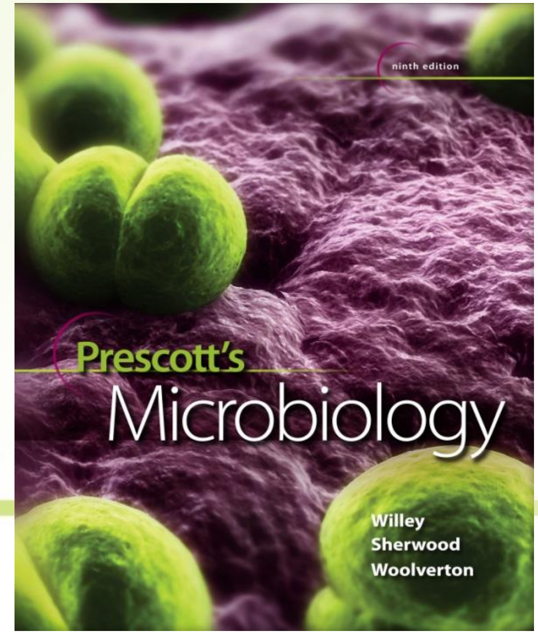


23

Firmicutes: The Low G + C Gram-Positive Bacteria

23.1 Class *Clostridia*

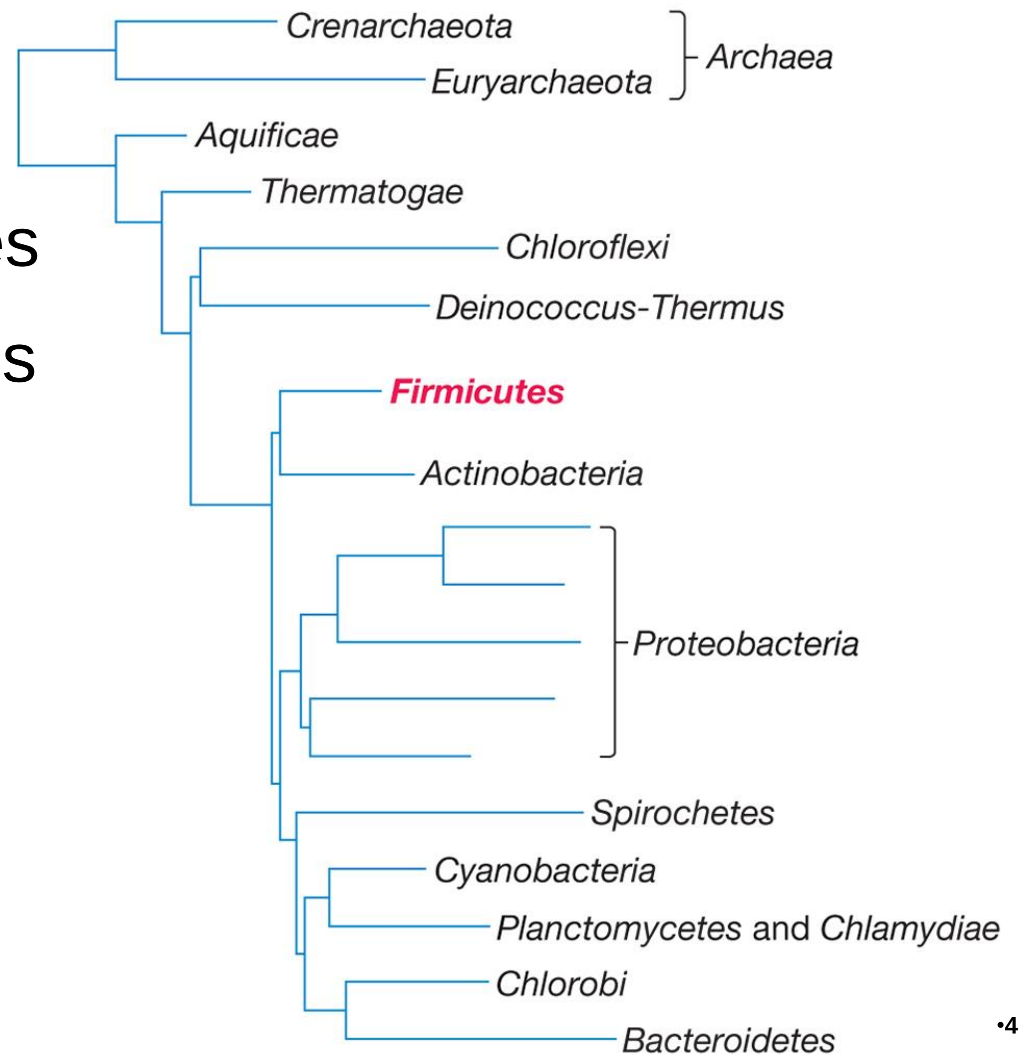
1. Identify several *Clostridia* spp. that form endospores
2. Outline the reaction by which some *Clostridia* can ferment amino acids, and relate this carbon substrate to their environmental distribution and pathogenic potential
3. Identify the terminal electron acceptors used by *Desulfotomaculum* spp.
4. Distinguish phototrophy in the heliobacteria from that of other anoxygenic phototrophic bacteria
5. Discuss the importance of *Veillonella* spp. to human disease

