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Actinobacteria

Morphology, Physiology, biochemistry, diversity & Industrial Applications of genus Actinobacteria

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Contents

1) Introduction to Phylum Actinobacteria

High G + C **gram positive** bacteria are in the phylum Actinobacteria. Many bacteria in this phylum are **highly pleomorphic** in their morphology; the genera (examples : *Corynebacterium* and *Gardnerella*) several genera such as *Streptomyces* grow only as extended, often **branching filaments**. Several important **pathogenic genera** are found in the Actinobacteria, such as the *Mycobacterium* species causing tuberculosis is and leprosy.

The genera *Streptomyces*, *Frankia*, *Actinomyces*, and *Nocardia* are often informally called as **Actinomycetes** (from the Greek Actina =ray) because they have a radiate, or star like, form of growth by reason of their often-branching filaments. Superficially, their morphology resembles that of filamentous fungi. However, the actinomycetes are prokaryotic cells, and their filaments have a diameter much smaller than that of the eukaryotic molds. Some actinomycetes further resemble molds by their possession of externally carried asexual spores that are used for reproduction. *Corynebacteria* a genera of Actinobacteria has unusual method of cell division.

Filamentous bacteria in this phylum are like filamentous fungi. They are very common inhabitants in soil, where a filamentous pattern of growth has advantages. The filamentous organism can bridge water free gaps between soil particles to move to a new nutritional site. This morphology of Actinobacteria also gives the organism a **much higher surface to-volume ratio** and improves its ability to absorb nutrients in the highly competitive soil environment.

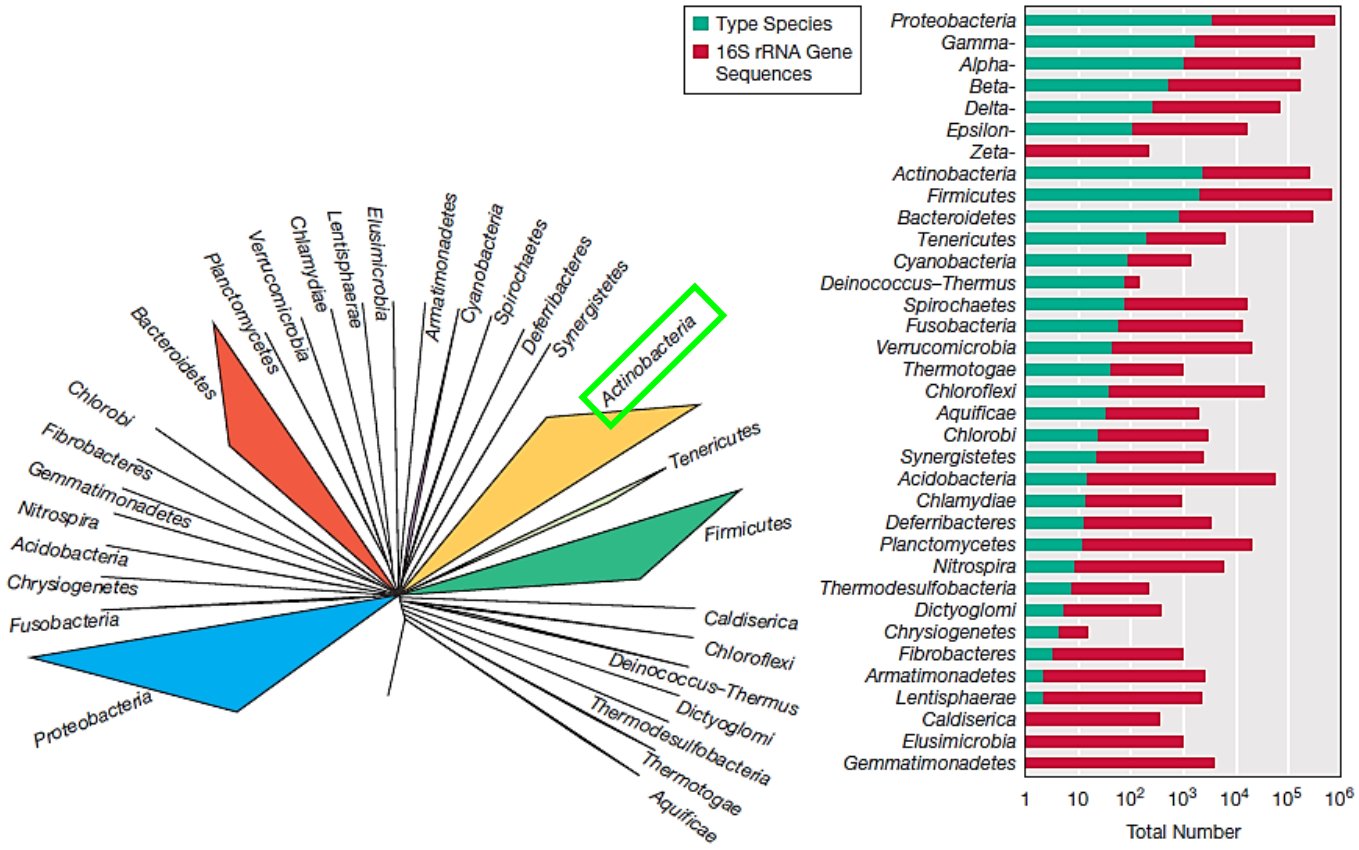


Fig 1: Some major phyla of *Bacteria* based on 16S ribosomal RNA gene sequence comparisons.

