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MICROBIOLOGY

WITH DISEASES BY TAXONOMY, THIRD EDITION

Chapter 11

Characterizing and Classifying Prokaryotes

原核生物的特性與分類

- Understand the general characteristics of prokaryotes.
- Understand prokaryotic classification
 - Archaea
 - Bacteria

General Characteristics of Prokaryotic Organisms

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- Prokaryotes

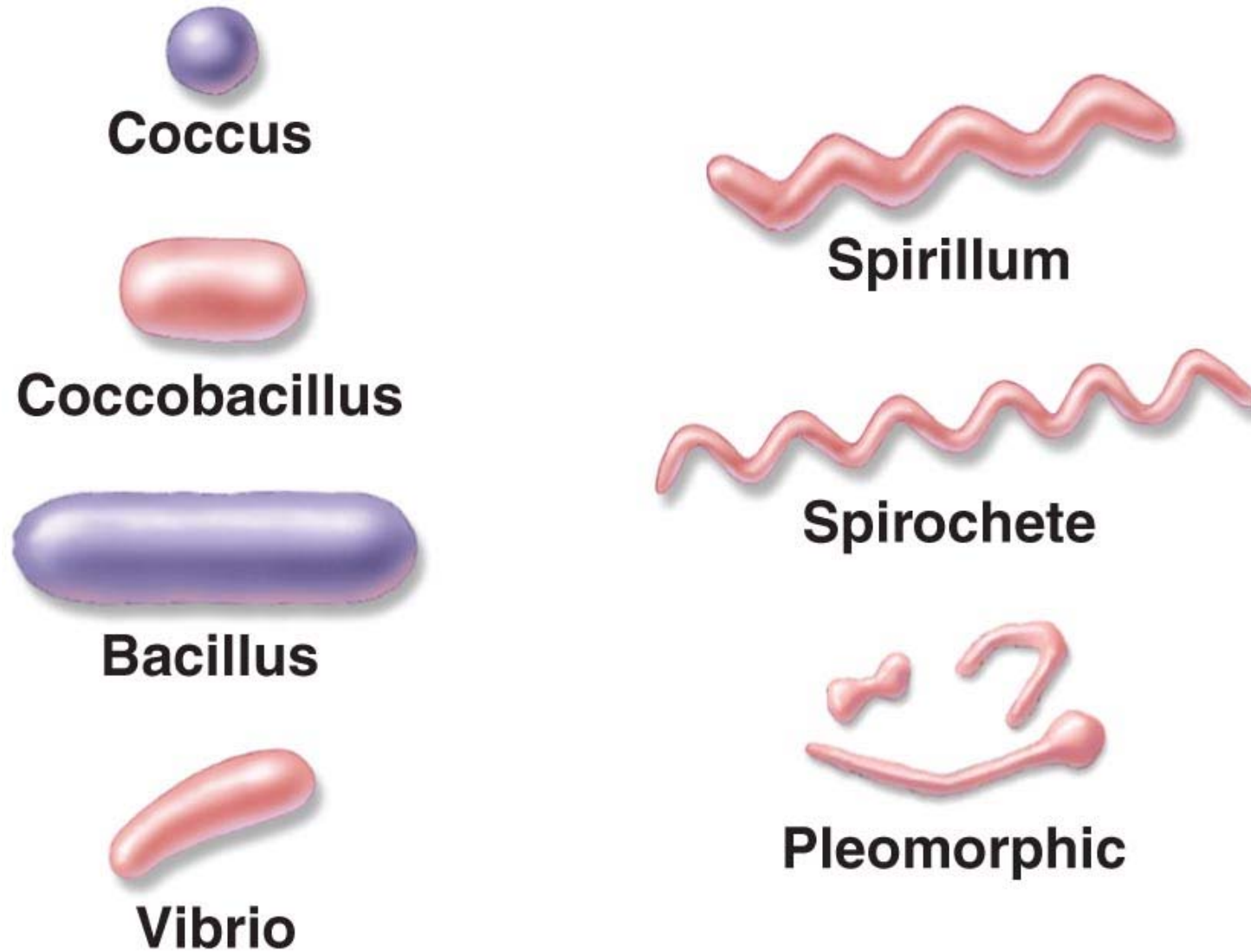
- Most diverse group of cellular microbes
- Habitats
 - From Antarctic glaciers to thermal hot springs
 - From colons of animals to cytoplasm of other prokaryotes
 - From distilled water to supersaturated brine
 - From disinfectant solutions to basalt rocks
- Only a few capable of colonizing humans and causing disease



basalt rocks 玄武岩

Typical prokaryotic morphologies

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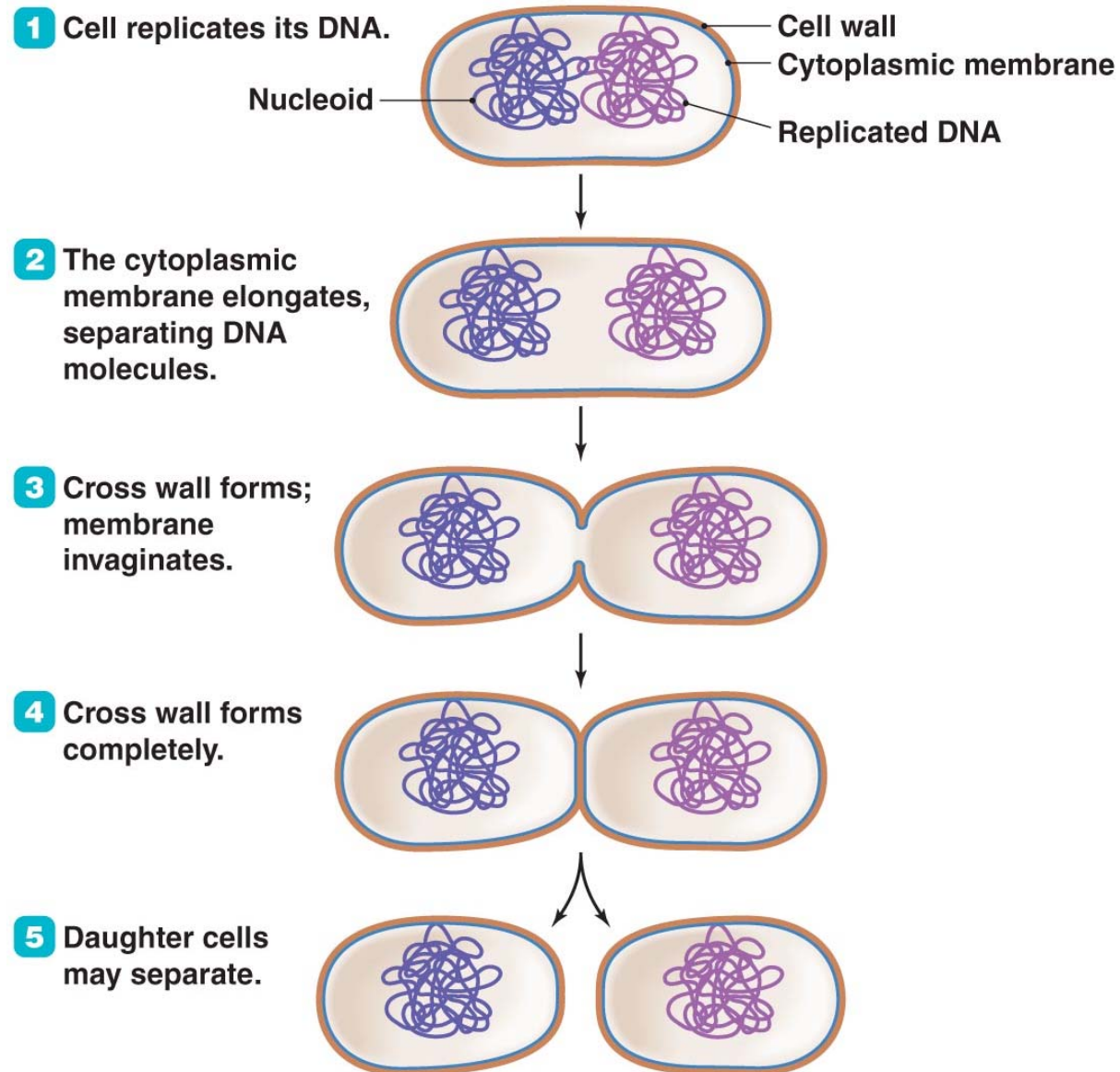
General Characteristics of Prokaryotic Organisms

5

- Reproduction of Prokaryotic Cells
 - All reproduce asexually
 - Three main methods
 - Binary fission (most common)
 - Snapping division
 - Budding

