Microbial Diversity

Many bacterial species have the capacity to differentiate: in other words- produce subpopulations with different shapes and/or function

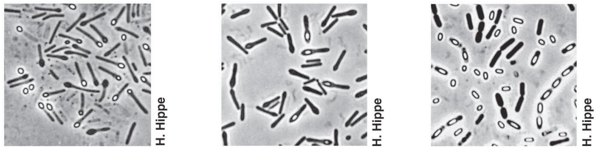
Sporulation: *Bacillus* and *Clostridium*

Heterocyst formation: filamentous cyanobacteria (*Anabaena*)

Endospore production by *Bacillus subtilis*

- ***Endospores***
  - Highly differentiated cells resistant to heat, harsh chemicals, and radiation
  - “Dormant” stage of bacterial life cycle
  - Ideal for dispersal via wind, water, or animal gut
  - Only present in some gram-positive bacteria

The Bacterial Endospore



***(a)* Terminal spores** ***(b)* Subterminal spores** ***(c)* Central spores**

Figure 4.38

Differences between Endospores and Vegetative Cells

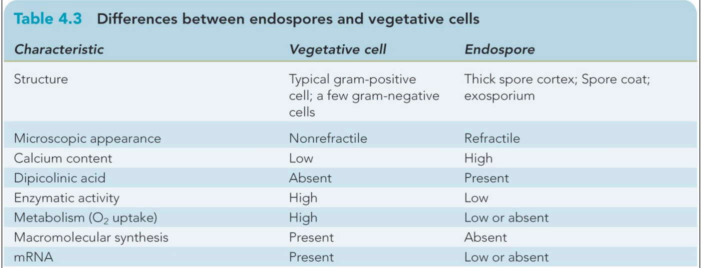


Table 4.3 **Differences between endospores and vegetative cells**

Characteristic	*Vegetative cell*	*Endospore*
Structure	Typical gram-positive cell; a few gram-negative cells	Thick spore cortex; Spore coat; exosporium
Microscopic appearance	Nonrefractile	Refractile
Calcium content	Low	High
Dipicolinic acid	Absent	Present
Enzymatic activity	High	Low
Metabolism (O_2 uptake)	High	Low or absent
Macromolecular synthesis	Present	Absent
mRNA	Present	Low or absent

Differences between Endospores and Vegetative Cells

DNA and ribosomes	Present	Present
Heat resistance	Low	High
Radiations resistance	Low	High
Resistance to chemicals (for example, H_2O_2) and acids	Low	High
Stainability by dyes	Stainable	Stainable only with special methods
Action of lysozyme	Sensitive	Resistant
Water content	High, 80–90%	Low, 10–25% in core
Small acid-soluble proteins (product of *ssp* genes)	Absent	Present
Cytoplasmic pH	About pH 7	About pH 5.5–6.0 (in core)

The Life Cycle of an Endospore-Forming Bacterium

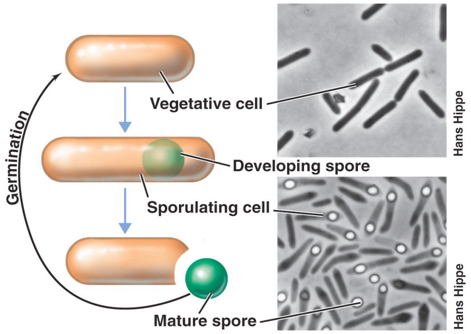


Figure 4.39

Endospore Structure

- Structurally complex
- Contains dipicolinic acid
- Enriched in Ca^{2+}
- Core contains small-acid soluble proteins (SASP)

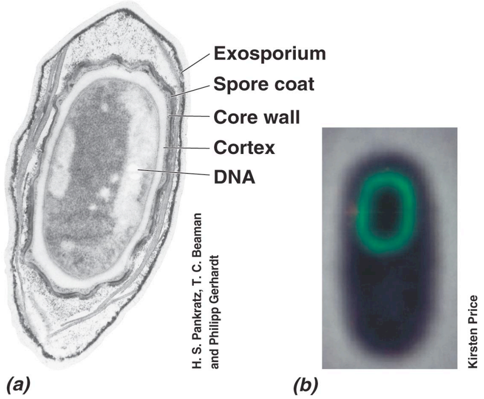
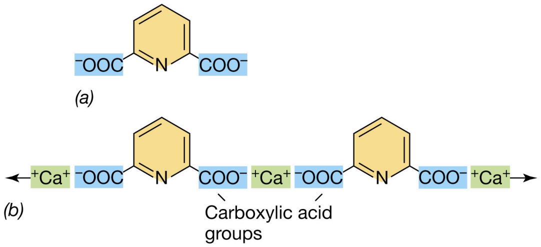