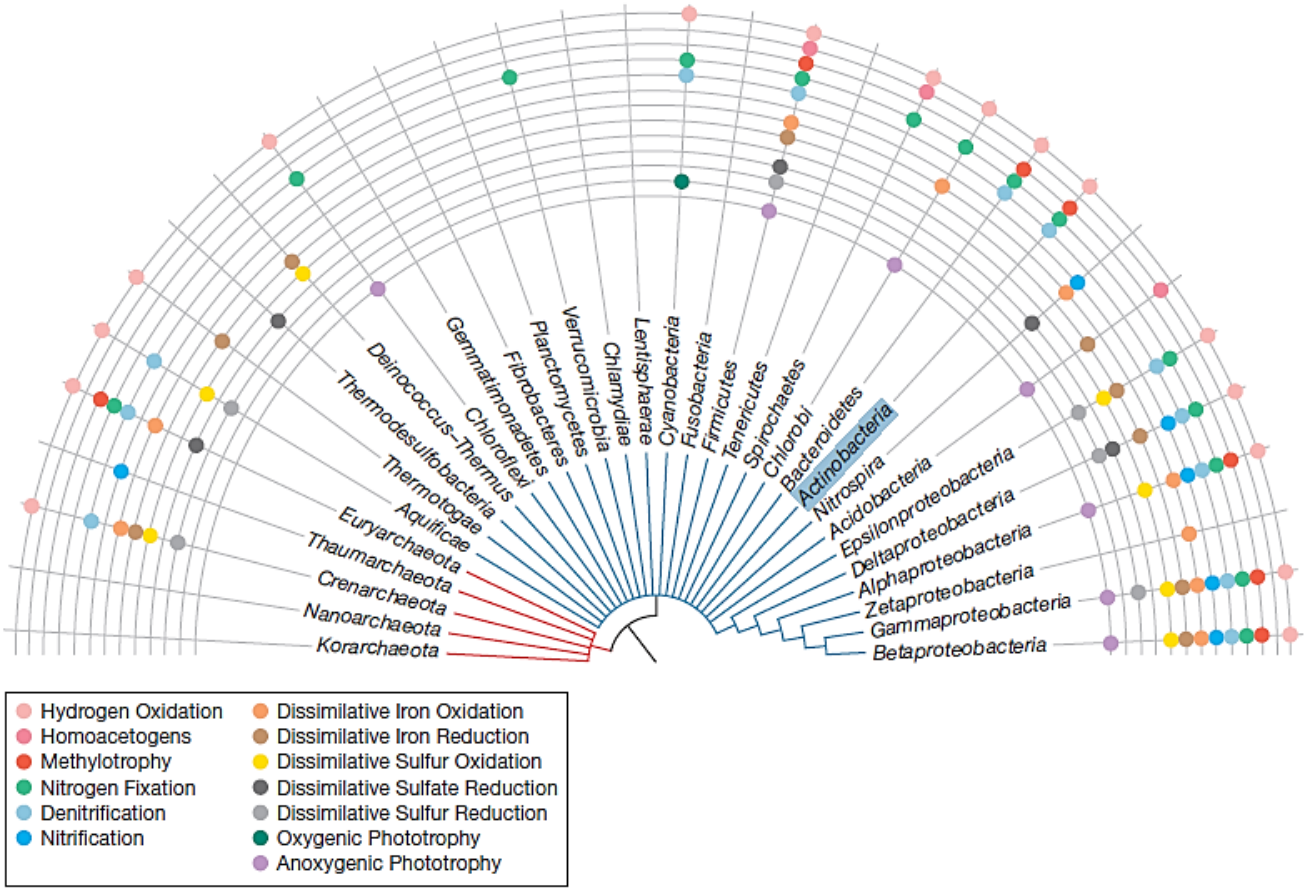


Fig 2: Major functional traits mapped across major phyla of *Bacteria* and *Archaea*

Phylum Class	Order	Important Genera	Special Features
Actinobacteria (The High G + C Gram-Positive Bacteria)			
	Actinomycetales	*Actinomyces*	Filamentous, branching, some human pathogens
		Corynebacterium	Human pathogens
		Frankia	Symbiotic nitrogen fixers
		Gardnerella	Human pathogens
		Mycobacterium	Acid-fast, human pathogens
		Nocardia	Filamentous, branching, opportunistic pathogens
		Propionibacterium	Propionic acid producers
		Streptomyces	Filamentous branching, many produce antibiotics

Fig 3: Actinomycetes Taxonomy from *Bergey's Manual of Systemic Bacteriology*, Second Edition

2) Coryneform bacteria

Coryneform bacteria are gram-positive, aerobic, **nonmotile**, **rodshaped** organisms that form irregular-shaped, club-shaped, or V-shaped cell arrangements during growth. V-shaped cells arise as a result of an abrupt movement that occurs just after cell division, a process called **snapping division**.

Snapping division occurs because the cell wall consists of two layers. Only the inner layer participates in cross-wall formation, and so after the cross-wall is formed, the two daughter cells remain attached by the outer layer of the cell wall. Localized rupture of this outer layer on only one side of the cell results in a bending of the two cells away from the ruptured side and thus development of V-shaped forms.

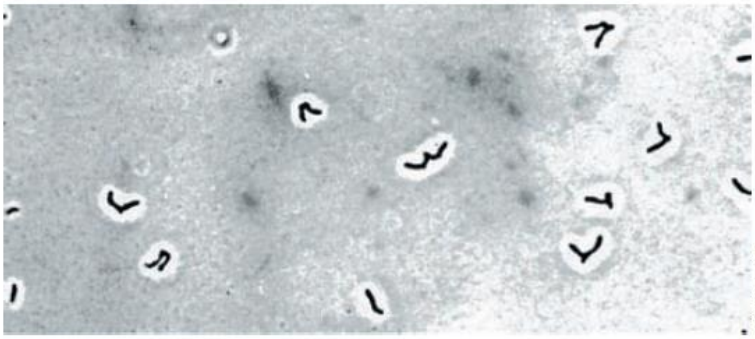
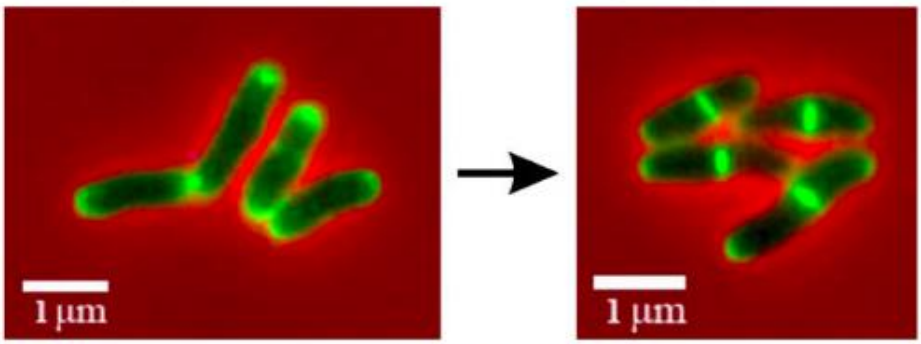
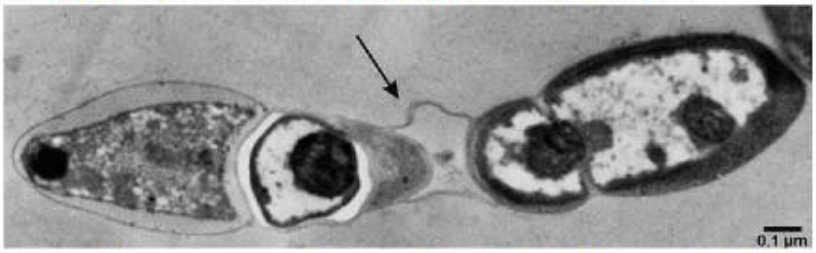


Fig 4: Snapping division in *Arthrobacter*

Corynebacterium - Snapping Division



Vancomycin-FL staining of *C. glutamicum*. It synthesizes peptidoglycan at the cell poles (cell elongation, left); when the correct size is reached the cells begin to synthesize peptidoglycan at the septum (cell division, right).



TEM of two *C. glutamicum* V-shaped cells, products of snapping division. The unknown compound present on the cell surface (arrow) may maintain the link between the two daughter cells.

Antonie van Leeu
2008. 94(1)99-10

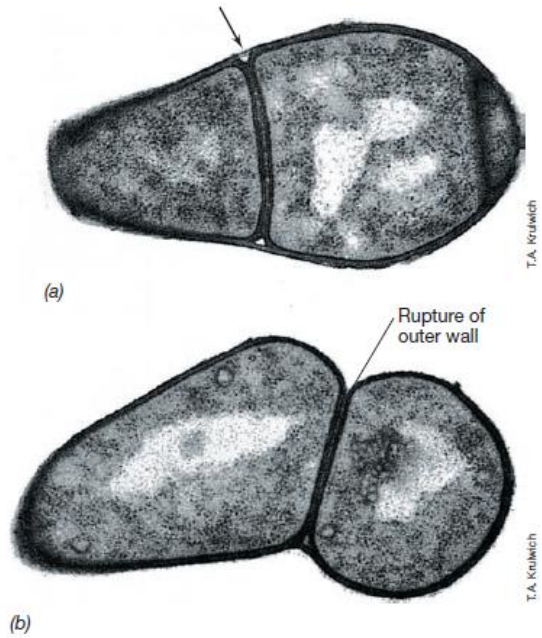


Fig 5: Cell division in *Arthrobacter*.
Transmission electron micrographof cell division in *Arthrobacter crystallopoietes*, illustrating how snapping division and V-shaped cell groups arise.
(a) Before rupture of the outer cell wall layer (arrow).
(b) After rupture of the outer layer on one side. Cells are 0.9–1 µm in diameter.

The main genera of coryneform bacteria are ***Corynebacterium*** and ***Arthrobacter***. The genus *The* corynebacteria (coryne = club-shaped) tend to be pleomorphic, and their morphology often varies with the age of the cells. The best-known species is *Corynebacterium diphtheriae*, the causative agent of Diphtheria .

The genus *Arthrobacter*, consisting primarily of soil organisms,is distinguished from *Corynebacterium* on the basis of a developmental cycle involving conversion from rod to coccus and back to rod again . However, some coryneform bacteria are **pleomorphic** and form coccoid cells during growth, and so the distinction between the two genera on the basis of life cycle is not absolute. The *Corynebacterium* cell frequently has a swollen end, so it has a club-shaped appearance, whereas *Arthrobacter* species are less commonly club-shaped.