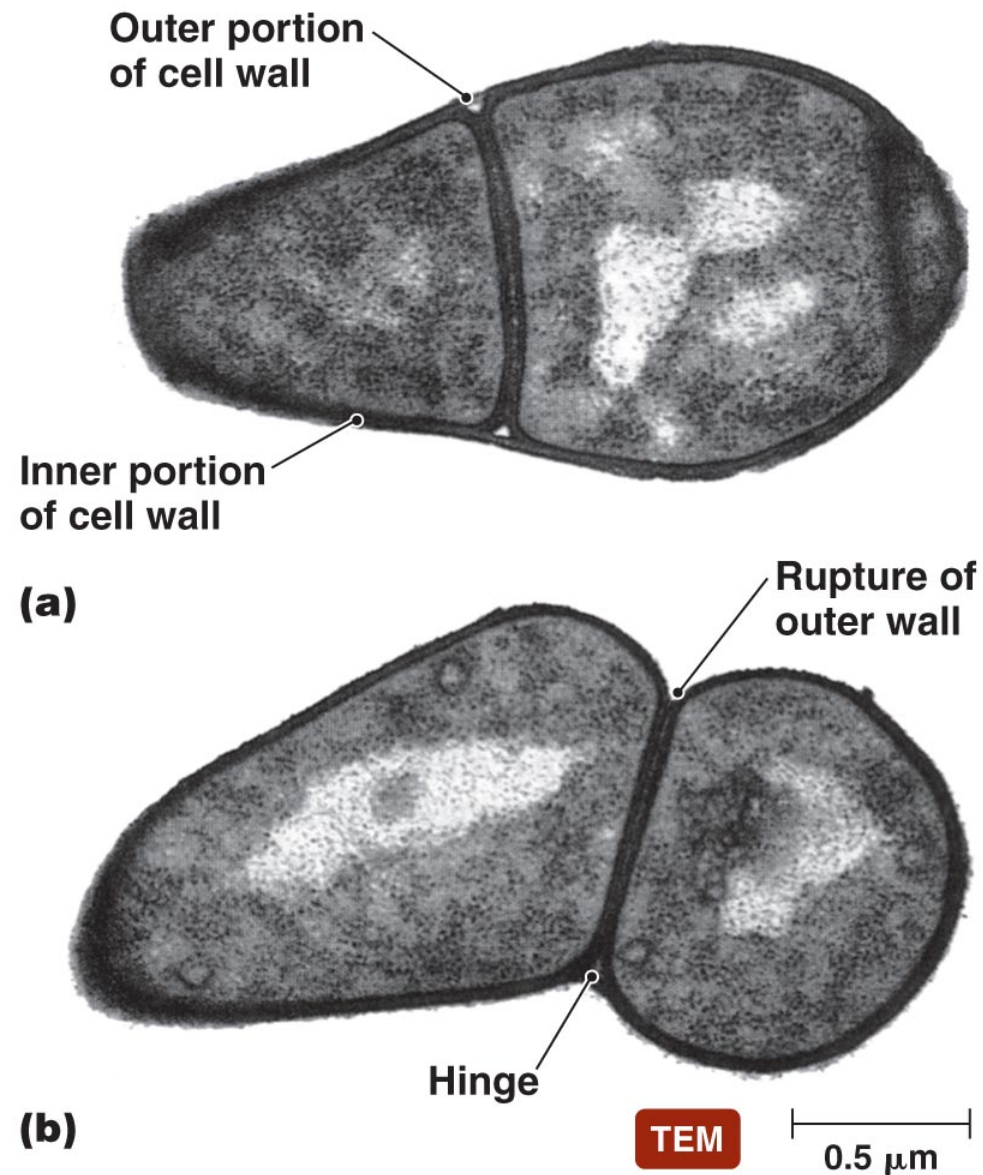
Binary fission

6



Snapping division, a variation of binary fission

7



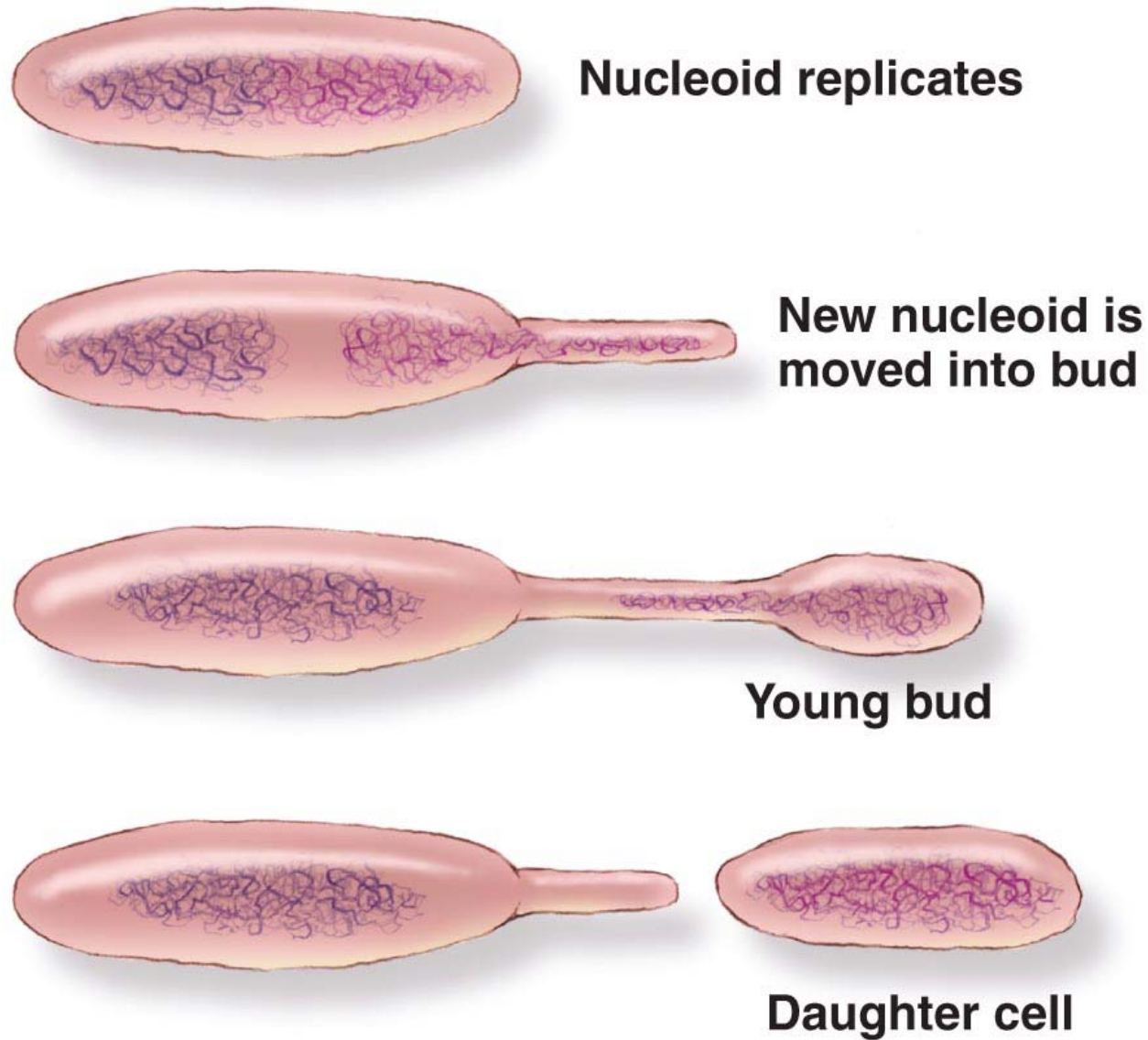
Spores of actinomycetes

8



Budding

9

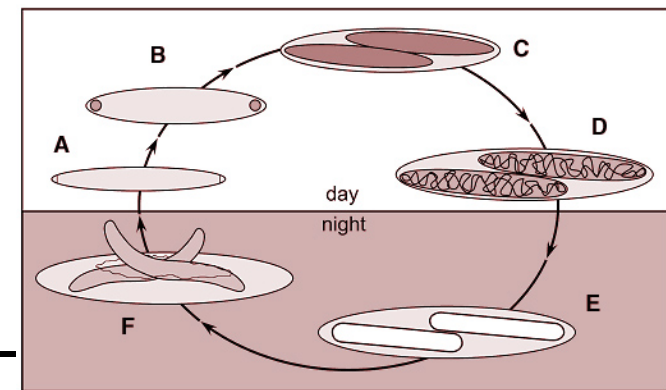
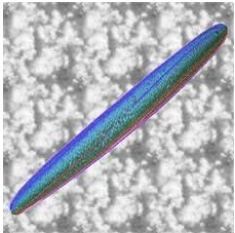


General Characteristics of Prokaryotic Organisms

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- Reproduction of Prokaryotic Cells

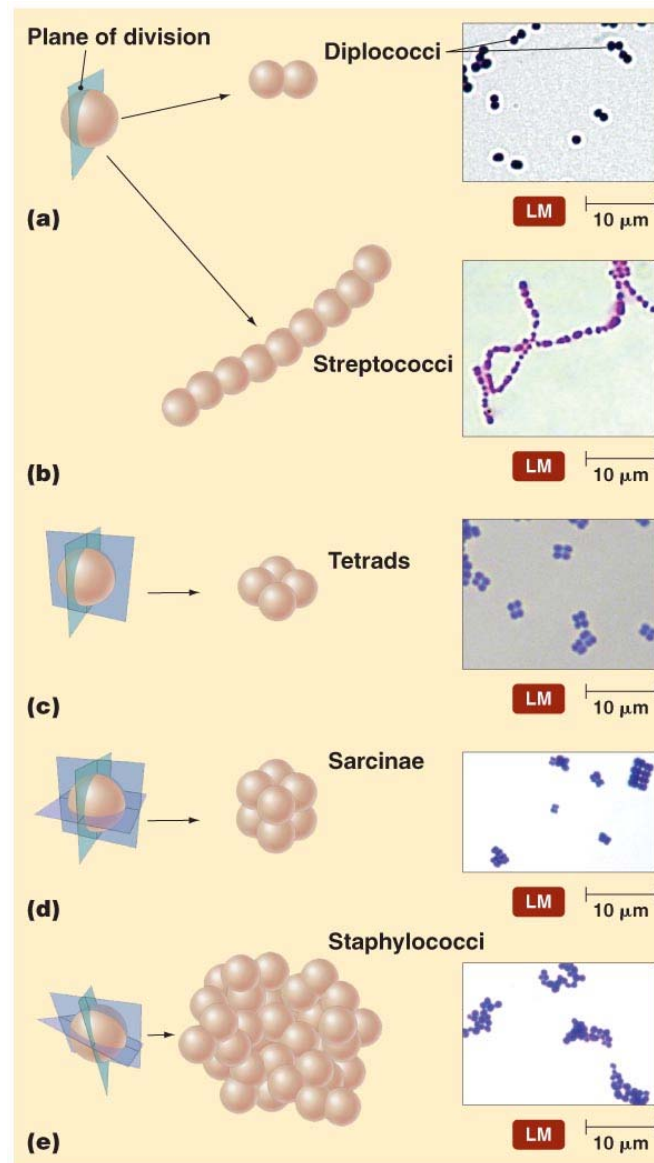
- *Epulopiscium fishelsoni* (費式刺骨魚菌) and its relatives have unique method of reproduction
 - Among one of the largest prokaryotic bacteria identified so far → visible with unaided eyes!!
 - Live offspring emerge from the body of the dead mother cell (viviparity 胎生)
 - First noted case of viviparous behavior in prokaryotic world



- Arrangement of Prokaryotic Cells
 - Result from two aspects of division during binary fission
 - Planes in which cells divide
 - Separation of daughter cells