Figure 4.41

Dipicolinic Acid (DPA)



10-15% dry weight of a endospore

Small Acid Soluble Proteins (SASPs)

Bind to DNA and protect molecule, and provide a carbon and energy source for germination

Fig. 4.49

Stages in *B. subtilis* endospore formation

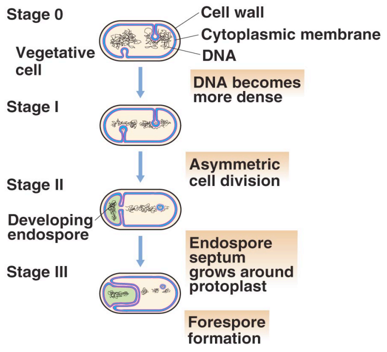


Figure 4.43

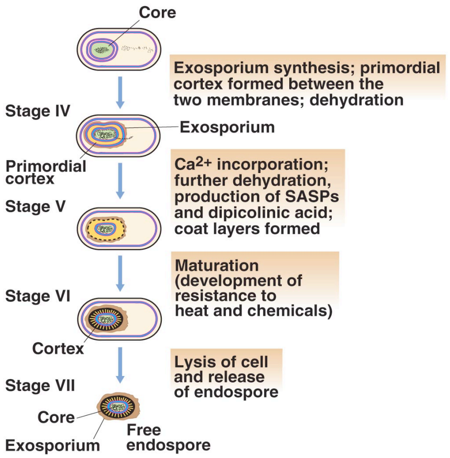
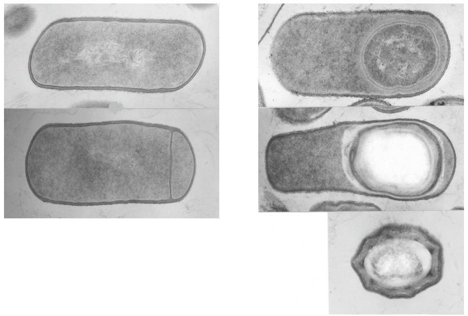


Figure 4.43

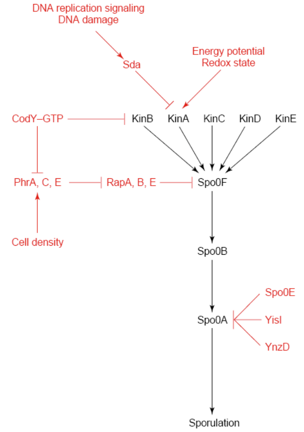
What these stages look like under the electron micrograph



Lets talk about the regulation of sporulation …

Sporulation in *B. subtilis* is a cascade
of gene expression
events in both the mother cell and the developing spore

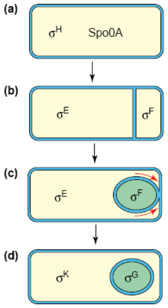
What controls initiation of Sporulation?



A cascade of sigma factors are important during spore formation

RNA polymerase: enzyme involved in transcription

β
β' } core
2α } holoenzyme
sigma σ



Different σ's direct core RNA pol to bind to a different set of genes

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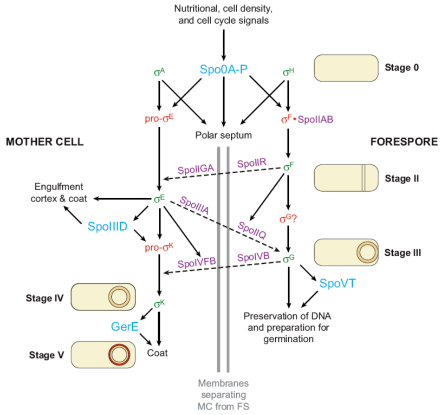
Spore formation involves signaling between the fore spore and mother cell compartments.



