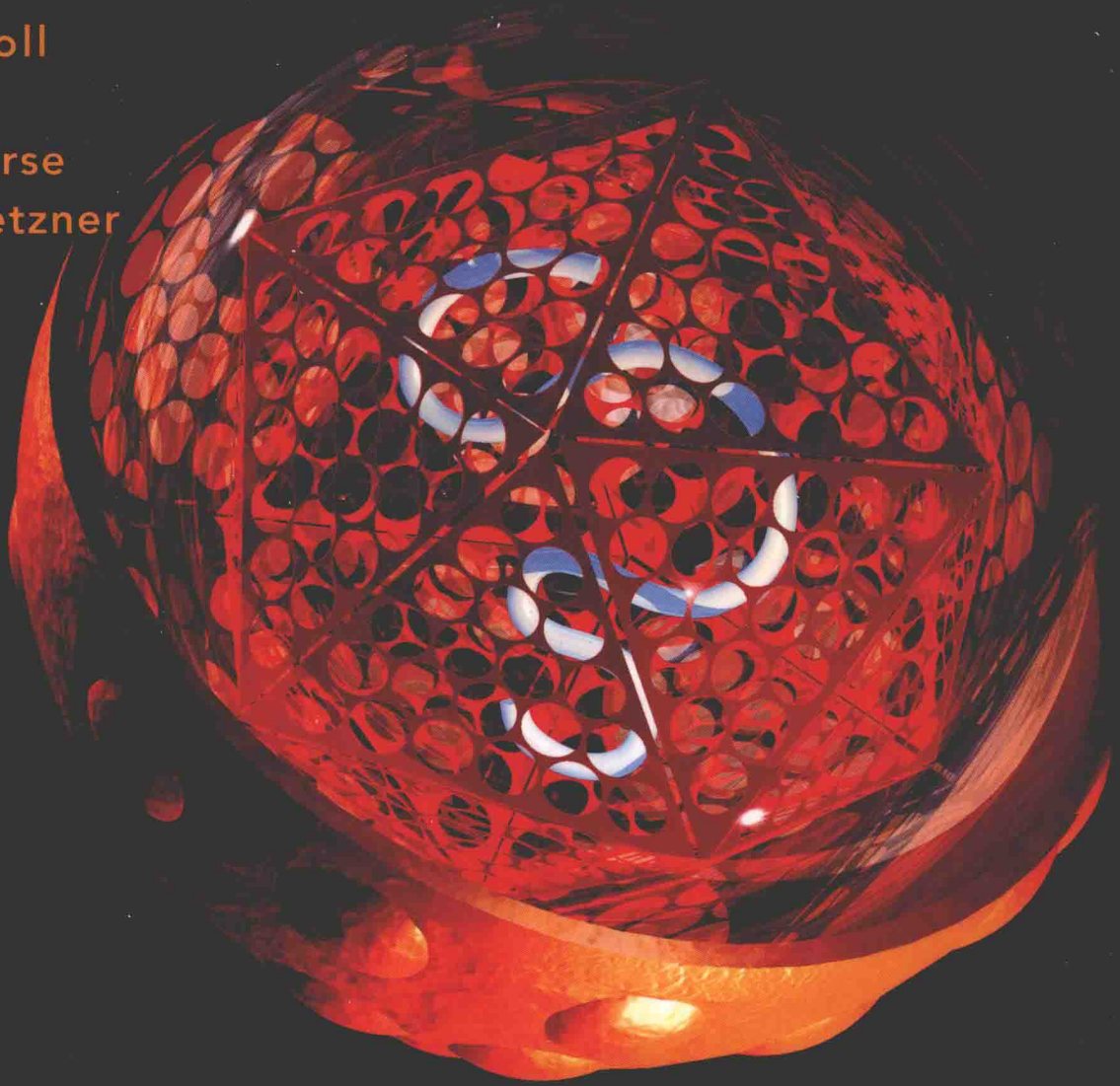

Jawetz, Melnick & Adelberg's

MEDICAL MICROBIOLOGY

26th Edition

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Jawetz, Melnick, & Adelberg's Medical Microbiology

Twenty-Sixth Edition

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SELECTED MEDICALLY IMPORTANT MICROORGANISMS

I. BACTERIA

AEROBIC AND FACULTATIVE BACTERIA

GRAM-POSITIVE COCCI

Catalase-Positive

- *Staphylococcus aureus*
- *Staphylococcus epidermidis*
- *Staphylococcus intermedius*
- *Staphylococcus lugdunensis*
- *Staphylococcus saprophyticus*
- *Staphylococcus* species

