



BIOLOGY

for

ENGINEERS

M. Srinivasan
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Biology for Engineers

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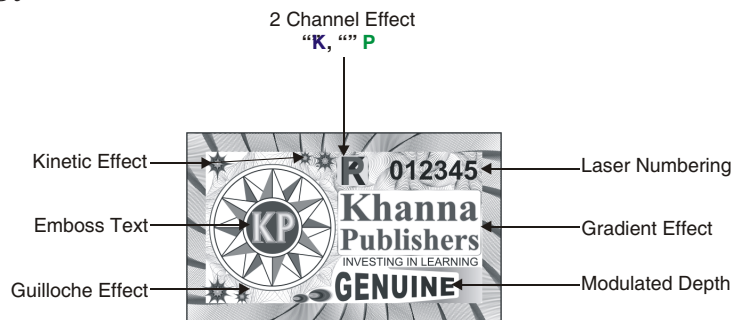
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Preface

The book contains the fundamental biological concepts required for the engineering graduates as per the AICTE recommendation and many other universities where the biology curriculum is compulsory during the first year of their studies. Though it has been prepared as per AICTE recommendation, the book would be a good resource for those who want a sense of biology. The book encompasses the vast area of biological science, and these topics have been prepared from the leading reference books of the respective topic.

The book aims to provide a reader with comprehensive information on the basic biological concepts from the beginning of evolution to advanced topics. The chapters are presented in a systemic way where the readers are first introduced to the need for biology in the present era. Then the following chapters discuss events that led to the origin of life, cell and their contents, biomolecules of cells, metabolic activities in cells, hereditary materials of cells, the microbial world around us and our body's defence system for protecting from disease-causing microbes.

Each chapter has been presented more immaculately with a simpler illustration that makes the reader understand the concepts. A set of practice questions for each chapter has been provided at the end of the textbook. The present book does not exhaust the biological concepts, and for many more advanced concepts, it is necessary to refer to specialized books for the respective topics.

It took nearly one and half years for us to shape the book and bring it to the present form. The request for the book came from Khanna Publishers, and they were prompt in completing different formalities to make it presentable.

We hope the book will benefit engineering graduates to pass biology and have a strong foundation on biological concepts. And we are sure that to make our world greener and cleaner, understanding biology is paramount and will lead to a sustainable future.

—Authors

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Origin of Life and Evolution

1.1. INTRODUCTION TO BIOLOGY

1.1.1. Biology and Engineering Sciences

From the beginning of human's creation, we are surrounded by nature, which is well organised and maintains harmony with other creations. Nature has never failed to inspire us and became a model for architectural, engineering and material sciences. Except for biology, other basic science branches are introduced to the engineering graduates in their first year of study. However, in the status quo, biology necessity has been realised and has become a part of the engineering curriculum. Continually increasing the world population increases the demand for food, sustainable fuels, a cleaner environment, good health, etc. Each of these aspects are closely associated with living organisms and demand a basic understanding of life. Having introduced the biology course, engineers may understand the process clearly and work more effectively to rectify the problems and find solutions. Besides, many of the landmark engineering inventions are derived or mimicked from nature. So, nature is a hidden treasure for the engineers to learn and adapt their design, efficacy, adaptability and self-sustainability. The engineering branches like agricultural engineering, bioengineering, chemical engineering, and food process engineering has the biology curriculum included from the very beginning.

The more sustainable designs developed by engineers are accomplished by biomimetics or biomimicry. It is related to learning from nature and then matching nature's design, processes, and ecosystems to solve design challenges. Some of such engineering marvels are discussed as follows.

Velcro is widely used as a fastener in most daily use items. It has a hook and loops that bind tightly. A Swiss electrical engineer invented it by observing burrs that were stuck on his dog and his clothes (Fig. 1.1). He observed the burrs under a microscope and found the small hooks on the burrs gripped well to the fabric loops. He artificially recreated the hook and loops which is now referred to as Velcro.

