

University of Melbourne

BIOL 10004

**BIOLOGY OF CELLS
AND ORGANISMS**

LECTURE NOTES

TABLE OF CONTENTS

Topic 1: Cell Biology

1.1 Introduction to Cell Biology	Pages 1 - 3
1.11 Evolution	
1.12 Reducing environments	
1.13 Panspermia theory	
1.14 Generalisations of Biology	
1.15 Cell Theory	
1.16 Cambrian explosion	
1.17 Stromatolites	
1.2 Prokaryotic Cells	Pages 3 - 6
1.21 Plasma membrane in prokaryotic cells	
1.22 Cytosol, ribosomes and nucleoid	
1.23 Pili, fimbriae, cell wall	
1.24 Structure and function of prokaryotic flagella	
1.25 Hyperthermophiles	
1.26 Chemoautotrophs	
1.27 Binary fission	
1.28 Similarities and differences between Bacteria and Archaea	
1.29 Cyanobacteria and the Great Oxygenation Event	
1.3 Eukaryotic Cells	Pages 7 - 12
1.31 Organelles, cytoplasm and protoplasm	
1.32 Structure and function of eukaryotic flagella (axoneme, dynein, basal body)	
1.33 Nucleus, nucleoli, nucleoplasm, histones, nucleosomes and chromatin	
1.34 Comparing heterochromatin and euchromatin	
1.35 Structure and function of ribosomes and polysomes	
1.36 Structure and function of mitochondria (cristae, enzyme complex)	
1.37 Structure and function of chloroplasts (plastids, stroma, proplastids)	
1.38 Sub-organelles of chloroplasts (thylakoids, grana, lamellae)	
1.39 Overview of proplastids (amyloplast, chromoplast, elaioplast, etioplast)	
1.4 Endosymbiosis	Pages 13 - 15
1.41 Origin of the nucleus	
1.42 Endosymbiosis	
1.43 Primary endosymbiosis of mitochondria and chloroplasts	
1.44 Cyanelles and phycobilin	
1.45 Secondary endosymbiosis (cryptomonads and nucleomorphs)	
1.5 Endomembrane System	Pages 16 - 19
1.51 Overview of the endomembrane system	
1.52 Structure and function of rough and smooth endoplasmic reticulum	
1.53 Structure and function of Golgi apparatus	
1.54 Structure and function of lysosomes (autophagy and endosomes)	
1.55 Structure and function of vacuoles	
1.56 Structure and function of microbodies (peroxisomes and glyoxysomes)	

1.6 Cytoskeleton

Pages 20 - 22

- 1.61 Structure and function of microfilaments, globular actin and myosin
- 1.62 Structure and function of microtubules
- 1.63 Structure and function of intermediate filaments
- 1.64 Plant cell walls

1.7 Macromolecules

Pages 22 - 34

- 1.71 Importance of water and its bonding and properties
- 1.72 Overview of macromolecules (monomers and polymers)
- 1.73 Structure and function of nucleic acids
- 1.74 Structure and function of proteins (alpha helix and beta sheets)
- 1.75 Importance of keratins, collagens, elastin, proteoglycans and glycoproteins
- 1.76 Structure and function of carbohydrates
- 1.77 Structure and function of lipids
- 1.78 Enzymes and coenzymes
- 1.79 Factors affecting enzyme activity

1.8 Cell Division

Pages 34 - 42

- 1.81 Cell division
- 1.82 Cell division in prokaryotes (binary fission, FtsZ proteins)
- 1.83 Cell cycle in eukaryotes (G1 phase, S phase, G2 phase, M phase)
- 1.84 Mitosis (prophase, prometaphase, metaphase, anaphase, telophase)
- 1.85 Cytokinesis (importance actin, myosin and phragmoplasts)
- 1.86 Control of cell division (cyclins and checkpoint controls)