Catalase-Negative

- *Aerococcus* species
- *Enterococcus faecalis*
- *Enterococcus faecium*
- *Enterococcus* species
- *Gemella* species
- *Lactococcus* species
- *Leuconostoc* species
- *Pediococcus* species
- *Streptococcus agalactiae* (Group B)
- *Streptococcus canis* (Group G)
- *Streptococcus gallolyticus* (Group D, formerly *S. bovis*)
- *Streptococcus infantarius* (Group D, formerly *S. bovis*)
- *Streptococcus pneumoniae*
- *Streptococcus pyogenes* (Group A)
- Viridans group streptococci
  - *Streptococcus anginosus*
  - *Streptococcus constellatus*
  - *Streptococcus intermedius*
  - *Streptococcus mitis*
  - *Streptococcus mutans*
  - *Streptococcus salivarius*
  - *Streptococcus sanguis*
- *Abiotrophia* species (nutritionally variant streptococci)
- *Granulicatella* species (nutritionally variant streptococci)

GRAM-NEGATIVE COCCI

- *Moraxella catarrhalis*
- *Neisseria gonorrhoeae*
- *Neisseria meningitidis*
- *Neisseria* species

GRAM-POSITIVE BACILLI

- *Arcanobacterium* species
- *Bacillus anthracis*
- *Bacillus cereus*
- *Corynebacterium diphtheriae*
- *Corynebacterium jeikeium*
- *Corynebacterium* species
- *Corynebacterium urealyticum*
- *Erysipelothrix rhusiopathiae*
- *Gardnerella vaginalis*
- *Gordonia* species
- *Listeria monocytogenes*
- *Mycobacterium abscessus*
- *Mycobacterium avium*
- *Mycobacterium bovis*
- *Mycobacterium chelonae*
- *Mycobacterium fortuitum*
- *Mycobacterium intracellulare*
- *Mycobacterium kansasii*
- *Mycobacterium leprae*
- *Mycobacterium marinum*
- *Mycobacterium tuberculosis*
- *Mycobacterium* species
- *Nocardia asteroides*
- *Rhodococcus equi*
- *Tropheryma whippeli*
- *Tsukamurella* species

GRAM-NEGATIVE BACILLI

Enterobacteriaceae

- *Citrobacter freundii*
- *Citrobacter koseri*
- *Citrobacter* species
- *Cronobacter sakazakii*
- *Edwardsiella tarda*
- *Enterobacter aerogenes*
- *Enterobacter cloacae*
- *Escherichia coli*
- *Escherichia* species
- *Klebsiella oxytoca*
- *Klebsiella granulomatis*
- *Klebsiella pneumoniae*
- *Klebsiella pneumoniae subspecies rhinocscleromatis*
- *Morganella morganii*
- *Plesiomonas shigelloides*
- *Proteus mirabilis*
- *Proteus vulgaris*
- *Providencia alcalifaciens*
- *Providencia rettgeri*
- *Providencia stuartti*
- *Salmonella* Choleraesuis
- *Salmonella* Paratyphi A
- *Salmonella* Paratyphi B
- *Salmonella* Typhi
- *Salmonella* species
- *Serratia liquefaciens*
- *Serratia marcescens*
- *Shigella boydii*
- *Shigella dysenteriae*
- *Shigella flexneri*
- *Shigella sonnei*
- *Yersinia enterocolitica*
- *Yersinia pestis*
- *Yersinia pseudotuberculosis*

Nonenterobacteriaceae—Fermentative Bacilli

- *Aeromonas caviae*
- *Aeromonas hydrophila*
- *Aeromonas* species
- *Aeromonas veronii biovar sobria*
- *Pasteurella multocida*
- *Vibrio cholerae*
- *Vibrio parahaemolyticus*
- *Vibrio* species
- *Vibrio vulnificus*

Nonenterobacteriaceae—Nonfermentative Bacilli

- *Acinetobacter* species
- *Alcaligenes* species
- *Brevundimonas* species
- *Burkholderia cepacia*
- *Burkholderia mallei*
- *Burkholderia pseudomallei*
- *Chryseobacterium* species
- *Comamonas* species
- *Eikenella corrodens*
- *Moraxella* species
- *Pseudomonas aeruginosa*
- *Pseudomonas fluorescens*
- *Pseudomonas* species
- *Ralstonia pickettii*
- *Roseomonas* species
- *Shewanella putrefaciens*
- *Sphingobacterium* species
- *Sphingomonas* species
- *Stenotrophomonas maltophilia*