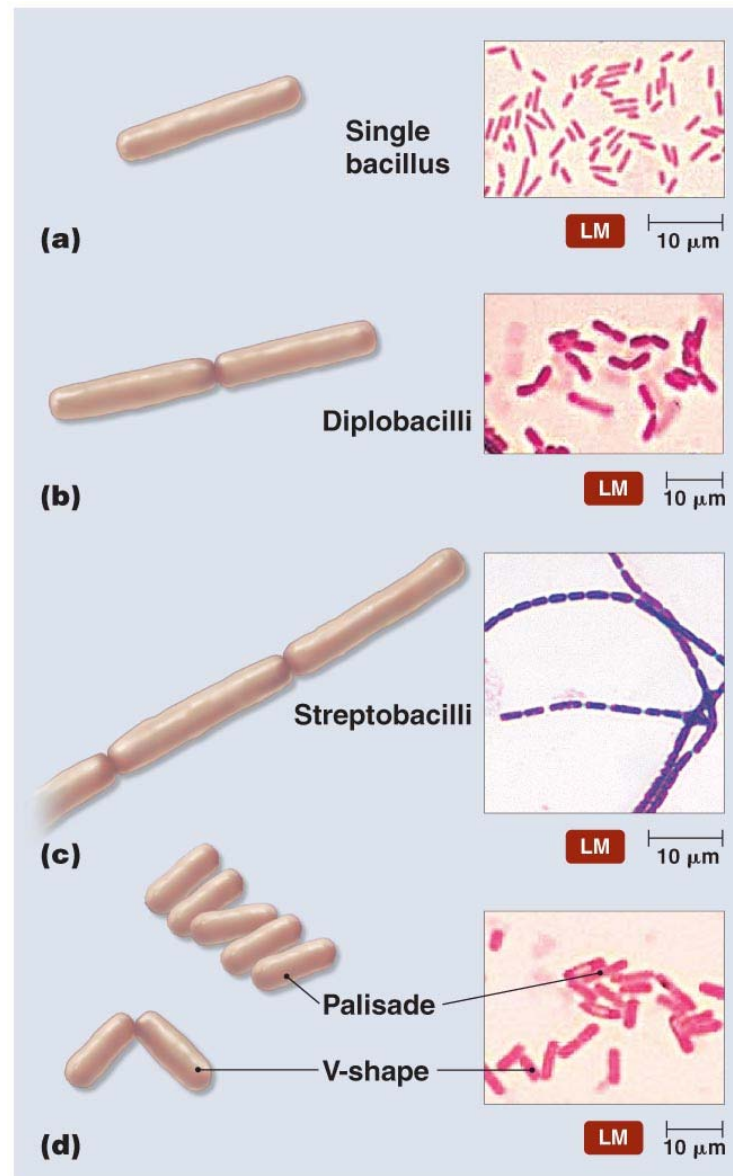
Arrangements of cocci

12



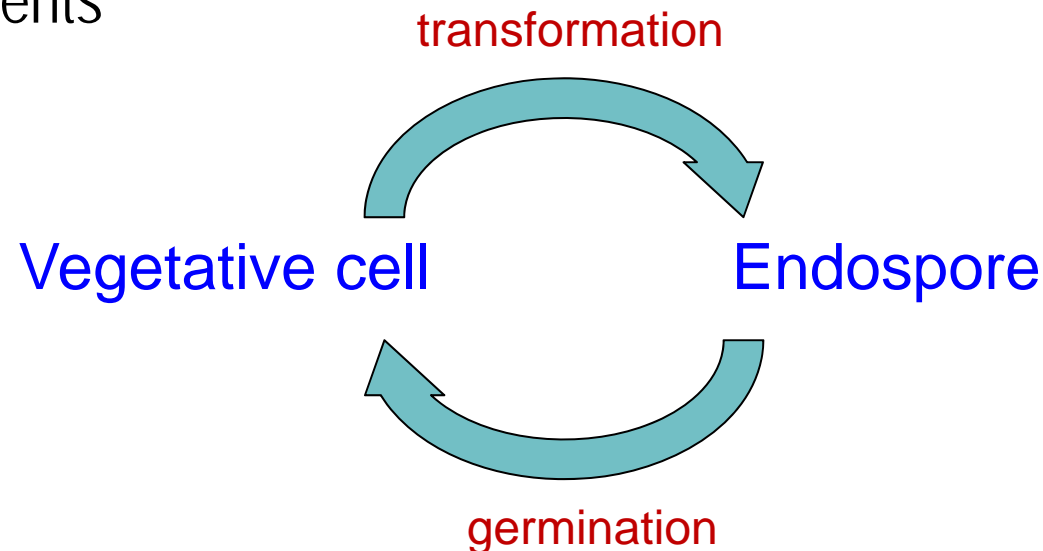
Arrangements of bacilli

13



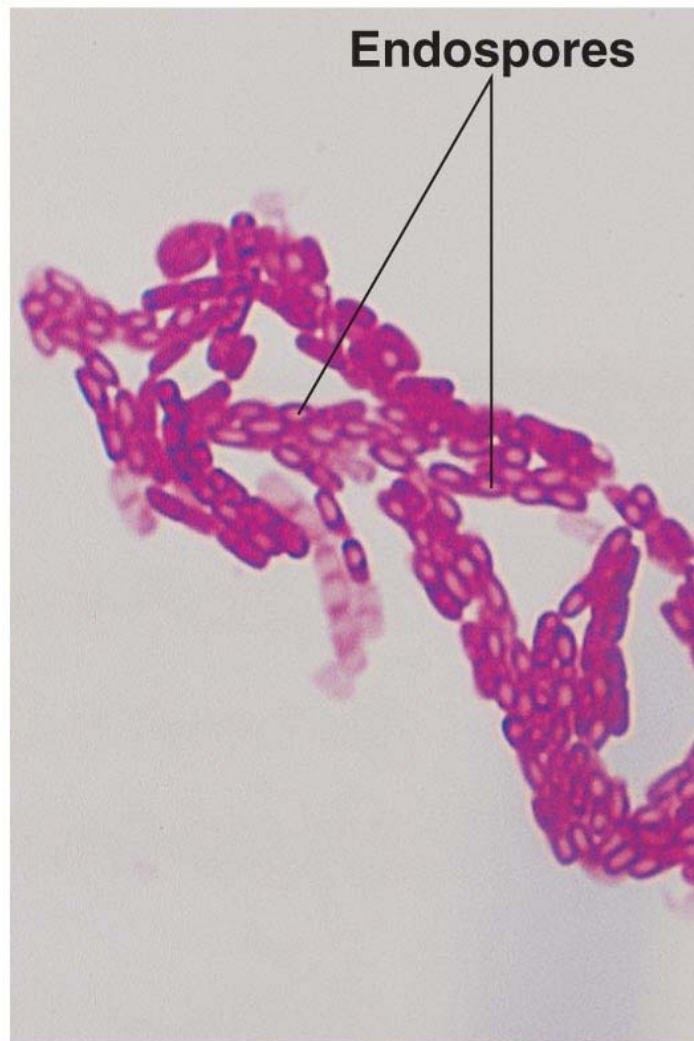
- Endospores

- Produced by *Gram (+) Bacillus* and *Clostridium*
- Each *vegetative cell* transforms into one endospore
- Each *endospore* germinates to form one vegetative cell
- Defensive strategy against unfavorable conditions
- Concern to food processors, health care professionals, and governments



Locations of endospores

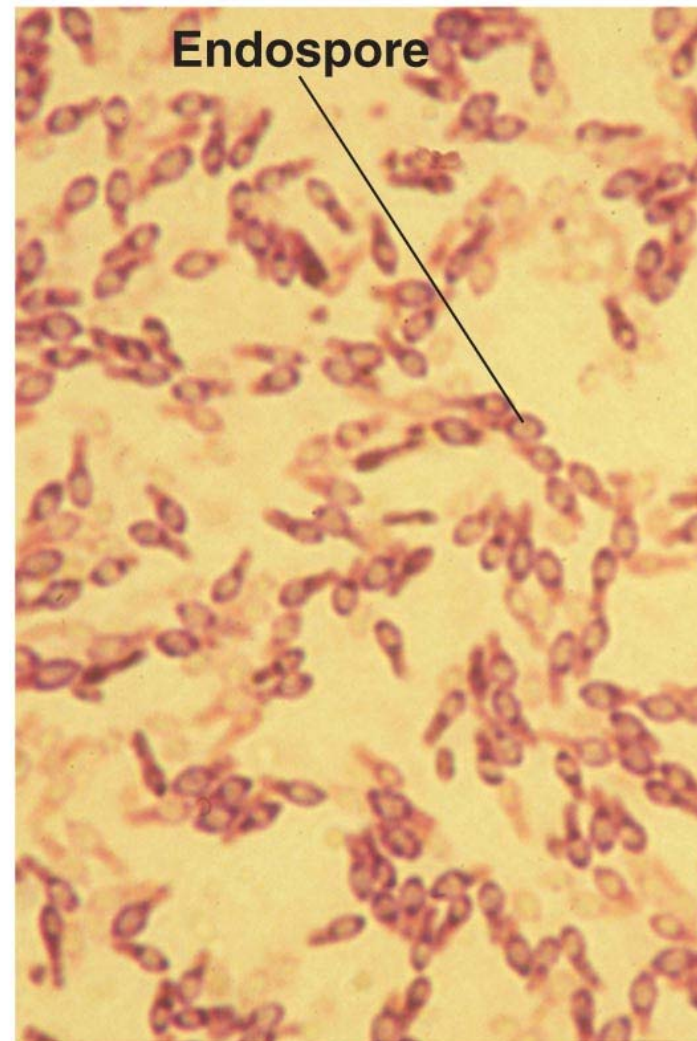
15



(a)

LM

10 μm



(b)

LM

10 μm

Modern Prokaryotic Classification

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- Currently based on genetic relatedness of rRNA sequences
- Three domains
 - Archaea
 - Bacteria
 - Eukarya

Biological classification

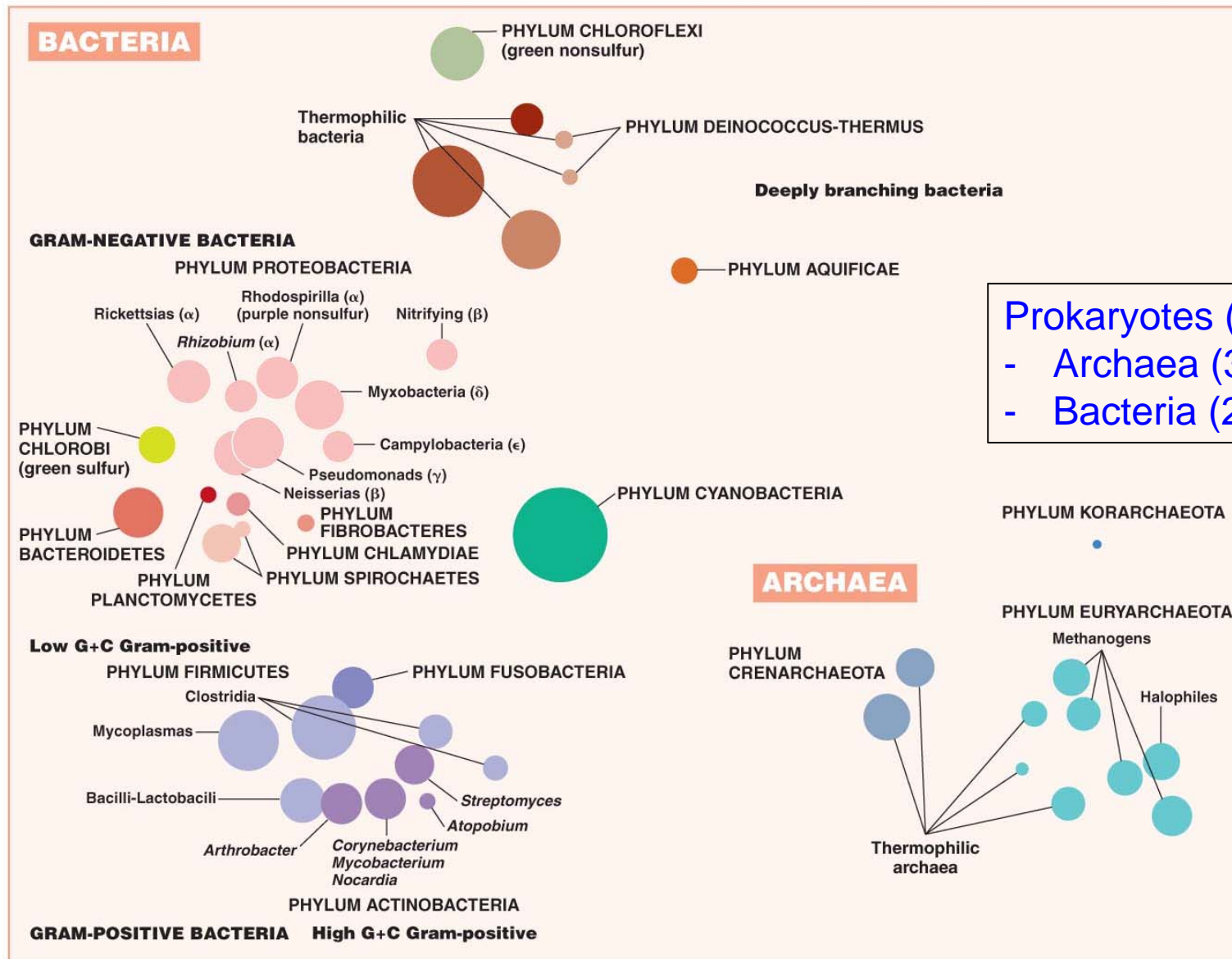
Kingdom – Phylum – Class – Order – Family – Genus - Species

界 門 綱 目 科 屬 種

Keep Pond Clean, Or Froggy Gets Sick.