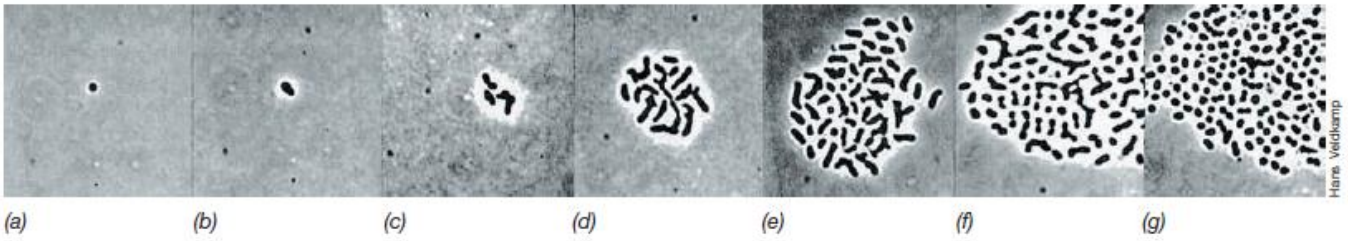


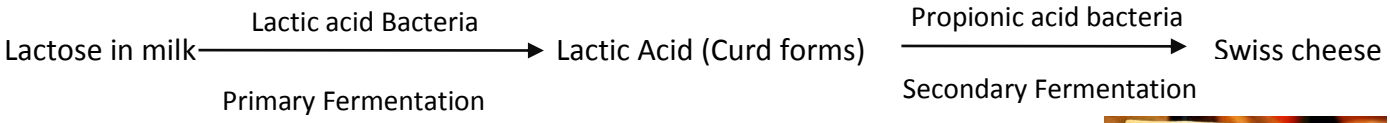
Fig 6: Stages in the life cycle of *Arthrobacter globiformis* as observed in slide culture.

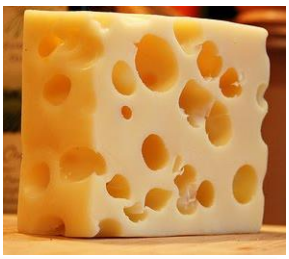
Along with the Actinobacteria, species of *Arthrobacter* are among the most common of all soil bacteria. They areremarkably resistant to desiccation and starvation, despite the fact that they **do not form spores or other resting cells**. Arthrobacters are a heterogeneous group that have considerable nutritional versatility,and strains have been isolated that decompose herbicides, caffeine, nicotine, phenols, and other unusual organic compounds.

3) Propionic Acid bacteria

Propionic acid producing bacteria are listed under *Propionibacterium.* The name of the genus *Propionibacterium* is derived from the organism's ability to produce propionic acid. Some species are important in the fermentation of Swiss cheese. *Propionibacterium acnes* are bacteria that are commonly found on human skin and are implicated as the primary bacterial cause of acne. The genus *Propionibacterium* was first discovered in Swiss (Emmentaler) cheese, where their fermentative production of CO_2 produces the characteristic holes and the propionic acid they produce is at least partly responsible for the unique flavor of the cheese.

The bacteria in this group are gram positive **anaerobes** that **ferment lactic acid**, **carbohydrates, and polyhydroxy alcohols**, **producing primarily propionic acid, acetic acid, and CO_2**. The fermentation of lactate is of interest because lactate itself is an end product of fermentation for many bacteria. The starter culture in Swiss cheese manufacture consists of **a mixture of homofermentative streptococci and lactobacilli, plus propionic acid bacteria**. The homofermentative organisms carry out the initial fermentation of lactose to lactic acid during formation of the curd (protein and fat). After the curd has been drained, the propionic acid bacteria develop rapidly. The eyes (or holes) characteristic of Swiss cheese are formed by the accumulation of CO_2, the gas diffusing through the curd and gathering at weak points. The propionic acid bacteria are thus able to obtain energy anaerobically from a product that other bacteria have produced by fermentation. This metabolic strategy is called a *secondary fermentation*.





Propionic acid Fermentation Pathway by *Propionibacterium*

When glucose is the starting substrate, it is first catabolized to pyruvate by the glycolytic pathway. Then pyruvate, produced either from glucose or from the oxidation of lactate, is converted to acetate plus CO_2 or carboxylated to form methylmalonyl-CoA, the latter is converted into oxaloacetate and, eventually, propionyl-CoA. Propionyl-CoA reacts with succinate in a step catalyzed by the enzyme CoA transferase, producing succinyl-CoA and propionate. This results in a lost opportunity for ATP production from propionyl-CoA but avoids the energetic costs of having to activate succinate with ATP to form succinylCoA. The succinyl-CoA is then isomerized to methylmalonyl-CoA and the cycle is complete; propionate is formed and CO_2 regenerated.NADH is oxidized in the steps between oxaloacetate and succinate. The reduction of fumarate to succinate is linked to electron transport reactions and the formation of a proton motive force, this yields one ATP by oxidative phosphorylation.

The propionate pathway also converts some lactate to acetate, CO_2, which allows for additional ATP to be made by substrate-level phosphorylation. Thus, in the propionate fermentation, both substrate-level *and* oxidative phosphorylation occur.

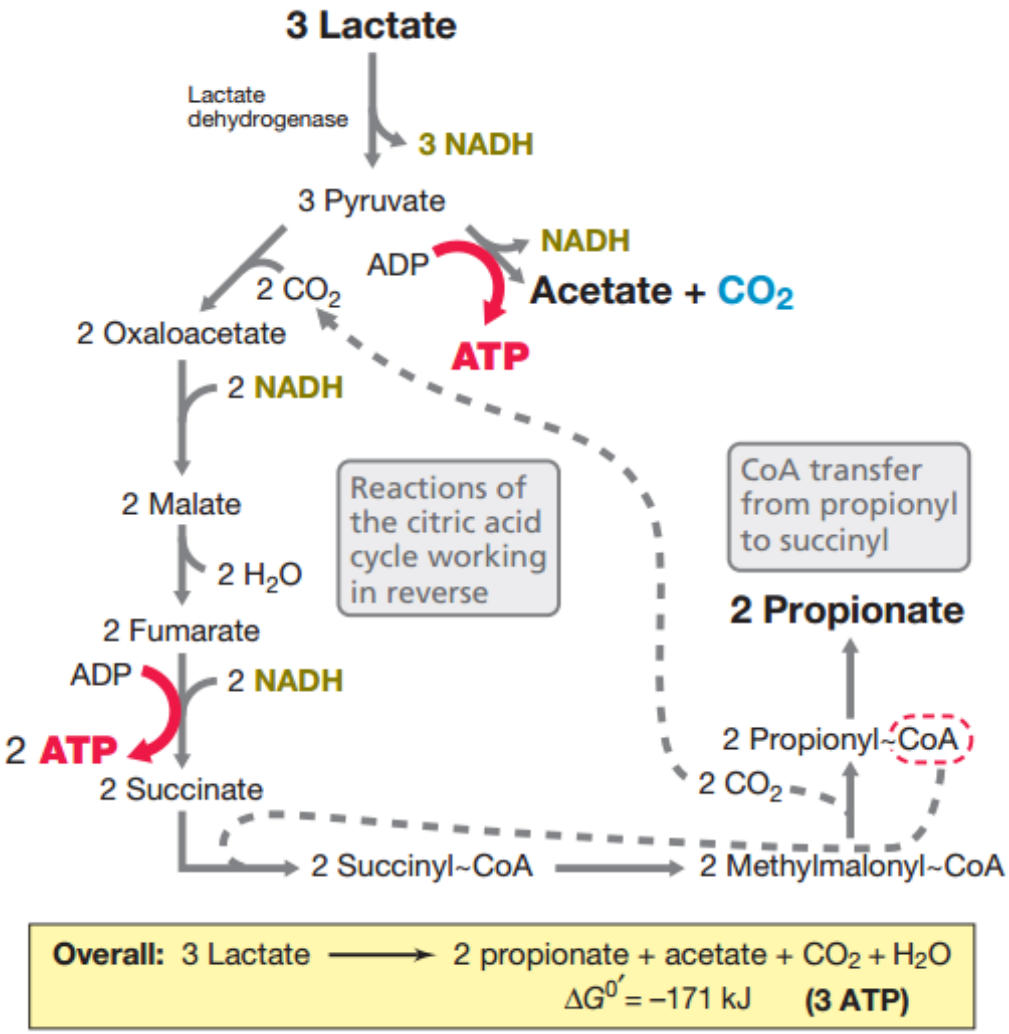
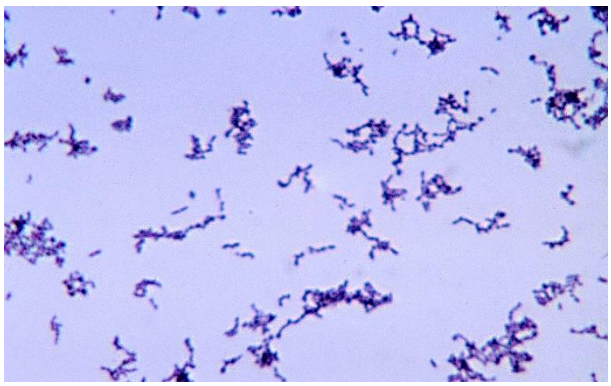