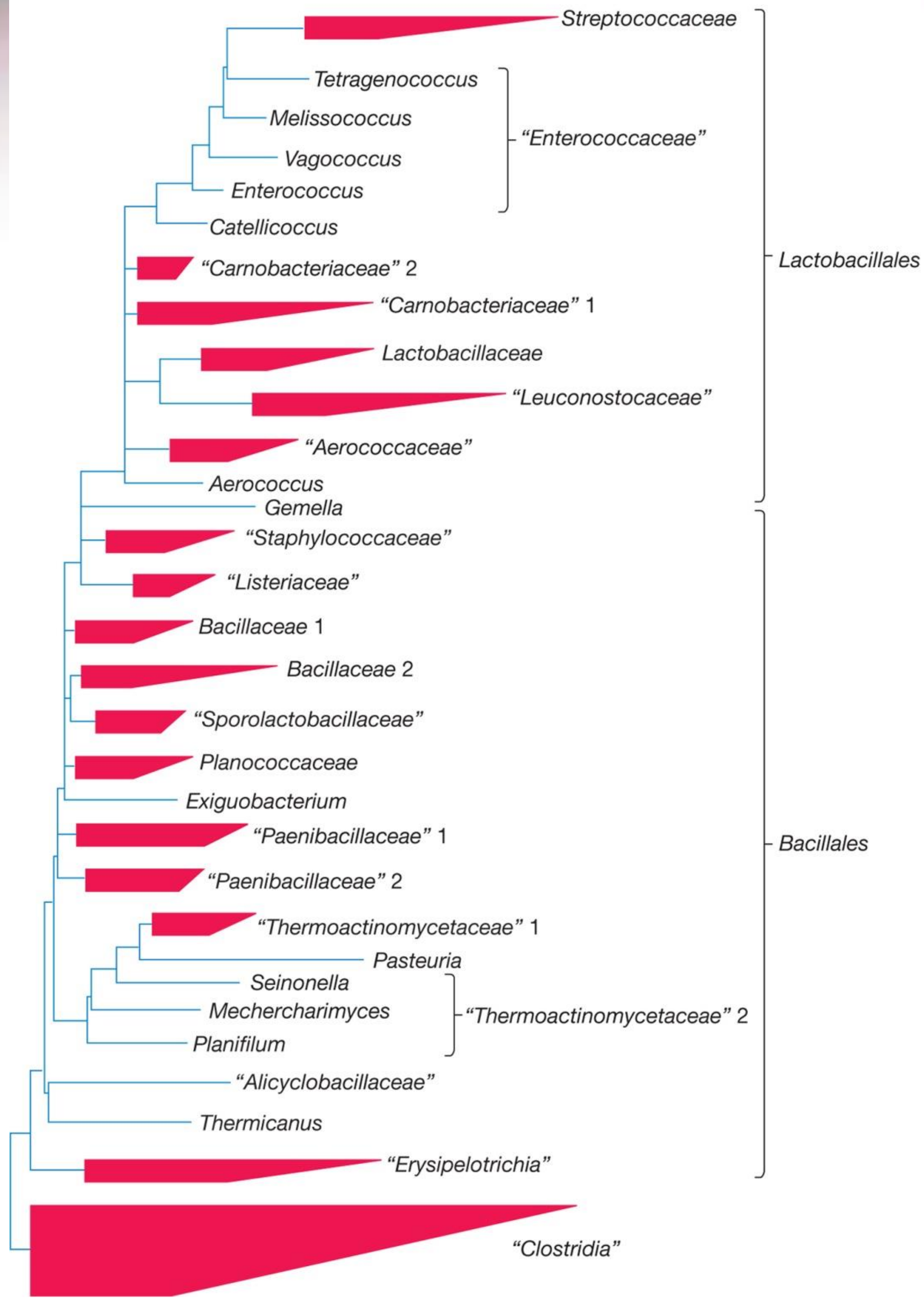
Gram-Positive *Bacteria*

- Grouped based on shape (rods, cocci, or irregular) and ability to form endospores
- *Bergey's Manual of Systematic Bacteriology,* 2nd edition used phylogenetic relationships
  - Low G + C (Volume 3)
  - High G + C (Volume 4)

Low G + C Gram-Positive *Bacteria Bergey's Manual*

- Placed in phylum Firmicutes
  - 10 orders, 34 families
  - divided into 2 classes
    - *Clostridia*
    - *Bacilli*




Streptococcaceae
Tetragenococcus
Melissococcus
Vagococcus
Enterococcus
"Enterococcaceae"
Catellicoccus
"Carnobacteriaceae" 2
"Carnobacteriaceae" 1
Lactobacillaceae
"Leuconostocaceae"
"Aerococcaceae"
Aerococcus
Lactobacillales
Gemella
"Staphylococcaceae"
"Listeriaceae"
Bacillaceae 1
Bacillaceae 2
"Sporolactobacillaceae"
Planococcaceae
Exiguobacterium
"Paenibacillaceae" 1
"Paenibacillaceae" 2
"Thermoactinomycetaceae" 1
Pasteuria
Seinonella
Mechercharimyces
Planifilum
"Thermoactinomycetaceae" 2
"Alicyclobacillaceae"
Thermicanus
"Erysipelotrichia"
Bacillales
"Clostridia"

Class *Clostridia*

- 3 orders, 11 families
- Largest genus is *Clostridium*