Prokaryotic Taxonomy (Bergey's Manual of Systematic Bacteriology)

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Survey of Archaea

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- Common features
 - Lack true peptidoglycan
 - Cell membrane lipids have branched hydrocarbon chains
 - AUG codon codes for methionine
- Three phyla: Crenarchaeota, Euryarchaeota, Korarchaeota
- Reproduce by binary fission, budding, or fragmentation
- Most are cocci, bacilli, or spiral forms; pleomorphic forms exist
- Not known to cause disease

Crenarchaeota	泉古菌
Euryarchaeota	廣古菌
Korarchaeota	初古菌

- **Extremophiles**
 - Require extreme conditions to survive
 - Temperature, pH, and/or salinity
 - Prominent members are thermophiles and halophiles

- Extremophiles

- Thermophiles 嗜熱菌

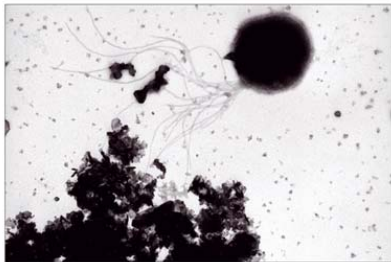
- DNA, RNA, cytoplasmic membranes, and proteins do not function properly below 45°C

- Hyperthermophiles – require temperatures over 80°C

- Two representative genera

- *Geogemma* (a)

- *Pyrodictium* (b)



(a)



(b)



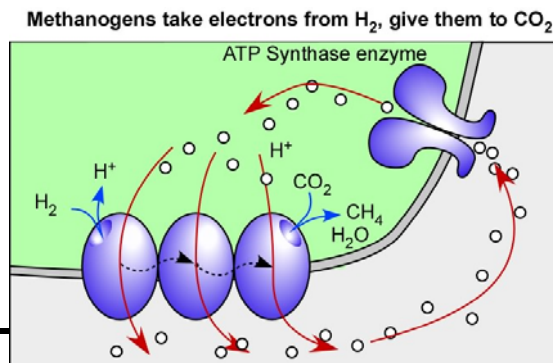
- Extremophiles

- Halophiles 嗜鹽菌

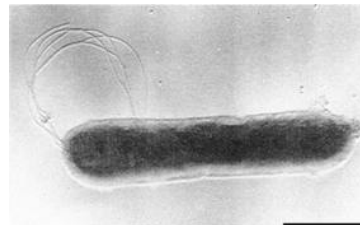
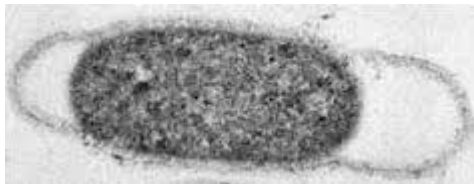
- Inhabit extremely saline habitats
 - Depend on greater than 9% NaCl to maintain integrity of cell walls
 - Many contain red or orange pigments
 - May protect from visible and UV light
 - Most studied – *Halobacterium salinarium* 嗜鹽菌



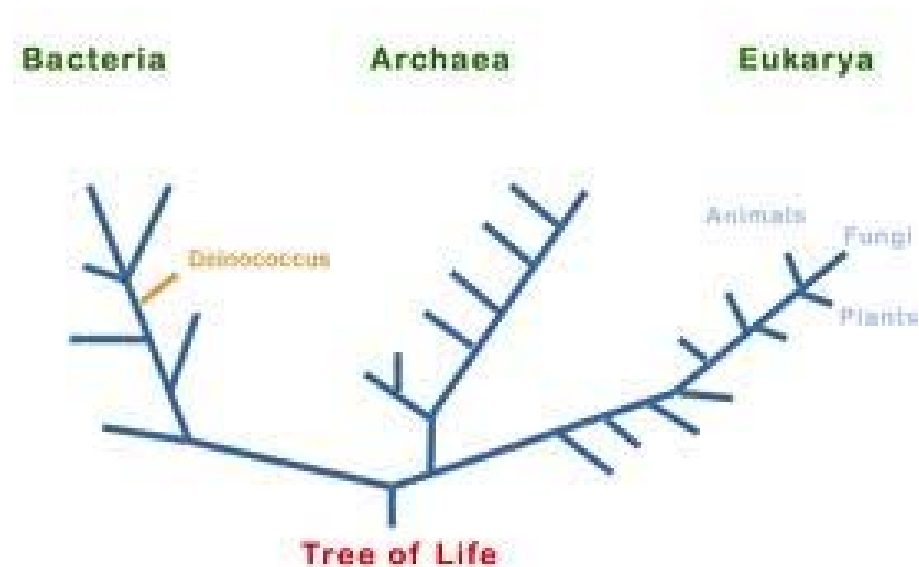
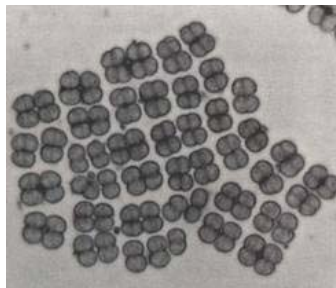
- **Methanogens 產甲烷菌**
 - Largest group of archaea
 - Convert carbon dioxide, hydrogen gas, and organic acids to **methane gas (CH₄)**
 - Convert organic wastes in pond, lake, and ocean sediments to **methane**
 - Some live in colons of animals
 - One of primary sources of environmental methane
 - Have produced ~10 trillion tons of methane that is buried in mud on ocean floor!!



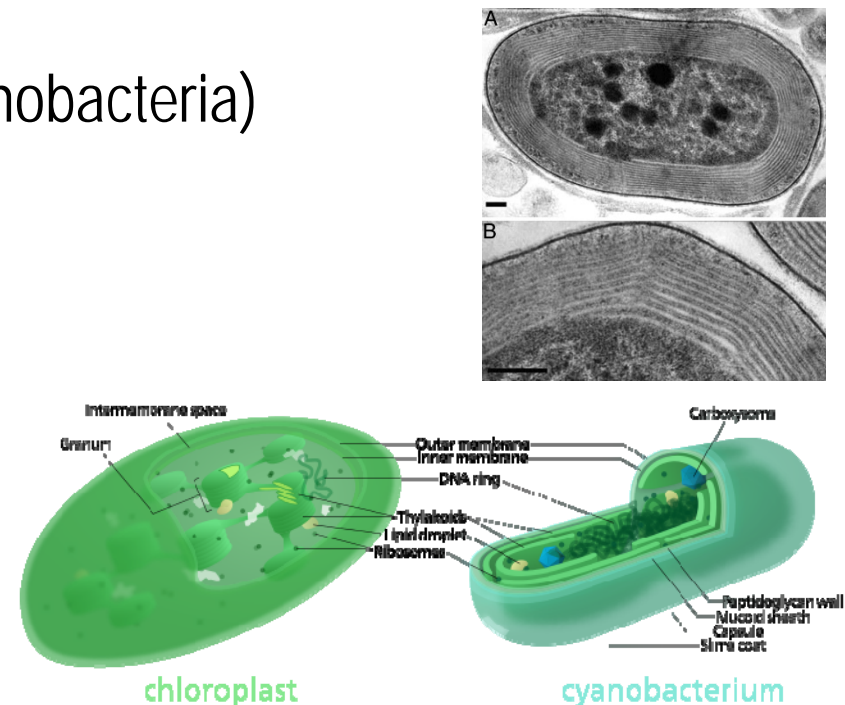
- Deeply Branching and Phototrophic Bacteria
 - Deeply branching bacteria
 - Scientists believe these organisms are similar to earliest bacteria
 - Autotrophic
 - Live in habitats similar to those thought to exist on early Earth
 - *Aquifex* 產水菌
 - Considered to represent earliest branch of bacteria
 - Chemoautotrophic, hyperthermophilic, anaerobic
 - Derives energy and carbon from inorganic matters in underwater hot habitats



- Deeply Branching and Phototrophic Bacteria
 - Deeply branching bacteria
 - *Deinococcus* 菩提奇異球菌/抗輻射球菌
 - Has outer membrane similar to Gram (-), but stains Gram (+)
 - Highly resistant to radiation



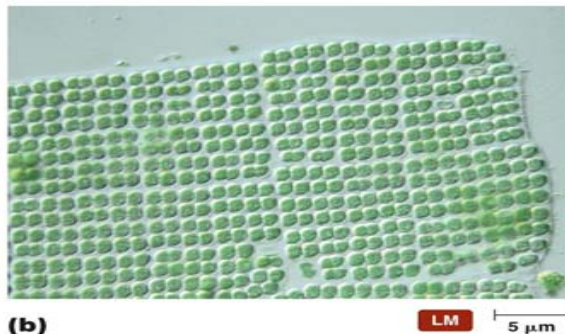
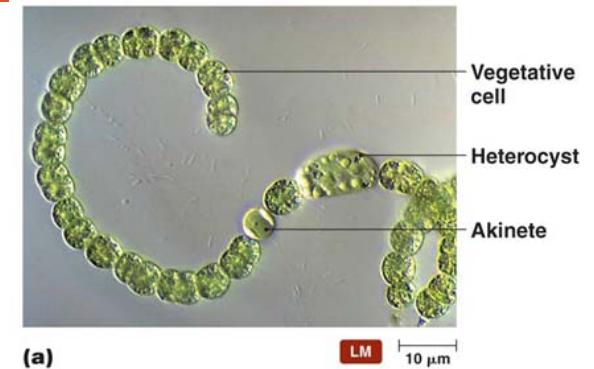
- Deeply Branching and Phototrophic Bacteria
 - **Phototrophic bacteria**
 - Phototrophs that contain **photosynthetic lamellae**
 - **Autotrophic**
 - Divided into **five** groups based on **pigments** and **source of electrons** for photosynthesis
 - Blue-green bacteria (cyanobacteria)
 - Green sulfur bacteria
 - Green nonsulfur bacteria
 - Purple sulfur bacteria
 - Purple nonsulfur bacteria



Cyanobacteria (Blue-green bacteria)

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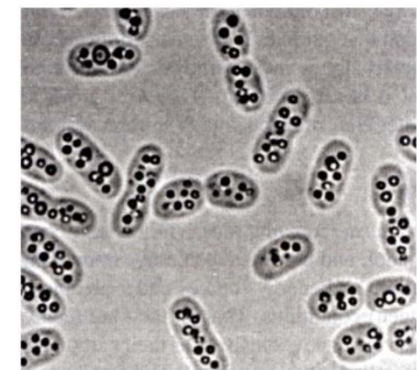
- G(-), varied in shapes (coccoid or disc-shaped)
- **Filaments** are often contained within a gelatinous glycocalyx called *sheath*
- Filaments move by **gliding**.
- Reproduce by **binary fission** or formation of **akinetes** 遊走孢子
- Are **oxygenic** during photosynthesis
- Play a crucial role in transforming anaerobic atmosphere into aerobic one during Earth evolution.
- Some species can also **fix N_2 from the atmosphere** ($N_2 \rightarrow NH_3$)
 - Segregated N_2 -fixation enzymes in **heterocysts** 異型孢



