NAME: ____ PER: _______ DATE: __________

BACTERIA COLORING PACKET

FORMS OF BACTERIA

The word "bacterium" may have been used for the first time in the 1850s when the French investigator Casimir Davaine used the term to mean "rod" or "staff." As the years unfolded it became apparent that many bacteria are not rodlike, but the name remained and soon it was applied to all microscopic organisms of that general size and with properties similar to the rods. In this plate three basic forms of bacteria and their arrangements are examined and related to their role as disease agents.

Color the subheading (a), the four different forms of the bacillus (a^1) through (a^4) and their titles, and the names of the related diseases. Use four different shades of the same color for these forms.

The rod form of a bacterium is called a bacillus (a; pl. bacilli). Bacilli vary in size, and may be as long as 20 µm or as short as 0.5 µm. Certain bacilli (*Bacillus anthracis*) are rectangular with sharply rounded ends (a^1); these bacilli cause anthrax (a^1), a disease of such animals as cows, goats, sheep, and deer. The disease is communicable to humans by air, contaminated meat, and contact with animals. Certain rod-shaped bacilli are wide at one end and tapered at the other end (club-shaped, a^2; e.g., *Cornybacterium diphtheriae*). They are known to cause diphtheria (a^2). In this disease of the respiratory tract, bacterial toxins damage the nerves and the heart. One type of bacillus (*Clostridium tetani*) is rod-like but swollen at one end (a^3). These swollen ends contain endospores, a very resistant form of the bacterium. Tetanus (a^3), a disease caused by these bacteria, is characterized by muscle spasms, seizures, and paralysis of respiratory muscles. There are several species of bacilli that occur in chains (a^4). A streptobacillus is shown here; *strepto-* refers to bacteria linked end-to-end in chains. Certain streptobacilli cause rat bite fever (a^4), a disease characterized by chills, vomiting, and fever.

Color the subheading (b), and the five different forms of the coccus and their titles, and the names of the related diseases. Use five shades of the same color or similar colors which contrast with the color used for (a).

The spherical form of a bacterium is known as a coccus (b; pl. cocci). A coccus is about 0.5 µm in diameter. Some cocci called diplococci are paired (diplo-, double). One species of diplococcus (*Streptococcus pneumoniae*) has tapered sides (b^1) and causes pneumonia (b^1), an inflammation of the air spaces of the lungs accompanied by fluid formation. Another type of diplococcus (*Neisseria gonorrhoeae*) (b^2) resembles two tiny beans lying face to face. *N. gonorrhoeae* causes gonorrhea (b^2), a disease transmitted by sexual contact. The streptococcus is a well-known group of cocci characterized by individuals in a chain (b^3). "Strep throat" (b^3), a serious infection of the pharynx, is caused by a species of streptococcus. In contrast, a harmless species of streptococcus is one of the "active cultures" in a cup of yogurt. A cubelike packet of four or eight cocci (b^4) is called a sarcina. One sarcina called *Micrococcus luteus* is a common nonpathogenic inhabitant of the human skin (b^4). Another type of coccus, called staphylococcus, occurs in clusters (b^5) and produces toxins in food resulting in staphylococcal food poisoning (b^5). Other staphylococci enter hair follicles and inflame the skin causing boils or "staph infection" (not shown).

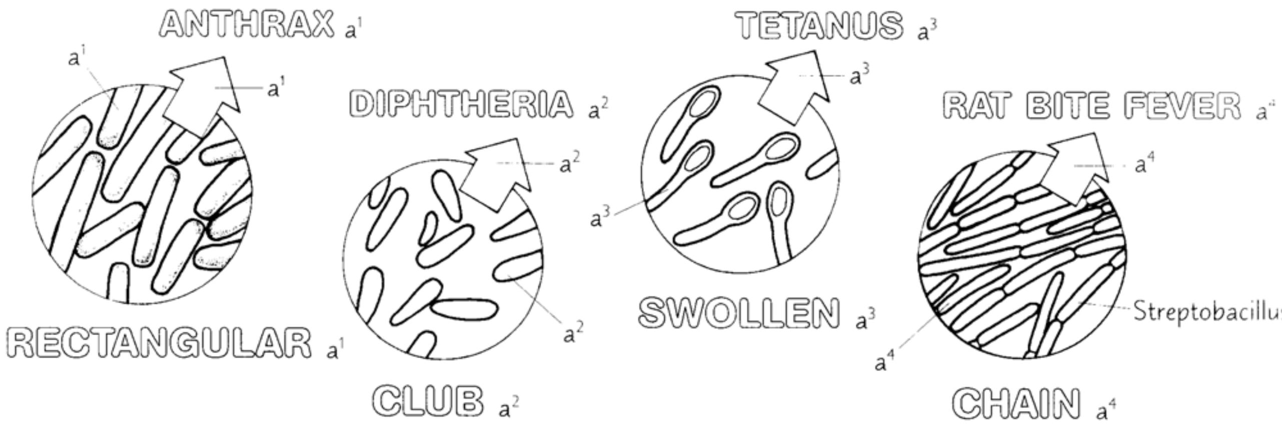
Color the subheading (c), the three different forms of the spiral and their titles, and the names of the related diseases. Use three shades of the same color which contrasts with the colors used for (a) and (b).