  - obligately anaerobic, fermentative, Gram-positive, endospore forming

Table 23.1 Characteristics of Selected Members of the Class *Clostridia*

Genus	Dimensions (μm), Morphology, and Motility	G + C Content (mol%)	Oxygen Relationship	Other Distinctive Characteristics
Clostridium	0.3–2.0 × 1.5–20; rod-shaped, often pleomorphic, nonmotile or peritrichous flagella	22–55	Anaerobic	Usually chemoorganotrophic, fermentative, and catalase negative; form oval or spherical endospores
Desulfotomaculum	0.3–1.5 × 3–9; straight or curved rods, peritrichous or polar flagella	37–50	Anaerobic	Reduce sulfate to H_2S, form subterminal to terminal endospores; stain Gram negative but have Gram-positive wall; catalase negative
Heliobacterium	1.0 × 4–10; rods that are frequently bent, gliding motility	52–55	Anaerobic	Photoheterotrophic with bacteriochlorophyll *g;* stain Gram negative but have Gram-positive wall; some form endospores
Veillonella	0.3–0.5; cocci in pairs, short chains, and masses; nonmotile	36–43	Anaerobic	Stain Gram negative; pyruvate and lactate fermented but not carbohydrates; parasitic in mouths, intestines, and respiratory tracts of animals

