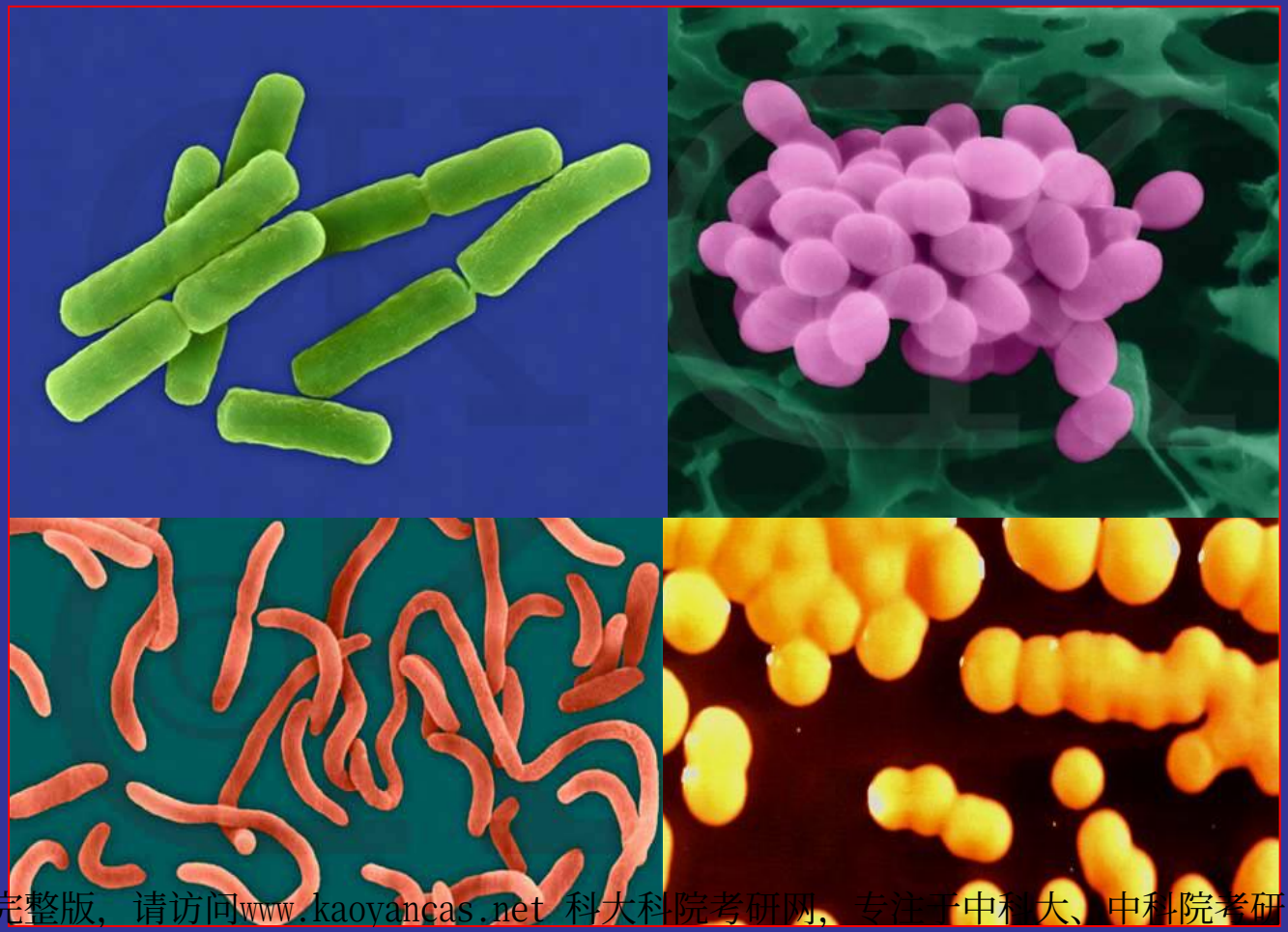
Chapter 3 *The Prokaryotes*



Chapter Outline

3.1 Bacteria
3.2 Actinomycetes
3.3 Cyanobacteria
3.4 Archaeobacteria
3.5 Other prokaryotes
3.6 Classification of bacteria

Concepts

- Microorganisms are too small to be seen without the use of a microscope. The techniques-such as sterilization and the use of culture medium are required to isolate and grow these microbes.
- Bacteria may be spherical (cocci), rod-shaped (bacilli), spiral, or filamentous.
- Most bacteria can be divided into gram-positive and gram-negative groups based on their cell wall structure and response to the Gram stain. Bacteria such as mycoplasmas lack a cell wall.

3.1 Bacteria

Size, Shape, and Arrangement of Bacterial Cells

Most bacteria fall within a range

from 0.2 to 2.0 μm in diameter

and from 2 to 8μm in length.

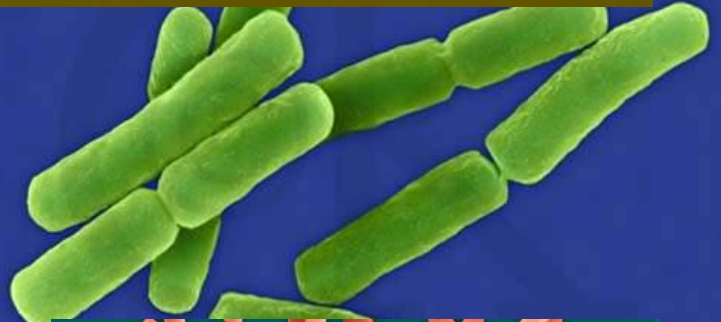
Cm = 10^{-2} meter

mm = 10^{-3} meter

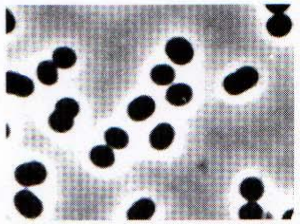
μm = 10^{-6} meter

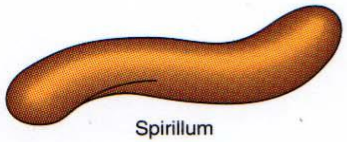
nm = 10^{-9} meter

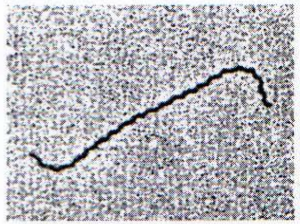
They have a few basic shapes-spherical coccus (plural, *cocci,* meaning berries), rod-shaped bacillus (plural, *bacilli,* meaning little staffs), and spiral.

