University of Melbourne

BIOL 10004

BIOLOGY OF CELLS AND ORGANISMS

LECTURE NOTES

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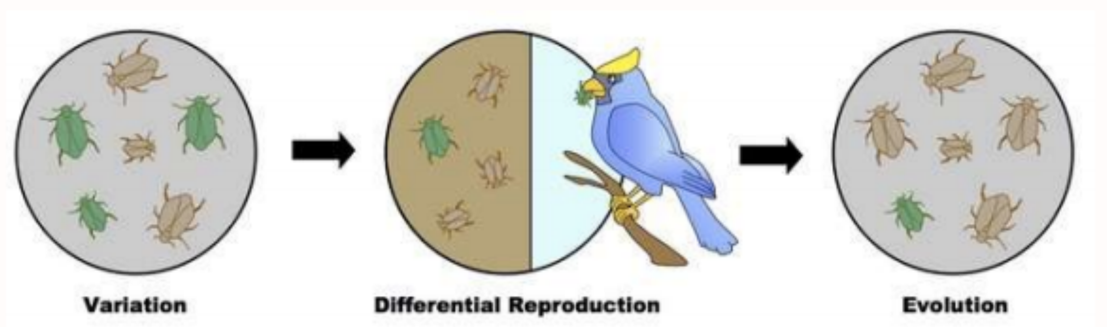
BIOLOGY 1 - LECTURE NOTES

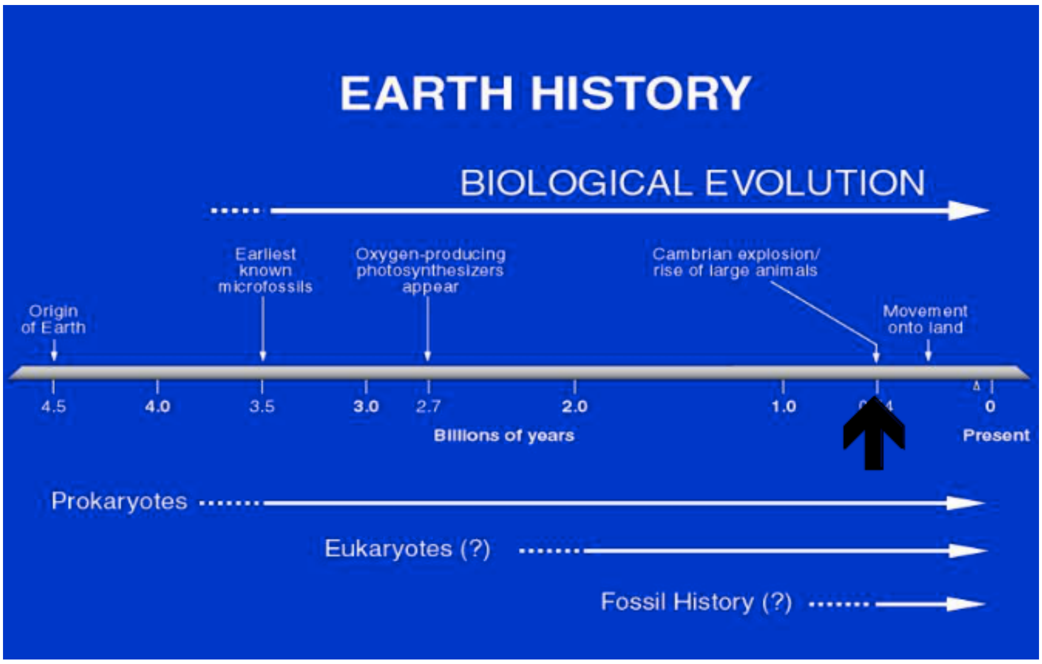
Introduction to Cell Biology

- **EVOLUTION** is the process of change and divergence among populations and species over time.
- Evolution through natural selection is the **FIRST GENERALISATION OF BIOLOGY**, the theory of common descent.
- In general, scientists since Darwin have been convicted that the earth has a long history, and that all organisms arose from more primitive forms. Therefore all organisms are related, as they share a common ancestry.
- Evolution is essentially a two step process: variability followed by natural selection.
    1. Individuals in a species show a wide range of variation.
    2. 'Fitter' individuals with characteristics best suited to the environment are more likely to survive and reproduce.
    3. Given enough time, a species will evolve.