OTHER GRAM-NEGATIVE BACILLI AND COCCOBACILLI

- *Aggregatibacter (Actinobacillus) actinomycetemcomitans*
- *Aggregatibacter (Haemophilus) aphrophilus*
- *Arcobacter* species
- *Bartonella bacilliformis*
- *Bartonella henselae*
- *Bartonella* species
- *Bordetella bronchiseptica*
- *Bordetella parapertussis*
- *Bordetella pertussis*
- *Bordetella* species
- *Brucella melitensis*
- *Brucella* species
- *Campylobacter fetus*
- *Campylobacter jejuni*
- *Campylobacter* species
- *Capnocytophaga* species
- *Cardiobacterium hominis*
- *Chlamydophila pneumoniae*
- *Chlamydophila psittaci*
- *Chlamydia trachomatis*
- *Ehrlichia chaffeensis*
- *Francisella tularensis*
- *Haemophilus aegyptius*
- *Haemophilus ducreyi*
- *Haemophilus influenzae*
- *Haemophilus parainfluenzae*
- *Haemophilus* species
- *Helicobacter pylori*
- *Kingella kingae*
- *Legionella micdadei*
- *Legionella pneumophila*
- *Legionella* species
- *Orientia tsutsugamushi*
- *Streptobacillus moniliformis*

MYCOPLASMAS

- *Mycoplasma genitalium*
- *Mycoplasma hominis*
- *Mycoplasma pneumoniae*
- *Mycoplasma* species
- *Ureaplasma urealyticum*

RICKETTSIA AND RELATED ORGANISMS

Anaplasma

Ehrlichia

- *Ehrlichia chaffeensis*
- *Ehrlichia ewingii*

Rickettsia

- *Rickettsia akari*
- *Rickettsia conorii*
- *Rickettsia mooseri*
- *Rickettsia prowazekii*
- *Rickettsia rickettsii*

SPIRAL ORGANISMS

- *Borrelia burgdorferi*
- *Borrelia recurrentis*
- *Leptospira interrogans*
- *Treponema pallidum*

ANAEROBIC BACTERIA

GRAM-NEGATIVE BACILLI

- *Bacteroides fragilis* group
  - *Bacteroides ovatus*
  - *B distasonis*
  - *B thetaiotamicron*
  - *B vulgatus*
- *Bacteroides* species
- *Fusobacterium necrophorum*
- *Fusobacterium nucleatum*
- *Mobiluncus* species

(Continued on inside back cover)

Preface

The twenty-sixth edition of *Jawetz, Melnick, & Adelberg's Medical Microbiology* remains true to the goals of the first edition published in 1954 "to provide a brief, accurate and up-to-date presentation of those aspects of medical microbiology that are of particular significance to the fields of clinical infections and chemotherapy." The 26th edition has included the following new features!

- Addition of concept checks after major sections within chapters.
- Chapter Summaries at the end of each chapter.
- Increased number of new and revised review questions.
- Full color photographs and photomicrographs of the previous edition.
- All chapters have been revised extensively consistent with the tremendous expansion of medical knowledge afforded by molecular mechanisms, advances in our understanding of microbial pathogenesis and the discovery of novel pathogens.

New also to this edition is Barbara Detrick, PhD, Professor in the Division of Clinical Immunology in the Department of Pathology at the Johns Hopkins University School of Medicine. Dr. Detrick's extensive expertise in clinical immunology, and in particular the role of cytokines in health and disease, will add significantly to the current and future editions and we welcome her participation.

The authors hope that the changes to this edition will be helpful to the student of microbiology.