Cyanobacteria (Green and Purple Photosynthetic Bacteria)

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- Differences from other photosynthetic plants, algae and cyanobacteria
 - Use **bacteriochlorophylls** (but *not* chlorophyll a)
 - **Anoxygenic** (not O₂-producing)
- Common habitats include **anaerobic** muds rich in H₂S
- Both produce sulfur, but vary in sulfur deposition
 - **Green-sulfur** bacteria: **outside** of the cell
 - **Purple-sulfur** bacteria: **inside** of the cell (Fig. 11-4)
- Not capable of N₂ fixation

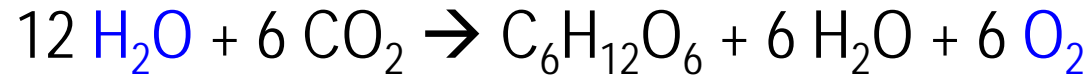


LM 4.0 μm

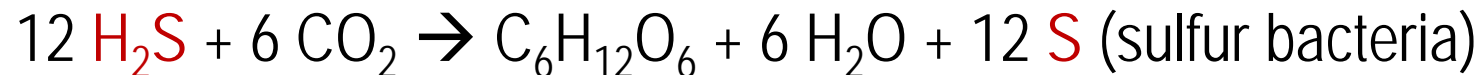
Comparison between photosynthetic reactions

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- Cyanobacteria (oxygenic)



-
- Green and purple phototrophic bacteria (anoxygenic)



electron source:

- non-sulfur bacteria: carbohydrates, organic acids
- sulfur bacteria: oxidation of H_2S to S

Phototrophic bacteria

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11.1

Characteristics of the Major Groups of Phototrophic Bacteria

TABLE

	Phylum				
	Cyanobacteria	Chlorobi	Chloroflexi	Proteobacteria	Proteobacteria
Class	Cyanobacteria	Chlorobia	Chloroflexi	Gammaproteobacteria	Alphaproteobacteria and one genus in betaproteobacteria
Common name(s)	Blue-green bacteria ("blue-green algae")	Green sulfur bacteria	Green nonsulfur bacteria	Purple sulfur bacteria	Purple nonsulfur bacteria
Major photosynthetic pigments	Chlorophyll <i>a</i>	Bacteriochlorophyll <i>a</i> plus <i>c</i> , <i>d</i> , or <i>e</i>	Bacteriochlorophylls <i>a</i> and <i>c</i>	Bacteriochlorophyll <i>a</i> or <i>b</i>	Bacteriochlorophyll <i>a</i> or <i>b</i>
Types of photosynthesis	Oxygenic	Anoxygenic	Anoxygenic	Anoxygenic	Anoxygenic
Electron donor in photosynthesis	H ₂ O	H ₂ , H ₂ S, or S	Organic compounds	H ₂ , H ₂ S, or S	Organic compounds
Sulfur deposition	None	Outside of cell	None	Inside of cell	None
Nitrogen fixation	Some species	None	None	None	None
Motility	Nonmotile or gliding	Nonmotile	Gliding	Motile with polar or peritrichous flagella	Nonmotile or motile with polar flagella

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- Low G+C Gram-Positive Bacteria

Botulism (by *C. botulinum*) and Botox

- *Clostridia*

- G(+), rod-shaped, obligate anaerobes
- Many species form endospores
- Important in medicine and industry (Ch 19)
- Microbes related to *Clostridium* include sulfate-reducing microbes and *Veillonella* 韋榮氏球菌



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【肉毒桿菌】致命毒素可以除皺？

肉毒桿菌素是由厭氧的梭狀桿菌(*Clostridia*)所分泌，是一種神經外毒素。不少食物中毒案件就是因誤食腐敗食物產生的毒素而中毒，會產生視力模糊、吞嚥不能、全身麻痺以及呼吸困難而死亡

二次世界大戰期間，美國原來想發展生化武器，便積極研究肉毒桿菌素，發現此毒素可分成七型，其中A型對人類最具毒性作用。在1977年，美國眼科醫師Alan B. Scott，首次用A型毒素來治療斜眼(Strabismus)病人，此後也逐漸運用在眼瞼痙攣、半面痙攣、斜視、小兒腦性麻痺、斜頸症，手汗症及除皺的治療。在醫學上的botox注射劑量十分微小，遠小於中毒致死的劑量，所以對人體不會造成任何危害。1989年，肉毒桿菌毒素Botulinum toxin A通過FDA核准，正式成為臨床治療藥物，由美國愛力根公司(Allergan Inc.)經營。



- Low G+C Gram-Positive Bacteria
 - *Mycoplasmas* 黴漿菌
 - Facultative or obligate anaerobes
 - Lack cell walls, cell membranes contain **sterols**
 - **Pleomorphic**, filamentous forms resemble filaments of fungi
 - **The smallest free-living cells** (0.2-0.8 μm)

Distinctive “fried egg” appearance of *Mycoplasma* colonies



LM 0.1 mm

- Low G+C Gram-Positive Bacteria
 - Low G+C bacilli and cocci
 - *Bacillus* – many common in soil
 - *Listeria* – contaminates milk and meat products
 - *Lactobacillus* – grows in the body but rarely causes disease
 - *Streptococcus* and *Enterococcus* – cause numerous diseases
 - *Staphylococcus* – one of the most common inhabitants of humans

- Low G+C Gram-Positive Bacteria

- *Bacillus* 桿狀菌

- Include endospore-forming aerobes and facultative anaerobes

- Commonly found in soil

- *B. thuringiensis*

- Produces *Bt toxin* during sporulation, toxic to caterpillars

- Antibiotics producers

- *B. polymyxa* (polymyxin) 多黏菌素

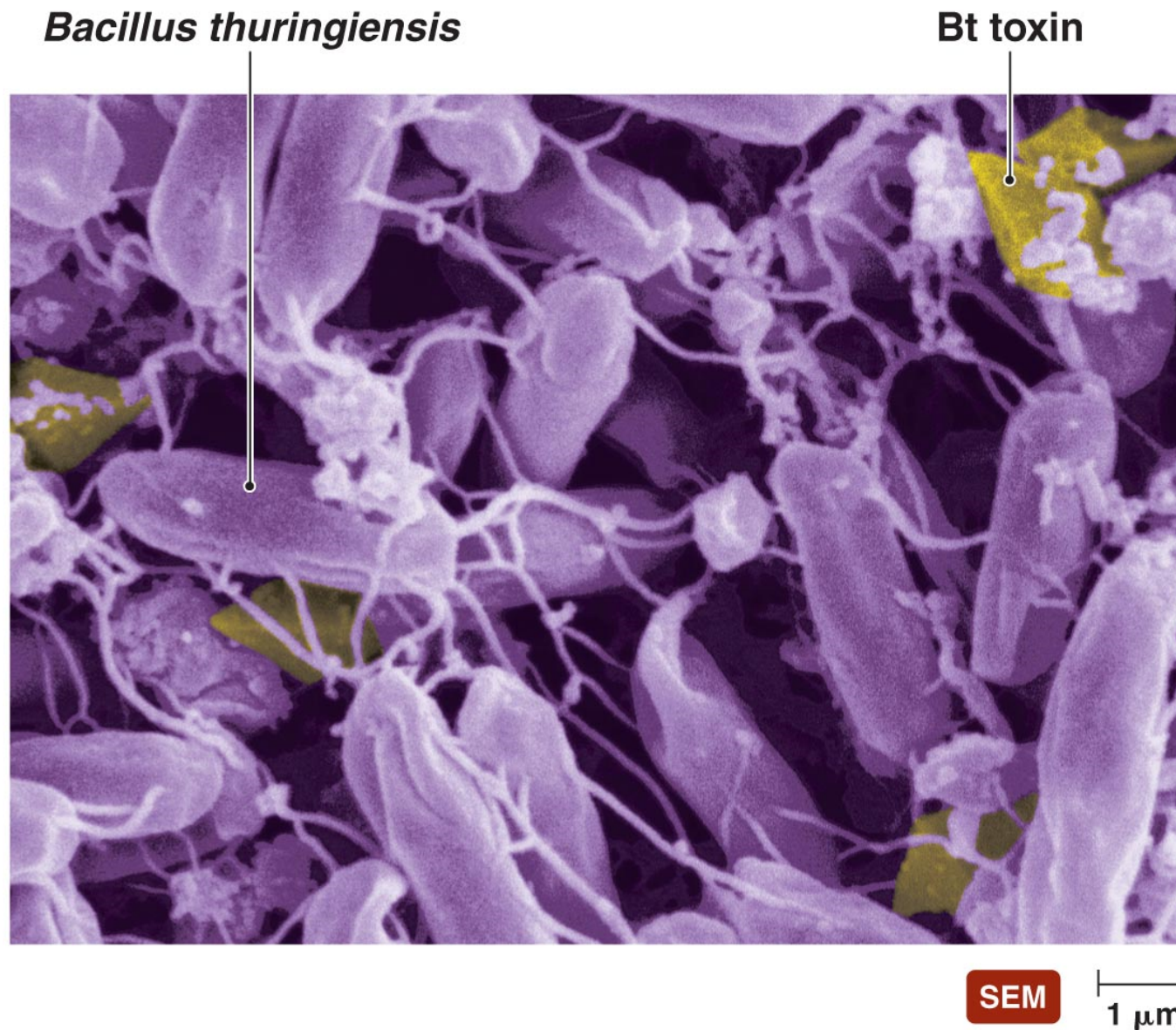
- *B. licheniformis* (bacitracin) 桿菌肽素

- *B. anthracis*

- Causative agent for anthrax

Crystals of Bt toxin, produced by *Bacillus thuringiensis*

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Survey of Bacteria

- Low G+C Gram-Positive Bacteria

- *Listeria* 李斯特菌

- Non-spore forming rod

- Capable of reproducing under refrigeration temperature (e.g. 4-10°C)

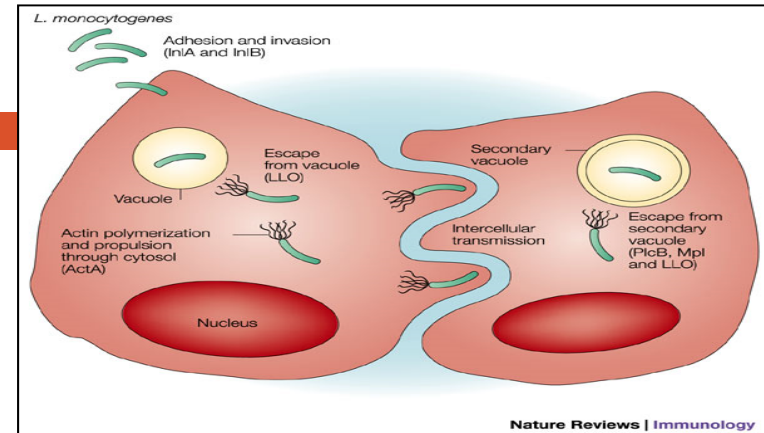
- Causative agent for food contamination