1.9 Cell Membranes

Pages 43 - 55

- 1.91 Structure and function of phospholipids
- 1.92 Structure and function of plasmalemma
- 1.93 Transmembrane proteins, glycoproteins and peripheral proteins
- 1.94 Diffusion
- 1.95 Facilitated diffusion
- 1.96 Active transport
- 1.97 Osmosis (osmotic potential, turgor pressure and plasmolysis)
- 1.98 Vesicle-mediated transport (endocytosis, pinocytosis, exocytosis)
- 1.99 Cellular communication (junctions, desmosomes, plasmodesmata)

Topic 2: Plant Biology

2.1 Cellular Respiration

Pages 55 - 62

- 2.11 Redox reactions
- 2.12 Biological electron carriers
- 2.13 Glycolysis and β -Oxidation
- 2.14 Citric Acid Cycle (proton pumps, ATP synthase, chemiosmosis)
- 2.15 Fermentation (creatine phosphate, phosphagen system)

2.2 Photosynthesis	Pages 62 - 72
2.21 Overview of photosynthesis (light, chlorophyll and photosystems)	
2.22 Light dependent reactions of photosynthesis	
2.23 Cyclic photophosphorylation	
2.24 Photosynthetic prokaryotes (anoxygenic photoautotrophs)	
2.25 Light independent reactions (Calvin-Benson Cycle)	
2.26 Factors influencing rates of photosynthesis	
2.27 Photorespiration (C4 photosynthesis and Kranz anatomy)	
2.3 Leaf Structure	Pages 72 - 75
2.31 Overview of leaves, phyllotaxy, simple and compound leaves	
2.32 Comparison of dorsiventral and isobilateral leaves	
2.33 Structure of leaf, including epidermis, palisade mesophyll, xylem and phloem	
2.34 Importance of guard cells and stomata, trichomes, parenchyma cells	
2.35 Modifications of leaf structure (sclerophylly, hydathodes, auxins)	
2.4 Root Structure	Pages 75 - 78
2.41 Overview of root anatomy (root cap, epidermis, exarch xylem, polyarch)	
2.42 Comparison of apoplastic and symplastic pathways	
2.5 Water and Sugar Transport	Pages 78 - 82
2.51 Overview of transpiration	
2.52 Vascular bundles; xylem and phloem, tracheids and lignin	
2.53 The effects of cavitation and embolism in plants	
2.54 Factors that affect transpiration rate	
2.55 Translocation of assimilates (sieve cells, aphids, companion cells)	
2.56 Mass-Flow Transport theory	
2.6 Plant Reproduction	Pages 82 - 91
2.61 Asexual reproduction in plants (vegetative propagation, budding)	
2.62 Alternation of generations	
2.63 Anatomy of the flower	
2.64 Structure of the anther (importance of tetrads and callose wall)	
2.65 Pollen and co-evolution of pollination (ornithophily, anemophily)	
2.66 Structure of the carpel (micropyle, megasporocyte, synergids, antipodal cell)	
2.67 Double fertilisation	
2.68 Pollination (protandry, protogyny, dioecy, monoecy, cleistogamy)	
2.69 Formation of seeds, germination and seed dispersal	
2.7 Organogenesis	Pages 91 - 95
2.71 Importance of totipotent cells in plants and overview of organogenesis	
2.72 Structure of the stem (nodes, internodes)	
2.73 Primary growth (stele, cortex, endarch xylem)	
2.74 Secondary growth (secondary xylem and phloem, ray cells, fusiform cells)	
2.75 Comparison of sapwood and heartwood	
2.76 Cork cambium (importance of periderm and phellogen)	

Topic 3: Animal Physiology

3.1 Homeostasis

Pages 96 - 104

- 3.11 Tissues (epithelium, muscle, connective tissue, nerves)
- 3.12 Cell signals and receptors
- 3.13 Overview of homeostasis (stenohaline and euryhaline animals)
- 3.14 Negative feedback regulation and positive feedback mechanisms
- 3.15 Neuron signalling (polarisation, action potential, hyper polarisation)
- 3.16 Functions of hormones (endocrine, paracrine, autocrine)
- 3.17 Anatomy of endocrine system

3.2 Body Fluids

Pages 104 - 109

- 3.21 Regulation of body fluids (osmolarity, osmolyte, tonicity)
- 3.22 Comparison of osmoconformers and osmoregulators
- 3.23 Osmoregulators in freshwater and seawater
- 3.24 Anatomy of the kidney (juxtamedullary nephrons)