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November 2012

Contents

SECTION I FUNDAMENTALS OF MICROBIOLOGY

CHAPTER 1

The Science of Microbiology

INTRODUCTION

Microbiology is the study of microorganisms, a large and diverse group of microscopic organisms that exist as single cells or cell clusters; it also includes viruses, which are microscopic but not cellular. Microorganisms have a tremendous impact on all life and the physical and chemical makeup of our planet. They are responsible for cycling the chemical elements essential for life, including carbon, nitrogen, sulfur, hydrogen, and oxygen; more photosynthesis is carried out by microorganisms than by green plants. Furthermore, there are 100 million times as many bacteria in the oceans (13×10^{28}) as there are stars in the known universe. The rate of viral infections in the oceans is about 1×10^{23} infections per second, and these infections remove 20–40% of all bacterial cells each day. It has been estimated that 5×10^{30} microbial cells exist on earth; excluding cellulose, these cells constitute about 90% of the biomass of the entire biosphere. Humans also have an intimate relationship with microorganisms; more than 90% of the cells in our bodies are microbes. The bacteria present in the average human gut weigh about 1 kg, and a human adult will excrete his or her own weight in fecal bacteria each year. The number of genes contained within this gut flora outnumber that contained within our genome 150-fold, and even in our own genome, 8% of the DNA is derived from remnants of viral genomes.

BIOLOGIC PRINCIPLES ILLUSTRATED BY MICROBIOLOGY

Nowhere is **biologic diversity** demonstrated more dramatically than by microorganisms, creatures that are not directly visible to the unaided eye. In form and function, be it biochemical property or genetic mechanism, analysis of microorganisms takes us to the limits of biologic understanding. Thus, the need for **originality**—one test of the merit of a scientific **hypothesis**—can be fully met in microbiology. A useful hypothesis should provide a basis for **generalization**, and microbial diversity provides an arena in which this challenge is ever present.

Prediction, the practical outgrowth of science, is a product created by a blend of technique and theory. **Biochemistry**, **molecular biology**, and **genetics** provide the tools required for analysis of microorganisms. **Microbiology**, in turn, extends the horizons of these scientific disciplines. A biologist might describe such an exchange as **mutualism**, that is, one that benefits all of the contributing parties. Lichens are an example of microbial mutualism. Lichens consist of a fungus and phototropic partner, either an alga (a eukaryote) or a cyanobacterium (a prokaryote). The phototropic component is the primary producer, and the fungus provides the phototroph with an anchor and protection from the elements. In biology, mutualism is called **symbiosis**, a continuing association of different organisms. If the exchange operates primarily to the benefit of one party, the association is described as **parasitism**, a relationship in which a **host** provides the primary benefit to the parasite. Isolation and characterization of a parasite—such as a pathogenic bacterium or virus—often require effective mimicry in the laboratory of the growth environment provided by host cells. This demand sometimes represents a major challenge to investigators.

The terms *mutualism*, *symbiosis*, and *parasitism* relate to the science of **ecology**, and the principles of environmental biology are implicit in microbiology. Microorganisms are

the products of **evolution**, the biologic consequence of **natural selection** operating on a vast array of genetically diverse organisms. It is useful to keep the complexity of natural history in mind before generalizing about microorganisms, the most heterogeneous subset of all living creatures.

A major biologic division separates the eukaryotes, organisms containing a membrane-bound nucleus, from prokaryotes, organisms in which DNA is not physically separated from the cytoplasm. As described in this chapter and in Chapter 2, further major distinctions can be made between eukaryotes and prokaryotes. Eukaryotes, for example, are distinguished by their relatively large size and by the presence of specialized membrane-bound organelles such as mitochondria.

As described more fully later in this chapter, eukaryotic microorganisms—or, phylogenetically speaking, the Eukarya—are unified by their distinct cell structure and phylogenetic history. Among the groups of eukaryotic microorganisms are the **algae**, the **protozoa**, the **fungi**, and the **slime molds**.

VIRUSES

The unique properties of viruses set them apart from living creatures. Viruses lack many of the attributes of cells, including the ability to replicate. Only when it infects a cell does a virus acquire the key attribute of a living system—reproduction. Viruses are known to infect all cells, including microbial cells. Recently, viruses called **virophages** have been discovered that infect other viruses. Host–virus interactions tend to be highly specific, and the biologic range of viruses mirrors the diversity of potential host cells. Further diversity of viruses is exhibited by their broad array of strategies for replication and survival.