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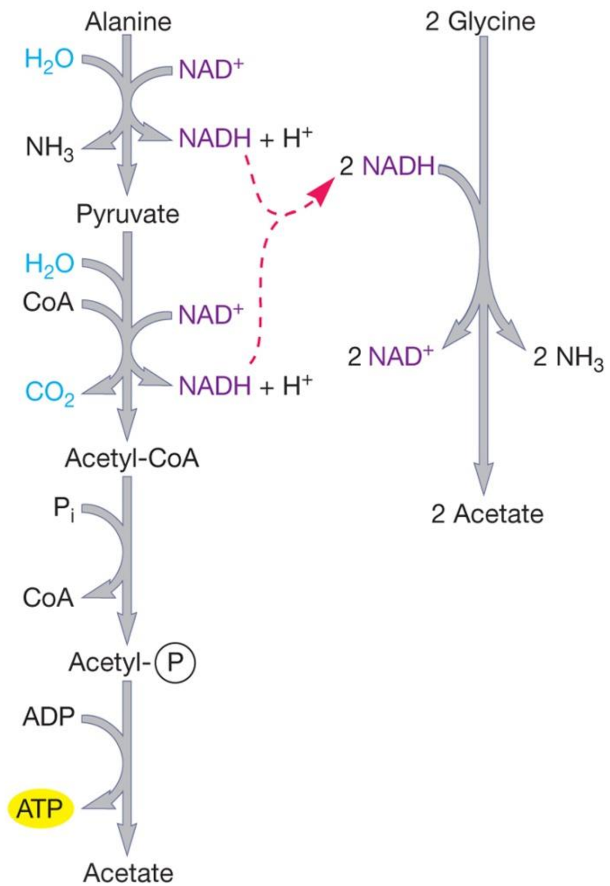
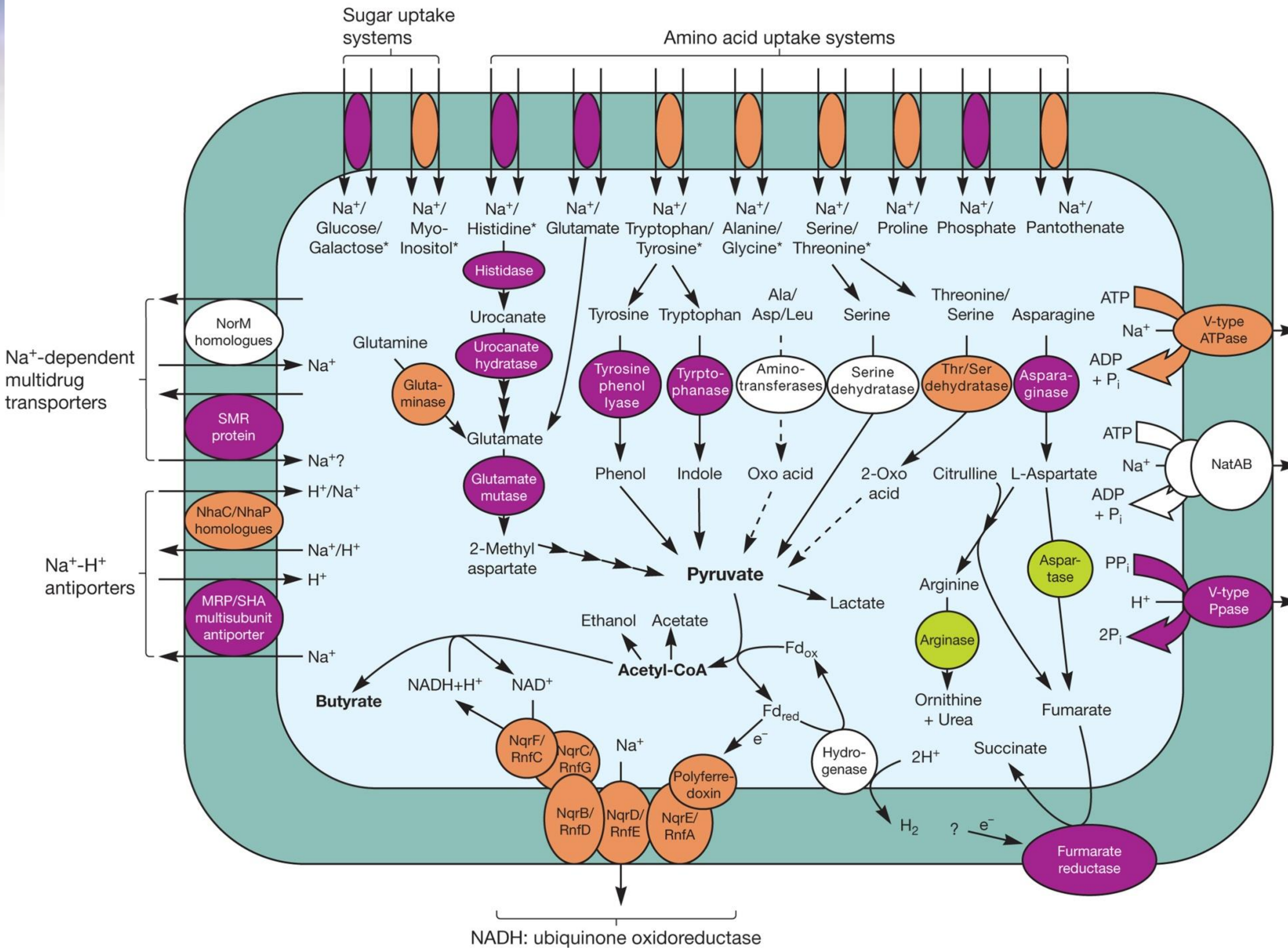
Genus *Clostridium*