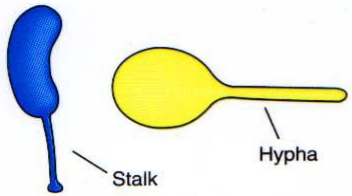


Representative Cell Shapes (Morphology) in Prokaryotes

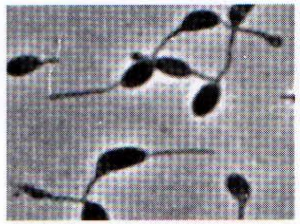








Budding and appendaged bacteria

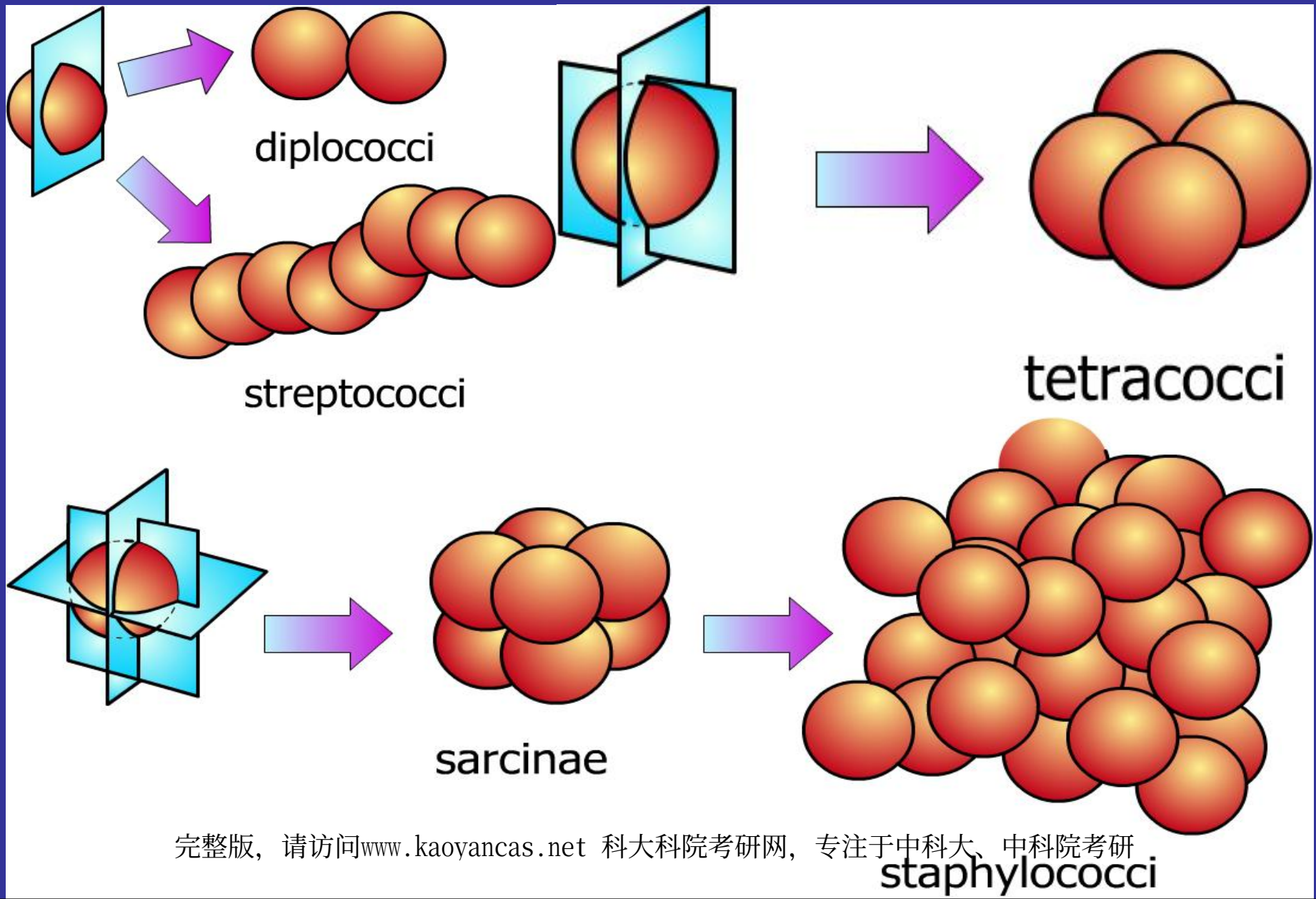


How to identify an unknown bacterial species ?

Factors:

- Morphology (shape)
- Chemical composition (often detected by staining reactions)
- Nutritional requirements
- Biochemical activities
- Source of energy (sunlight or chemicals)

Arrangement of Spherical Bacterial Cells

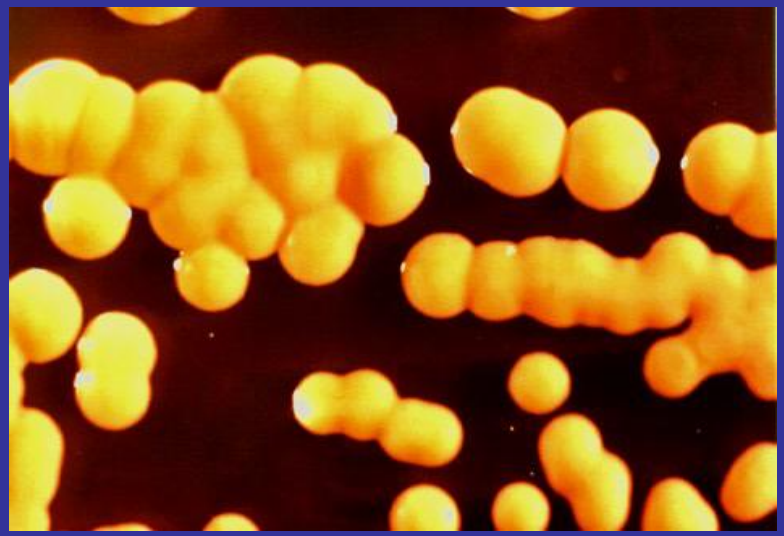


The Micrococcaceae

The family *Micrococcaceae* contains gram-positive cocci, 0.5-2.5 μm in diameter, that divide in more than one plane to form regular or irregular clusters of cells. All are aerobic or facultatively anaerobic. The peptidoglycan di-amino acid is L-lysine.

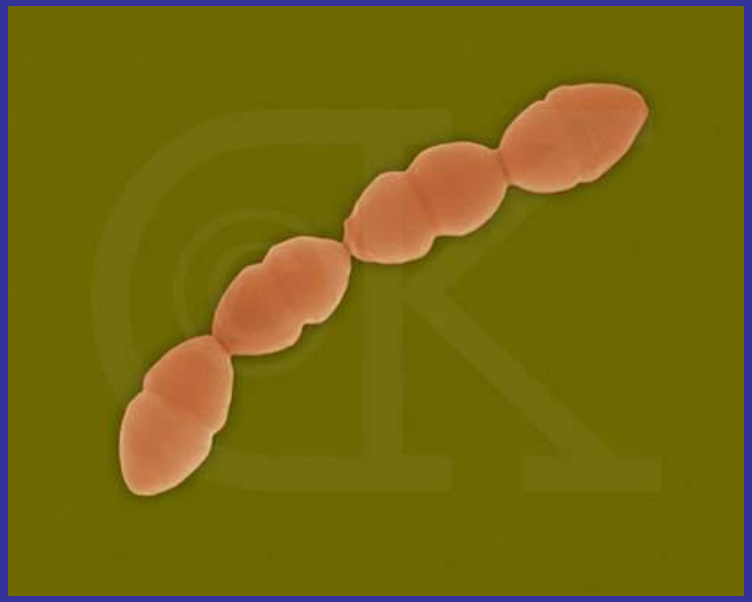
The three most important genera are:

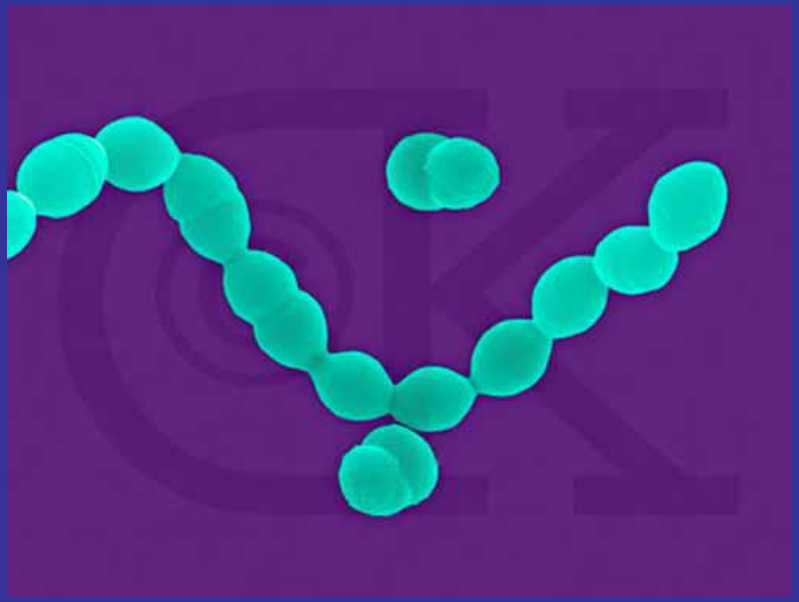
1. **Micrococcus**
2. **Staphylococcus**
3. **Streptococcus**



Micrococcus – aerobic, gram-positive, catalase positive, cell arranges mainly in pairs, tetrads, or irregular clusters, nonmotile. They are often yellow, orange or red in color

Staphylococcus - facultatively anaerobic, gram-positive, usually form irregular clusters, nonmotile, catalase positive but oxidase negative, ferment glucose anaerobically.