Fig 7: Propionic acid fermentation pathway by *Propionibacterium.*



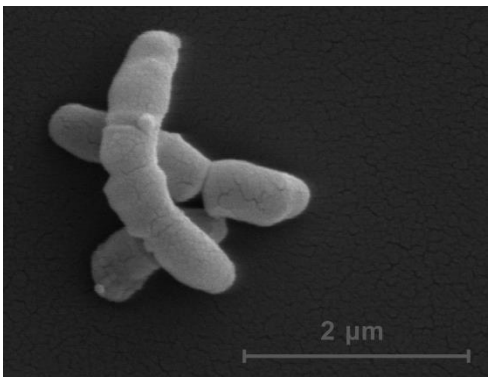


Fig 8: *Propionibacterium acnes* Gram staining SEM image

4) Genus *Mycobacterium*

The mycobacteria are **aerobic**, **non-endospore forming rods**. The name *myco,* meaning fungus like, was derived from their occasional exhibition of filamentous growth. Many of the characteristics of mycobacteria, such as **acid-fast staining**, drug resistance, and pathogenicity, are related to their distinctive cell wall, which is structurally bit similar to gram-negative bacteria. However, the outermost lipopolysaccharide layer in mycobacteria is replaced by **mycolic acids**, which form a waxy, water resistant layer. This makes the bacteria resistant to stresses such as drying. Also, few antimicrobial drugs are able to enter the cell. Nutrients enter the cell through this layer very slowly, which is a factor in the slow growth rate of mycobacteria, it sometimes takes weeks for visible colonies to appear. The mycobacteria include the important pathogens *Mycobacterium tuberculosis*, which causes tuberculosis, *Mycobacterium leprae* which causes leprosy.

The slow-growing mycobacteria are more likely to be pathogenic to humans. The rapidly growing group also contains a number of occasional, nontuberculous human pathogens, which most commonly infect wounds. However, these mycobacteria are more likely to be nonpathogenic soil and water microbes.

Acid-fast staining is a distinctive property that can be observed in the life cycle of *Mycobacterium*. This property is due to the presence of unique lipids called **Mycolic acids**, found only in species of the genus *Mycobacterium*, on the surface of the mycobacterial cell. Mycolic acids are a group of complex branched-chain hydroxylated lipids covalently bound to peptidoglycan in the cell wall, the complex gives the cell surface a waxy, hydrophobic consistency. It provides water resistant ability to the cell.

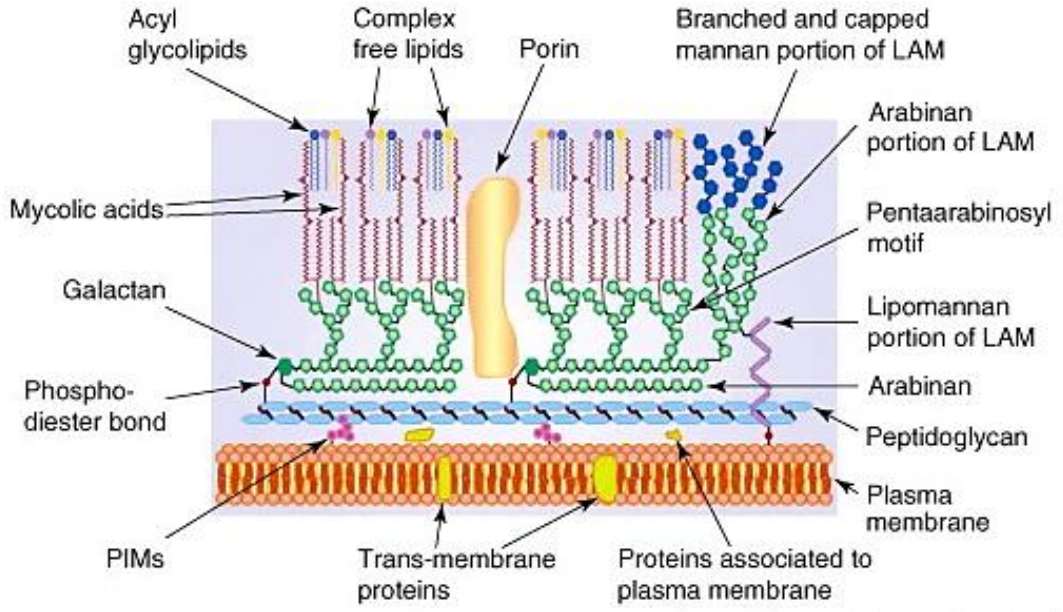
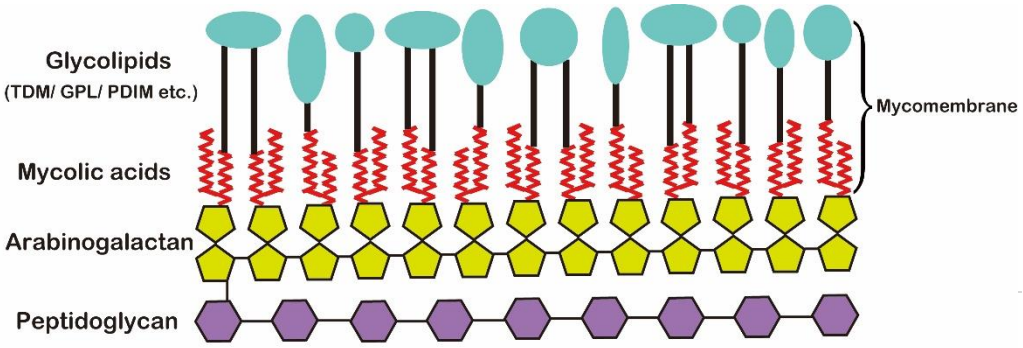
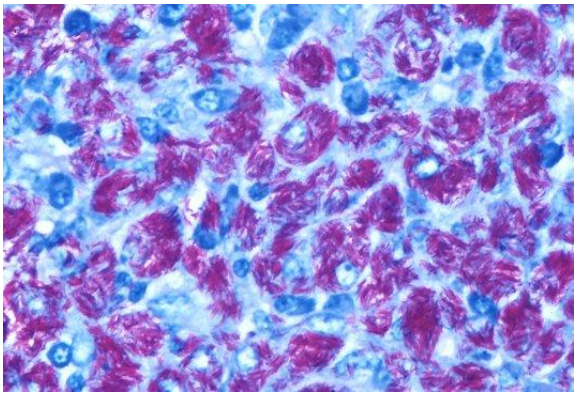