3.3 Thermoregulation

Pages 109 - 113

- 3.31 Types of heat transfer (conduction, convection, radiation)
- 3.32 Types of thermoregulators (poikilothermic, homeothermic)
- 3.33 Comparison of ectotherms and endotherms
- 3.34 Homeothermy of endotherms and thermoneutral zone
- 3.35 Regulation of temperature in hot environments
- 3.36 Regulation of temperature in cold environments (thermogenesis, piloerection)
- 3.37 Adaptive hypothermia (torpor, hibernation and therapeutic hypothermia)

3.4 Circulatory System

Pages 113 - 122

- 3.41 Overview of open and closed circulatory systems
- 3.42 Comparison of systole and diastole
- 3.43 Heart cycle (sinoatrial node, Purkinje fibres)
- 3.44 Anatomy and physiology of the heart
- 3.45 Structure and function of blood vessels
- 3.46 Capillary exchange
- 3.47 Control of heart rate and blood pressure
- 3.48 Blood (types of blood cells, myeloid multipotent lineage)
- 3.49 Bone marrow and erythrocytes (haematopoiesis)

3.5 Respiratory System

Pages 123 - 129

- 3.51 Comparison of respiration and ventilation
- 3.52 Fick's Law
- 3.53 Overview of respiratory surfaces
- 3.54 Comparison of countercurrent exchange and co-current flow
- 3.55 Anatomy and physiology of lungs
- 3.56 Transportation of oxygen (respiratory pigments, Bohr effect)

3.6 Digestive System

Pages 129 - 135

- 3.61 Animal nutrition (vitamins, minerals, metabolic rate)
- 3.62 Digestion (physical and enzymatic)
- 3.63 Anatomy and physiology of the digestive system
- 3.64 Types of nutrition and diets

3.7 Reproductive System

Pages 135 - 145

- 3.71 Asexual reproduction (parthenogenesis, budding)
- 3.72 Sexual reproduction (Red Queen hypothesis)
- 3.73 Male reproductive anatomy
- 3.74 Female reproductive anatomy
- 3.75 Internal and external fertilisation
- 3.76 Overview of reproductive strategies
- 3.77 Spermatogenesis (Sertoli and Leydig cells)
- 3.78 Oogenesis (folliculogenesis, corpus luteum, theca and granulosa cells)
- 3.79 Contraception

Topic 3: Animal Diversity and Behaviours

4.1 Species Diversity

Pages 146 - 148

- 4.11 Types of diversity
- 4.12 Evolutionary forces (mutations, gene flow, genetic drift, natural selection)
- 4.13 Comparison of abiotic and biotic factors
- 4.14 Benign Batesian mimicry
- 4.15 Facultative and obligatory mutualism
- 4.16 Anthropogenic selection

4.2 Co-Evolutionary Processes

Pages 148 - 152

- 4.21 Co-Evolution
- 4.22 Parasites and predatory relationships
- 4.23 Sub-species and races
- 4.24 Evolution of resistance
- 4.25 Meiosis