A third form of a bacterium is the spiral (c). These bacteria are about 15 µm in length. In the spiral form called the vibrio (c^1), the bacterium has only a single turn, appearing curved, like a comma. One vibrio causes cholera (c^1), a serious disorder characterized by vomiting, diarrhea, and cramps. Severe dehydration caused by *Vibrio cholerae* is induced by toxins that interfere with sodium absorption in the intestines. Another form of spiral bacteria is the spirillum (pl. spirilla). The spirillum resembles a corkscrew, with the spiral making several turns (c^2). The spirillum possesses a rigid cell wall with flagella for movement. This bacterium causes rat bite fever (c^2), which is similar in symptoms to the rat bite fever caused by streptobacilli. A spirochete is a spiral bacterium that has the corkscrew form but a flexible cell wall and no flagella (c^3). It uses axial filaments to move in a snakelike manner. A spirochete (*Treponema pallidum*) is responsible for syphilis (c^3), a disease in which the bacteria enter the tissues through breaks in the skin, such as the skin of the genital organs.

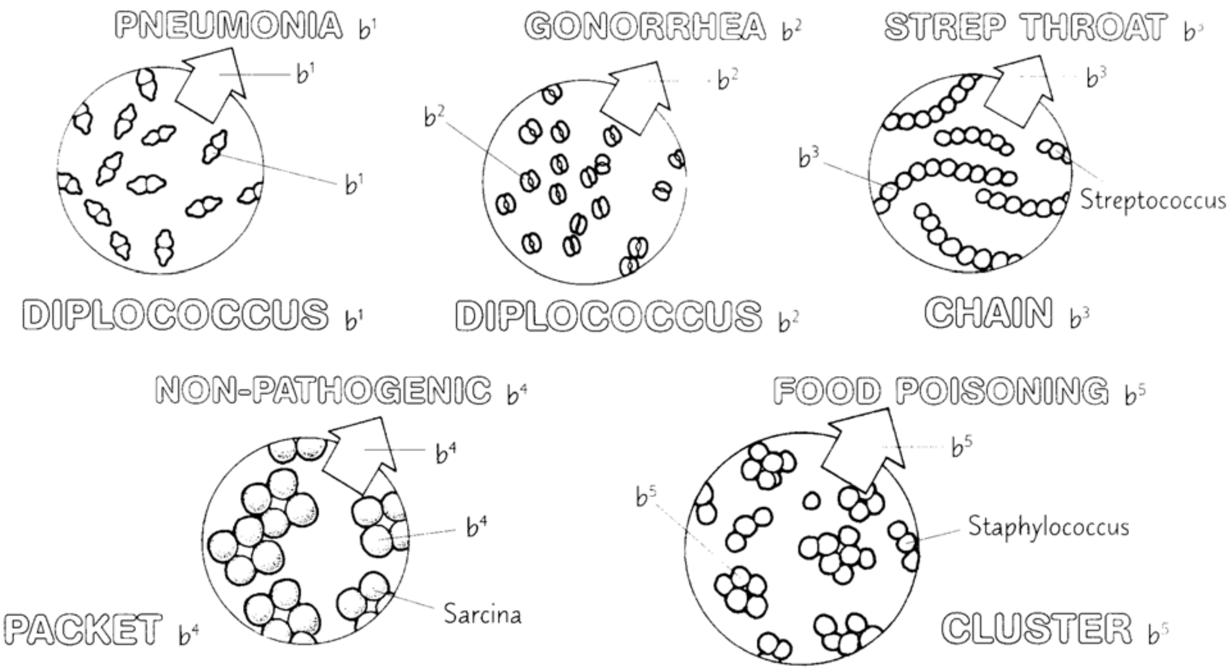
The anatomical pattern of a bacterium can be of great practical value. In the diagnostic laboratory, for example, a technician may note the characteristic diplococci of gonorrhea in a patient's urine sample and report this observation to the physician. The diagnosis of syphilis is aided considerably by locating the characteristic spirochetes in material from a skin lesion. And strep throat may be pinpointed by observing streptococci in bacterial colonies isolated from the throat.