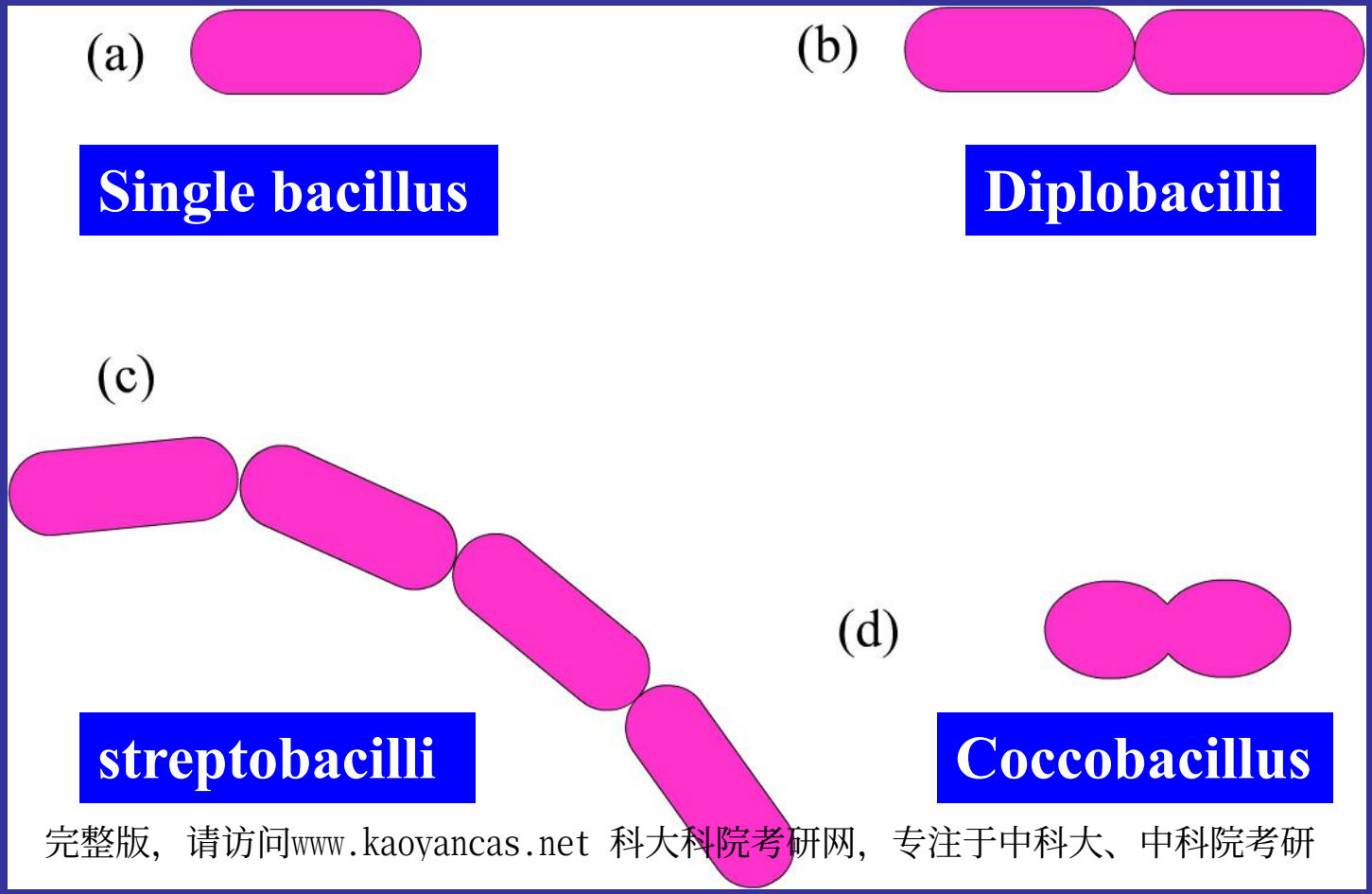


Streptococcus - facultatively anaerobic or microaerophilic, catalase negative, gram-positive, Cell arranges in pairs or chains, usually nonmotile,

A few species are anaerobic rather than facultative.

Rod-shaped bacteria

Bacilli divide only across their short axis, so there are fewer groupings of bacilli than of cocci.



Spore-forming rod shaped bacteria

Almost all Spore-forming bacteria are Gram$^+$

***Bacillus* – Aerobic**

Bacillus subtilis,

B. Mycoides

B. Pastturii

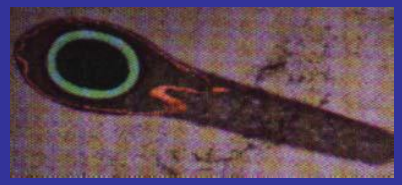
B. megaterium

B. Thuringiensis

B. Anthracis

B. Botulinus

B. cereus



***Clostridium* – Anaerobic**

Clostridium botulinus

C. butyricum

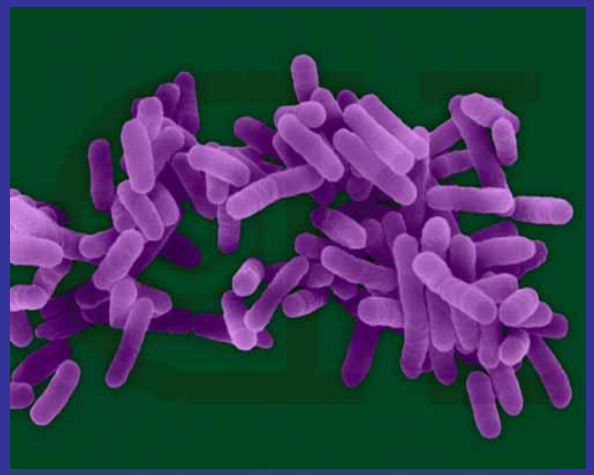
C. aceticum

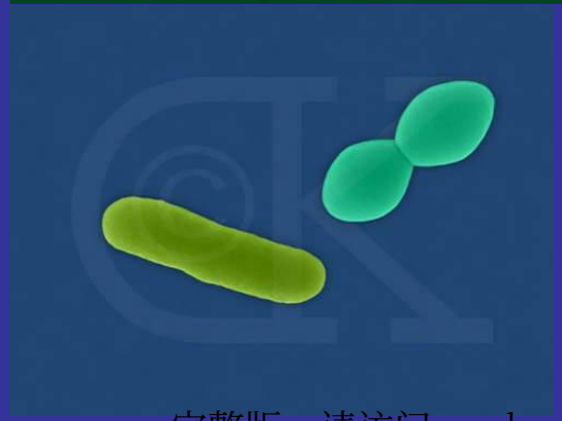
C. tetani

C. putrificum

Nonspore - forming rod shaped bacteria

Most nonspore – forming rod shaped bacteria are Gram -





Representatives:

Escherchia coli

Alcaligenes

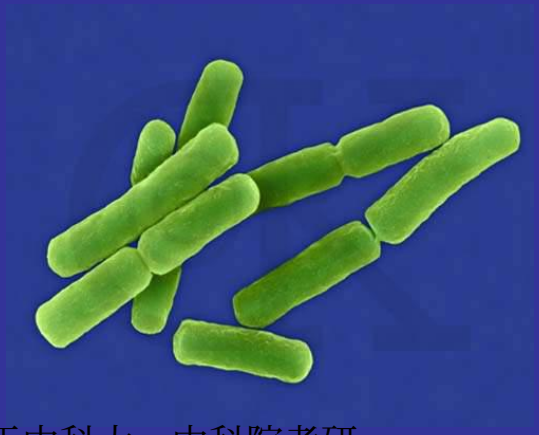
Proteus

Flavobacteria

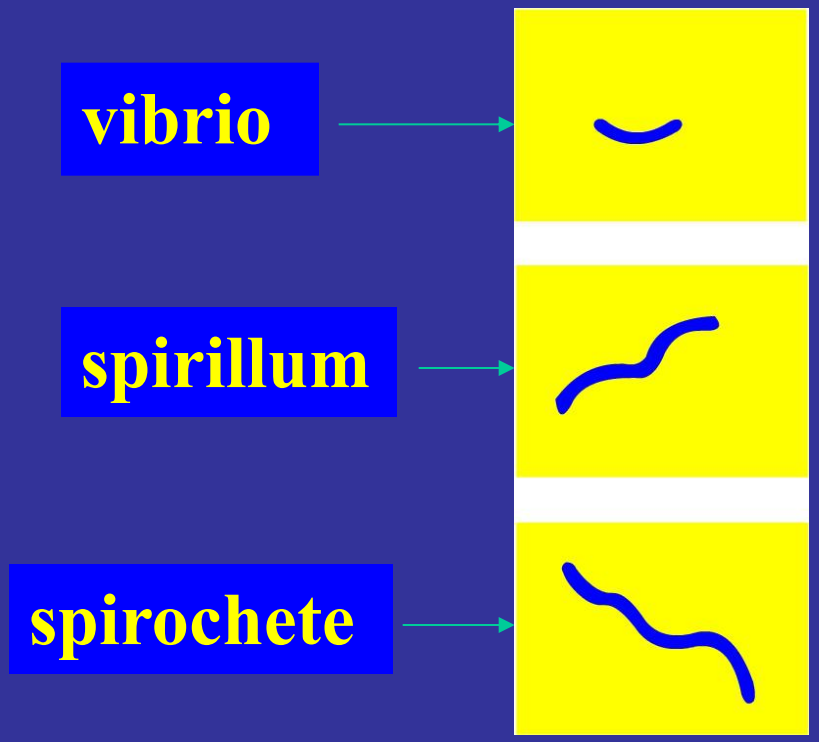
Pseudomonas

Rhizobium

Azotobacter



Vibrio, Spirillum and Spirochete



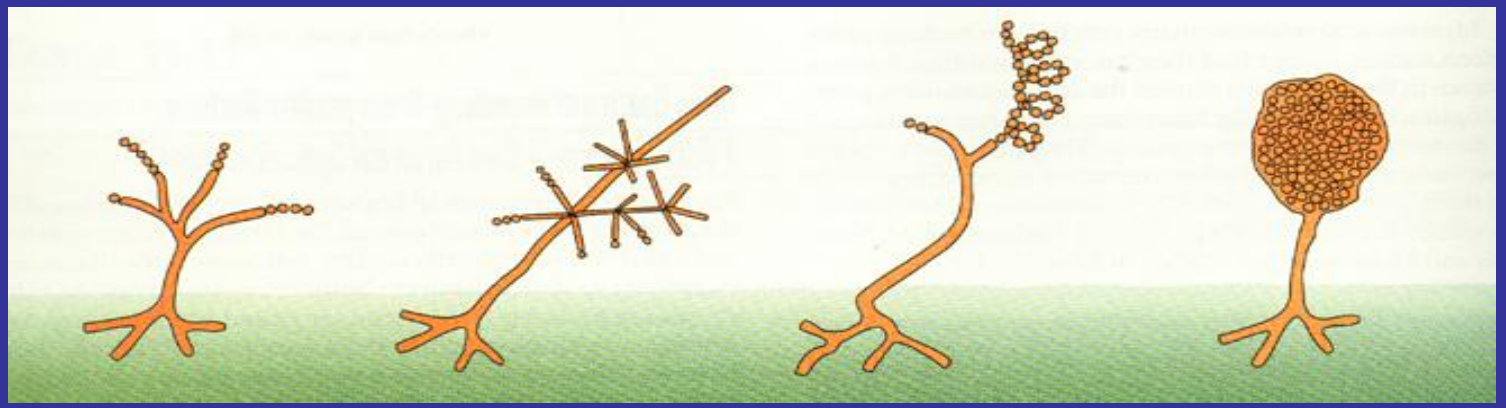
Some bacteria are shaped like long rods twisted into spirals or helices; they are called vibrios (like commas or incomplete spirals), spirilla if rigid and spirochetes when flexable.