- The earth 4.6 billion years ago was volcanically very active, and thus the surface conditions were dominated by volcanic emissions.
- According to modern volcanoes, these emissions would have included vaporised water, which condensed to form the oceans, carbon dioxide, nitrogen gas, methane, sulphurous compounds and hydrogen gas.
- Since hydrogen atoms and electrons were plentiful and there was very little oxygen associated with the early earth, conditions were very **reducing**.
- A **REDUCING ENVIRONMENT** would have allowed the formation of organic molecules without the input of as much energy as it would in today's oxygen-rich atmosphere.
- Electrical storm activity in the atmosphere and the geothermal energy associated with hot vents and volcanoes under the ocean would have been likely to generate a rich soup of life's building blocks.
- Interplanetary meteorites are known to contain organic compounds, providing proof of their abiotic synthesis, and possibly were another source of such molecules as meteorites rained down on the early earth, known as **PANSPERMIA**.
- Essentially, life formed spontaneously on early Earth through a reducing environment that facilitated organic molecule formation, such as RNA polymers.
- Unity of biochemical processes is the **SECOND GENERALISATION OF BIOLOGY** states that because all organisms share a common ancestor, there is a unity of biochemical processes.
- Hence, all organisms share certain biochemical reactions.

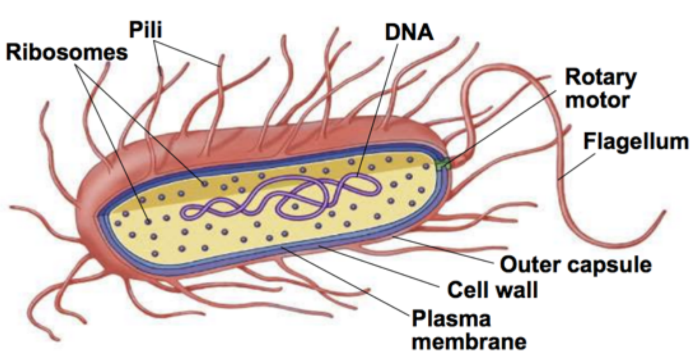
- For example, all organisms have genetic material, DNA, that contains the instructions for how that organism will develop.
- Organisms also have the machinery to carry out the instructions - proteins.
- The **THIRD GENERALISATION OF BIOLOGY** states that all organisms consist of cells.
- A **CELL** is a bag, a closed domain where the chemical reactions required for life are carried out.
- The **CELL THEORY** states that all living organisms are composed of cells, all cells come from pre-existing cells and the cell is the smallest organisational unit.
- Cells have succeeded because of the presence of a cell membrane, a barrier between the living protoplast and its environment.
- About 4 billion years ago, the first cells were much like the bacteria today, small in size and simple in structure, known as prokaryotes.
- The origin of these cells is unknown, a dilemma one still shares with Darwin.
- The second important episode in the pre-Cambrian led to the emergence of a new kind of cell, a cell where the genetic material is aggregated into a distinct nucleus bound by membranes, known as eukaryotes.
- The evolution of this second type of cell greatly accelerated the pace of evolutionary change.
- The **CAMBRIAN EXPLOSION** is an explosion of animal diversity in very little little (5-10 million years) that occurred 542 million years ago.
- **STROMATOLITES** are layered mounds originally formed by the growth of layer upon layer of cyanobacteria, a single-celled photosynthesising microbe, commonly referred to as ‘living fossils’.
- The origin of life includes the fact that:
    1. A life form can **replicate** itself and, in so doing, passes on cellular information from its parents so that it bears a likeness to the parent cells.
    2. There is capacity to **alter** cellular information, allowing populations to change over time and adapt to their environment.
    3. **Metabolic activity** occurs, with chemical reactions building and breaking down complex molecules with both the input and extraction of energy.
    4. All of these functions are concentrated and **contained** in space, surrounded by a barrier or membrane.