- Over 100 species in distinct phylogenetic clusters
- Fermentative metabolism
  - ferment amino acids using Stickland reaction
    - oxidation of one amino acid using another as electron acceptor
    - sodium motive force to drive amino acid uptake
  - fermentation products responsible for unpleasant odors associated with putrefaction


Sugar uptake systems
Amino acid uptake systems
Na+/ Glucose/ Galactose*
Na+/ Myo-Inositol*
Na+/ Histidine*
Na+/ Glutamate
Na+/ Tryptophan/ Tyrosine*
Na+/ Alanine/ Glycine*
Na+/ Serine/ Threonine*
Na+/ Proline
Na+/ Phosphate
Na+/ Pantothenate
Histidase
Urocanate
Urocanate hydratase
Glutamine
Gluta-minase
Glutamate
Glutamate mutase
2-Methyl aspartate
Tyrosine
Tryptophan
Ala/ Asp/Leu
Serine
Threonine/ Serine
Asparagine
Tyrosine phenol lyase
Tyrpto-phanase
Amino-transferases
Serine dehydratase
Thr/Ser dehydratase
Aspara-ginase
Phenol
Indole
Oxo acid
2-Oxo acid
Citrulline
L-Aspartate
Pyruvate
Lactate
Arginine
Arginase
Ornithine + Urea
Aspar-tase
Fumarate
Succinate
Fumarate reductase
Ethanol
Acetate
Acetyl-CoA
Butyrate
NADH+H+
NAD+
Fdox
Fdred
e−
Hydro-genase
2H+
H2
?
NqrF/ RnfC
NqrC/ RnfG
NqrB/ RnfD
NqrD/ RnfE
NqrE/ RnfA
Polyferre-doxin
Na+
NADH: ubiquinone oxidoreductase
Na+-dependent multidrug transporters
NorM homologues
SMR protein
Na+
Na+?
H+/Na+
Na+/H+
H+
Na+-H+ antiporters
NhaC/NhaP homologues
MRP/SHA multisubunit antiporter
ATP
Na+
ADP + Pi
V-type ATPase
NatAB
V-type Ppase
PPi
H+
2Pi