FORMS OF BACTERIA

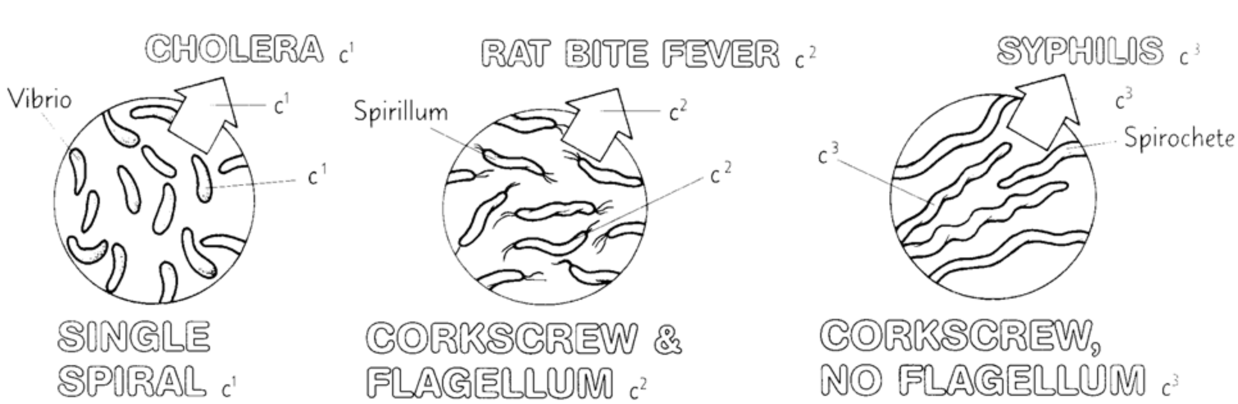
BACILLUS (a)



COCCUS (b)



SPIRAL (c)



BACTERIAL ULTRASTRUCTURE

The transmission electron microscope magnifies bacteria over 100,000 times and reveals a wealth of detailed structures that can be closely correlated with cellular function. In this plate, bacterial structures will be examined and related to cellular behavior.

Set aside a light yellow color for (i). Color the titles (a) through (k) and related structures. Try to select colors that do not obscure cellular detail. Use darker colors for very small structures. Color over the flagellum/flagella (a) on the bacteria shown in motion on the plate and represented in the illustration by their capsules (b).

Many species of bacilli and spirilla, and a few species of cocci, move by means of one or more flagella (a). The flagellum is composed of thin fibers made of protein. The movement of the bacterial flagellum is rotary thereby creating a propellerlike motion that drives the bacterium forward.

Some species of bacteria, many of them pathogenic, have a capsule (b). The capsule is secreted by the bacterium and adheres to the outer surface of the cell wall. It is composed of complex polysaccharides and small proteins. When the capsule has a looser consistency, it is called a glycocalyx. The capsule is a storehouse for nutrients, a depot for cellular waste products, and a protective shield against dehydration and potentially harmful changes in the external environment. It also retards phagocytosis by white blood cells of the host's immune system.

The cell wall (c) is composed primarily of complex organic acids and is found in virtually all species of bacteria. This structure provides a rigid framework for the organism and helps determine its shape. The molecular construction of the bacterial cell wall is unique, and the nature and significance of this structure is explored in Plate 13.

The cell or plasma membrane (d) is the outermost border of the cytoplasm and internal to the cell wall. The cell membrane (Plate 13) is constructed of protein globules suspended in lipids. It is a boundary layer and a dynamic vehicle for the transport of material into and out of the cell. It holds many of the cell's enzymes, and it is the functional equivalent of the mitochondrion in eukaryotic cells. Antimicrobial substances, such as certain detergents and antibiotics, can interfere with the function of the cell membrane, spelling death to the bacterium.