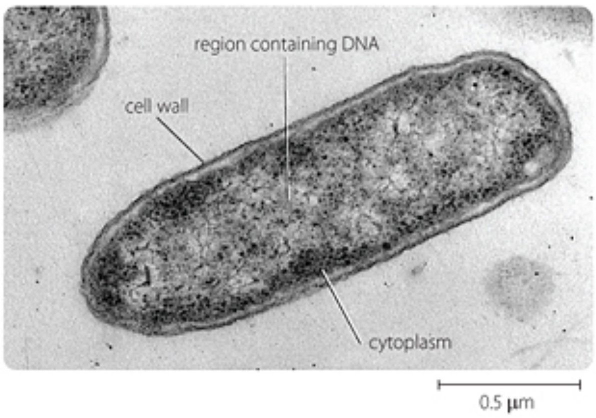


- **RNA** is a polymer, a molecule made of a number of similar subunits (nucleotide monomers).
- RNA polymers are among the molecules that have been shown to occur spontaneously. They have two properties that are relevant to the criteria that define life:
    1. Store information in the sequence order of their different nucleotide monomers.
    2. Possess a wide range of catalytic activities capable of providing metabolic function.
- Thus, RNA could have been capable of using and modifying the early earth's chemical environment through its catalytic activities, and replicating itself to go on further and exploit these resources.
- Also, errors or mutations that occur during RNA copying would have led to changes in catalytic functions, allowing RNA polymers to improve and adapt to changed or new environments.
- The evolutionary process of natural selection would, therefore, have begun to act on these molecules, with those able to reproduce fastest coming to dominate the RNA populations, carrying their inherited sequence information forward.

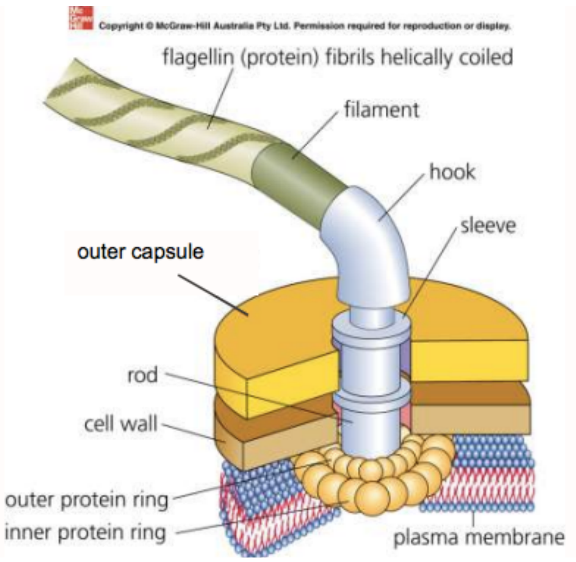
Prokaryotic Cells

- The first inhabitants of the earth were prokaryotes.
- Early in earth's history, the atmosphere and oceans had zero oxygen, high CO2, ammonia, methane and intense radiation; photosynthetic cyanobacteria changed all of that.
- All cells are enclosed by a membrane called the **PLASMA MEMBRANE**, which is the boundary of living cells separating a cell from its environment; it is formed from a phospholipid bilayer.
- All cells contain a semifluid matrix called the **CYTOSOL**, which is an a question solution of molecules with a gel-like consistency within the cytoplasm of eukaryotic cells.
- The first cells to evolve were **PROKARYOTES**, which is a small single-celled organism that has a simple structure.
- The hereditary material, a double-helical strand of DNA, lies free within the cell in an area called the nucleoid.
- The **NUCLEOID** is the circular DNA molecule of prokaryotes compressed with the aid of folding proteins and RNA and is located in the cytosol.
- A prokaryotic cell lacks membrane organelles such as membrane-bound nucleus, mitochondria or chloroplasts.
- Prokaryotic cells were smaller than eukaryotes, about 1μm in diameter.
- They have a semirigid cell wall that surrounds the plasma membrane.
- Enclosed by the plasma membrane, the cytosol contains hundreds of **RIBOSOMES**, which is a cytoplasmic organelle where protein synthesis occurs; it is formed from two rRNA subunits in association with an mRNA molecule.
- Prokaryotic ribosomes are about 15 nm and are smaller than eukaryotic ribosomes.