4.3 Animal Behaviour

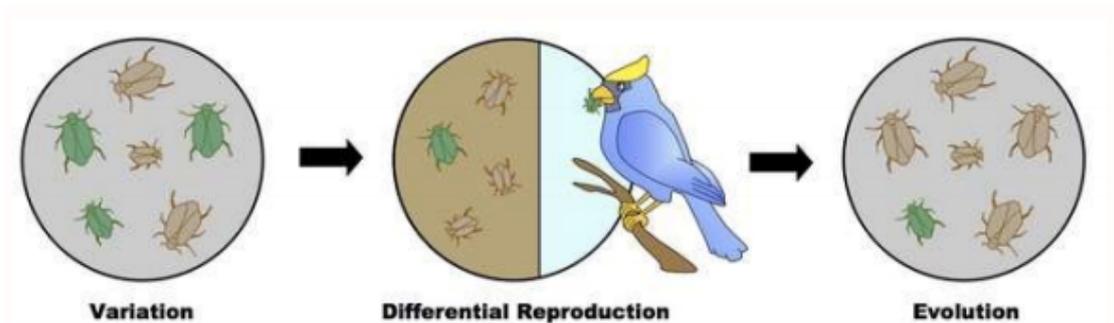
Pages 152 - 157

- 4.31 Parental behaviour
- 4.32 Types of systems (sensory, motor and integrating systems)
- 4.33 Foraging behaviour
- 4.34 Echolocation
- 4.35 Innate and learned behaviour
- 4.36 Comparison of proximate and ultimate views
- 4.37 Oestrous synchrony and infanticide

BIOLOGY 1 - LECTURE NOTES

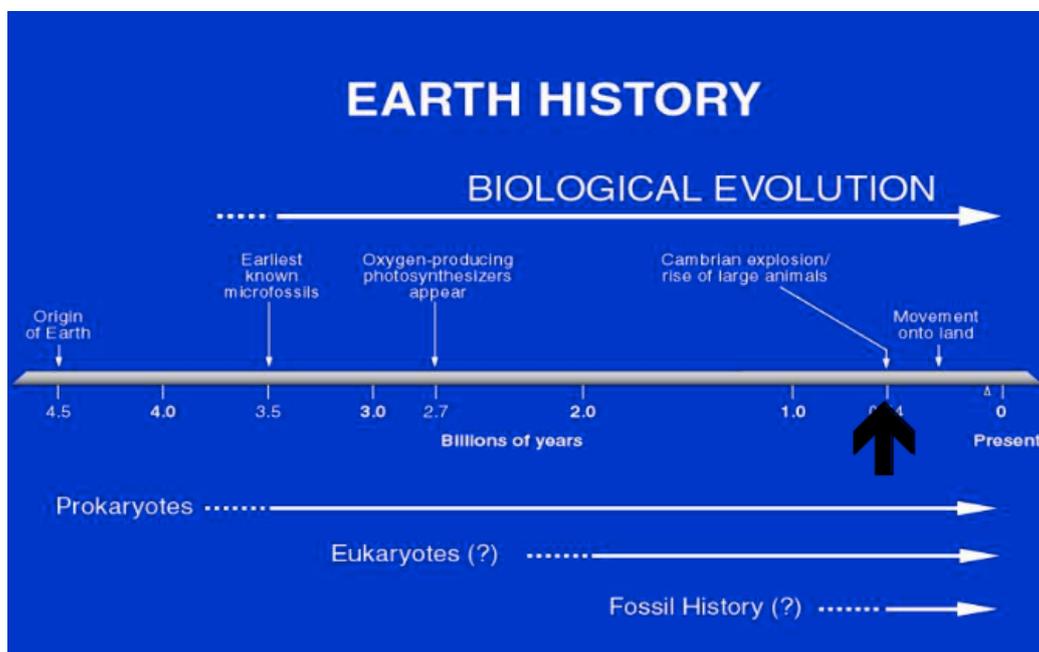
Introduction to Cell Biology

- **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 convinced 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.

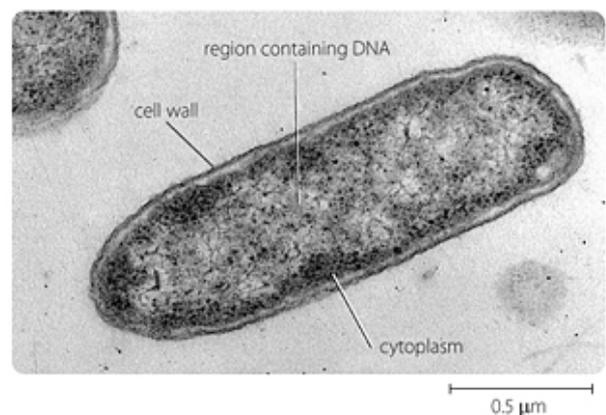
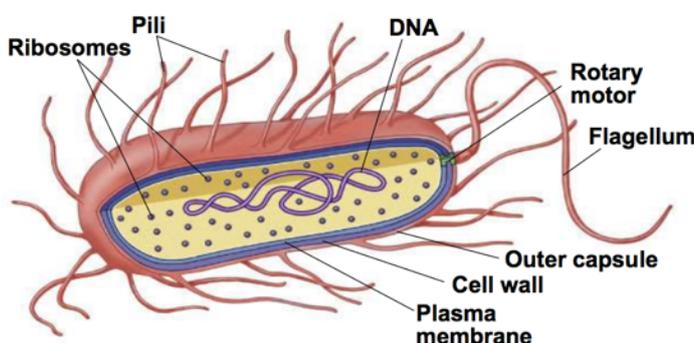
- For example, all organisms have genetic material, DNA, that contains the instructions for how that organism will develop.
- Organisms also have the machinery to carry out the instructions - proteins.
- The **THIRD GENERALISATION OF BIOLOGY** states that all organisms consist of cells.
- A **CELL** 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 time (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.