- Rarely cause diseases in adults, but often fatal to fetus

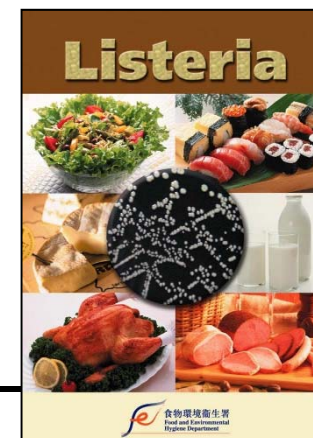
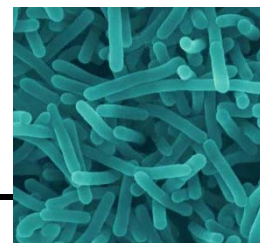
- Transferrable across placenta

- Causes meningitis, bacteremia in immunocompromised patients

- AIDS, cancer or diabetes patients



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- Low G+C Gram-Positive Bacteria
 - *Lactobacillus* 乳桿菌
 - Non-spore forming rod
 - Normal flora in human mouth, stomach, intestinal tract
 - Source of pro-biotic
 - Microflora inhibiting growth and proliferation of other pathogens (termed “microbial anatagonism”)
 - Industrial use for the production of
 - Yogurt, buttermilk, pickles and sauerkraut

- Low G+C Gram-Positive Bacteria
 - *Streptococcus* and *Enterococcus*
 - G(+) cocci
 - Diseases
 - Pharyngitis (strep throat)
 - Scarlet fever
 - Impetigo膿疱病
 - Fetal meningitis
 - Wound infections
 - Pneumonia
 - Multi-drug-resistant *streptococci*
 - By flesh-eating *streptococci*

Survey of Bacteria

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- High G+C Gram-Positive Bacteria

- *Corynebacterium* 棒狀桿菌

- **Pleomorphic** aerobes and facultative anaerobes

- Produces **metachromatic granules**

- *Mycobacterium* 分歧桿菌

- Aerobic rods that sometimes form filaments

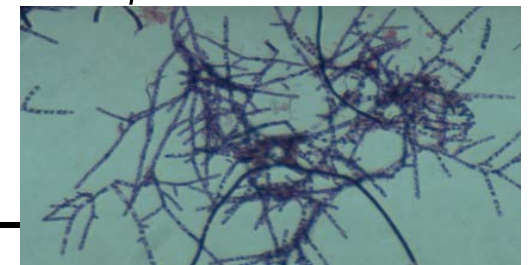
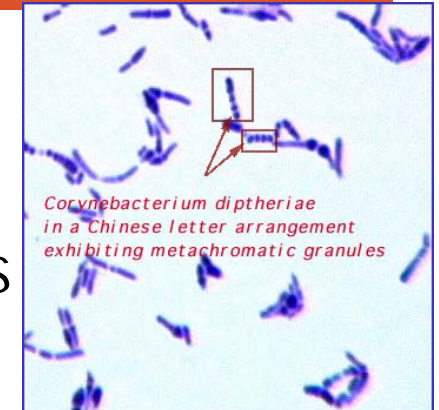
- Slow growth partly due to **mycolic acid** in its cell walls

- Stained with acid-fast staining

- *Actinomycetes* 放線菌

- Form **branching filaments** resembling fungi

- Important genera include *Actinomyces*, *Nocardia*, *Streptomyces*



Branching filaments of actinomycetes

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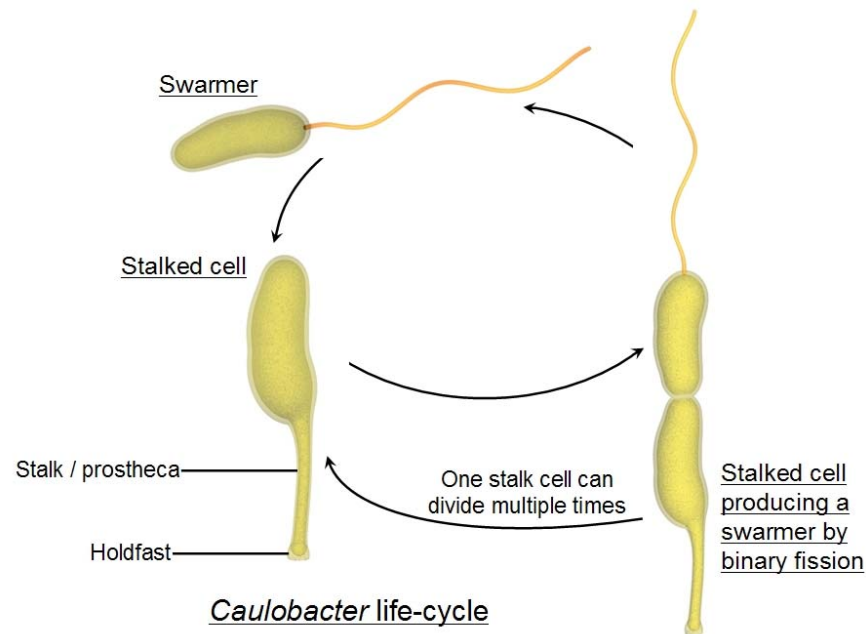
LM

10 μm

Characteristics of Selected Gram-Positive Bacteria

Phylum/Class	G + C Ratio	Representative Genera	Special Characteristics	Diseases
Firmicutes				
Clostridia	Low (less than 50%)	Clostridium	Obligate anaerobic rods; endospore formers	Tetanus Botulism Gangrene Severe diarrhea
		Epulopiscium	Giant rods	
		Veillonella	Part of oral biofilm on human teeth; stain like Gram-negative bacteria (pink)	Dental caries
Mollicutes	Low (less than 50%)	Mycoplasma	Lack cell walls; pleomorphic; smallest free-living cells; stain like Gram-negative bacteria (pink)	Pneumonia Urinary tract infections
Bacilli	Low (less than 50%)	Bacillus	Facultative anaerobic rods; endospore formers	Anthrax
		Listeria	Contaminates dairy products	Listeriosis
		Lactobacillus	Produce yogurt, buttermilk, pickles, sauerkraut	Rare blood infections
		Streptococcus	Cocci in chains	Strep throat, scarlet fever, and others
		Staphylococcus	Cocci in clusters	Bacteremia, food poisoning, and others
Actinobacteria				
Actinobacteria	High (greater than 50%)	Corynebacterium	Snapping division; metachromatic granules in cytoplasm	Diphtheria
		Mycobacterium	Waxy cell walls (mycolic acid)	Tuberculosis and meningitis
		Actinomyces	Filaments	Actinomycosis
		Nocardia	Filaments; degrade pollutants	Lesions
		Streptomyces	Produce antibiotics	Rare sinus infections

- Gram-Negative Proteobacteria 變形菌
 - Largest and most diverse group of bacteria
 - Many have extensions called prosthecae 菌柄
 - Used for attachment and to increase surface area for nutrient absorption



- Gram-Negative Proteobacteria
 - Alphaproteobacteria (α proteobacteria)
 - Nitrogen fixers
 - *Azospirillum*
 - *Rhizobium*
 - Nitrifying bacteria
 - *Nitrobacter*
 - Purple nonsulfur phototrophs

Nitrogen fixation 固氮作用

- Conversion of atmospheric H_2 into NH_3

Nitrification 硝化作用

- Conversion of NH_3 or NH_4^+ into NO_3^- (nitrate)



Nodules on soybean roots

Survey of Bacteria

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- Gram-Negative Proteobacteria

- Alphaproteobacteria

- Pathogenic alphaproteobacteria

- *Rickettsia*

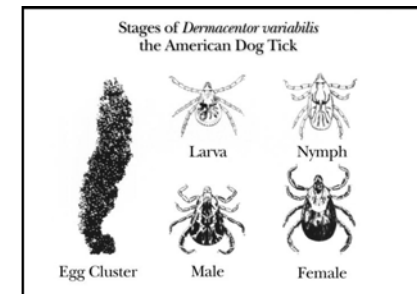
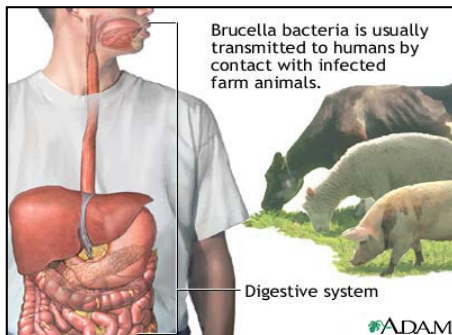
- G(-) aerobic rods, causes Rocky Mountain spotted fever; do not use Glucose as nutrient

- *Brucella*

- Coccobacillus

- causes brucellosis

- Spontaneous abortion, sterility

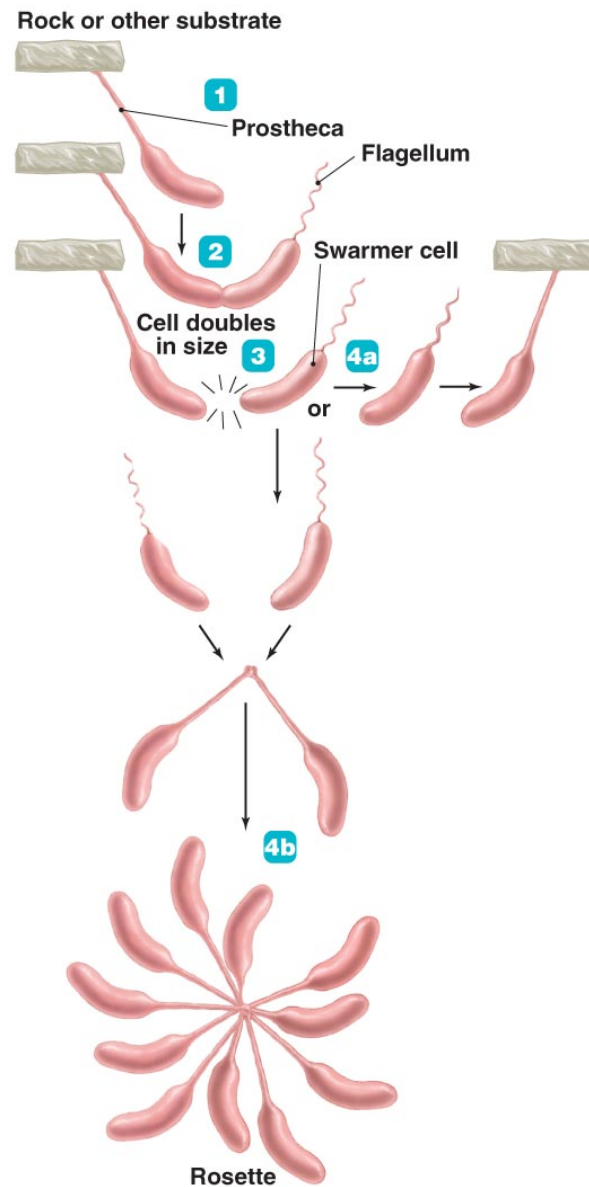


Ticks (壁蝨, 蜱)

- Gram-Negative Proteobacteria
 - Alphaproteobacteria
 - Other alphaproteobacteria
 - *Acetobacter*, *Gluconobacter* → producers of acetic acid
 - *Caulobacter*
 - Commonly seen in nutrient-poor seawater/freshwater, lab water bath