Viral particles are generally small (eg, adenovirus is 90 nm) and consist of a nucleic acid molecule, either DNA or RNA, enclosed in a protein coat, or capsid (sometimes itself enclosed by an envelope of lipids, proteins, and carbohydrates). Proteins—frequently glycoproteins—in the capsid determine the specificity of interaction of a virus with its host cell. The capsid protects the nucleic acid and facilitates attachment and penetration of the host cell by the virus. Inside the cell, viral nucleic acid redirects the host's enzymatic machinery to functions associated with replication of the virus. In some cases, genetic information from the virus can be incorporated as DNA into a host chromosome. In other instances, the viral genetic information can serve as a basis for cellular manufacture and release of copies of the virus. This process calls for replication of the viral nucleic acid and production of specific viral proteins. **Maturation** consists of assembling newly synthesized nucleic acid and protein subunits into mature viral particles, which are then liberated into the extracellular environment. Some very small viruses require the assistance of another virus in the host cell for their duplication. The delta agent, also known as hepatitis D virus, is too small to code for even a single capsid protein and needs help from hepatitis B virus for transmission. Viruses are known to infect a wide variety of plant and animal hosts as well as protists, fungi, and bacteria. However, most viruses are able to infect specific types of cells of only one host species.

Some viruses are large and complex. For example, Mimivirus, a DNA virus infecting *Acanthamoeba*, a free-living soil ameba, has a diameter of 400–500 nm and a genome that encodes 979 proteins, including the first four aminoacyl tRNA synthetases ever found outside of cellular organisms and enzymes for polysaccharide biosynthesis. An even larger marine virus has recently been discovered (Megavirus); its genome (1,259,197-bp) encodes 1120 putative proteins and is larger than that of some bacteria (Table 7-1). Because of their large size, these viruses resemble bacteria when observed in stained preparations by light microscopy; however, they do not undergo cell division or contain ribosomes.

A number of transmissible plant diseases are caused by **viroids**—small, single-stranded, covalently closed circular RNA molecules existing as highly base-paired rodlike structures. They range in size from 246 to 375 nucleotides in length. The extracellular form of the viroid is naked RNA—there is no capsid of any kind. The RNA molecule contains no protein-encoding genes, and the viroid is therefore totally dependent on host functions for its replication. Viroid RNA is replicated by the DNA-dependent RNA polymerase of the plant host; preemption of this enzyme may contribute to viroid pathogenicity.

The RNAs of viroids have been shown to contain inverted repeated base sequences at their 3′ and 5′ ends, a characteristic of transposable elements (see Chapter 7) and retroviruses. Thus, it is likely that they have evolved from transposable elements or retroviruses by the deletion of internal sequences.

The general properties of animal viruses pathogenic for humans are described in Chapter 29. Bacterial viruses are described in Chapter 7.

PRIONS

A number of remarkable discoveries in the past 3 decades have led to the molecular and genetic characterization of the transmissible agent causing **scrapie**, a degenerative central nervous system disease of sheep. Studies have identified a scrapie-specific protein in preparations from scrapie-infected brains of sheep that is capable of reproducing the symptoms of scrapie in previously uninfected sheep (Figure 1-1). Attempts to identify additional components, such as nucleic acid, have been unsuccessful. To distinguish this agent from viruses and viroids, the term **prion** was introduced to emphasize its proteinaceous and infectious nature. The cellular form of the prion protein (PrP^c) is encoded by the host's chromosomal DNA. PrP^c is a sialoglycoprotein with a molecular mass of 33,000–35,000 daltons and a high content of α-helical secondary structure that is sensitive to proteases and soluble in detergent. PrP^c is expressed on the surface of neurons via a glycosylphosphatidyl inositol anchor in both infected and

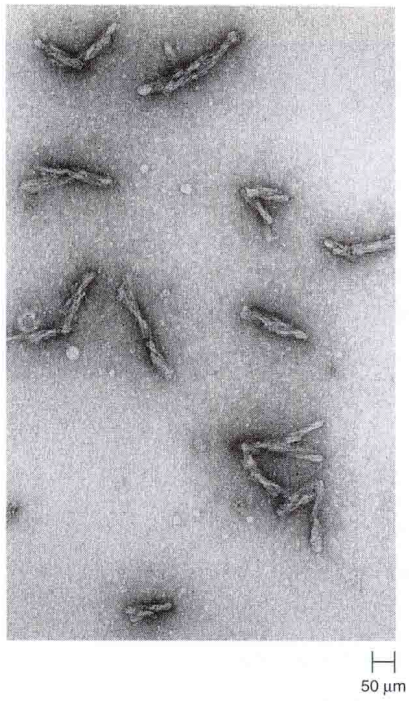

FIGURE 1-1 Prion. Prions isolated from the brain of a scrapie-infected hamster. This neurodegenerative disease is caused by a prion. (Reproduced with permission from Stanley B. Prusiner.)