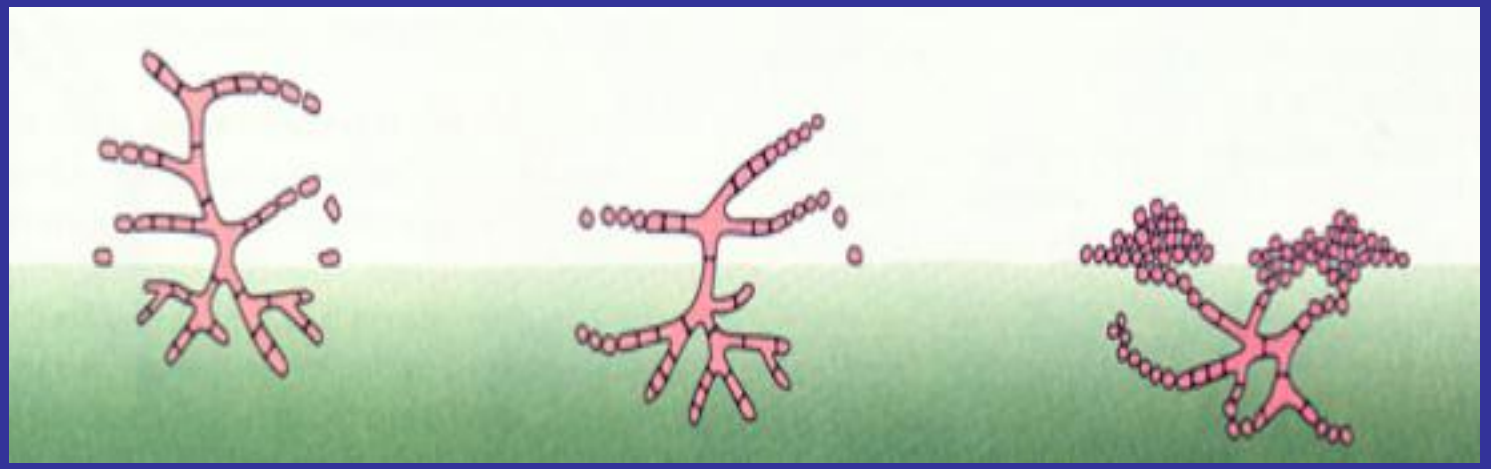
3.2 Actinomycetes

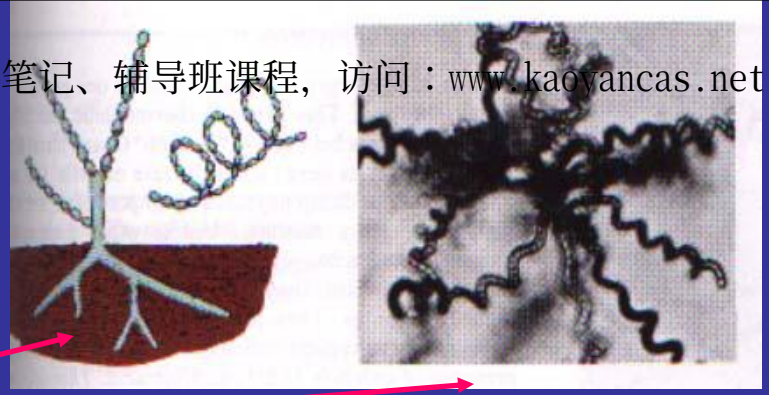
Actinomycetes are filamentous bacteria. Their morphology resembles that of the filamentous fungi; however, the filaments of actinomycetes consist of procaryotic cells. Some actinomycetes resemble molds by forming externally carried asexual spores for reproduction.

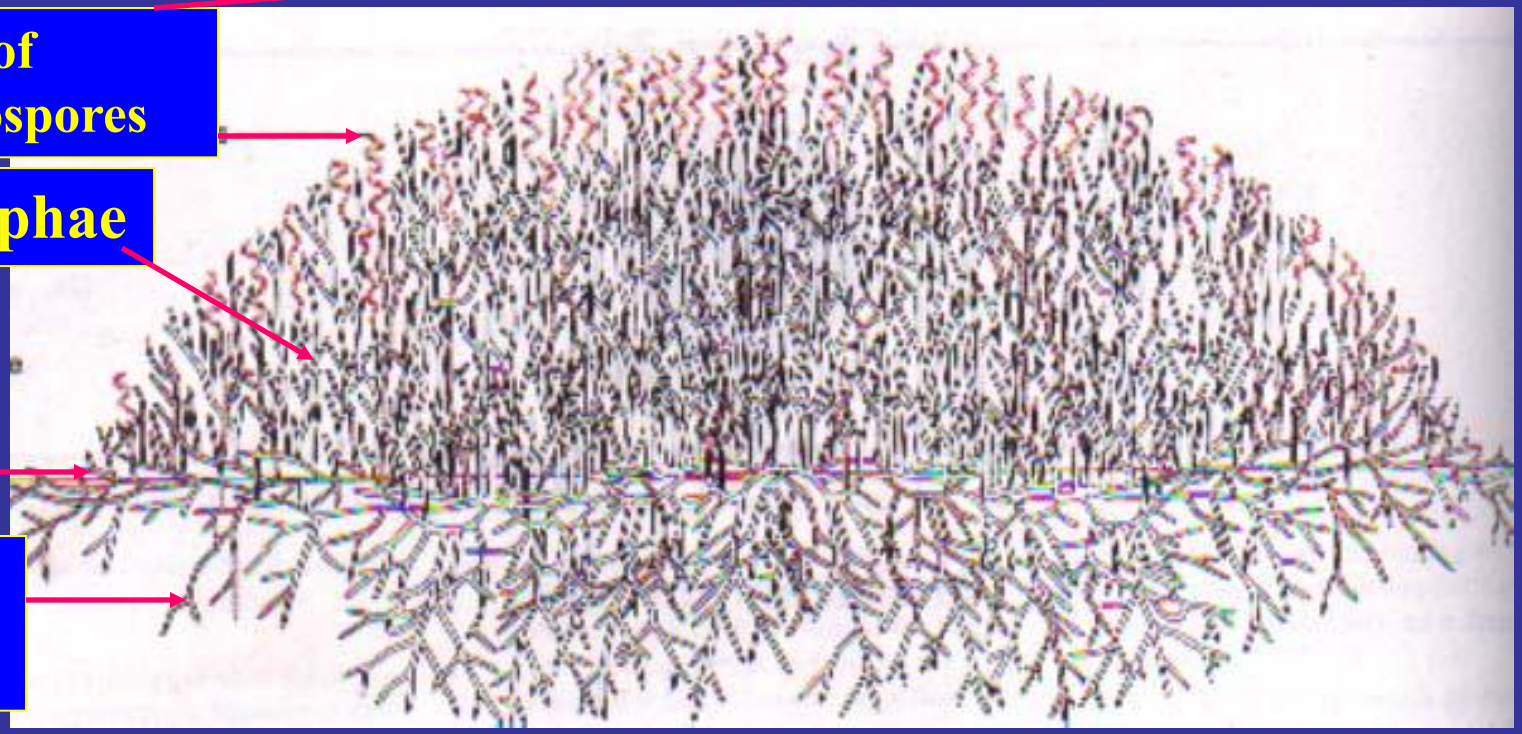
Filamentous, High G + C content, Gram-positive

(63 – 78% GC)



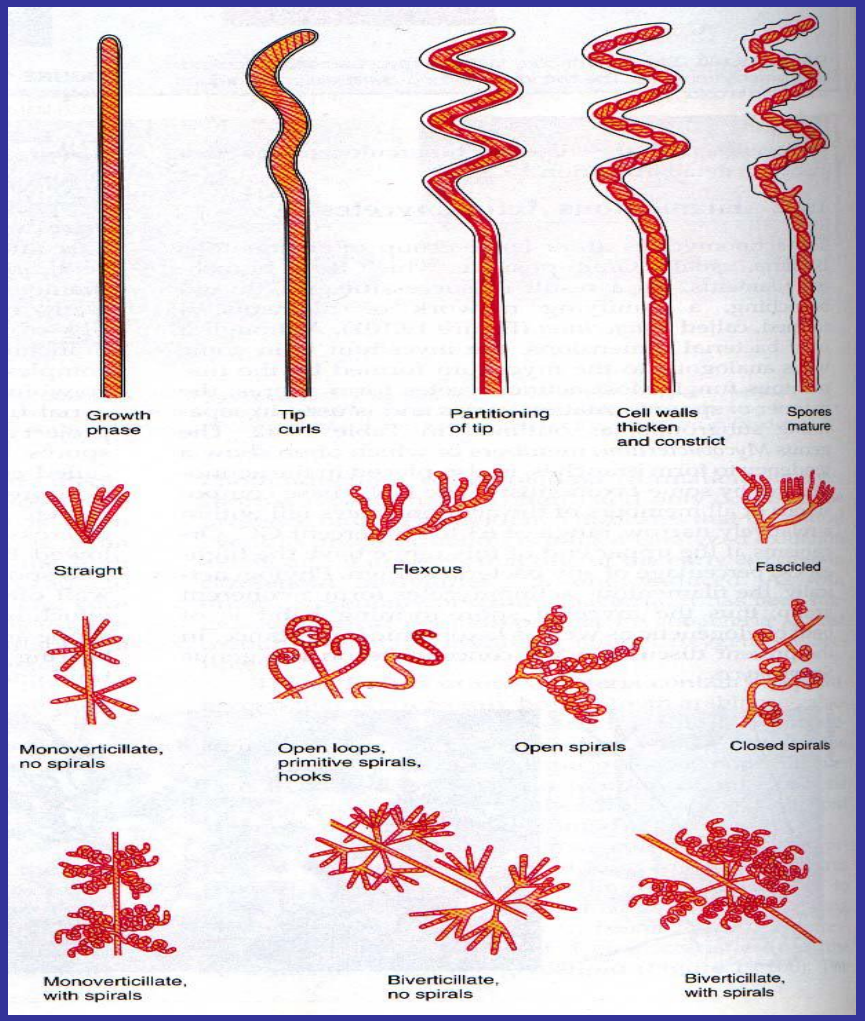






The cross section of an actinomycete colony showing the substrate mycelium and aerial mycelium with chains of conidiospores