Genus *Clostridium*…

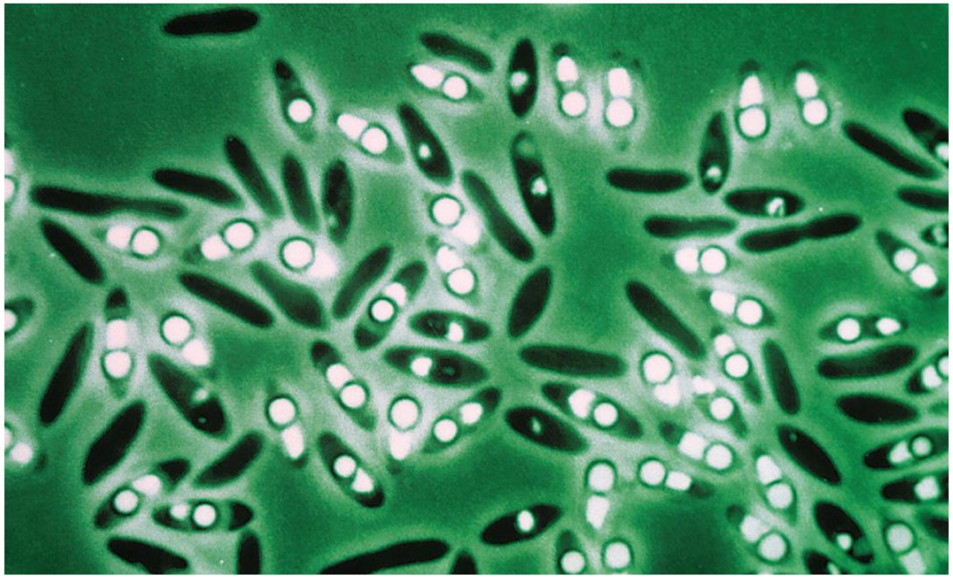
- Great practical importance
  - food spoilage through the Strickland reaction
  - industrial production of butanol
  - toxin production

Important Species of *Clostridium*

- *C. botulinum*
  - food spoilage (especially canned foods); botulism
- *C. tetani* – tetanus
- *C. perfringens* – gas gangrene
- *C. acetobutylicum*
  - manufacture of butanol