Heterocyst Formation

Only certain prokaryotes have the ability to carryout nitrogen fixation

N_2 -------> NH_3 (NH_4^+) ← NO_3^-

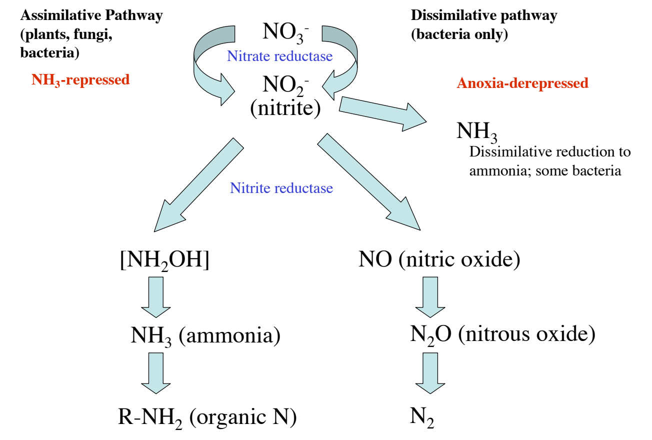
↘ organic nitrogen

Two groups

Free-living nitrogen fixers

Symbiotic nitrogen fixers

Nitrate (NO_3^-) Metabolism



Assimilative Pathway (plants, fungi, bacteria)

NH$_3$-repressed

Dissimilative pathway (bacteria only)

Anoxia-derepressed

NO_3^-

Nitrate reductase

NO_2^- (nitrite)

NH_3

Dissimilative reduction to ammonia; some bacteria

Nitrite reductase

[NH_2OH]

NH_3 (ammonia)

R-NH_2 (organic N)

NO (nitric oxide)

N_2O (nitrous oxide)

N_2

Assimilation of Inorganic Nitrogen

Two Mechanisms:

1. Glutamic dehydrogenase

α-ketoglutarate + NH_3 -----> glutamic acid

2. Second mechanism uses a 2 enzyme system: L-glutamine synthetase and glutamate synthetase or GOGAT enzyme.

$$\text{Glutamic acid} + NH_3 + ATP \xrightarrow{GS} \text{glutamine}$$

$$\text{Glutamine} + \alpha\text{-ketoglutarate} \xrightarrow{GOGAT} 2\ \text{glutamic acids}$$

Transamination Reactions

Glutamic acid + OAA → Aspartic acid + α-ketoglucerate

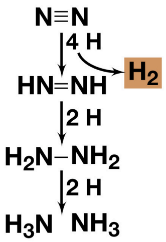
Glutamic acid + pyruvate → Alanine + α-ketoglucerate

Nitrogen Fixation

Nitrogenase Complex

- Dinitrogenase reductase
- Dinitrogenase

Nitrogenase sensitive to oxygen



Overall reaction

$$8\,H^+ + 8\,e^- + N_2 \longrightarrow 2\,NH_3 + H_2$$

$$16\text{–}24\,ATP \longrightarrow 16\text{–}24\,ADP + 16\text{–}24\,P_i$$

(b)

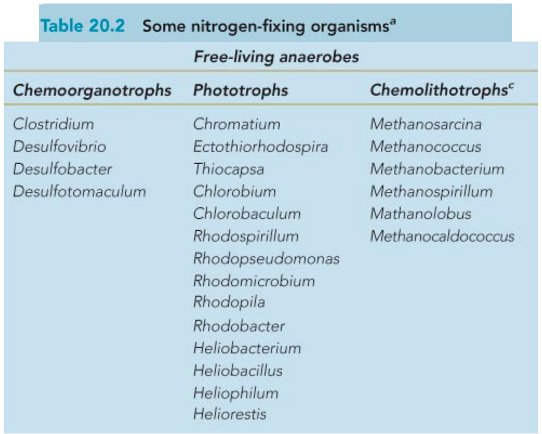


Table 20.2 Some nitrogen-fixing organisms[a]

Free-living anaerobes

Chemoorganotrophs	*Phototrophs*	*Chemolithotrophs*[c]
Clostridium	*Chromatium*	*Methanosarcina*
Desulfovibrio	*Ectothiorhodospira*	*Methanococcus*
Desulfobacter	*Thiocapsa*	*Methanobacterium*
Desulfotomaculum	*Chlorobium*	*Methanospirillum*
	Chlorobaculum	*Mathanolobus*
	Rhodospirillum	*Methanocaldococcus*
	Rhodopseudomonas	
	Rhodomicrobium	
	Rhodopila	
	Rhodobacter	
	Heliobacterium	
	Heliobacillus	
	Heliophilum	
	Heliorestis	

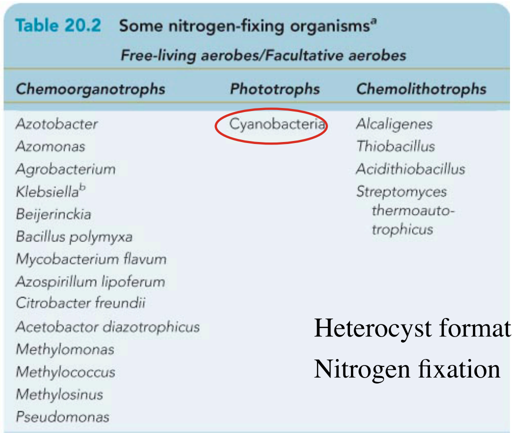


Table 20.2 Some nitrogen-fixing organisms[a]