Fig 9: Acid-fast Cell wall structure of *Mycobacterium*



Because of their waxy surface, mycobacteria do not stain well with Gram stain. A mixture of the red dye basic fuchsin and phenolis used in the acid-fast (Ziehl–Neelsen) stain. The stain is driven into the cells by slow heating, and the role of the phenol is to enhance penetration of the fuchsin into the lipids. After washing in distilled water, the preparation is decolorized with acid alcohol and counterstained with methylene blue. Cells of acid-fast organisms stain red, whereas the background and non-acid-fast organisms appear blue



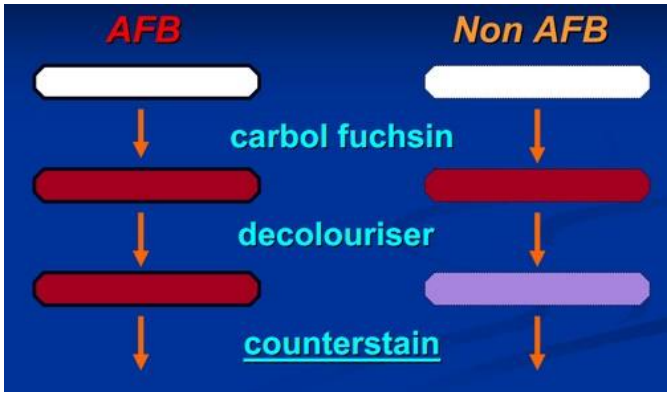


Fig 10: Light micrograph of *Mycobacterium tuberculosis* (Red colour) acid fast staining

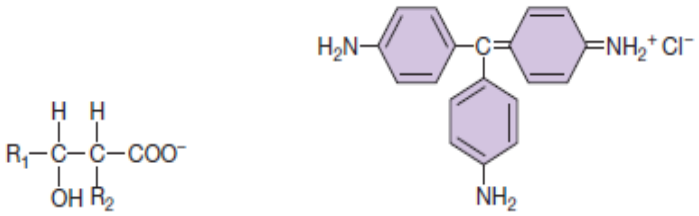


Fig 11: **Acid-fast staining.** Structure of *(a)* mycolic acid and *(b)* basic fuchsin, the dye used in the acid-fast stain. The fuchsin dye combines with mycolic acids in the cell wall via ionic bonds between COO^- and NH_2^+.

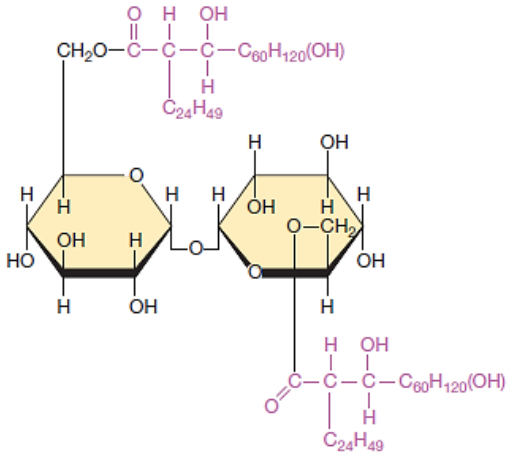


Fig 12: Mycobacteria Cord factor structure

Mycobacteria are somewhat pleomorphic and may undergo branching or even filamentous growth. However, in contrast to the filaments of the Actinomycetes, the filaments of the mycobacteria do not form a true mycelium.

The mycobacteria are generally separated into two groups:
(1) The slow growers, such as *M. tuberculosis, M. avium*, *M. bovis*, and *M. gordonae*
(2) The fast, or rapid, growers, which form visible colonies on appropriate media within 7 days. Such as *M. smegmatis*, *M. phlei*, *M. chelonae*, *M. parafortuitum*

Mycobacterium tuberculosis is a typical slow grower, and visible colonies are produced from dilute inoculum only after days to weeks of incubation. When growing on solid media, mycobacteria form **tight, compact, often wrinkled colonies** (Fig 10). This colony morphology is probably due to the high lipid content and hydrophobic nature of the cell surface, which facilitates cells sticking together.

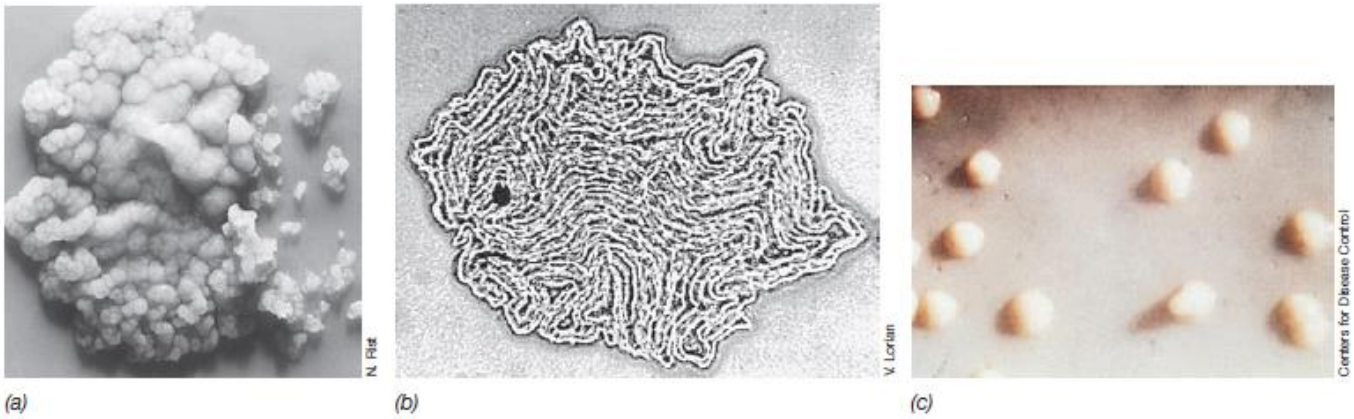


Fig 13 : Characteristic colony morphology of mycobacteria. *(a) Mycobacterium tuberculosis*, showing the compact, wrinkled appearance of the colony. The colony is about 7 mm in diameter. *(b)* A colony of virulent *M. tuberculosis* at an early stage, showing the characteristic cordlike growth. Individual cells are about 0.5 µm in diameter. *(c)* Colonies of *Mycobacterium avium* from a strain of this organism isolated as an opportunistic pathogen from an AIDS patient.
Source : Brock biology of Microorganisms

For the most part, mycobacteria have relatively simple nutritional requirements. Most species can grow aerobically in a simple mineral salts medium with ammonium as the nitrogen source and glycerol or acetate as the sole carbon source and electron donor. Growth of *M. tuberculosis* is more difficult and is stimulated by lipids and fatty acids. The virulence of *M. tuberculosis* cultures has been correlated with the **formation of long, cordlike structures that form due to side-to-side aggregation** and chains of bacteria. Growth in cords reflects the presence of a characteristic Inter twining of long glycolipid, the *cord factor*, on the cell surface. The pathogenesis of tuberculosis, along with the related mycobacterial disease leprosy.