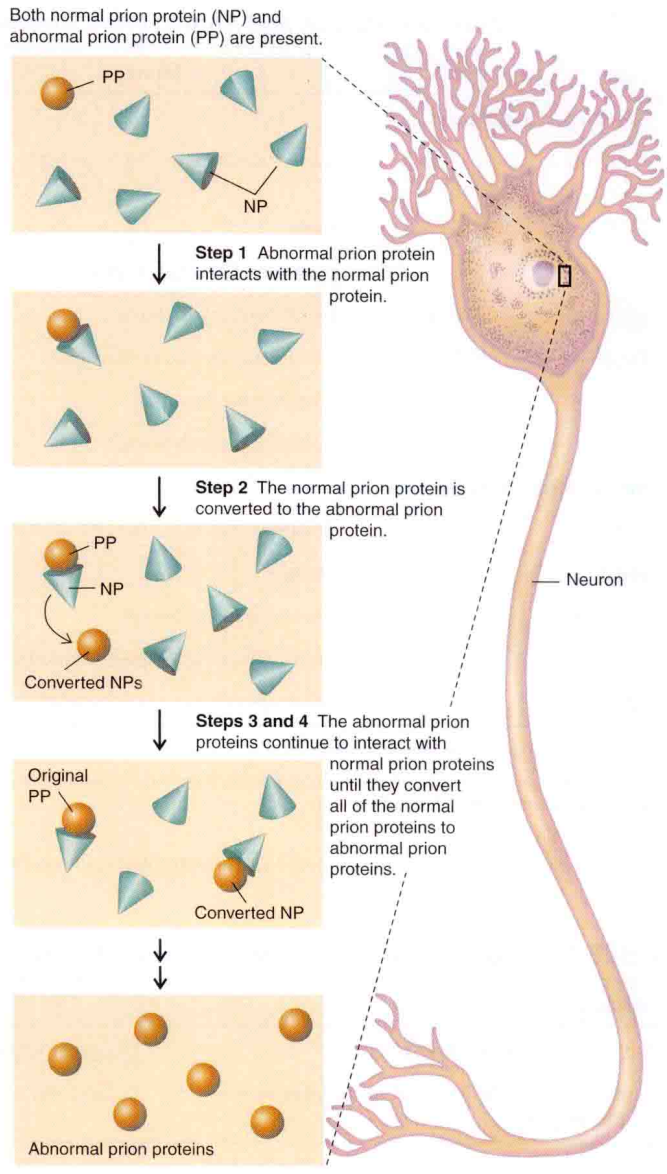

FIGURE 1-2 Proposed mechanism by which prions replicate. The normal and abnormal prion proteins differ in their tertiary structure. (Reproduced with permission from Nester EW, Anderson DG, Roberts CE, Nester MT (editors): *Microbiology: A Human Perspective*, 6th ed. McGraw-Hill, 2009, p. 342.)

uninfected brains. A conformational change occurs in the prion protein, changing it from its normal or cellular form PrP^{c} to the disease-causing conformation, PrP^{Sc} (Figure 1-2). When PrP^{Sc} is present in an individual (owing to spontaneous conformational conversion or to infection), it is capable of recruiting PrP^{c} and converting it to the disease form. Thus, prions replicate using the PrP^{c} substrate that is present in the host.

There are additional prion diseases of importance (Table 1-1 and Chapter 42). Kuru, Creutzfeldt-Jakob disease (CJD), Gerstmann-Sträussler-Scheinker disease, and fatal familial insomnia affect humans. Bovine spongiform encephalopathy, which is thought to result from the ingestion of feeds and bone meal prepared from rendered sheep offal, has been responsible for the deaths of more than 184,000 cattle in Great Britain since its discovery in 1985. A new variant of CJD (vCJD) has been associated with human ingestion of prion-infected beef in the United Kingdom and France. A common feature of all of these diseases is the conversion of a host-encoded sialoglycoprotein to a protease-resistant form as a consequence of infection.

Human prion diseases are unique in that they manifest as sporadic, genetic, and infectious diseases. The study of prion biology is an important emerging area of biomedical investigation, and much remains to be learned.

The distinguishing features of the nonliving members of the microbial world are given in Table 1-2.