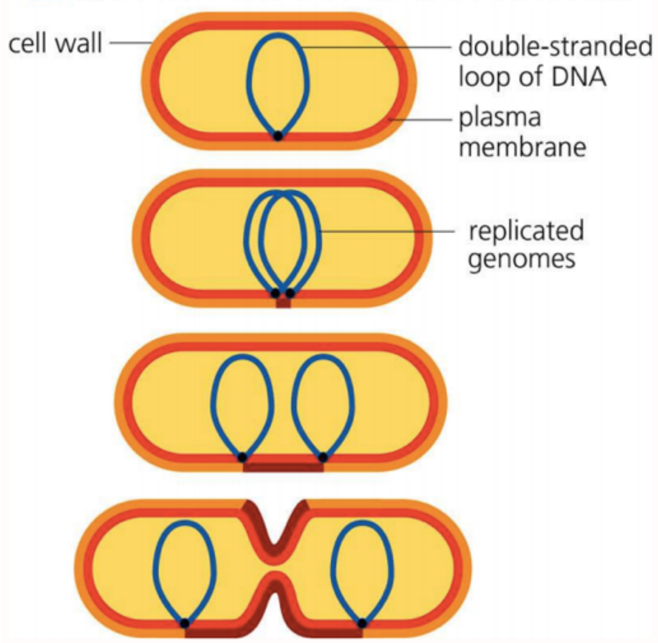


- The DNA serves as a template for mRNA synthesis; ribosomes bind to the mRNA and use the sequence of nucleotides as a code for protein synthesis.
- As prokaryotic DNA is not segregated into a nucleus, bacterial ribosomes can attach directly to mRNA molecules even while they are being synthesised in the cytoplasm.
- Together, the cytosol and ribosomes constitute the **CYTOPLASM** of the prokaryotic cells.
- The short attachment of **PILI** or **FIMBRIAE** are organelles of adhesion allowing prokaryotes (bacteria) to colonise environmental surfaces or cells and resist flushing.
- It also is involves in the exchange of genetic material between prokaryotes.
- The **CELL WALL** is a rigid structure composed of peptidoglycan, providing the cell with structural support.
- The **OUTER CAPSULE** is a large structure composed of a polysaccharide layer that enhances the ability of bacteria to cause disease and protects the cell from engulfment by eukaryotic cells.
- Prokaryotic cells also lack cytoskeletal structures, such as microfilaments and microtubules.
- Prokaryotes have **FLAGELLA**, whip-like appendages that propel the cells through their surrounding medium and are extracellular.



- Prokaryotic flagella are made of proteinaceous fibres, composed of **FLAGELLIN**, which forms a stiff coiled filament.
- The flagellum projects from a motor-like structure in the membrane known as the **ROTARY MOTOR**, consisting of the hook, sleeve and rod.
- Rotation of the motor complex in the plasma membrane spins the helically coiled flagellin filaments like a propeller and this propels the cell forward.
- Spontaneous mutations occur at high frequencies in prokaryotes, generating enormous biochemical diversity.
- Prokaryotes are ubiquitous and metabolically diverse as they are extremophiles, particularly **HYPERTHERMOPHILES** (thrive in extremely hot environments).
- Some are able to oxidise inorganic compounds and harvest energy, known as **CHEMOAUTOTROPHS**.
- Prokaryotes reduce sulphur to sulphide for energy, doesn't use oxygen or light, nor fixes CO2 into organic carbon.
- Prokaryotes are the cause of main diseases (e.g. typhoid, cholera, dysentery, tetanus).