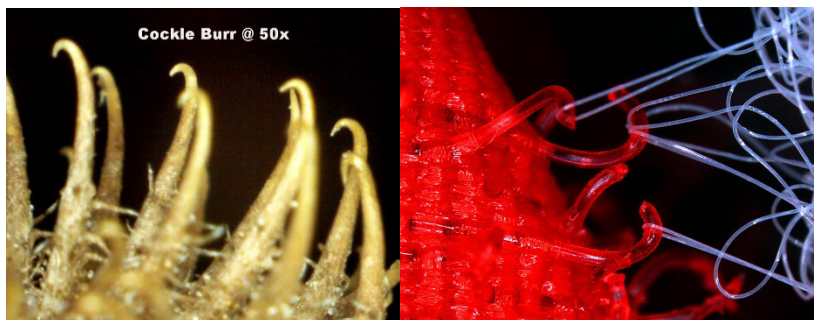


Fig. 1.1. Microscopic view of cockle burr and Velcro having a similar pattern of hooks that stuck to the loops.

Many natural designs are adopted in architecture to reduce the natural environment impact and to remain sustainable. Maintaining the temperature in a larger building is responsible for a significant share of energy consumption. Nature has beautiful mechanisms for ventilation which are adopted by living organism. One such wonder is that termite mounds are structurally stable and regulate the internal temperature by ventilation through structures (Fig. 1.2). In 1991, Mick Pearce designed a large building that cools itself based on a termite mound's blueprint. The building was designed with large ventilation chimneys through which warm air rises and exits the building. The cool air is introduced into the building with fans, and they were used to cool the buildings concrete structure in the night and during the day concrete structure cools the warm day time air. This design brought down 35% less energy consumption for the Eastgate Centre in Zimbabwe.

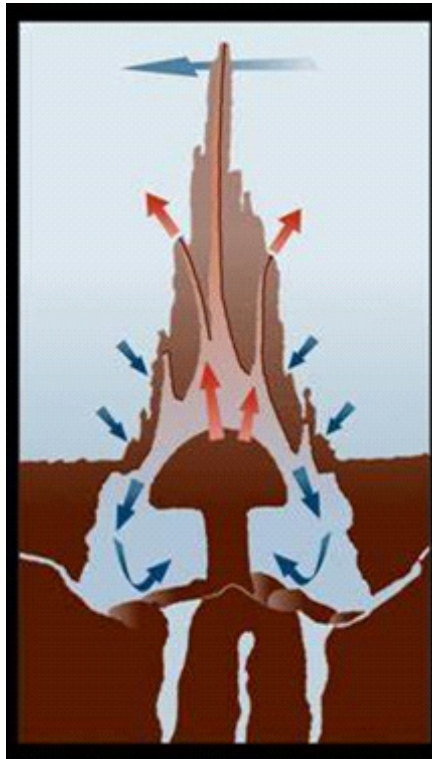


Fig. 1.2. The ventilation system of a termite mound based on which Eastern gate building in Zimbabwe was designed.

Have you ever wondered that DNA can become a storage medium for our data? DNA stores the information of a biological system which is decoded at the necessary times. The hard drive stores the information in the binary format while DNA has information coded into four nucleotides ATGC (Fig. 1.3). The binary digits are recoded into the letters ATGC to store information and decoded back to the binary format. Scientists have successfully encoded audio, image and text files into a DNA molecule with 99.99 % accuracy. Interestingly, the physical size of such devices will be significantly smaller to store a massive amount of data.