PROKARYOTES

The primary distinguishing characteristics of the prokaryotes are their relatively small size, usually on the order of 1 μm in diameter, and the absence of a nuclear membrane. The DNA of almost all bacteria is a circle with a length of about 1 mm; this is the prokaryotic chromosome. Most prokaryotes have only a single chromosome. The chromosomal DNA must be folded more than 1000-fold just to fit within the prokaryotic cell membrane. Substantial evidence suggests that the folding may be orderly and may bring specified regions of the DNA

TABLE 1-1 Common Human and Animal Prion Diseases

Type	Name	Etiology
Human prion diseases		
Acquired	Variant Creutzfeldt-Jakob disease[a]	Associated with ingestion or inoculation of prion-infected material
	Kuru	
	Iatrogenic Creutzfeldt-Jakob disease[b]	
Sporadic	Creutzfeldt-Jakob disease	Source of infection unknown
Familial	Gerstmann-Sträussler-Scheinker	Associated with specific mutations within the gene encoding PrP
	Fatal familial insomnia	
	Creutzfeldt-Jakob disease	
Animal prion diseases		
Cattle	Bovine spongiform encephalopathy	Exposure to prion-contaminated meat and bone meal
Sheep	Scrapie	Ingestion of scrapie-contaminated material
Deer, elk	Chronic wasting disease	Ingestion of prion-contaminated material
Mink	Transmissible mink encephalopathy	Source of infection unknown
Cats	Feline spongiform encephalopathy[a]	Exposure to prion-contaminated meat and bone meal

[a]Associated with exposure to bovine spongiform encephalopathy–contaminated materials.

[b]Associated with prion-contaminated biologic materials, such as dura mater grafts, corneal transplants, and cadaver-derived human growth hormone, or prion-contaminated surgical instruments.

PrP, prion protein.

Reproduced with permission from the American Society for Microbiology. Priola SA: How animal prions cause disease in humans. *Microbe* 2008;3(12):568.

TABLE 1-2 Distinguishing Characteristics of Viruses, Viroids, and Prions

Viruses	Viroids	Prions
Obligate intracellular agents	Obligate intracellular agents	Abnormal form of a cellular protein
Consist of either DNA or RNA surrounded by a protein coat	Consist only of RNA; no protein coat	Consist only of protein; no DNA or RNA

Reproduced with permission from Nester EW, Anderson DG, Roberts CE, Nester MT (editors): *Microbiology: A Human Perspective*, 6th ed. McGraw-Hill, 2009, p. 13.

into proximity. The specialized region of the cell containing DNA is termed the **nucleoid** and can be visualized by electron microscopy as well as by light microscopy after treatment of the cell to make the nucleoid visible. Thus, it would be a mistake to conclude that subcellular differentiation, clearly demarcated by membranes in eukaryotes, is lacking in prokaryotes. Indeed, some prokaryotes form membrane-bound subcellular structures with specialized function such as the chromatophores of photosynthetic bacteria (see Chapter 2).

Prokaryotic Diversity

The small size of the prokaryotic chromosome limits the amount of genetic information it can contain. Recent data based on genome sequencing indicate that the number of genes within a prokaryote may vary from 468 in *Mycoplasma genitalium* to 7825 in *Streptomyces coelicolor*, and many of these genes must be dedicated to essential functions such as energy generation, macromolecular synthesis, and cellular replication. Any one prokaryote carries relatively few genes that allow physiologic accommodation of the organism to its environment. The range of potential prokaryotic environments is unimaginably broad, and it follows that the prokaryotic group encompasses a heterogeneous range of specialists, each adapted to a rather narrowly circumscribed niche.

The range of prokaryotic niches is illustrated by consideration of strategies used for generation of metabolic energy. Light from the sun is the chief source of energy for life. Some prokaryotes such as the purple bacteria convert light energy to metabolic energy in the absence of oxygen production. Other prokaryotes, exemplified by the blue-green bacteria (**Cyanobacteria**), produce oxygen that can provide energy through respiration in the absence of light. **Aerobic organisms** depend on respiration with oxygen for their energy.

Some **anaerobic organisms** can use electron acceptors other than oxygen in respiration. Many anaerobes carry out **fermentations** in which energy is derived by metabolic rearrangement of chemical growth substrates. The tremendous chemical range of potential growth substrates for aerobic or anaerobic growth is mirrored in the diversity of prokaryotes that have adapted to their utilization.