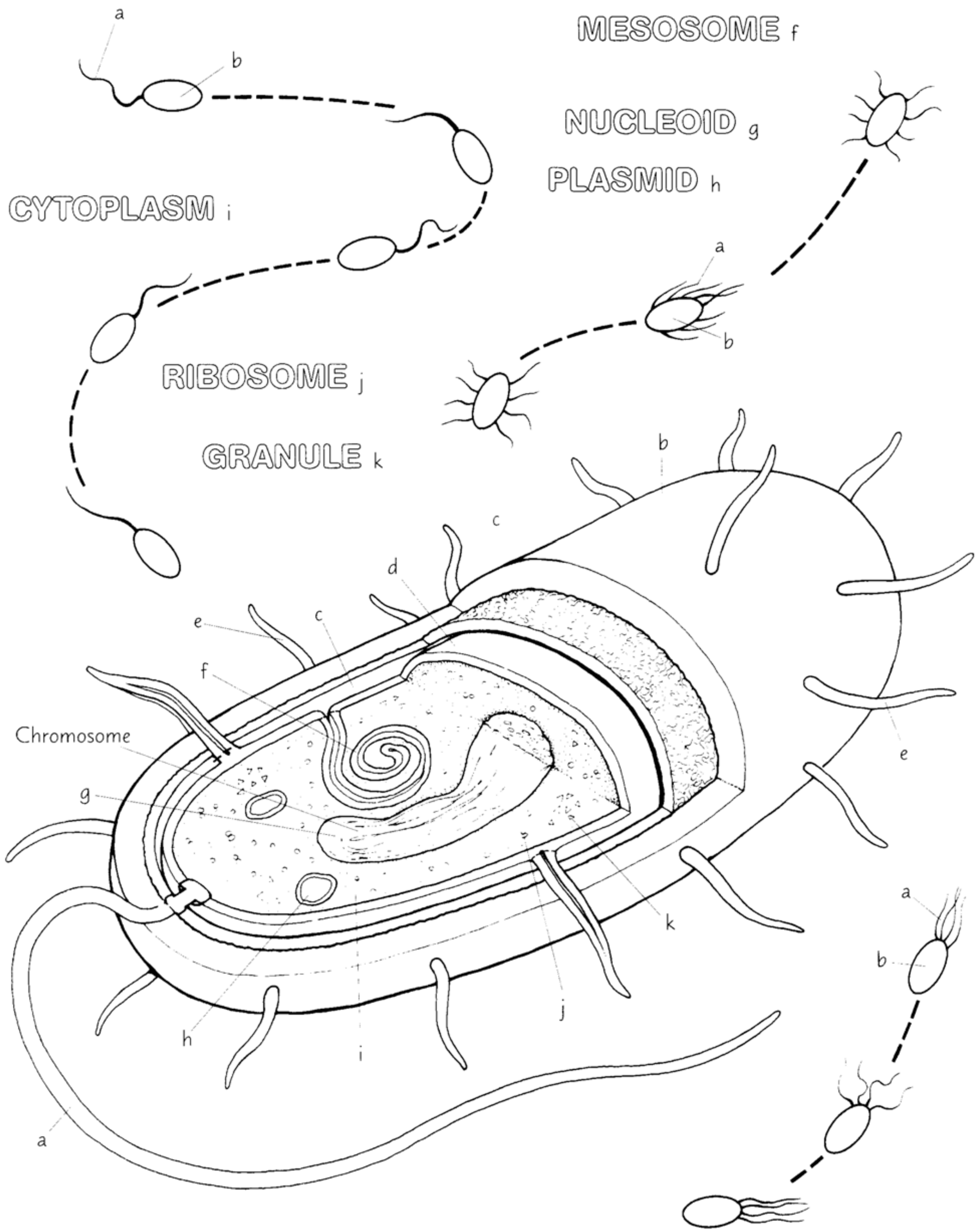
Certain bacteria, usually Gram-negative bacteria (see Plate 14), have hairlike pili (e; sing. pilus; also called fimbriae) extending from the surface of the cell. They are not to be confused with the larger flagella. Pili help anchor the bacterium to a surface. In some cases, they assist the transfer of genetic material between bacterial cells. Many bacterial species display a coiled inward extension of the cell membrane called the mesosome (f). The function of this structure may be to serve as a site for attachment of deoxyribonucleic acid (DNA) during replication in bacterial reproduction. The mesosome may also be an artifact introduced by chemicals used in fixation for electron microscopy.

As in other prokaryotes, there is no nuclear membrane around the bacterial genetic material. A bacterium exhibits a single long chromosome of DNA arranged as a closed loop folded over itself many times. The chromosome is suspended in the cytoplasm without a covering or membrane. The region of cytoplasm occupied by this chromosome is called the nucleoid (g). The chromosome contains all the hereditary information of the cell, and provides all the necessary "instructions" for producing the proteins essential to the life of the cell. Smaller molecules of DNA, called plasmids (h), form closed loops in the cytoplasm apart from chromosomes. A single bacterium may have several dozen plasmids, each with a few genes. In the plates ahead, the activity of plasmids in genetic recombination will be examined.

The bacterial cytoplasm (i) is a gelatinous mass of proteins, carbohydrates, and other organic and inorganic chemical substances. The cytoplasm is the site of bacterial growth, metabolic reactions, and reproduction. Suspended within it are such bodies as the nucleoid and plasmids, as well as the ribosomes, and inclusions called granules. The ribosomes (j) are composed of ribonucleic acid (RNA) and protein. They are the sites of protein synthesis. They are the places where amino acids, the unit molecules of protein, are bound together by enzymes in the precise sequence that gives each protein its functional character. Granules (k) appear to be protein membrane-lined storage sites for starch, glycogen, lipid, or other essential materials.

BACTERIAL ULTRASTRUCTURE

FLAGELLUM a
CAPSULE b
CELL MEMBRANE d
CELL WALL c
PILUS e
MESOSOME f
NUCLEOID g
PLASMID h
CYTOPLASM i
RIBOSOME j
GRANULE k



BACTERIAL REPRODUCTION

In living things, reproduction can occur by two methods: sexual reproduction and asexual reproduction. When sexual reproduction takes place (not shown), parent organisms produce special cells called gametes, each containing one set of chromosomes. The gametes then come together and fuse, thereby reconstituting the two sets of chromosomes in a new cell. Then the cell multiplies until the organism resembles the parent. When asexual reproduction occurs, the chromosome and cell structure replicate. The cell then splits to yield two new cells, and each new cell acquires an equal amount of chromosomal and other cell material.