Growth and reproduction of *Caulobacter*

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11.3

Characteristics of Selected Gram-Negative Bacteria

TABLE

Phylum/Class	Representative Members	Special Characteristics	Diseases
Proteobacteria			
Alphaproteobacteria	<i>Azospirillum</i>	Nitrogen fixer	
	<i>Rhizobium</i>	Nitrogen fixer	
	<i>Nitrobacter</i>	Nitrifying bacterium	
	Purple nonsulfur bacteria	Anoxygenic phototrophs	
	<i>Rickettsia</i>	Intracellular pathogen	Typhus and Rocky Mountain spotted fever
	<i>Brucella</i>	Coccobacillus	Brucellosis
	<i>Acetobacter</i> , <i>Gluconobacter</i>	Synthesize acetic acid	
	<i>Caulobacter</i>	Prosthecae bacterium	
	<i>Agrobacterium</i>	Causes galls in plants; vector for gene transfer in plants	

- Gram-Negative Proteobacteria
 - Betaproteobacteria
 - Pathogenic betaproteobacteria
 - *Neisseria*
 - *Bordetella*
 - *Burkholderia*
 - Nonpathogenic betaproteobacteria
 - *Thiobacillus*
 - *Zoogloea*
 - *Sphaerotilus*



N. Gonorrhoeae (diplococcic)

11.3

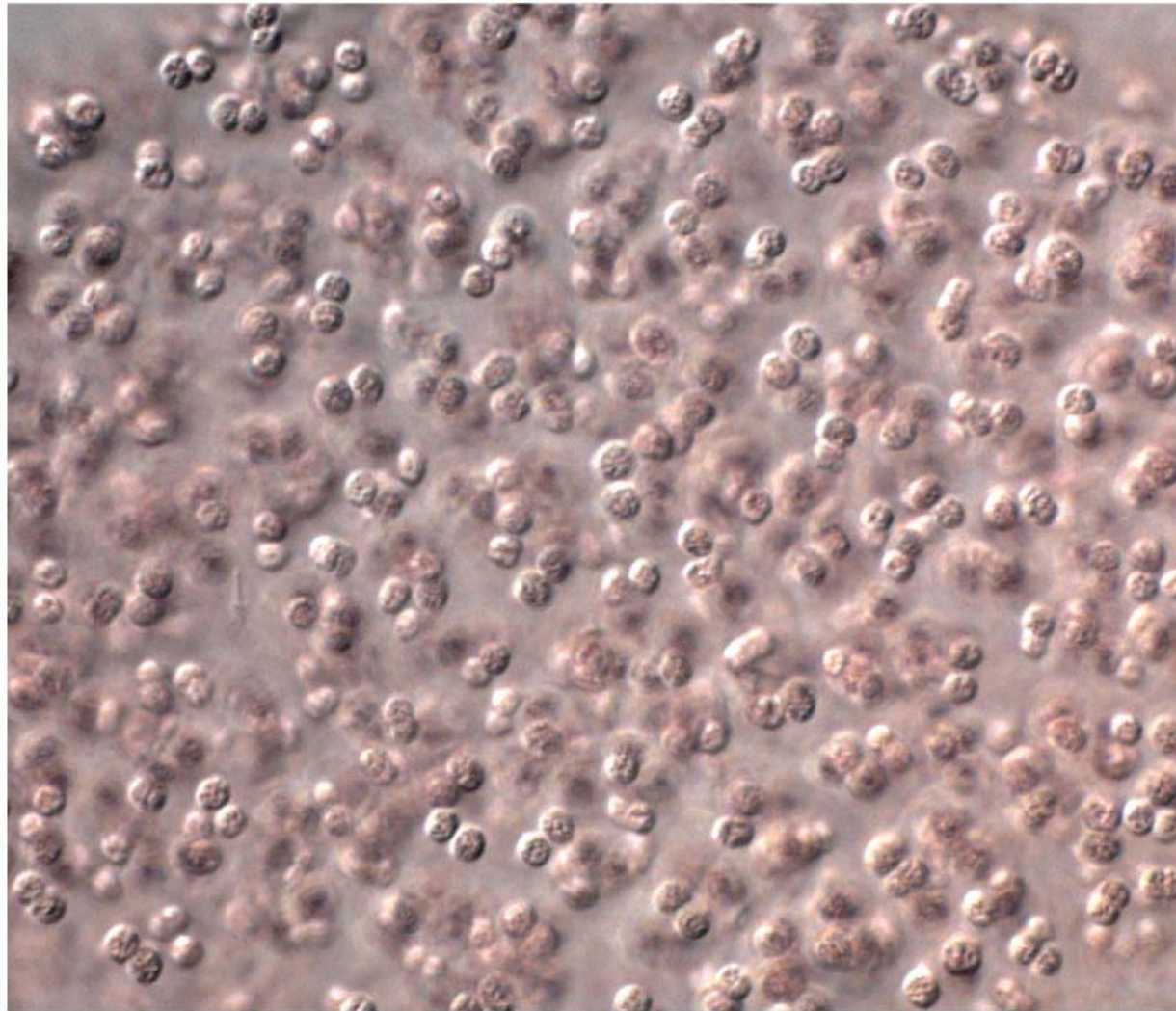
Characteristics of Selected Gram-Negative Bacteria

Phylum/Class	Representative Members	Special Characteristics	Diseases
Proteobacteria			
Betaproteobacteria	<i>Nitrosomonas</i>	Nitrifying bacterium	
	<i>Neisseria</i>	Diplococcus	Gonorrhea and meningitis
	<i>Bordetella</i>		Pertussis
	<i>Burkholderia</i>		Lung infection of cystic fibrosis patients
	<i>Thiobacillus</i>	Colorless sulfur bacterium	
	<i>Zoogloea</i>	Used in sewage treatment	
	<i>Sphaerotilus</i>	Blocks sewage treatment pipes	

- Gram-Negative Proteobacteria
 - Gammaproteobacteria
 - Purple sulfur bacteria
 - Intracellular pathogens
 - *Legionella* (Loginnaires disease)
 - *Coxiella* (Q fever)
 - Methane oxidizers
 - Glycolytic facultative anaerobes
 - Family enterobacteriaceae
 - Pseudomonads
 - *Pseudomonas*
 - *Azotobacter*: Nitrogen-fixer