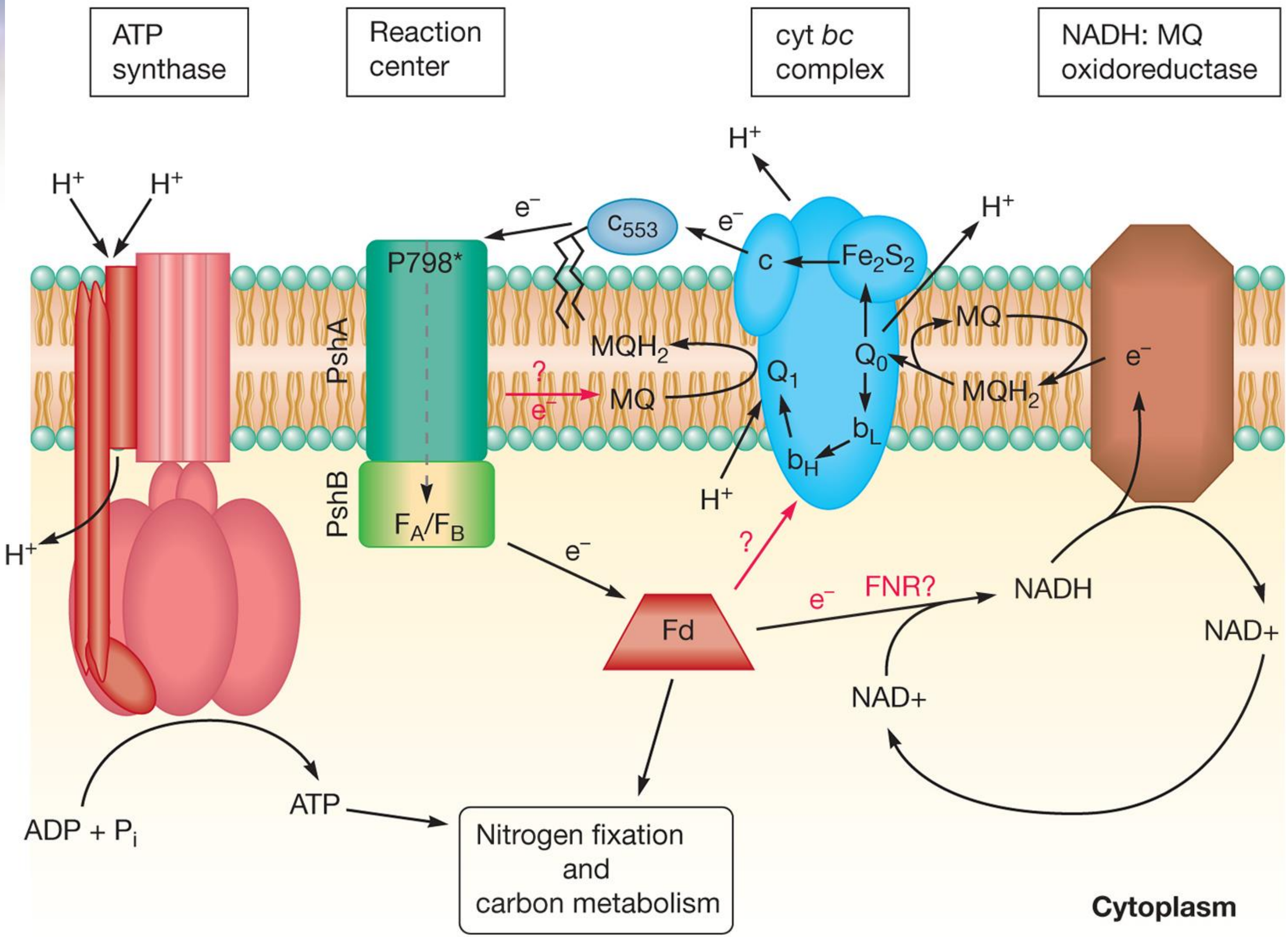
Genus *Desulfotomaculum*

- Endospore forming
- Reduces sulfate and sulfite to hydrogen sulfide during anaerobic respiration
- Stains Gram-negative but in electron micrographs is seen to have a Gram-positive cell wall



Genera *Heliobacterium* and *Heliophilum*

- Anaerobic, photosynthetic
  - bacteriochlorophyll *g*
  - have photosystem similar to green sulfur bacteria
  - pigments in plasma membrane
  - differ from anoxygenic photosynthetic bacteria in that they grow autotropically


ATP synthase
Reaction center
cyt bc complex
NADH: MQ oxidoreductase
H+
H+
H+
H+
H+
H+
e−
e−
e−
e−
e−
e−
c553
P798*
PshA
PshB
FA/FB
c
Fe2S2
MQH2
MQ
?
Q1
Q0
bL
bH
MQ
MQH2
Fd
FNR?
NADH
NAD+
NAD+
ADP + Pi
ATP
Nitrogen fixation and carbon metabolism
Cytoplasm

Genus *Veillonella*

- Gram-negative but placed in order *Clostridiales*
- Anaerobic, chemoheterotrophic
  - all have complex nutritional requirements
- Normal biota of mouth, GI tract, urogenital tract of humans and animals
- Found in infections of head, lung, female genital tract