Asexual reproduction in bacteria is referred to as binary fission: one cell will split (fission) to yield two (binary) cells. The process, though relatively simple, involves several key steps that must take place in the proper sequence if the process is to be successful. In this plate, we shall examine the steps by which bacteria reproduce by binary fission.

Color the title (a), the single bacterium as seen under the microscope, and the arrow labeled (a). Color the titles (b) through (f), and (a^1), and related structures, starting at the top of the plate and working down. Color the vertically oriented subheading Generation Time gray. As you color through a particular phase of the generation time, color the time period gray. Use a light pastel color for (e).

The process of binary fission begins with the parent cell (a), here taken from a culture of bacteria. The main structures to observe during binary fission are the cell wall (b), the cell membrane (c), the nucleoid that contains DNA (d), and the cytoplasm of the cell (e). Binary fission occurs after the cell has had a period of growth and metabolism.

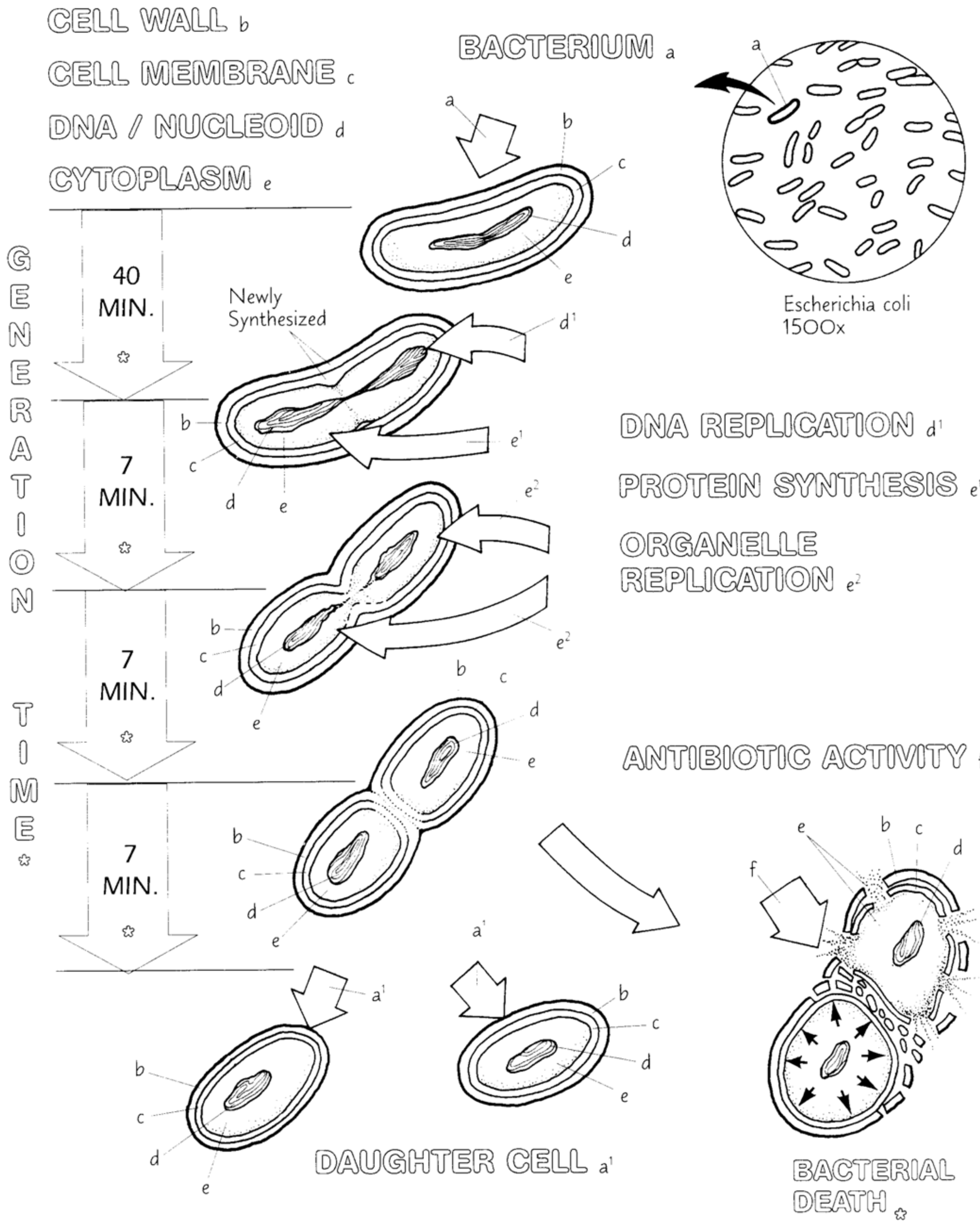
The process of binary fission begins as the bacterium elongates slightly. While this is taking place, the DNA of the cell replicates (d^1) to form twice the normal amount of DNA. A bacterial cell normally has its DNA incorporated into a single chromosome in the form of a closed loop but with the replication of DNA, it now has two chromosomes. The two chromosomes contain identical molecules of DNA.