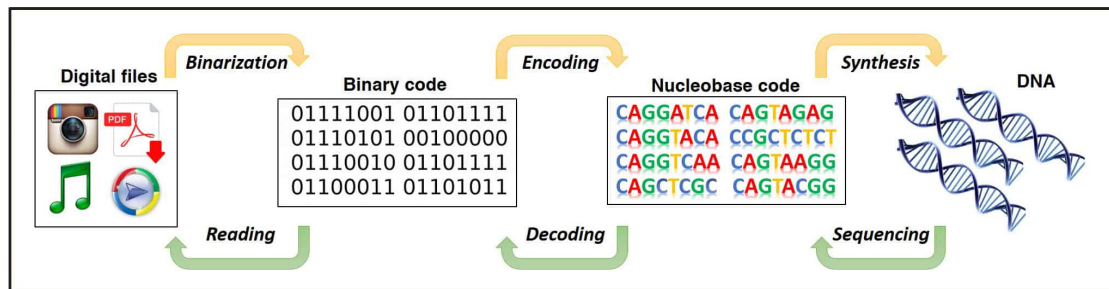


Fig. 1.3. Digital information is coded into the nucleotide sequence for storing information in DNA and subsequently recoded back to binary format.

Self-healing concrete is another engineering marvel that uses bacteria to repair the cracks in the building. Such technology has taken the construction standard to a new height. Bacteria such as *Bacillus sphaericus* and calcium lactate, nutrition for bacteria, are used in the construction materials. During the dry condition, the bacteria remain as a dormant spore; when the crack appears, they are exposed to water which activates the bacteria. They produce insoluble limestone after consuming calcium lactate. The limestone hardens to seal the crack.

The present chapter will familiarise the basic biological concepts to help engineers understand the biological system functionality. The future engineering challenges will have solutions in nature, and we need to mimic them to sustain our natural resources. The biological blueprints are likely to be our strategies to preserve mother nature

1.2. ORIGIN OF LIFE AND EVOLUTION

Life on earth has many peculiar attributes defined as the ability of an organism to reproduce, growth and development and energy processing through chemical reactions. However, there are several questions related to life which have always kept scientists and philosophers intrigued. These questions are related to understanding the origin of life and how it has reached its current form. There have been several scientific as well as nonscientific theories put forward by many scientists and philosophers to explain the origin of life and its evolution.

1.2.1 Origin of Life

At first glance, the study of the origin of life appears to be historical in nature. However, it involves multidisciplinary approach to study the events related to the formation of first protocell representing the primitive cellular life. The most accepted theory of universe formation is the “big bang theory” which postulates that the universe is continuously expanding. In 1920, Edwin Hubble also provided the evidence supporting the expansion of the universe. Our earth formed around 4.5 billion years ago, and the early earth conditions were very hostile for the development of any kind of life forms. The temperature and earth surface conditions changed gradually to generate conducive surrounding for the origin and development life forms.

There are several hypotheses to understand the quest of origin of life however among them “primordial soup theory” proposed simultaneously by Oparin of Russia and Haldane of England in 1920s has attracted the most interest. They proposed that the chemical evolution of diverse organic molecules, ‘building blocks of biomolecules like amino acids, nucleotides and sugar, happens gradually from inorganic molecules. This theory was further substantiated by the experimental evidence provided by Stanley L. Miller and Harold Urey in 1952. They created early earth like reducing conditions in laboratory scale by creating electric discharge in a flask containing CH_4 , H_2 , NH_3 gas along with water vapour at 800°C (Fig. 1.4). The analysis of

products synthesised in this experiment and other similar experiments suggest the formation of amino acids, nucleobases, pigments, fat, and sugar molecules. These experimental evidences strongly support the chemical evolution of biomolecules and from abiogenic molecules. These building blocks then polymerise to synthesise complex biopolymers.