Free-living aerobes/Facultative aerobes

Chemoorganotrophs	*Phototrophs*	*Chemolithotrophs*
Azotobacter	Cyanobacteria	*Alcaligenes*
Azomonas		*Thiobacillus*
Agrobacterium		*Acidithiobacillus*
Klebsiella[b]		*Streptomyces thermoautotrophicus*
Beijerinckia		
Bacillus polymyxa		
Mycobacterium flavum		
Azospirillum lipoferum		
Citrobacter freundii		
Acetobactor diazotrophicus		
Methylomonas		
Methylococcus		
Methylosinus		
Pseudomonas		

Heterocyst formation

Nitrogen fixation

Anabaena heterocyst
spaced every 10-20 cells

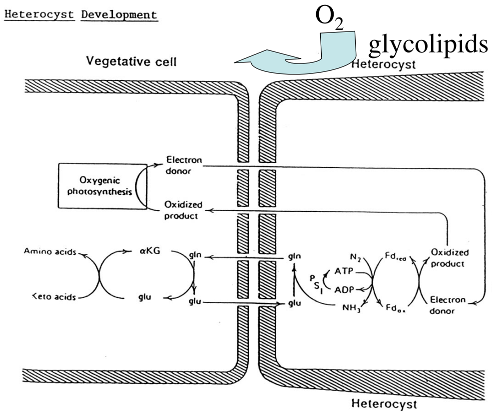


Fig. 12.80

Oxygenic Photosynthes

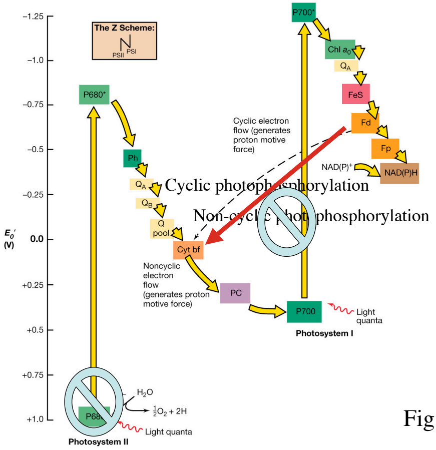
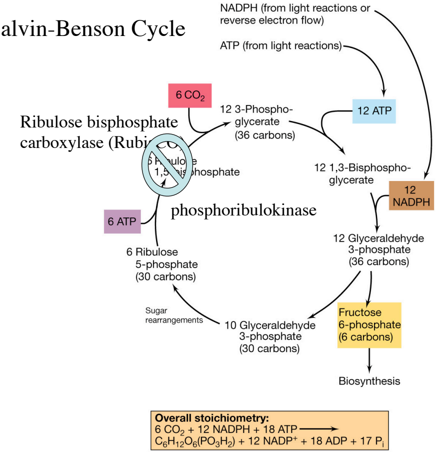


Fig. 17.19

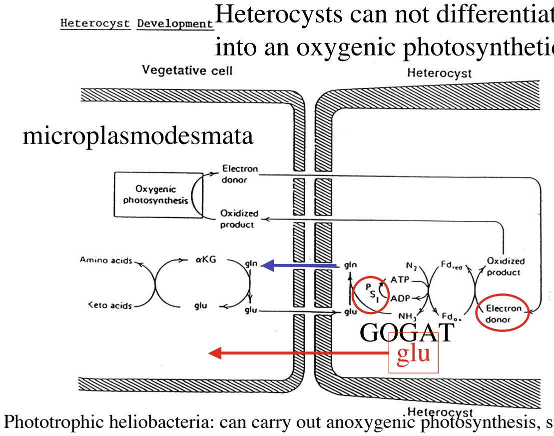
Calvin-Benson Cycle



Overall stoichiometry:
$6\ CO_2 + 12\ NADPH + 18\ ATP \longrightarrow$
$C_6H_{12}O_6(PO_3H_2) + 12\ NADP^+ + 18\ ADP + 17\ P_i$

Fig. 17.22

Only a few cells undergo differentiation
Heterocysts can not differentiate back into an oxygenic photosynthetic cell!



Phototrophic heliobacteria: can carry out anoxygenic photosynthesis, sporulate, and fix nitrogen!