Various types of spore-bearing structures on the streptomyces



Actinomycetes → Antibiotics

Representive genera:

Streptomyces

Nocardia

Actinomyces

Micromonospora

Streptosporangium

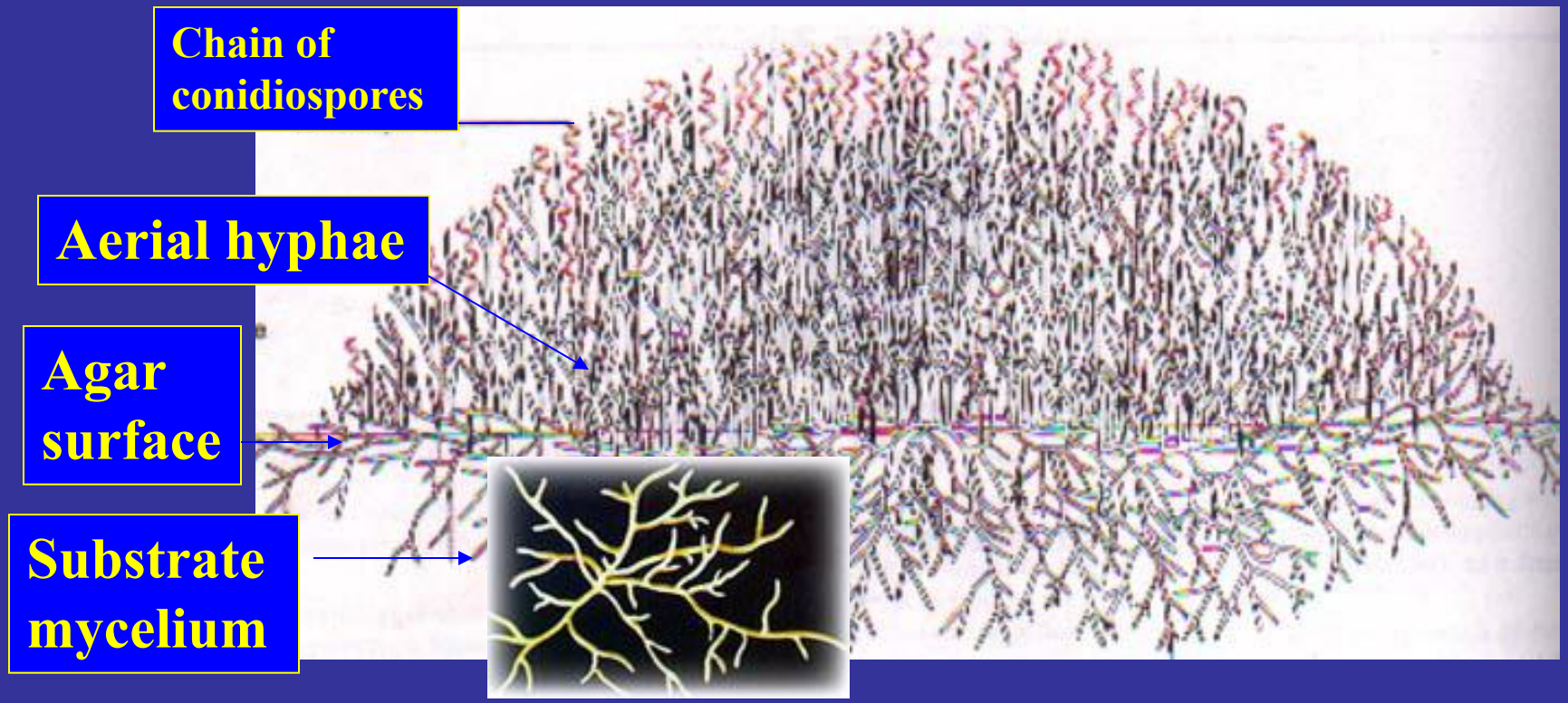
Actinoplanes

Frankia

Over 500 distinct antibiotic substances have been shown to be produced by streptomycete.

Most antibiotics are efficient against different bacteria.

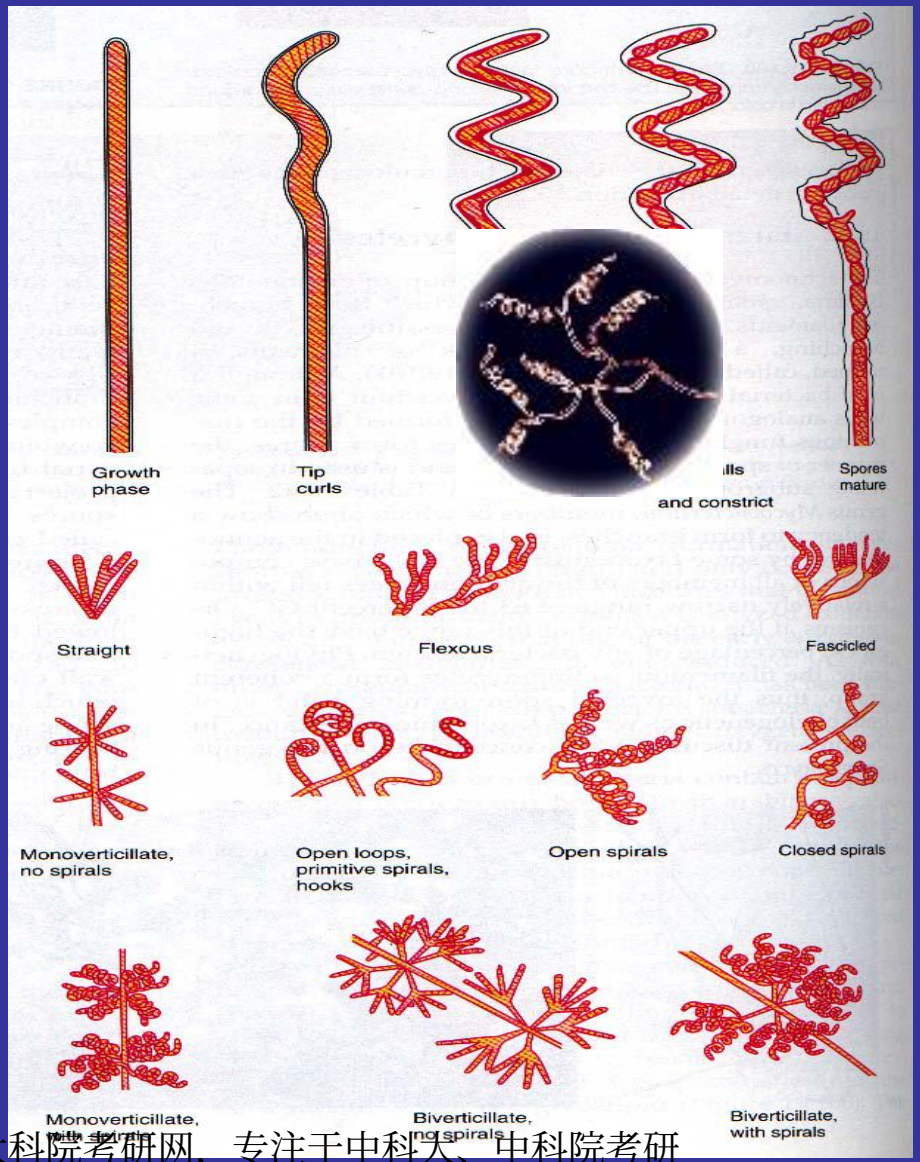
More than 50 antibiotics have been used in human and veterinary medicine, agriculture and industry

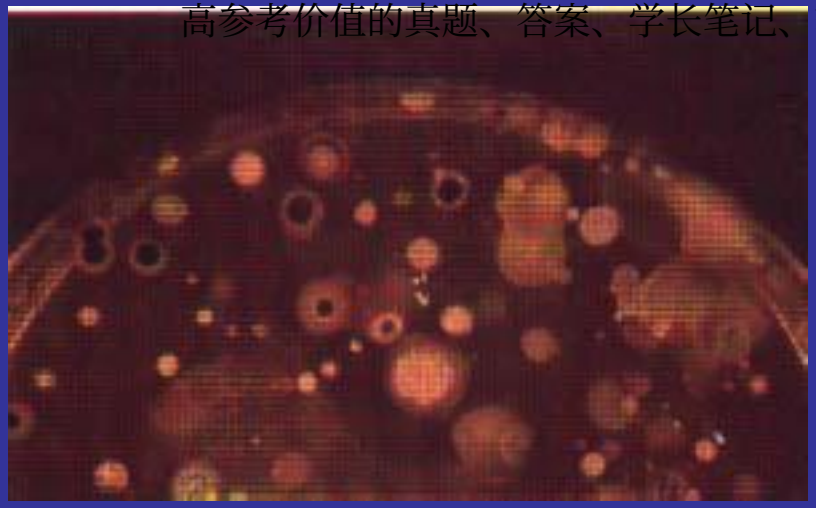


The cross section of an actinomycete colony showing the substrate mycelium and aerial mycelium with chains of conidiospores

Various types of spore-bearing structures on the streptomyces

Streptomyces spores, called conidia, are not related in any way to the endospores of *Bacillus and Clostridium* because the streptomycete spores are produced simply by the formation of cross-walls in the multinucleate sporophores followed by separation of the individual cells directly into spores.