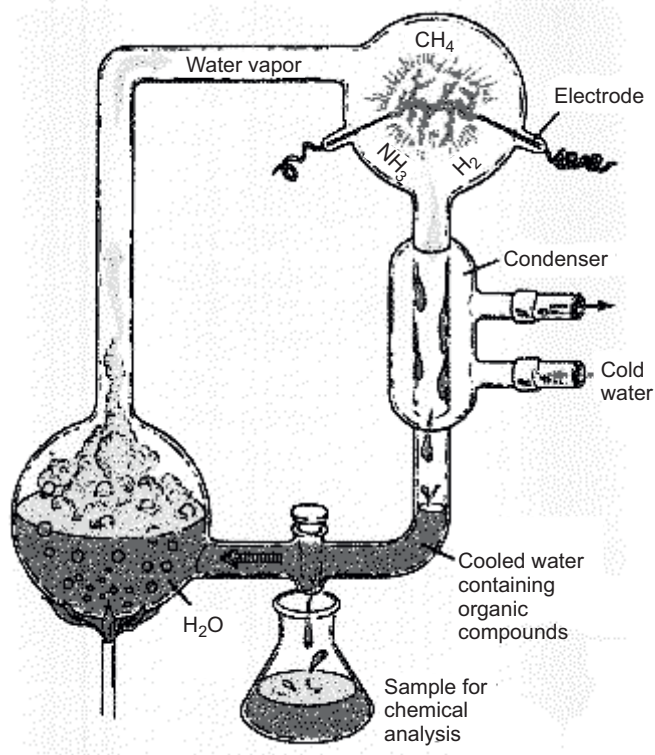


Fig. 1.4. Schematic for the Miller and Urey experimental setup.

Earlier it was thought that the first molecules to be synthesised with polymerisation ability would have been proteins giving rise to several protein centric approaches to study origin of life. However, recent discovery of enzymatic property of RNA has led to proposal of “RNA first” or “RNA world” hypothesis supporting the earliest arrival of RNA. Many recent theories also support the “Lipid first” approach as it will form the close compartments necessary for the efficient enzymatic activity by either proteins or nucleic acids (DNA, and RNA) and also prebiotic non-enzymatic polymerisation of monomers.

Evolution of life forms: For a very long time (spanning throughout Hadean and early archaean eon) there was no development of life forms, probably this was the time when nature was trying different approaches to evolve a functional and sustainable life form. Archaean eon marks the evolution of first primitive life forms as unicellular cyanobacteria and blue-green algae. They were the only life form available during archaean. As the earth temperature condition and oxygen levels changed during Proterozoic eon it gave rise to development of some more advanced multicellular organisms (Table 1.1). These included mostly sponges and some early forms of soft-bodied arthropods. The end Proterozoic eon (also referred as Precambrian time), 540 million years ago, is marked with sudden increase in the diversity of

life forms. As the name of this period is Cambrian, this phenomena of divergence of life forms is also termed as “Cambrian explosion” or “Cambrian radiation”. During Cambrian explosion almost all major phyla animals evolved including arthropods with legs and compound eyes, worms with feathery gills and swift predators. This was followed by the evolution of more complex metazoan forms with amphibian and terrestrial habitats. The evolution of different fish species, first amphibians, first reptiles and treelike ferns happened. This was followed by the Mesozoic era, also known as “age of dinosaurs”. During Mesozoic dinosaurs occupied almost all types of habitats and in conifer long with palmlike plants were dominant flora. The Cenozoic era meaning “new life” is also the current era in which we are living. This era is also recognised as age of mammals because most of the mammalian species including modern day apes, and different species of humans evolved during this era only. This is also the era of flowering plants and trees.

Table 1.1: Geological Timescale showing brief history of life on earth.