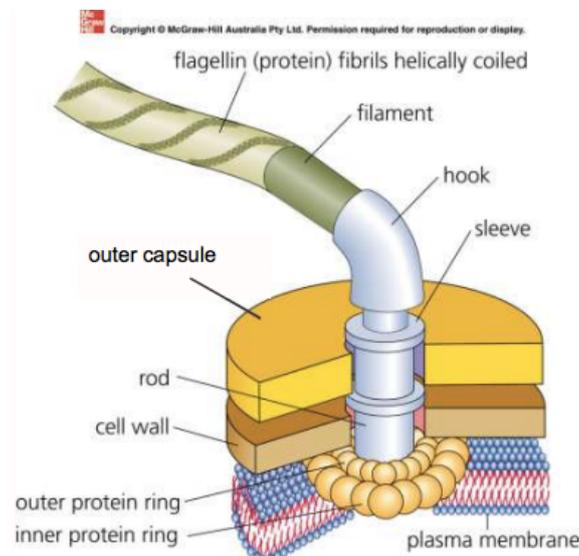
- **RNA** is a polymer, a molecule made of a number of similar subunits (nucleotide monomers).
- RNA polymers are among the molecules that have been shown to occur spontaneously. They have two properties that are relevant to the criteria that define life:
 1. Store information in the sequence order of 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 aqueous 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 1 μm 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.

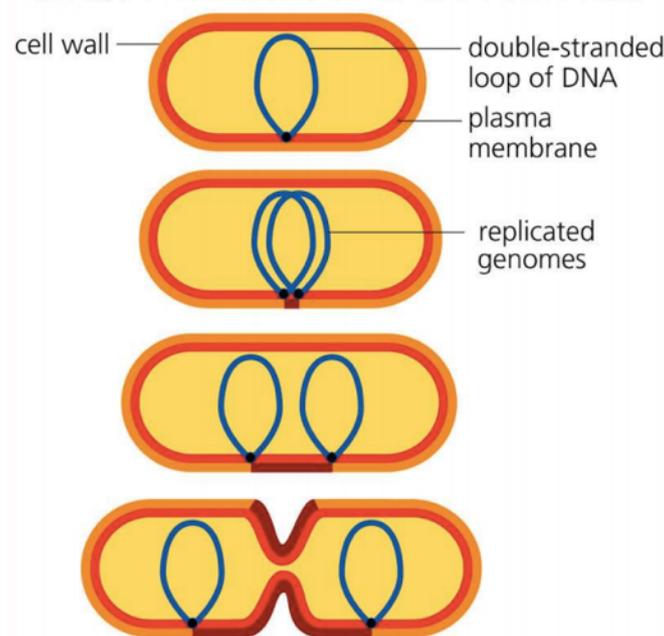


- The DNA serves as a template for mRNA synthesis; ribosomes bind to the mRNA and use the sequence of nucleotides as a code for protein synthesis.
- As prokaryotic DNA is not segregated into a nucleus, bacterial ribosomes can attach directly to mRNA molecules even while they are being synthesised in 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 involved 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 Archaeal 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 Archaeal pathogens are known.

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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 30°C and 50°C).
- 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.
- This 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.