Ecology and isolation of *Streptomyces*:

- Alkaline and neutral soils are more favorable for the development of *Streptomyces* than are acid soils.
- *Streptomyces* require a lower water potential for growth than many other soil bacteria.
- Media often selective for *Streptomyces* contain the usual assortment of inorganic salts

Concept

- The streptonycetes are a large group of filamentous, gram positive bacteria that form spores at the end of aerial filaments.
- They have the highest GC percentagein the DNA base composition of any bacteria known.
- Many clinically important antibiotics have come from Streptomycetes species

3.3 Cyanobacteria

The cyanobacteria have typical prokaryotic cell structures and a normal gram-negative cell wall.

They range in diameter from about 1 – 10 μm and may be unicellular or form filaments.

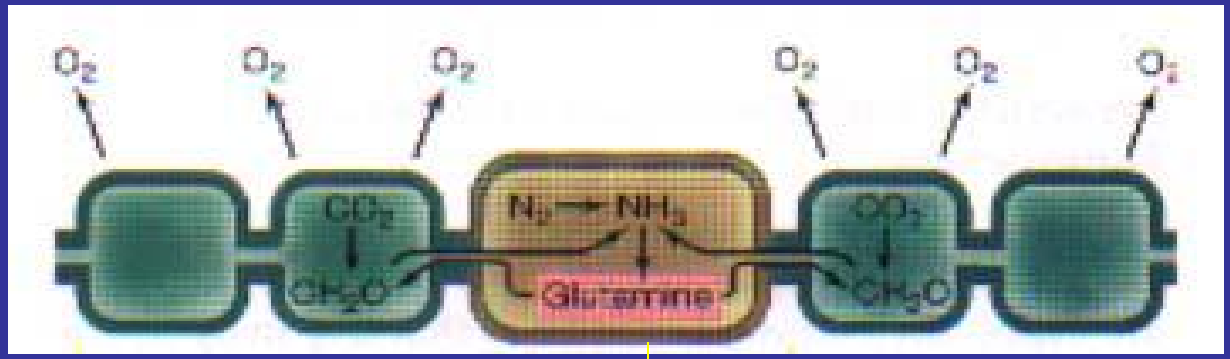
They have chlorophyll and carry out oxygen-producing photosynthesis, much as plants and the eukaryotic algae do.

Nonfilamentous cyanobacteria

Filamentous Cyanobacterium,
Anabaena sp.
(SEM x5,000)

The morphological diversity of the cyanobacteria is considerable. Both unicellular and filamentous forms are known, and considerable variation within these morphological types occurs.

Heterocysts have intercellular connections with adjacent vegetative cells, and there is mutual exchange of materials between these cells, with products of photosynthesis moving from vegetative cells to heterocysts and products of nitrogen fixation moving from heterocysts to vegetative cells.



Main function of Cyanobacteria

- **Photosynthesis**
- **Nitrogen fixation**

• The cyanobacteria are the largest and most diverse group of photosynthetic bacteria.

• The structure and physiology of the heterocyst ensures that it will remain anaerobic; it is dedicated to nitrogen fixation. It should be noted that nitrogen fixation also is carried out by cyanobacteria that lack heterocysts.

• Cycnobacteria are capable of considerable metabolic flexibility.

Physiology of cyanobacteria:

The nutrition of cyanobacteria is simple. Vitamins are not required, and nitrate or ammonia is used as nitrogen source.

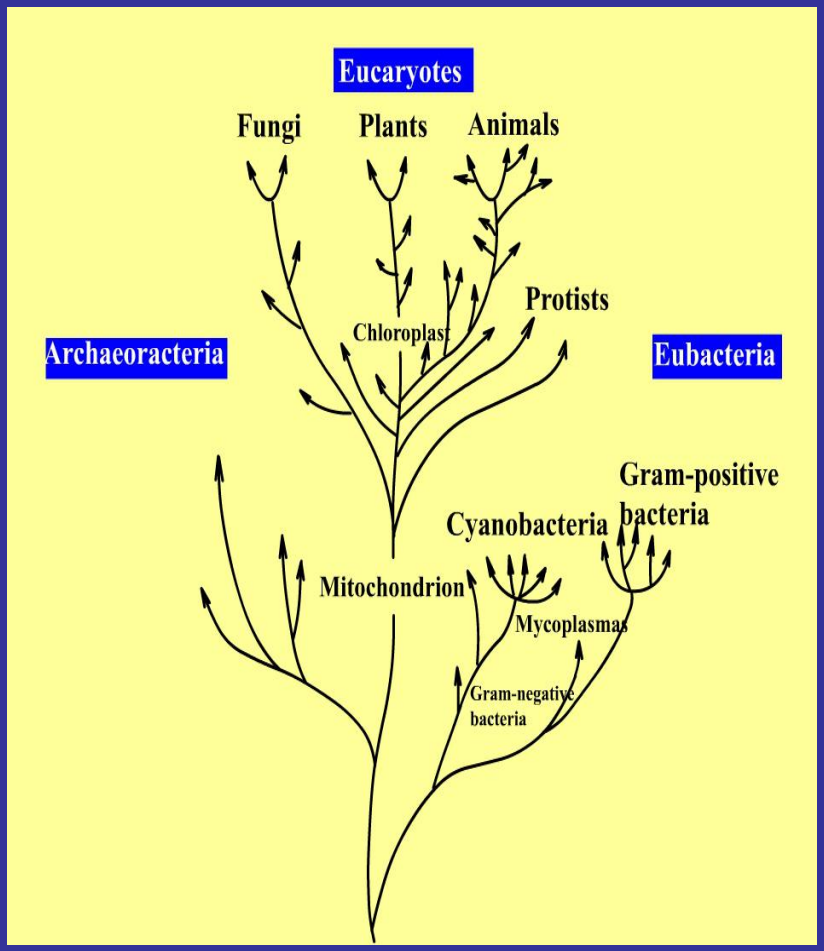
Nitrogen-fixing species are common.

Most species tested are obligate phototrophs, However, some cyanobacteria are able to grow in the dark on organic compounds, using the organic material as both carbon and energy source.

Problems !

Many cyanobacteria produce potent neurotoxins, and during water blooms when massive accumulations of cyanobacteria may develop, animals ingesting such water may succumb rapidly.

3.4 The Archaebacteria



Although archaebacteria are classified as procaryotes, these cells appear to be fundamentally different from typicaI bacteria or cyanobacteria. In fact, they represent a cell type that seems to be neither eucaryotic nor eubacterial.

The archaebacteria have the following unique combination of traits:

Prokaryotic traits:

- They are about 1 micrometer (*u*m) in diameter, the size of typical procaryotes.
- They lack membrane-bound organelles.
- They have nuclear bodies (nucleoids) rather than true, menbranee bound nuclei.
- Their ribosomes are 70 S, the size of those found in typical prokaryotes.

Eukaryotic traits:

- Their cell walls completely lack peptidoglycan.
- Their protein synthesis machinery is sensitive to inhibitors that typically affect only eukaryotes and is resistant to many inhibitors that affect prokaryotes.
- Some of their proteins, pigments, and biochemical processes closely resemble those found in eukaryotic cells.

Archaebacteria include three groups:

1. The methanogens, strict anaerobes that produce methane (CH_4) from carbon dioxide and hydrogen.

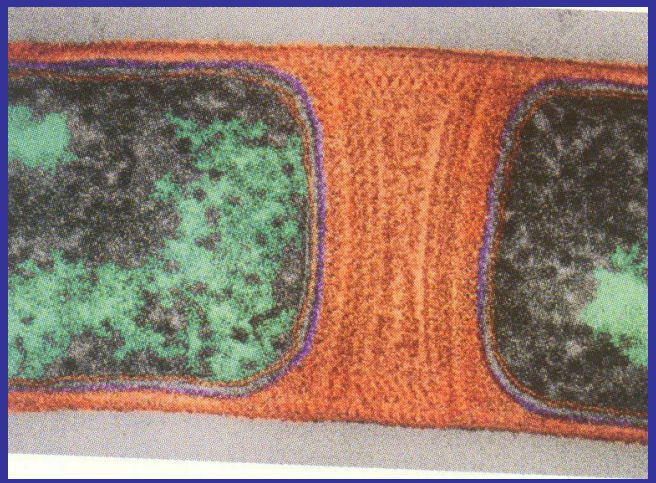
2. Extreme halophiles, which require high concentrations of salt for survival.

3. Thermoacidophiles, which normally grow in hot, acidic environments.

Methanogenic bacteria are strict anaerobes that obtain energy by converting $C0_2$, H_2, formate, acetate, and other compounds to either methane or methane and $C0_2$.

$$C0_2 + 4\ H_2 \longrightarrow CH_4 + 2\ H_2O$$

$$CH_3\ C00\ H \longrightarrow C0_2 + CH_4$$



Sewage treatment plants use the methane produced to generate heat and electricity.

Methanogenesis may eventually serve as a major source of pollution–free energy? !