Some mycobacteria produce yellow carotenoid pigments (Fig: 13©), and pigmentation can aid in identification. Mycobacteria can either be non-pigmented (e.g.: *M. tuberculosis*, *M. bovis*, *M. smegmatis*, *M. chelonae*), or can form pigments only when cultured in light, a property called *photochromogenesis* (e.g., *M. parafortuitum*), or can form pigment even when cultured in the dark, a property called *scotochromogenesis* (e.g., *M. gordonae*, *M. phlei*). Photochromogenesis is triggered by the blue region of the visible spectrum and is characterized by the photoinduction of one of the early enzymes in carotenoid biosynthesis. As with other carotenoid containing bacteria, it is likely that carotenoids protect mycobacteria against oxidative damage from singlet oxygen

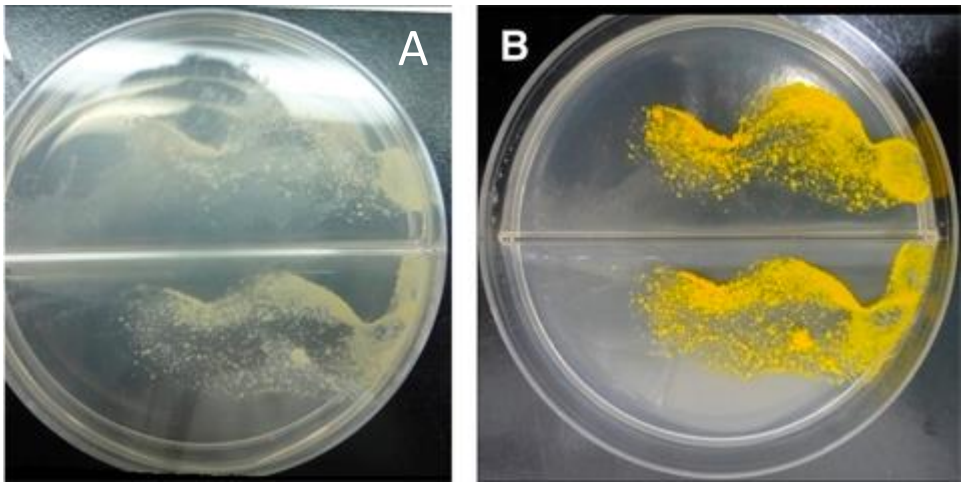


Fig 14 :*Mycobacterium marinum* colonies on Middlebrook 7H11 agar plates showed the photochromogenic characteristic, which are white when grown in the dark (A) and turn a brilliant yellow soon after exposure to light (B)

5) Genus *Streptomyces*

Actinomycetes are filamentous soil bacteria which are composed with four genera (*Streptomyces*, *Frankia*, *Actinomyces*, and *Nocardia)* which are listed under Actinobacteria.

The genus *Streptomyces* is the best known of the **Actinomycetes** and is one of the bacteria most commonly isolated from soil. The reproductive **asexual spores** of *Streptomyces* are formed at the ends of aerial filaments. If each spore lands on a suitable substrate, it is capable of germinating into a new colony. These organisms are **strict aerobes**. They often produce **extracellular enzymes** that enable them to utilize proteins, polysaccharides (such as starch and cellulose), and many other organic materials found in soil.

Streptomyces characteristically produce a gaseous compound called **Geosmin,** which gives fresh soil its typical musty odor. Species of *Streptomyces* are valuable because they produce most of our commercial antibiotics. There are nearly 500 described species in this genus. *Streptomyces* filaments are typically 0.5–1.0 µm in diameter and of indefinite length, and often lack cross-walls in the vegetative phase. *Streptomyces* grow at the tips of the filaments and may branch often. Thus, the vegetative phase consists of a complex, tightly woven matrix, resulting in a compact, convoluted mycelium and subsequent colony. As the colony ages, characteristic aerial filaments called **Sporophores** (asexual reproductive spores) are formed, which project above the surface of the colony and give rise to spores. (**Fig 17**)

Streptomyces spores, called *conidia*, are quite distinct from the endospores of *Bacillus* and *Clostridium*. Unlike the elaborate cellular differentiation that leads to the formation of an endospore, conidia are produced by the formation of cross-walls in the multinucleate sporophores followed by separation of the individual cells directly into spores. (**Fig 16**)

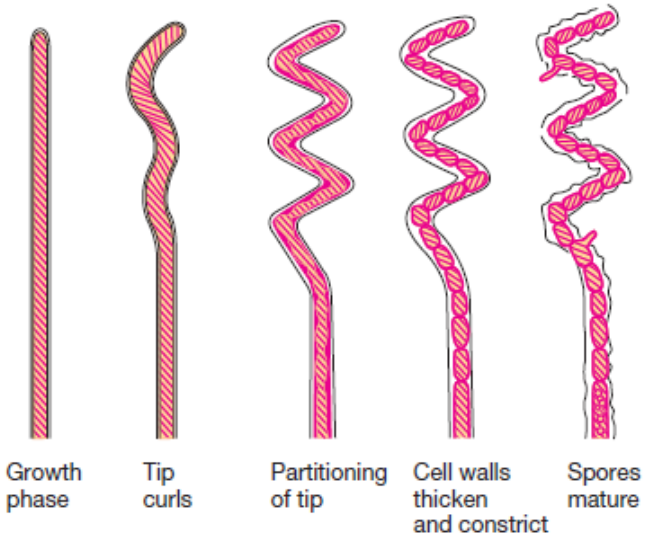
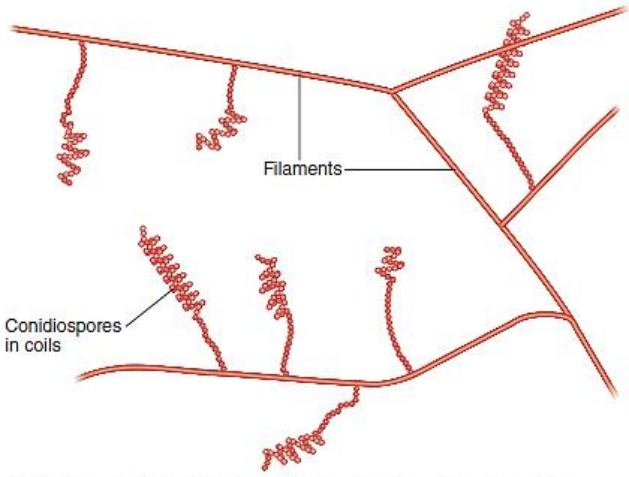
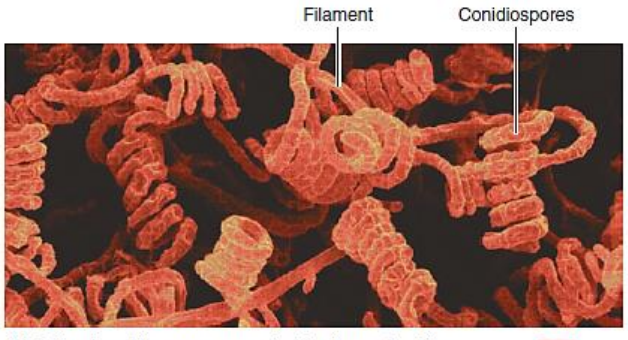


Fig 16: Spore formation in *Streptomyces*. Diagram of stages in the conversion of an aerial hypha (sporophore) into spores (conidia)



(a) Drawing of a typical streptomycete showing filamentous, branching growth with asexual reproductive conidiospores at the filament tips



(b) Coils of conidiospores supported by filaments of the streptomycete

Fig 15

(a)

(b)

Fig 17: Spore-bearing structures of actinomycetes. Phase-contrast micrographs. *(a) Streptomyces*, a monoverticillate type. *(b) Streptomyces*, a closed spiral type. Filaments are about 0.8 µm wide in both types.

Differences in the shape and arrangement of aerial filaments and spore-bearing structures of various species are among the fundamental features used in classifying the *Streptomyces* species (**Fig 18**). The conidia and sporophores are often pigmented and contribute a characteristic color to the mature colony (**Fig 19**). The dusty appearance of the mature colony its compact nature, and its color make detection of *Streptomyces* colonies on agar plates relatively easy (**Fig 19(b)**).