- Prokaryotes are decomposers and recyclers, and are hence critical in removing dead organic matter, recycling carbon, nitrogen and sulphur, and degrading toxic chemicals.
- For example, prokaryotes are utilised by humans for recycling such as the Werribee sewage treatment plant, where bacteria do the work of cleaning up wastes in water to a level safe enough for release into Port Phillip Bay.
- Prokaryotes are also agents in industrial and agricultural processes.
- Bacteria are used to make many **FERMENTED FOODS**, which are produced via the action of microbes (bacteria or fungi) to produce yoghurt, cheese, wine, beer, vinegar and so on.
- Nitrogen-fixing bacteria form symbiosis with some plant species such as legumes.
- Atmospheric nitrogen is converted to ammonia in root nodules.
- For biotechnological applications, genetically modified bacteria make pharmaceuticals.
- For example, E. coli has been engineered to produce human insulin, human growth hormone and human interferon.
- The bacterial species *Agrobacterium tumefaciens* is also used to make genetically modified crops. More than 180 million hectares of genetically modified crops were sown in 28 countries.
- Prokaryotes replicate by **BINARY FISSION**, which is asexual reproduction by a separation of the body into two new bodies.
- In the process of binary fission, an organism duplicates its genetic material, or DNA, and then divides into two parts, known as **CYTOKINESIS**, with each new organism receiving one copy of DNA.



Bacteria and Archaea

- Two of the three domains of life are prokaryotes: the Bacteria and the Archaea.
- The **BACTERIA** is a super kingdom of prokaryotes; also termed the **EUBACTERIA**.
- The **ARCHAEA** is a super kingdom of prokaryotes.
- The domain Archaea is more closely related in evolutionary terms to the domain Eukarya.
- Morphologically, Archaea do not differ from Bacteria.
- Over half of Archaean genes were new to science.
- Biochemically, Archaea are nearly as different from Bacteria as they are from Eukarya (making them a separate domain).

- The two central biological processes in Archaea, genetic transcription and translation, are more similar to those of eukaryotes than bacteria.
- Features of the Archaean lipids and their membranes are unusual and Archaea lack a **PEPTIDOGLYCAN** wall (cell wall).
- Archaea are known to be found in many environments.
- Archaea have not been found to produce resting spores.
- No clear examples of Archaean pathogens are known.

TABLE 35.2 A comparison of structural and biochemical features of typical members of the three domains: Bacteria, Archaea and Eukarya

Feature	Domain Bacteria	Domain Archaea	Domain Eukarya
Membrane-bound nucleus and organelles	Absent	Absent	Present
Plasmids	Present	Present	Rare
Introns in genes	Absent	Absent	Present
RNA polymerases	Single	Multiple	Multiple
Ribosome size	70 S	70 S	80 S
Protein synthesis–initiation tRNA	Formylmethionine	Methionine	Methionine
Protein synthesis sensitive to:			
• diphtheria toxin	No	Yes	Yes
• streptomycin	Yes	No	No
• cycloheximide	No	No	Yes
Peptidoglycan as the major cell wall polymer	Yes	No	No
Membrane lipids	Esters	Ethers	Esters
Methane-generating	No	Yes (some species)	No
Nitrification	Yes (some species)	No	No
Nitrogen fixation	Yes (some species)	Yes (some species)	No
Photosynthesis	Yes (some species)	No	Yes (some species)
Chemoautotrophy using H_2, S, Fe^{2+}	Yes (some species)	Yes (some species)	No

- As Archaea have largely continued to occupy specialised habitats (anaerobic, hot and salty places), they have retained their primitive attributes and have not developed the metabolic diversity of Bacteria, and are also **EXTREMOPHILES** (an organism that thrives in extreme conditions).
- The domain Archaea includes **HALOPHILES** (bacterium that survive in highly saline environments), **ACIDOPHILES** (type of bacteria that survives in highly acidic environments) and **THERMOPHILES** (an organisms that grows best in hot conditions between 30ºC and 50ºC).
- These tend to be found in extreme environments not generally colonised by members of Bacteria.
- Bacteria share many habitats of moderate temperature with water freely available, low in salt or other solutes, and where sunlight or organic compounds are plentiful.
- **CYANOBACTERIA** are photosynthetic prokaryotes that have **CHLOROPHYLL A** and produce oxygen as a by-production of photosynthesis.
- They generate molecular oxygen during photosynthesis and are major primary producers.
- Contain phycocyanin and phycoerythrin as accessory pigments, essential for light harvesting and for photosynthesis.
- Oceanic cyanobacteria are believed to have become the first microbes to produce oxygen by photosynthesis.
- The was the point in time when oxygen, produced by cyanobacteria, was free to escape into the atmosphere as O2.
- UV rays broke down O2 into oxygen atoms, which facilitated the reaction with O2 to form ozone.