23.2 Class *Bacilli* - 1

1. List terminal electron acceptors and fermentation products produced by *Bacillus* spp. and staphylococci
2. Discuss reasons that make *Bacillus subtilis* an important model organism
3. List three reasons why *Bacillus* spp. are of practical importance
4. Summarize the evolution and emergence of MRSA, and list at least two diseases caused by *Staphylococcus aureus*
5. Describe the structure and medical importance of *Listeria monocytogenes*

23.2 Class *Bacilli* - 2

6. Identify the genera that are considered lactic acid bacteria, and discuss their importance in the food industry
7. Distinguish between enterococci and streptococci
8. Name bacterial genera capable of hemolysis, and differentiate between α-hemolysis and β-hemolysis

Class *Bacilli*

- Large variety of Gram-positive organisms
- Contains two orders, *Bacillales* and *Lactobacillales*, 17 families and over 70 genera
  – includes cocci, rods, and nonspore forming rods

Table 23.2 Characteristics of Members of the Class *Bacilli*

Genus	Dimensions (μm), Morphology, and Motility	G + C Content (mol%)	Genome Size (Mb)	Oxygen Relationship	Other Distinctive Characteristics
Bacillus	0.5–2.5 × 1.2–10; straight rods, peritrichous flagella, spore-forming	32–69	4.2–5.4	Aerobic or facultative	Catalase positive; chemoorganotrophic
Caryophanon	1.5–3.0 × 10–20; multicellular rods with rounded ends, peritrichous flagella, nonsporing	41–46	Nd[1]	Aerobic	Acetate only major carbon source; catalase positive; trichome cells have greater width than length; trichomes can be in short chains
Enterococcus	0.6–2.0 × 0.6–2.5; spherical or ovoid cells in pairs or short chains, nonsporing, sometimes motile	34–42	3.2	Aerotolerant	Ferment carbohydrates to lactate with no gas; complex nutritional requirements; catalase negative; occur widely, particularly in fecal material
Lactobacillus	0.5–1.2 × 1.0–10; usually long, regular rods, nonsporing, rarely motile	32–53	1.9–3.3	Facultative or microaerophilic	Fermentative, at least half the end product is lactate; require rich, complex media; catalase and cytochrome negative
Lactococcus	0.5–1.2 × 0.5–1.5; spherical or ovoid cells in pairs or short chains, nonsporing, nonmotile	38–40	2.4	Aerotolerant	Chemoorganotrophic with fermentative metabolism; lactate without gas produced; catalase negative; complex nutritional requirements; in dairy and plant products
Leuconostoc	0.5–0.7 × 0.7–1.2; cells spherical or ovoid, in pairs or chains; nonmotile and nonsporing	38–44	Nd	Facultative	Require fermentable carbohydrate and nutritionally rich medium for growth; fermentation produces lactate, ethanol, and gas; catalase and cytochrome negative
Staphylococcus	0.9–1.3; spherical cells occurring singly and in irregular clusters, nonmotile and nonsporing	30–39	2.5–2.8	Facultative	Chemoorganotrophic with both respiratory and fermentative metabolism; usually catalase positive; associated with skin and mucous membranes of vertebrates
Streptococcus	0.5–2.0; spherical or ovoid cells in pairs or chains, nonmotile and nonsporing	34–46	1.8–2.2	Aerotolerant	Fermentative, producing mainly lactate and no gas; catalase negative; commonly attack red blood cells (α- or β-hemolysis); complex nutritional requirements; commensals or parasites on animals
Thermoactinomyces	0.4–1.0 in diameter; branched, septate mycelium resembles those of actinomycetes	52–54.8	Nd	Aerobic	Usually thermophilic; true endospores form singly on hyphae; numerous in decaying hay, vegetable matter, and compost

1 Nd: Not determined; genome not yet sequenced.