<i>Eons</i>	<i>Era</i>	<i>Period</i>	<i>Epoch</i>	<i>Age/ Years before present</i>	<i>Life/Major Events</i>
	(from 65 million year to the present time)	Quaternary	Holocene Pleistocene	0–10,000 10,000–2 million	Modern man Homo sapiens
		Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	2–5 million 5–24 million 24–37 million 37–58 million 57–65 million	Early human ancestor Ape : Flowering Plants & trees Anthropoid ape Rabbits and Hare Small mammals : Rats - Mice
	Mesozoic 65–245 million mammals	Cretaceous		65–144 million	Extinction of Dinosaurs
		Jurassic		144–208 million	Age of Dinosaurs
		Triassic		208–245 million	Frogs and turtles
	Paleocene 245–570 million	Permian		245–286 million	Reptile dominate-replace amphibians
		Carboniferous		286–360 million	First reptiles Vertebrates : Coal beds
			Devonian		360–408 million
		Silurian		408–438 million	First trace of life on land: Plants First fish
		Ordovician Cambrian		438–505 million 505–570 million	No terrestrial life Marin Invertebrate
Proterozoic	Pre-cambrian 570 million–4800 million				
Archean			570–2500 m. 2500–3800 m.	Soft-bodied arthropods Blue green Algae: Unicellular bacteria	
Hadean			3800–4800 m.	Oceans and continents form-ocean and atmosphere are rich in carbon dioxide	
	5000–13700 million			5,000 million 12000 million 13700 million	Origin of the sun Origin of the universe

Theories of evolution: The process of evolution is strongly criticised by the creationist view of thinking which follow the theory of “special creation”. According to this theory all the living organisms were created in their present form as they are today, similar diversity of organisms was present at the time of creation also, and the earth is only around 4000 years

old. However, now there are several strong evidences which refute all these connotations of special creation theory.

1. In the past numerous theories of evolution have been proposed to explain the process and mechanism of evolution. Among all these theories of evolution one of the first and best-known theory was given by French biologist Chevalier de Lamarck (also known as Lamarckism). His theory is also known as the “theory of inheritance of acquired characters” and was published in 1809 in his famous book “Philosophie zoologique”. The main postulates of his theory were, (a) continuously changing environmental condition create “**new needs**” for the organisms, (b) in order to fulfil these new needs the organisms start using or disusing organ which helps them to “**acquire new characters**” and (c) these acquired characters are then inherited to the next generation. Thus, “**the inheritance of acquired characters**” results in addition of new traits for better adaptation of the organisms for evolution. Lamarck used his hypothesis to explain many examples of evolution. Some of these examples include the evolution of Giraffe with long neck and forelimbs, and development of cylindrical body shape and disappearance of the legs in snakes (Fig. 1.5).



Fig. 1.5. Examples of the Lamarckian evolution

2. Lamarckism faced many criticisms and challenges from the contemporary evolutionary biologist as it could not explain several observations. One of the strongest criticisms came for the experiments performed by August Weismann and his theory of “**continuity of germplasm**”. According to this theory acquired characters remain within the somatic cells only and they are not inherited. Only germ cell is responsible for the inheritance of characters. Another theory of evolution which has changed the thinking of the world was given by English naturalist Charles Darwin and published as book “On the Origin of Species”

in 1859. His theory was based on the observation and evidence collected from his famous 5 years long sea voyage on H.M.S. Beagle around the world. He made several conclusions from the observation made on similarities and difference among organism during this expedition to draw evolution relationship. The postulates of his theory include (a) that every organism has enormous capability to reproduce (b) the natural resources however are limited only (c) this situation creates competition among the individual organisms and results in struggle for existence (d) some individuals have better ability to deal with this competition so they are naturally selected (e) the individuals with better traits (variation) inherit these character to the offspring's (f) thus accumulation of useful variations over several generation leads to new species formation (speciation).

Darwin explained the evolution of several new character and species using the theory of natural selection or Darwinism.

1.3. BIOLOGICAL SYSTEMS AND CLASSIFICATIONS

Biological systems are a complex network involving a group of units or organs or macromolecules or organisms to perform a specific function. It has a hierarchy ranging from ecosystem to molecules. In a broad sense, the ecosystem (biological system) consists of different organisms to perform a function, e.g. nitrogen cycle involving a group of bacteria and plants to recycle the nitrogen in the biological system. At an organism level, the biological system consists of an organ system that performs a specialised task and makes an organism alive. The different organ systems are the nervous system, digestive system, endocrine system, reproductive system, immune system, lymphatic system etc. Each of this system is a biological system comprising different cells and structures. At the cellular level, the biological system comprises macromolecules like protein, lipid, carbohydrates, nucleic acid and other organelles that make the cell functional and alive.