Extremely thermophilic bacteria

They are gram-negative, aerobic, irregularly lobed spherical bacteria with a temperature optimum around 70-80 ^{0}C and a pH optimum of 2 to 3. Their cell wall contains lipoprotein and carbohydrates but lacks peptidoglycan.

Extreme halophilic bacteria

Their most distinctive characteristic is their requirement of a high concentration of sodium chloride for growth. They are aerobic chemoheterotrophs with respiratory metabolism and require complex nutrients, usually proteins and amino acids, for growth.

3.5 Other prokaryotes

- *Rickettsia*
- *Chlamydia*
- *Mycoplasma*
- Bdellovirio

Rickettsia

1. 0.2-0.5μm in diameter. obligate intracellular parasites. The majority of them are gram-negative and multiply only within host cells.
2. Binary fission within host cells.They lack the enzymatic capability to produce sufficient amounts of ATP to support their reproduction. They obtain the ATP from host cells.
3. Many species of them cause disease in humans and other animals.

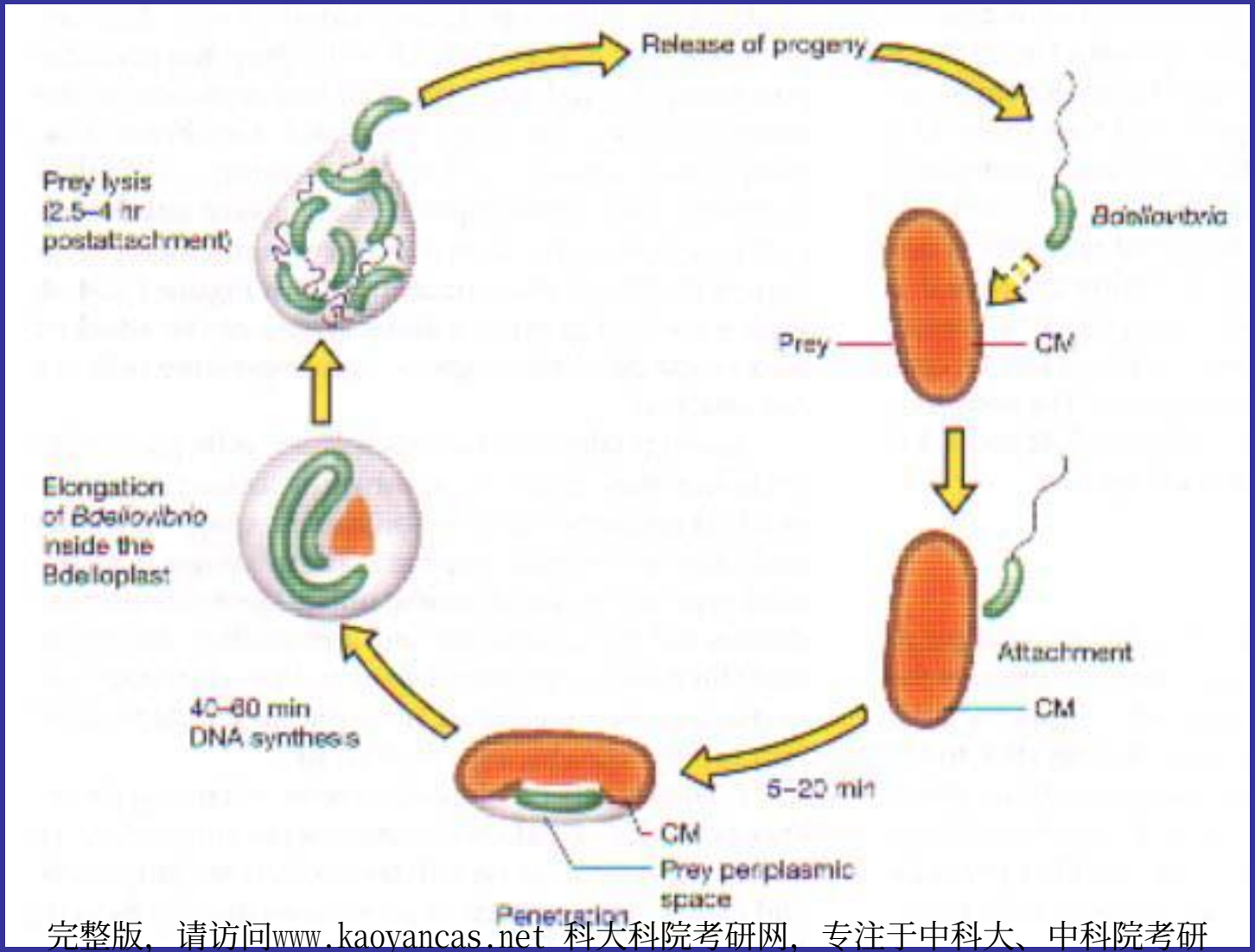
Chlamydia

- Obligate intracellular parasites, unable to generate sufficient ATP to support their reproduction.
- Gram-negative and cell divides by binary fission
- Cause human respiratory and genitourinary tract disease, and in birds they cause respiratory disease.

Mycoplasma

- Diameter=0.1-0.25 μm. They lack cell wall, are bounded by a single triple-layered membrane.
- They are the smallest organisms capable of self-reproduction.
- The colony is "fried egg" appearance.
- Several of them cause diseases in humans. (pneumonia, respiratory tract disease)