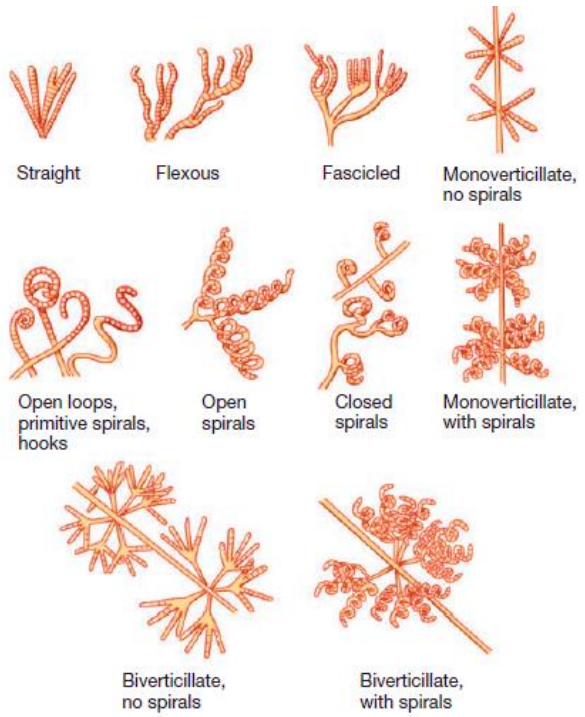
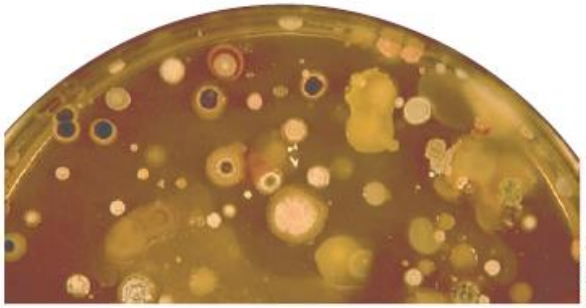


Fig 18: Morphologies of spore-bearing structures in the Streptomycetes



(a)

(b)

Fig 19: *Streptomycetes*. *(a)* Colonies of *Streptomyces* and other soil bacteria derived from spreading a soil dilution on a casein–starch agar plate. The *Streptomyces* colonies are of various colors (several black *Streptomyces* colonies are near the top of the plate) but can easily be identified by their opaque, rough, non-spreading morphology. *(b)* Close-up photo of colonies of *Streptomyces coelicolor*

- **Antibiotics of *Streptomyces***

Perhaps the most striking physiological property of the Streptomycetes is the extent to which they produce **antibiotics**. Evidence for antibiotic production is often seen on the agar plates used in their initial isolation. Adjacent colonies of other bacteria show zones of inhibition. About 50% of all *Streptomyces* isolated have been found to be antibiotic producers. Over 500 distinct antibiotics are produced by streptomycetes and many more are suspected, most of these have been identified chemically. Some species produce more than one antibiotic, and often the several antibiotics produced by one organism are chemically unrelated. Although an **antibiotic-producing organism is resistant to its own antibiotics**, it usually remains sensitive to antibiotics produced by other streptomycetes. Many genes are required to encode the enzymes for antibiotic synthesis, and because of this, the **genomes of *Streptomyces* species are typically quite large**. More than 60 streptomycete antibiotics have been used in human and veterinary medicine, and some of the most commonly used are listed in following table.

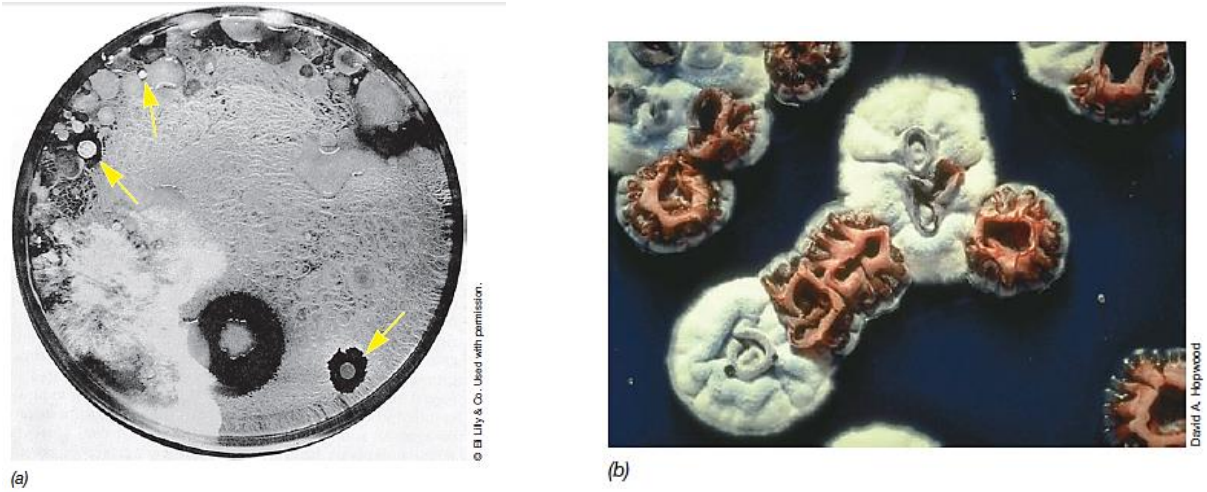


Fig 20: Antibiotics from *Streptomyces*. *(a)* Antibiotic action of soil microorganisms on a crowded plate. The smaller colonies surrounded by inhibition zones (arrows) are streptomycetes; the larger, spreading colonies are *Bacillus* species, some of which are also producing antibiotics. *(b)* The red-colored antibiotic undecylprodigiosin is being excreted by colonies of *S. coelicolor*.

The ecology of Streptomycetes are poorly understood yet. One hypothesis for why *Streptomyces* species produce antibiotics is that antibiotic production, which is linked to sporulation (a process itself triggered by nutrient depletion), might be a mechanism to inhibit the growth of other organisms competing with *Streptomyces* cells for limiting nutrients. This would allow the *Streptomyces* to complete the sporulation process and form a dormant structure that would increase their chances of survival.

Table 1 **Some common antibiotics synthesized by species of *Streptomyces* and related *Actinobacteria***

Chemical class	*Common name*	*Produced by*	*Active against*[a]
Aminoglycosides	Streptomycin	*S. griseus*[b]	Most gram-negative *Bacteria*
	Spectinomycin	*Streptomyces* spp.	*Mycobacterium tuberculosis*, penicillinase-producing *Neisseria gonorrhoeae*
	Neomycin	*S. fradiae*	Broad spectrum, usually used in topical applications because of toxicity
Tetracyclines	Tetracycline	*S. aureofaciens*	Broad spectrum, gram-positive and gram-negative *Bacteria*, rickettsias and chlamydias, *Mycoplasma*
	Chlortetracycline	*S. aureofaciens*	As for tetracycline
Macrolides	Erythromycin	*Saccharopolyspora erythraea*	Most gram-positive *Bacteria*, frequently used in place of penicillin; *Legionella*
	Clindamycin	*S. lincolnensis*	Effective against obligate anaerobes, especially *Bacteroides fragilis*, the major cause of anaerobic peritoneal infections
Polyenes	Nystatin	*S. noursei*	Fungi, especially *Candida* (a yeast) infections
	Amphotericin B	*S. nodosus*	Fungi
None	Chloramphenicol	*S. venezuelae*	Broad spectrum; drug of choice for typhoid fever

6) Genus *Actinomyces*

Next group of Actinomycetes are genus Actinomyces. *Actinomyces* consists of **facultative anaerobes** (except A. meyeri, a strict anaerobe) that are found in the mouth and throat of humans and animals. All species grow best under anaerobic conditions.They occasionally form filaments that can fragment. *Actinomyces* species may form endospores, and, while individual bacteria are rod shaped, *Actinomyces* colonies form fungus-like branched networks. The aspect of these colonies initially led to the incorrect assumption that the organism was a fungus and to the name "Actinomyces" or ray fungus. One species, *Actinomyces israelii* causes **Actinomycosis**, a tissue destroying disease usually affecting the head, neck, or lungs. So that organism is a pathogenic one. Since Actinomyces are a group of Actinomycetes, some species belong to this genus play an important role in Soil ecology. They produce a number of enzymes that help degrade organic plant material, lignin, and chitin. As such, their presence is important in the formation of compost.