Biological classification arranges/classifies the living organism in a hierarchical series of groups based on the similarity and differences among them, and a binomial system of nomenclature is adopted for naming which involves two components on the name, genus followed by species (e.g. *Escherichia coli*, *Homo sapiens* and *Azadirachta indica*).

1.3.1. Taxonomy

It is the science of identification, classification and nomenclature of the living organism. Carolus Linnaeus is regarded as the father of taxonomy, and he first introduced the classification of the living organism, two kingdom classification. However, with advances in understanding living organisms evolved the classification to a five-kingdom system, a widely accepted system of classification.

The five-kingdom classification considered structure, complexity, mode of nutrition and phylogenetic relationship of cell or organism. The entire living world is placed under five kingdoms (Fig. 1.6), Monera, Protista, Fungi, Plantae and Animalia. In biological classification a hierarchy of Kingdom, Phylum, Class, Order, Family,

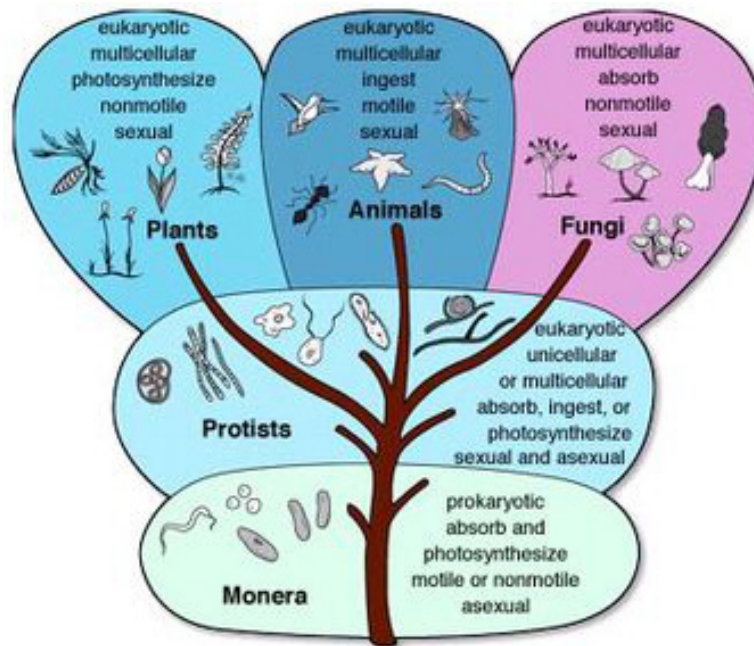


Fig. 1.6. Five kingdom classification of living organism.

Monera – It is the most primitive form of life on the earth and includes prokaryotic organism. Bacteria and Archaeobacteria are the only members of this kingdom, and these single-celled organisms lack membrane-bound organelles. These organisms are seen everywhere on earth. Scientists believe that life originated from organisms of this kingdom. (In six kingdom classification instead of Monera, eubacteria and archaeobacteria are included as a separate kingdom)

Protista – Eukaryotic unicellular organism that is microscopic. Protista - Eukaryotic single-celled organism having different modes of nutrition. Plants like protists are autotrophs that can synthesise their food with sunlight, and animal & fungal, like protists, are heterotrophs that rely on other organisms for food. Protists reproduce sexually by gametes or asexually by binary fission, budding etc.

Mycota (fungi) – Eukaryotic, multicellular organism Mycota (fungi) – fungi are eukaryotic organism that may be unicellular or multicellular. They have a cell wall made of chitin, different from plants and bacteria. Their mode of nutrition is heterotrophic, may be parasitic (relying on another living organism), saprophytic (growing on the dead and decomposing matter) or symbiotic (association with another living organism with mutual benefits). Fungi reproduce asexually and sexually.