Prokaryotic Communities

A useful survival strategy for specialists is to enter into **consortia**, arrangements in which the physiologic characteristics of different organisms contribute to survival of the group as a whole. If the organisms within a physically interconnected community are directly derived from a single cell, the community is a **clone** that may contain up to 10^8 cells. The biology of such a community differs substantially from that of a single cell. For example, the high cell number virtually ensures the presence within the clone of at least one cell carrying a variant of any gene on the chromosome. Thus, genetic variability—the wellspring of the evolutionary process called natural selection—is ensured within a clone. The high number of cells within clones also is likely to provide physiologic protection to at least some members of the group. Extracellular polysaccharides, for example, may afford protection against potentially lethal agents such as antibiotics or heavy metal ions. Large amounts of polysaccharides produced by the high number of cells within a clone may allow cells within the interior to survive exposure to a lethal agent at a concentration that might kill single cells.

Many bacteria exploit a cell–cell communication mechanism called **quorum sensing** to regulate the transcription of genes involved in diverse physiologic processes, including bioluminescence, plasmid conjugal transfer, and the production of virulence determinants. Quorum sensing depends on the production of one or more diffusible signal molecules termed **autoinducers** or **pheromones** that enable a bacterium to monitor its own cell population density. It is an example of multicellular behavior in prokaryotes.

A distinguishing characteristic of prokaryotes is their capacity to exchange small packets of genetic information. This information may be carried on **plasmids**, small and specialized genetic elements that are capable of replication within at least one prokaryotic cell line. In some cases, plasmids may be transferred from one cell to another and thus may carry sets of specialized genetic information through a population. Some plasmids exhibit a **broad host range** that allows them to convey sets of genes to diverse organisms. Of particular concern are **drug resistance plasmids** that may render diverse bacteria resistant to antibiotic treatment.

The survival strategy of a single prokaryotic cell line may lead to a range of interactions with other organisms. These may include symbiotic relationships illustrated by complex nutritional exchanges among organisms within the human gut. These exchanges benefit both the microorganisms and their human host. Parasitic interactions can be quite deleterious to the host. Advanced symbiosis or parasitism can lead to loss of functions that may not allow growth of the symbiont or parasite independent of its host.

The **mycoplasmas**, for example, are parasitic prokaryotes that have lost the ability to form a cell wall. Adaptation of these organisms to their parasitic environment has resulted in incorporation of a substantial quantity of cholesterol into their cell membranes. Cholesterol, not found in other prokaryotes, is assimilated from the metabolic environment provided by the host. Loss of function is exemplified also by obligate intracellular parasites, the **chlamydiae** and **rickettsiae**. These bacteria are extremely small (0.2–0.5 μm in diameter) and depend on the host cell for many essential metabolites and coenzymes. This loss of function is reflected by the presence of a smaller genome with fewer genes (see Table 7-1).

The most widely distributed examples of bacterial symbionts appear to be chloroplasts and mitochondria, the energy-yielding organelles of eukaryotes. A substantial body of evidence points to the conclusion that ancestors of these organelles were **endosymbionts**, prokaryotes that established symbiosis within the cell membrane of the ancestral eukaryotic host. The presence of multiple copies of the organelles may have contributed to the relatively large size of eukaryotic cells and to their capacity for specialization, a trait ultimately reflected in the evolution of differentiated multicellular organisms.

Classification of the Prokaryotes

An understanding of any group of organisms requires their **classification**. An appropriate classification system allows a scientist to choose characteristics that allow swift and accurate categorization of a newly encountered organism. The categorization allows prediction of many additional traits shared by other members of the category. In a hospital setting, successful classification of a pathogenic organism may provide the most direct route to its elimination. Classification may also provide a broad understanding of relationships among different organisms, and such information may have great practical value. For example, elimination of a pathogenic organism will be relatively long-lasting if its habitat is occupied by a nonpathogenic variant.

The principles of prokaryotic classification are discussed in Chapter 3. At the outset, it should be recognized that any prokaryotic characteristic might serve as a potential criterion for classification. However, not all criteria are equally effective in grouping organisms. Possession of DNA, for example, is a useless criterion for distinguishing organisms because all cells contain DNA. The presence of a broad host range plasmid is not a useful criterion because such plasmids may be found in diverse hosts and need not be present all of the time. Useful criteria may be structural, physiologic, biochemical, or genetic. **Spores**—specialized cell structures that may allow survival in extreme environments—are useful structural criteria for classification because well-characterized subsets of bacteria form spores. Some bacterial groups can