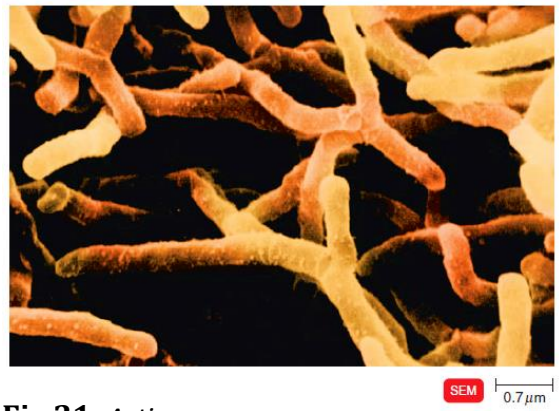


Fig 21: *Actinomyces*

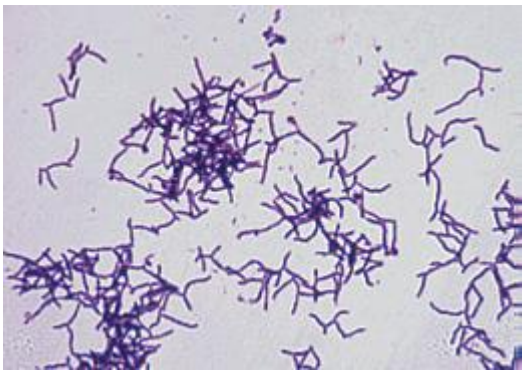


Fig 22: *Actinomyces israelii*

7) Genus *Frankia*

The next group of Actinomycetes is genus *Frankia* causes nitrogen-fixing nodules (filamentous bacteria) to form in alder tree roots, much as rhizobia cause nodules on the roots of legumes in the Fabaceae family. The organisms are able to convert atmospheric nitrogen into ammonia via the enzyme **Nitrogenase**, a process known as **nitrogen fixation.** The bacteria can supply most or all of the nitrogen requirements of the host plant. As a result, actinorhizal plants colonise and often thrive in soils that are low in plant nutrients. Therefore they are symbiotic organisms.

Fig 23: Root nodules of *Frankia*

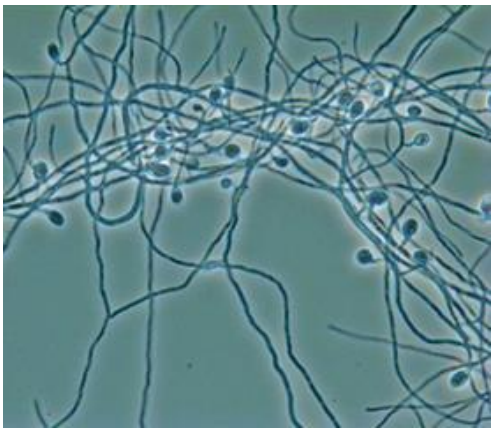


Fig 24: *Frankia*

8) Genus *Nocardia*

Another group of Actinomycetes is Genus *Nocardia*. The genus *Nocardia* morphologically resembles *Actinomyces* however, these bacteria are **aerobic**. To reproduce, they form **rudimentary filaments**, which fragment into short rods. The structure of their cell wall resembles that of the mycobacteria, therefore, they are often **acid-fast**. They are catalase-positive organisms. *Nocardia* species are common in soil. Some species, such as *Nocardia asteroids*, occasionally cause a chronic, **difficult to-treat pulmonary infection (COPD)**. *N. asteroides* is also one of the causative agents of **mycetoma**, a localized destructive infection of the feet or hands. Most *Nocardia* infections are acquired by inhalation of the bacteria or through traumatic introduction. Therefore Biosafety Level 2 organism.

Some species of this genera are acid fast (meaning a less concentrated solution of sulfuric or hydrochloric acid should be used during the staining procedure) due to the presence of **intermediate-length mycolic acids** in their cell wall (**Fig 10, Fig 11**). Majority of strains possess the **cord factor** (trehalose 6-6' dimycolate), an important virulence factor (**Fig 12**).

The various species of *Nocardia* are pathogenic bacteria with low virulence, therefore clinically significant disease most frequently occurs as an opportunistic infection in those with a weak immune system, such as small children, the elderly, and the immunocompromised (most typically, HIV). Nocardial virulence factors are the enzymes catalase and superoxide dismutase (which inactivate Reactive Oxygen Species that would otherwise prove toxic to the bacteria), as well as a "**cord factor**" (which interferes with phagocytosis by macrophages by preventing the fusion of the phagosome with the lysosome)

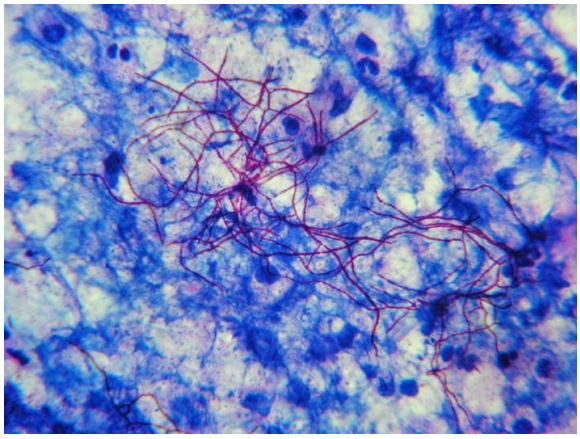


Fig 25: Light micrograph of *Nocardia* (acid fast staining)

Fig 26: Colony of *Nocardia*

9) Genus *Gardnerella*

Gardnerella vaginalis is a bacterium that causes one of the most common forms of vaginitis. There has always been some difficulty in assigning a taxonomic position in this species, which is **gram variable**,and which exhibits a **highly pleomorphic morphology**. It is a **facultative anaerobic bacteria** of which *G. vaginalis* is the only species. The organisms are **small non-spore forming**, **non-motile coccobacilli**.

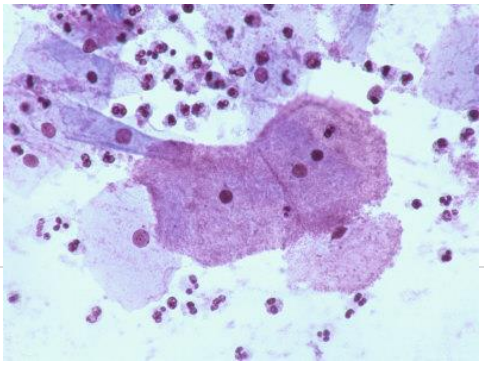


Fig 27: Vaginal epithelial cells are coated by *Gardnerella vaginalis*

10) Industrial value of Actinobacteria

Actinobacteria can be taxonomically divided in to 8 common genera as described above. Since it is a widely spread phylum, there are vast biochemical and physiological differences between each genera and each species. There are so many importance of these species. Actinomycetes are well recognized for their metabolic versatility that is frequently accompanied by the production of primary and secondary metabolites of economic importance. Some importance have industrial values as well as some are advantageous for humans. Some of their advantageous and dis-advantageous importance can be listed as below

- Actinomycetes are soil microorganisms, they are important for improving fertility in soil.
- Some Actinobacteria produce **Enzymes**, **Antibiotics**, **Inhibitors** and various biochemically important compounds. These bacteria are used to produce these compounds in industrial scale
- Some species form symbiotic associations with plant roots.
- Some species are extremely pathogens some are opportunistic pathogens, both of them cause diseases for humans and animals.
- Some Actinobacteria are used as secondary fermenters during Swiss cheese production.
- They have the ability to degrade a wide range of hydrocarbons, pesticides, and aliphatic and aromatic compounds.
- They perform microbial transformations of organic compounds, a field of great commercial value.
- Members of many genera of actinomycetes have potential for use in the bioconversion of underutilized agricultural and urban wastes into high-value chemical products.
- A large fraction of antibiotics in the market are obtained from actinomycetes. They produce **Enzyme inhibitors** useful for cancer treatment and **Immunomodifiers** that enhance immune response.
- Actinomycetes are also important in plant biotechnology as strains with antagonistic activity against plant pathogens are useful in biocontrol.

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