Plantae – This kingdom includes plants, a eukaryotic, multicellular organism with a cell wall composed of cellulose. Plants have a specialised organelle called chloroplast which harvests sunlight energy for CO₂ fixation. They show the autotrophic mode of nutrition with both sexual and asexual reproduction mechanism.

Further plants classified based on their following properties (Fig. 1.7)

- (a) **Thallophyta** – Plants that do not have defined plant bodies (leaves, roots and stem) are called thallophytes. It is a group of non-mobile and relatively simple plants described as “thalloid plants”. The thallophytes have an undifferentiated body called thalli (thalli) Eg Brown algae and Lichens.
- (b) **Bryophyta** – Vascular tissues helps in the transportation of water and nutrient across the plant tissues. The plants that do not have such vascular structure are called non-vascular plants which include the division bryophyta. These are small terrestrial plants with differentiation in the body design with stem, leaf-like structures, and root-like structures. Bryophyta does not have vascular tissue to conduct water and other substances. They are the amphibians of the plant kingdom that thrive in damp and sandy habitats. Examples are Mosses and liverwort.
- (c) **Pteridophyta**: Oldest form of vascular plants with a well-differentiated plant body. They conduction water and nutrients via the vascular system. Pteridophyte reproduces through the release of spores a naked embryo. Examples are Ferns and Marseli.
- (d) **Phanerogamae**: It includes the plants bearing seeds, well-developed plant bodies like root, leaves and stem, reproductive tissues and vascular system. This division is subdivided into Gymnosperms and Angiosperms.

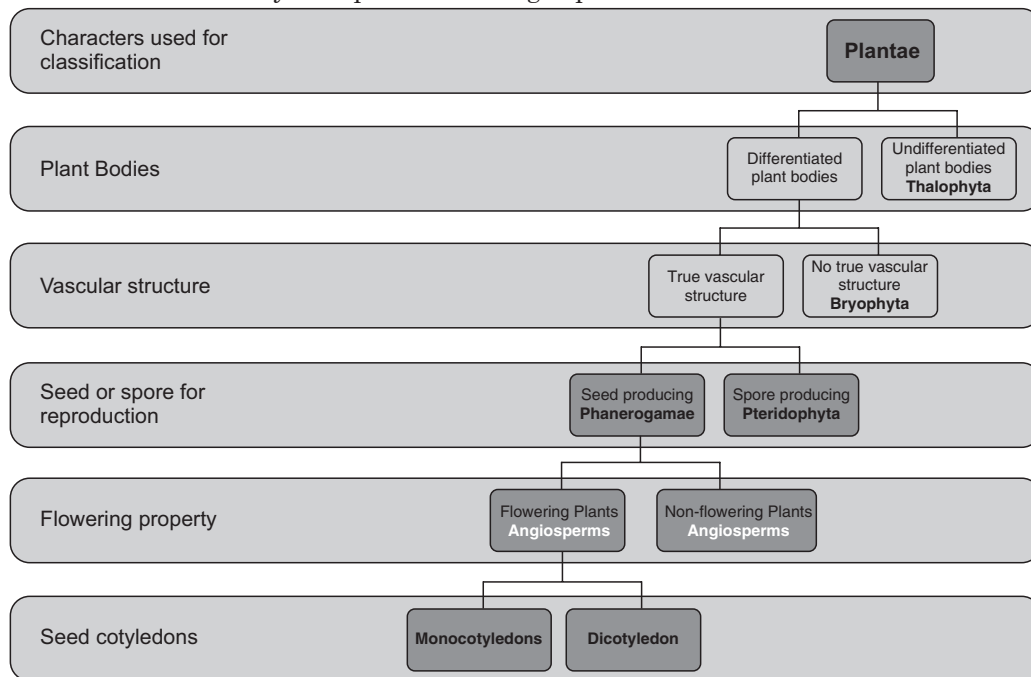


Fig. 1.7. Kingdom Plantae classification based on their fundamental properties.