Protein synthetic activity (e^1) increases early during binary fission to accommodate the need for added structure. Once the cell has elongated and the DNA replicated, the process continues with organelle replication (e^2) and cytoplasmic separation into opposite halves of the dividing cell. The separated chromosomes move to either side of the cell. Note that at this point in the process, the cell membrane begins to pinch inward from opposite sides of the cell. In the period of a few minutes, the cell membrane continues to pinch the parent cell into two equal halves, each with an identical chromosome.

It is at about this point in binary fission that penicillin activity (f) can inhibit bacterial reproduction. Penicillin interferes with cell wall synthesis. A defective cell wall is incapable of structurally reinforcing the cell membrane during periods of increased internal pressures associated with metabolic activity. As a result, the cell becomes swollen and eventually bursts and dies.

The process of binary fission concludes with the separation of the two halves of the cell, forming daughter cells (a^1). The daughter cells have identical DNA and each is chemically identical. With further metabolic activity, these new cells will become mature bacteria, each capable of binary fission. The period of growth and maturation of the bacterial cell will continue for several minutes. Binary fission will take place once again. The interval between the onset of one division and the beginning of the next is the generation time. Generation time is the time it takes the bacterial population to double. The generation time is unique for each bacterial species. For example, in the bacterium shown here, the generation time is a brief 61 minutes: 40 minutes for chromosome doubling followed by a 21 minute period of cell division.

BACTERIAL REPRODUCTION



BACTERIAL SPORES

Most bacteria cannot survive extremes in environmental temperature, pressure, and chemistry. For instance, they cannot endure lengthy dehydration or nutritional deprivation. Certain Gram-positive bacteria, however, can do so. Members of the genera *Bacillus* and *Clostridium* have the ability to develop a highly resistant body that can survive such extremes. This body is called an endospore, or simply, spore. The spore is released from the parent bacterial cell on its death.

An endospore is remarkably resistant to severe changes in the immediate environment. For example, most bacteria die quickly when water reaches a temperature of 80° C, but spores can remain alive for up to two hours in water that is boiling (100° C). Bacterial spores have also been recovered alive from the intestines of Egyptian mummies! Bacterial spores carry their own food supply, enzymes, and DNA. When the environment becomes favorable, the spore can convert to a vegetative, reproducing cell. Until that occurs, the spore is dormant, i.e., it has no metabolic activity.

The right side of the plate is to be colored first. Color the subheading, Spore Structure, and the related titles and structures (a, a^1). Then color the titles (b) through (g) and the related structures in the electron microscopic view of the spore at lower right. Light colors for (b), (d), and (g) are recommended. Try to use contrasting colors for (b) through (g).

Spores are round to oval bodies existing free (a) in the environment or within the swollen bacterial cells that produced them (a^1). Note that only one spore forms per bacterial cell. Once their formation is complete, these spores will be freed to the environment as the parent cell disintegrates.

Seen under the transmission electron microscope, spore structure can be appreciated in detail. The core of the spore (b) consists of DNA and dehydrated cytoplasm taken from the parent cell. The core is surrounded by a core membrane or wall (c) taken from the ingrown bacterial cell membrane (spore septum). Outside of and adjacent to the core wall is the cortex (d). This cortex, the thickest of the spore layers, is composed of an unusual loose arrangement of peptidoglycan. Surrounding the cortex, inner (e) and outer (f) membranes of protein make up the spore coat. This layer confers chemical resistance to the endospore. The outermost layer is the exosporium basal layer (g) composed of glyco- and lipoproteins.

Now color the subheading Sporulation at the upper left side of the plate. Color the titles and structures (b^1) and (b^2) in the bacteria at stations 1 and 2, and then color the developing spore structures (b) through (g) in stations 3 through 6. The electron microscopic view is a magnified view of the spore seen in station 6.

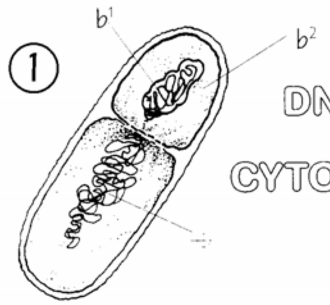
The progressive development of the spore within the parent cell is called sporulation. The process begins when the bacterial DNA replicates and half of the DNA (b^1) gathers at one end with a small amount of cytoplasm (b^2; station 1). The cell membrane turns inward (spore septum) to form a double membrane enclosing the DNA and cytoplasm (station 2). This double membrane becomes the core wall (c; station 3). Cortex material (d) develops within the core wall and thickens externally (station 3). As the spore forms, the parent cell swells at the spore end (station 4). The protein inner (e) and outer membranes (f) or spore coat appear (station 5), followed by the appearance of the exosporium basal layer (g; station 6). Spore formation is now complete. The cell membrane ruptures (station 6), and the spore is freed.