Purple sulfur bacteria

50

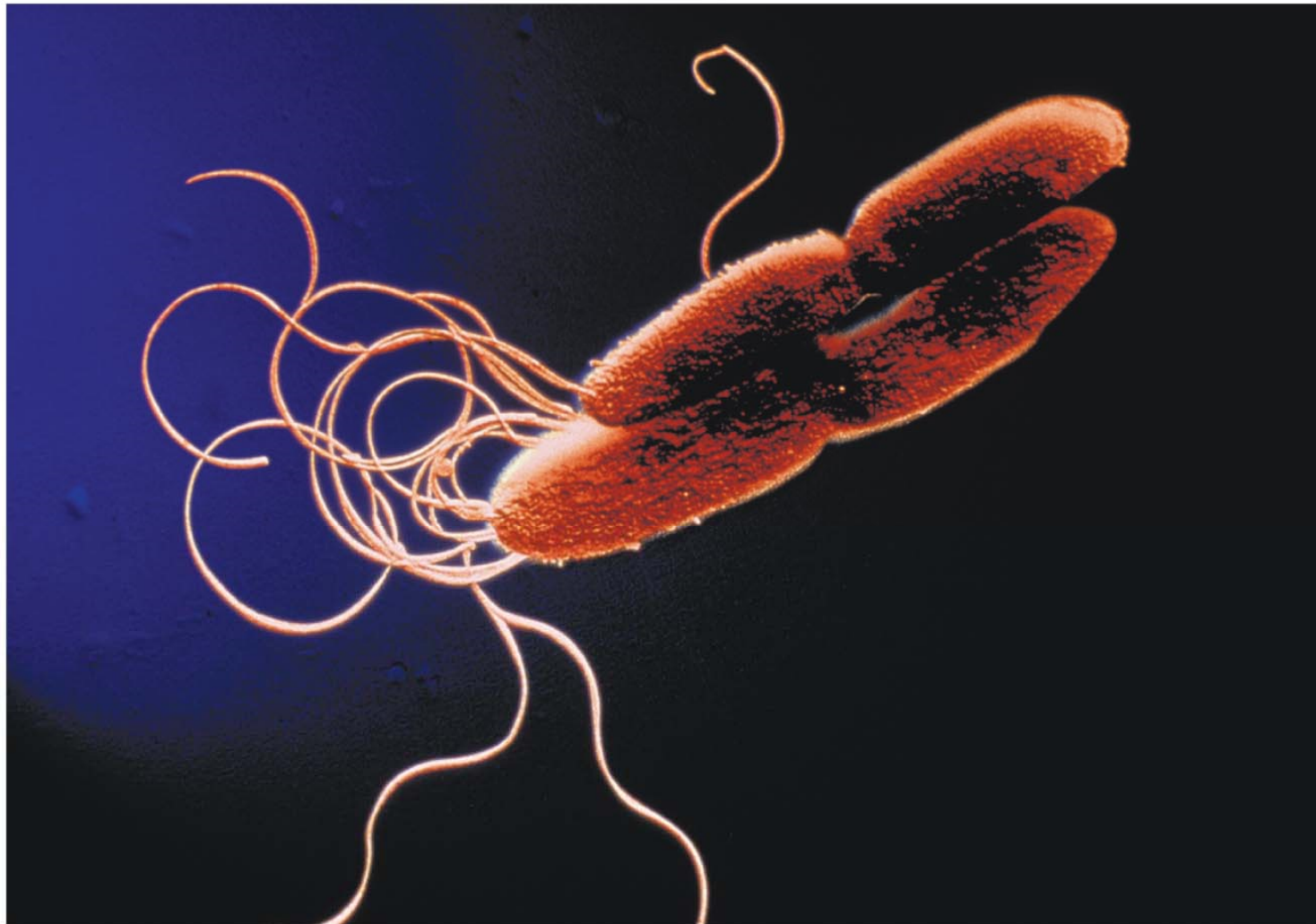


LM

5 μ m

Two dividing *Pseudomonas* cells and their polar flagella

51



SEM

2.0 μm

11.3

Characteristics of Selected Gram-Negative Bacteria

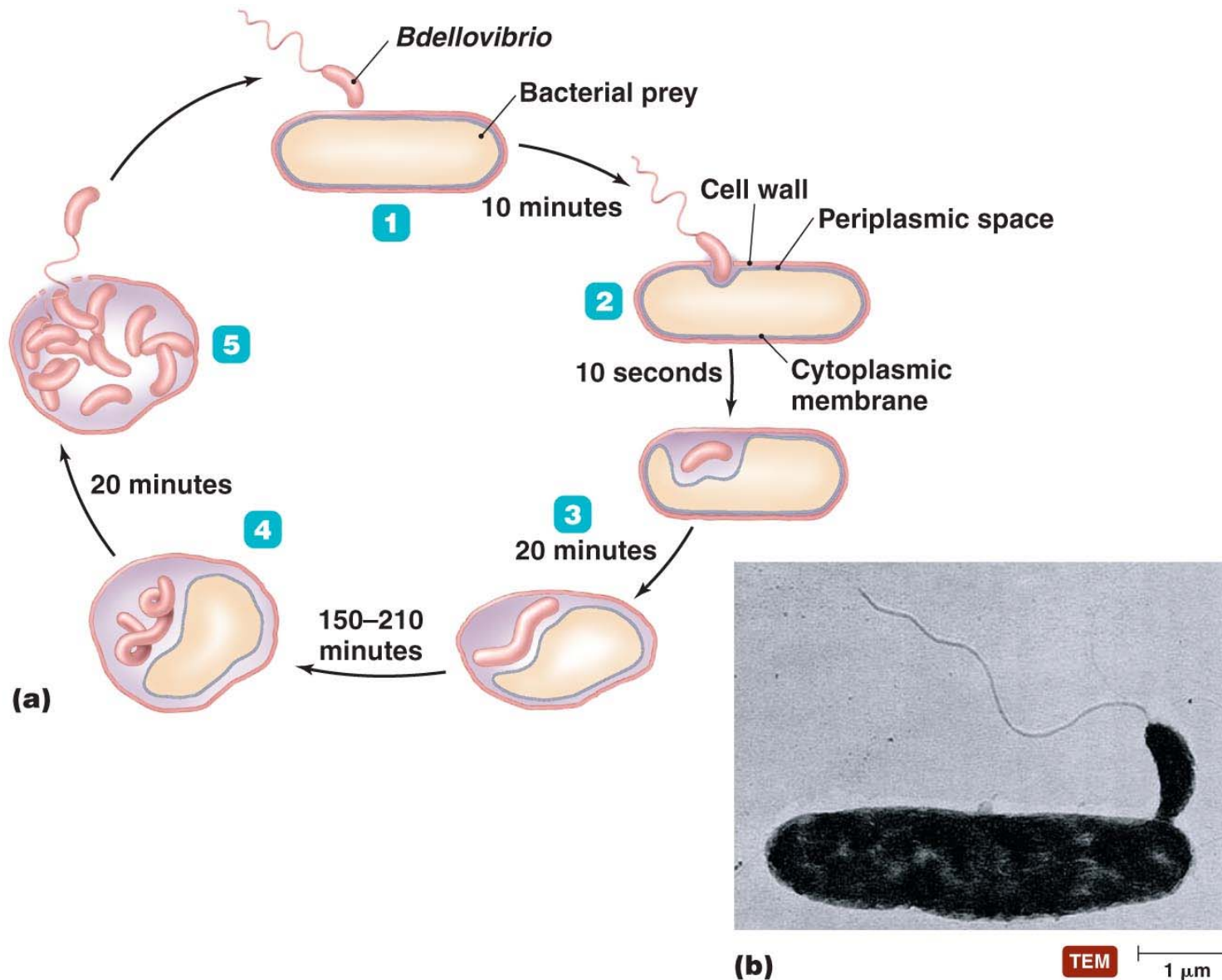
TABLE 11.3

Phylum/Class	Representative Members	Special Characteristics	Diseases
Proteobacteria			
Gammaproteobacteria	Purple sulfur bacteria		
	<i>Legionella</i>	Intracellular pathogen	Legionnaires' disease
	<i>Coxiella</i>	Intracellular pathogen	Q fever
	<i>Methylococcus</i>	Oxidizes methane	
	Glycolytic facultative anaerobes	Facultative anaerobes that catabolize carbohydrates via glycolysis and the pentose phosphate pathway	See Table 11.4 on p. 332
	<i>Pseudomonas</i>	Aerobe that catabolizes carbohydrates via Entner-Doudoroff and pentose phosphate pathways	Urinary tract infections, external otitis
	<i>Azotobacter</i> <i>Azomonas</i>	Nitrogen fixers not associated with plant roots	

- Gram-Negative Proteobacteria
 - *Deltaproteobacteria*
 - *Desulfovibrio*
 - *Bdellovibrio* (predator or G(-) bacteria)
 - Myxobacteria

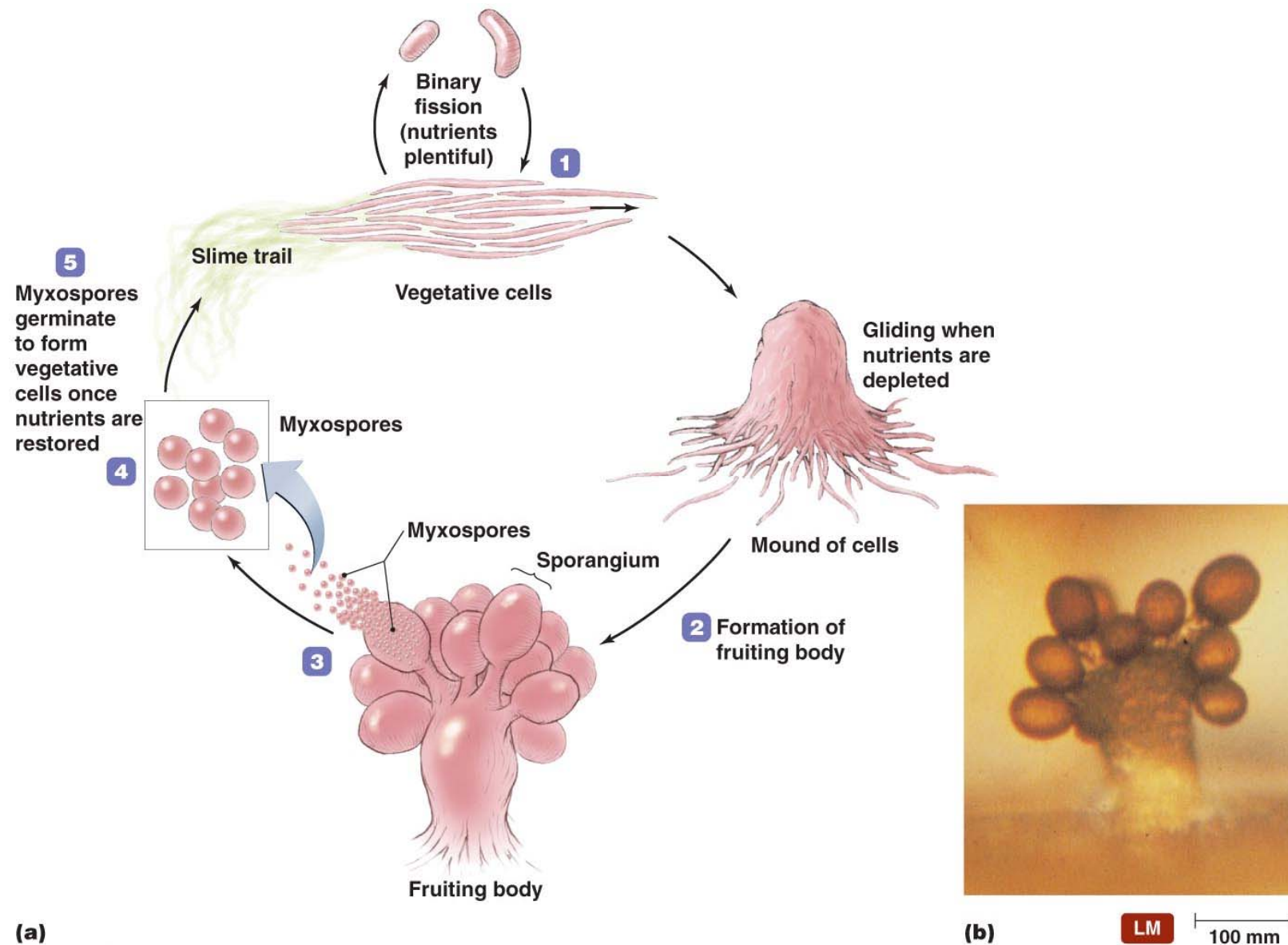
Bdellovibrio, Gram-negative pathogen of other bacteria

54



Life cycle of myxobacteria

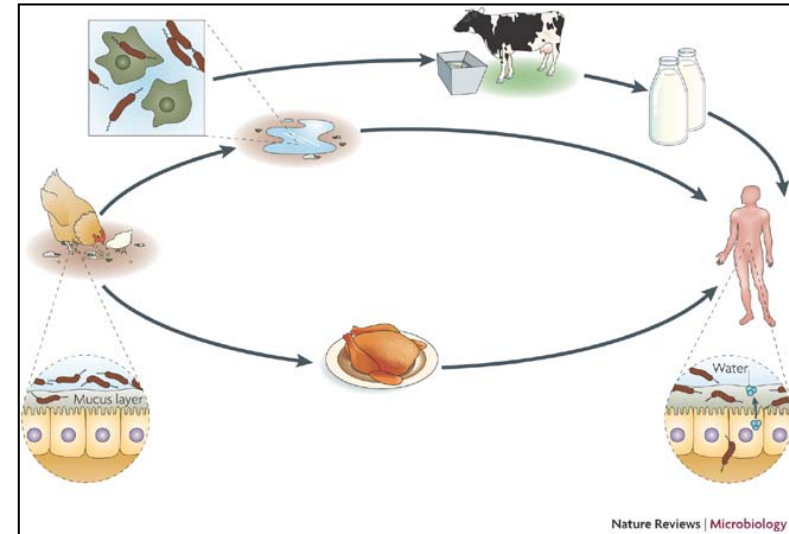
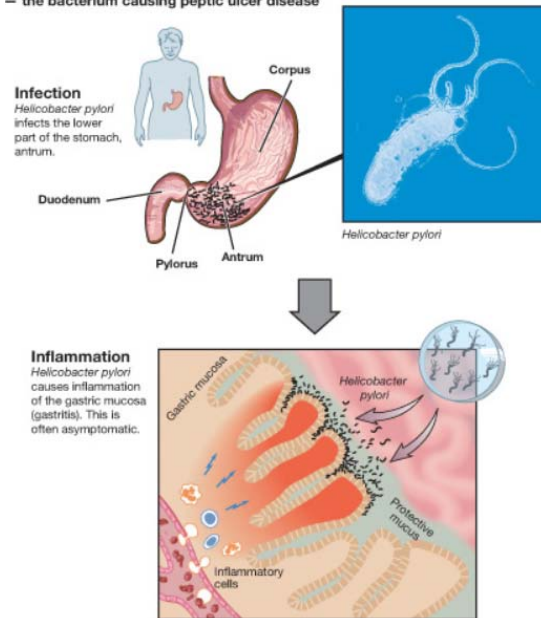
55



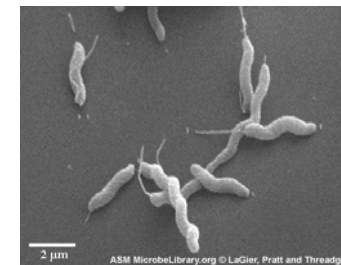
- Gram-Negative Proteobacteria
 - Epsilonproteobacteria
 - *Campylobacter*
 - *Helicobacter*

Helicobacter pylori

– the bacterium causing peptic ulcer disease



Infectious route of *C. jejuni*



11.3

Characteristics of Selected Gram-Negative Bacteria

TABLE

Phylum/Class	Representative Members	Special Characteristics	Diseases
Proteobacteria			
Deltaproteobacteria	<i>Desulfovibrio</i>	Sulfate reducer	
	<i>Bdellovibrio</i>	Pathogen of Gram-negative bacteria	
	Myxobacteria	Reproduces by forming differentiated fruiting bodies	
Epsilonproteobacteria	<i>Campylobacter</i>	Curved rod	Gastroenteritis
	<i>Helicobacter</i>	Spiral	Gastric ulcers

- Other Gram-Negative Bacteria
 - Chlamydias 披衣菌
 - *Chlamydia*
 - Spirochetes 螺旋菌
 - *Treponema*
 - *Borrelia*
 - Bacteroids 類桿菌
 - *Bacteroides*
 - *Cytophaga*

End of Chapter

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