Bdellovirio



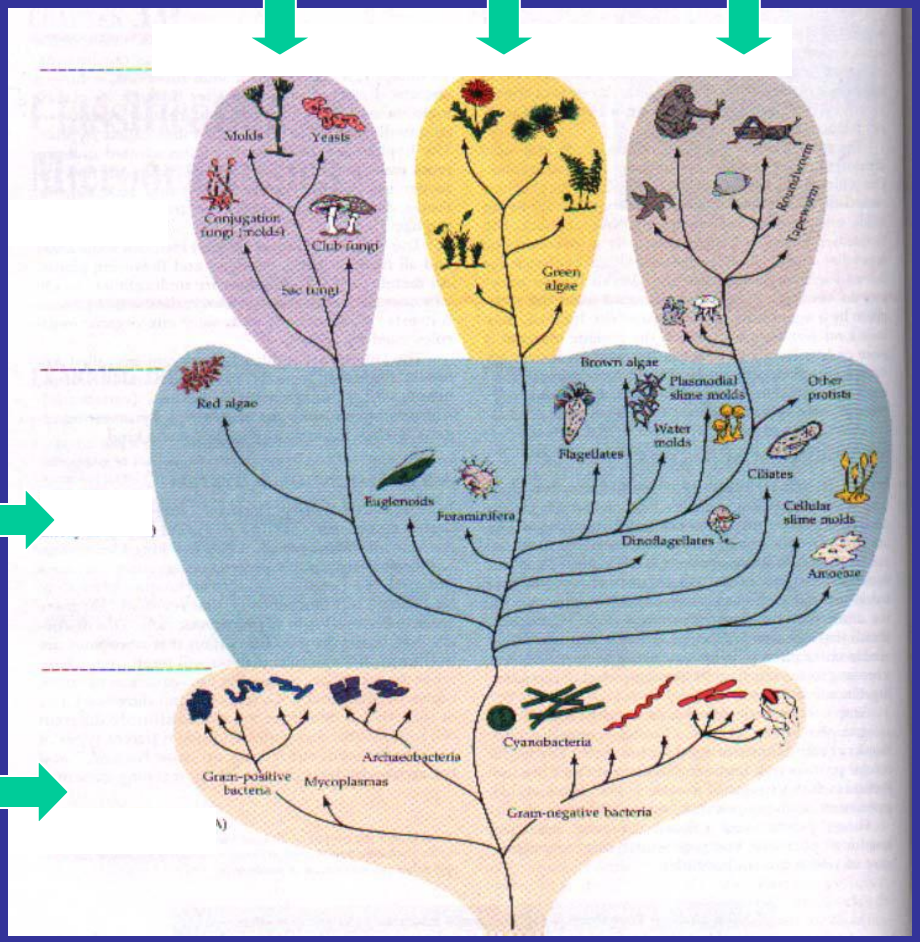
3.6 Classification of bacteria

1. MORPHOLOGICAL CHARACTERISTICS
2. DIFFERENTIAL STAINING
3. NUCLEIC ACID HYBRIDIZATION
4. NUMERICAL TAXONOMY

Fungi

Plant

Animal



Protista

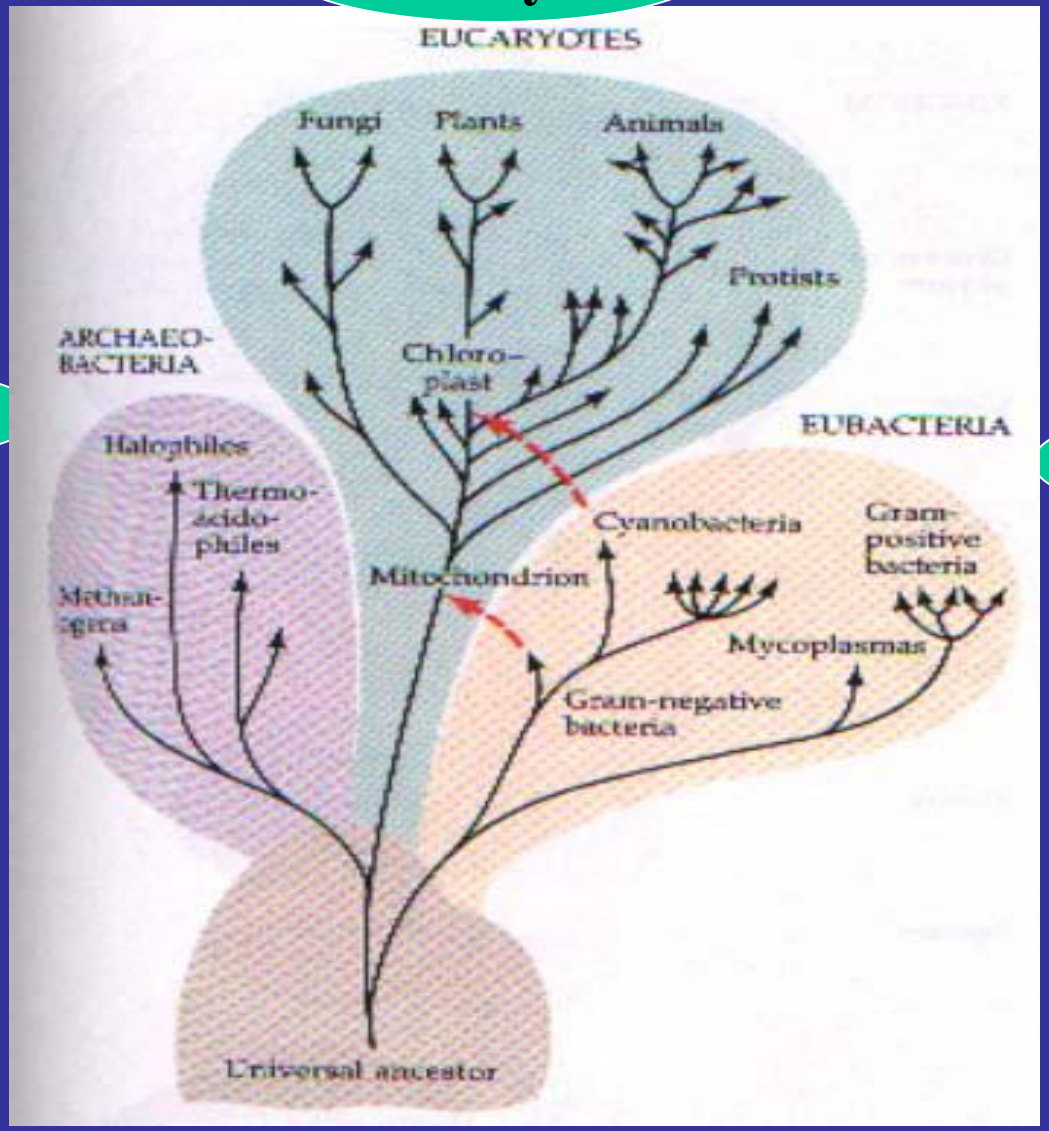
Prokaryotae

Five-kingdom system is a commonly accepted system of classification

Eukaryotes

Archaebacteria

Eubacteria



Universal Phylogenetic Tree derived from comparative sequencing of 16S or 18S RNA. Note the *three* major domains of living organisms.

Divisions and Classes in the Kingdom Procaryotae (Monera) Identified by Common Names

DIVISION	*CLASS*
Typical gram-negative cell wall	Nonphotosynthetic bacteria
	Anaerobic photosynthetic bacteria
	Cyanobacteria
Typical gram-positive cell wall	Rods and cocci Actionmycetes and related organisms
Wall-less procaryotes	Mycopeanas
Unusual walls	Archaeobacteria

The taxonomic classification scheme for bacteria may be found in ***Bergey's Manual of Systematic Bacteriology.***

In Bergey's Manual, bacteria are divided into four divisions. Three divisions consist of eubacterial cells, and the fourth division consists of the archaeobacteria. Each division is divided into classes

Classes are divided into orders → families → genera → species

Bacterial species is defined simply as a population of cells with similar characteristics.

Strain is a group of cells all derived from a single cell.

MORPHOLOGICAL CHARACTERISTICS

Morphological characteristics are useful in identifying bacteria. For example, differences in such structures as endospores or flagella can be helpful. However, many microorganisms appear too similar to be classified by their structures.

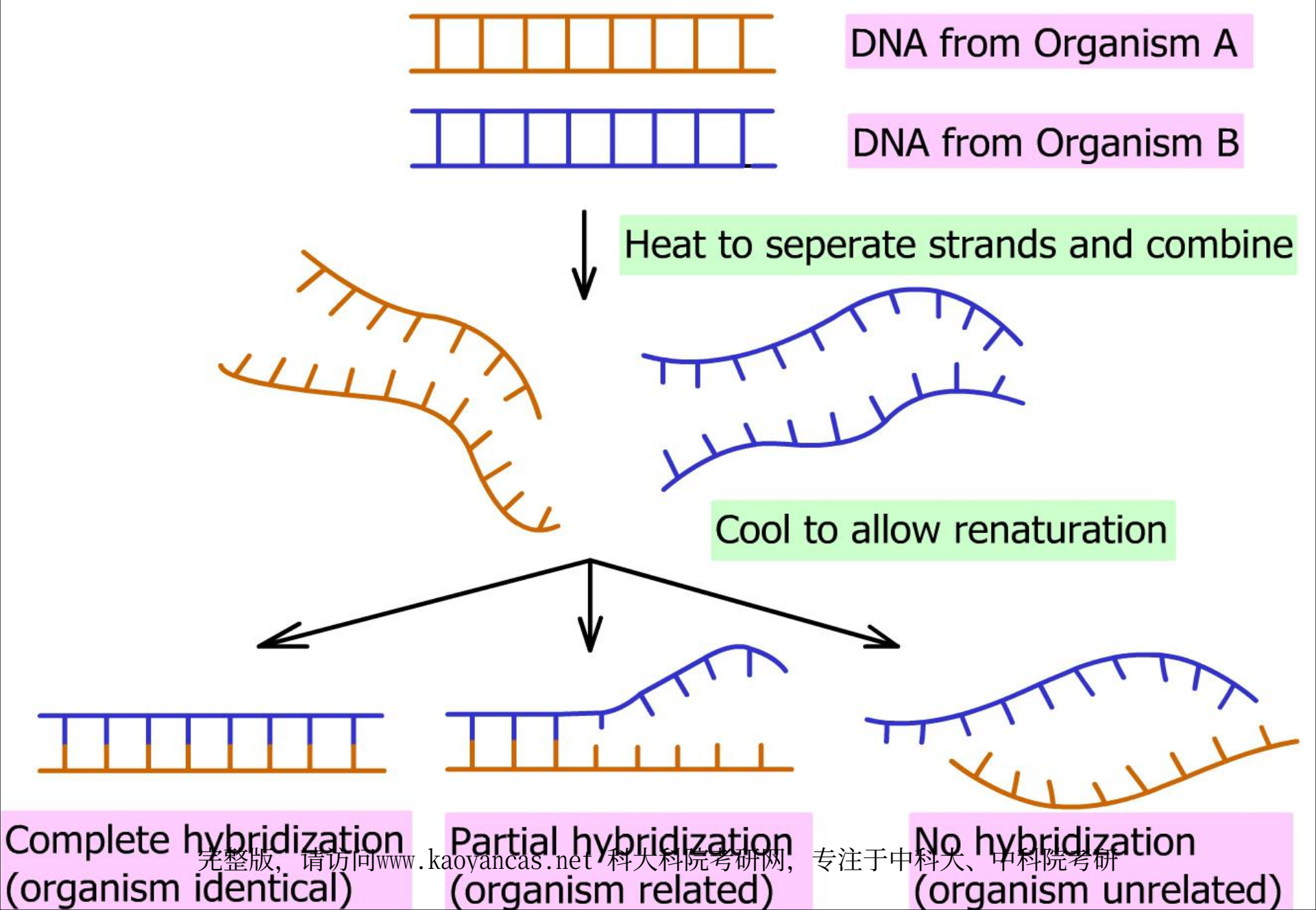
DIFFERENTIAL STAINING

(For example Gram staining) Most bacteria are either gram-positive or gram-negative. But not useful in identifying either the wall-less bacteria or the archaeobacteria with unusual walls.

NUCLEIC ACID HYBRIDIZATION

- The similarity between genomes can be compared more directly by use of nucleic acid hybridization studies.
- If a mixture of single-stranded DNA formed by heating dsDNA is cooled and held at a temperature below the *T*m, strands with complementary base sequences will reassociate to form stable dsDNA, whereas noncomplementary strands will remain single.

NUCLEIC ACID HYBRIDIZATION



NUMERICAL TAXONOMY

The development of computers has made possible the quantitative approach known as *numerical taxonomy*.Information about the properties of organisms is converted into a form suitable for numerical analysis and then compared by means of a computer.

The resulting classification is based on general similarity as judged by comparison of many characteristics,each given equal weight.

REVIEW QUESTIONS

1. Describe the characteristics most important in distinguishing between members of the following groups of genera: *Staphylococcus* and *Streptococcus*, *Bacillus* and *Clostridium*.

2. How do spores and the process of sporulation in a *Streptomyces* species differ from that in a *Bacillus* species?

3. Why is nitrogen fixation an oxygen-sensitive process? How are *cyanobacteria* able to fix nitrogen when they also carry out oxygenic photosynthesis?
4. What is a *heterocyst* and what is its function ?
5. How would you select the best features to use in identification of unknown procaryotes and determination of relatedness?