Gymnosperms are ancient plants bearing naked seeds and best-known for their characteristic cones called strobili. Leaves of the gymnosperms are well adapted to their extreme habitats like temperature, wind and humidity. Examples include ginkgos, conifers and cycads.

Angiosperms form of plants dominant the terrestrial ecosystem. These plants have their seeds embedded in the fruit. They are the major source of food, fodder, fuel, medicine and other commercial importance products. Based on seeds covering seen in angiosperms, they are

subdivided into monocotyledons and dicotyledons. Cotyledon seed leaf, is a part of a embryo within the seed having the embryonic leaf. Monocotyledon seeds have a single cotyledon (e.g. Rice and maize) which cannot be split. The dicotyledon seeds have two cotyledons (e.g. Tomato, Peas) which can be split into equal halves.

Animalia — All animals fall under this category, and they possess no cell wall and photosynthetic pigments. Animals are heterotrophic organisms with holozoic nutrition, i.e., ingest, digest, absorb and assimilate the food to produce energy. They reproduce both sexually and asexually. Animals have sensory organs and a different nervous system.

Animals are further classified based on their following feature:

- (a) The cellular level of organisation: All the Animalia members are multicellular but have a different cellular organisation. In the phylum Porifera, cells are loosely organised with a few specialised cells and division of labour can be observed between different cells. Other than Porifera, all species have a tissue organisation, cells performing similar function are aggregated to form tissue, and organ system, tissues are aggregated to perform a specialised function. For instance, Pancreas is an organ made of different tissues like parenchymal tissue and epithelial tissues.
- (b) Body plane or symmetry: It is based on how the animal's body parts are distributed along the body axis. There is three types of symmetry: asymmetry, radial symmetry and bilateral symmetry. Asymmetry is seen in the phylum Porifera where the organism cannot be split into equal halves resembling each other (e.g. sponges). Radial symmetry animals can be split into identical halves when any planes pass through the animal's central axis (e.g. starfish and hydra). Bilateral symmetry is seen among insects, mammals etc., where the body can be divided into equal halves, i.e. left and right halves (Eg humans, dogs)
- (c) Segmentation: In some animals, their body is arranged in the form of segments. Segments may perform similar or different functions. In the earthworm, the body shows a segmentation pattern called metameric segmentation. Other examples for the segmented body are Arthropoda, Chordata etc
- (d) The nature of coelom: The body cavity is filled with fluid and separates the organism's outer body wall from the gut and internal organs. Jellyfish and flatworms are acoelomates; they do not have such cavity that separates their body wall from internal organs. The members of the phylum Aschelminthes have a body cavity filled with mesodermal cells and are called pseudocoelomates. Eucoelomates are the organism with a real body cavity having coelomic fluid. All the member of the phylum chordate has a body cavity in which internal organs are present.
- (e) Number of Germlayer: The number of germline cell layers formed during embryonic development defines the animals as diploblastic or triploblastic. In jellyfish and related organism, the embryo contains only two layers of cells, ectoderm and endoderm and called diploblastic. In triploblastic animals (most animals, e.g. mammals), three layers of cells are formed during embryo development. The additional layer is mesoderm sandwiched between ectoderm and endoderm.
- (f) Notochord or vertebra: The notochord is the embryo structure that gives rise to vertebrate in animals. Animals under the phylum chordate (e.g. birds, humans, reptiles) have vertebrate, backbone and non-chordate are those without vertebrate (e.g. molluscs, insects etc.)

Based on all the above properties that organism are classified into different phylum as given in the following flow chart (Fig 1.8)

BIOLOGY FOR ENGINEERS

About the Book

Biology is introduced in the engineering curriculum by the AICTE and other universities for teaching the basics of biology to engineering graduates. The objective of this book is to provide comprehensive knowledge of the topics. We have explained the topics in simple language without losing the meaning of the content. The practice questions for each chapter is provided at the end. In all the possible places, we have used TMfigures and tables to explain the concepts. This book will be the right choice for all the B.E. and B.Tech branches.

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