When the external environment is favorable, spores revert back to vegetative bacilli in a process called germination. In this process (not shown), the spore layers break down and the vegetative bacillus emerges. The bacillus soon undergoes binary fission. The daughter cells begin a new cycle of sporulation (sporulation cycle) when confronted with an unfavorable environment.

At least four serious diseases (anthrax, tetanus, botulism and gas gangrene) are known to be caused by spore formers. These diseases will be discussed in future plates.

BACTERIAL SPORES

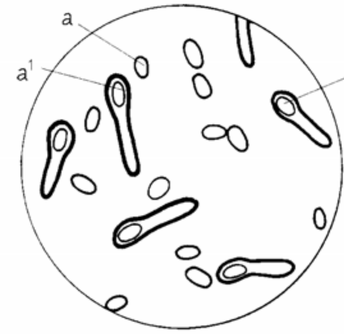
SPORULATION ✿



DNA b^1

CYTOPLASM b^2

SPORE STRUCTURE ✿



Light microscopic view

FREE SPORE a

BACTERIAL CELL a^1

SPORE CORE b

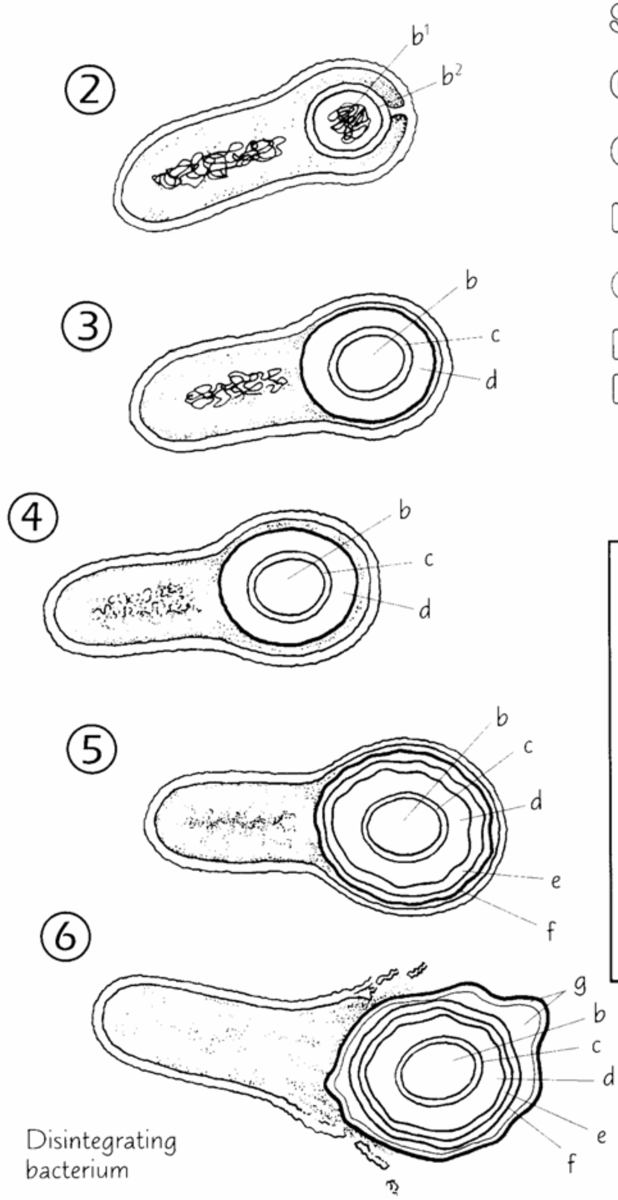
CORE MEMBRANE / WALL c

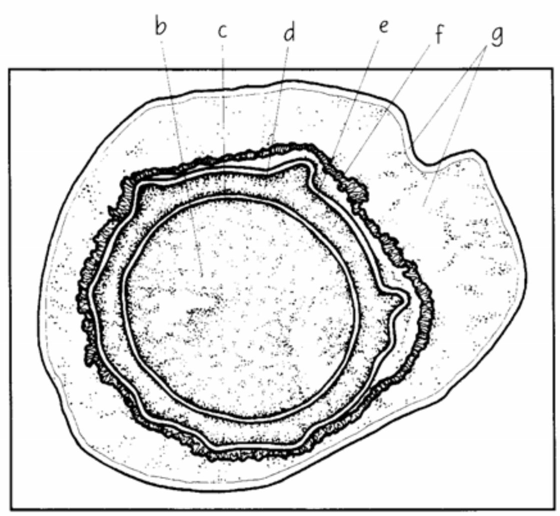
CORTEX d

INNER MEMBRANE e

OUTER MEMBRANE f

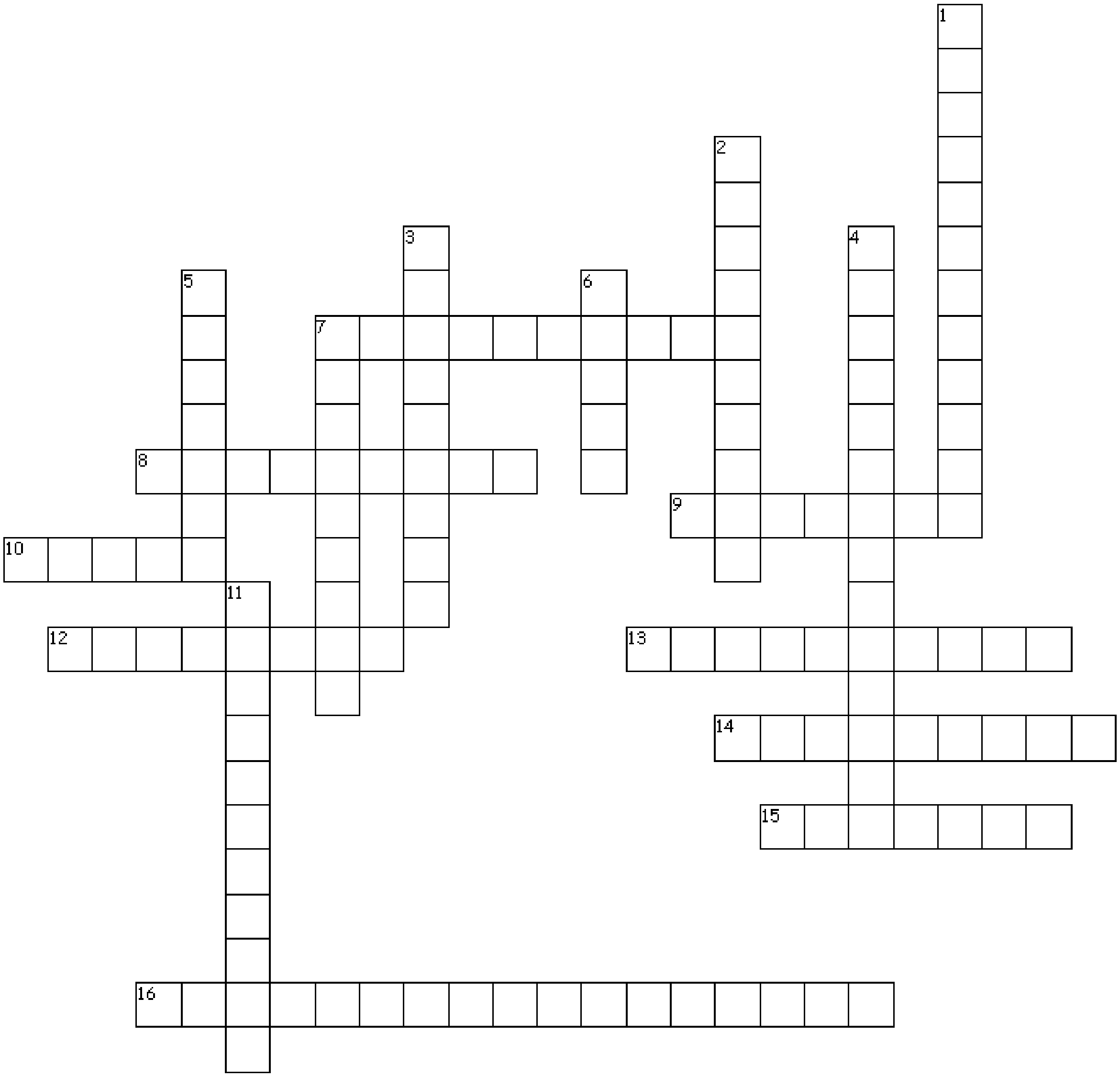
EXOSPORIUM BASAL LAYER g





Electron microscopic view

BACTERIA CROSSWORD



Across

7. Organisms which make their own chemical energy.
8. Long whip-like tail, used for locomotion.
9. Organisms which need oxygen to survive
10. Attachment points for bacteria
12. Small organelles involved in making proteins.
13. Name for true, modern bacteria.
14. Name for "squiggly" shaped bacteria.
15. Small circular segment of DNA. Often exchanged between bacteria.
16. Photosynthetic bacteria containing chlorophyll a & b.

Down

1. Organisms which obtain energy by consuming organic material.
2. Structures which bacteria form to endure adverse situations.
3. Name for all contents of a cell, except for nucleus.
4. Ancient bacteria often found in harsh environments
5. Name for rod-shaped bacteria.
6. Name for round shaped bacteria.
7. Organisms which do not require oxygen to survive.
11. The act of two bacteria joining and exchanging DNA.