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Understanding cell biology

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ABSTRACT

The cell is the structural and functional unit of all living organisms and is sometimes called the "building block of life." All living things are made from one or more cells. A cell is the simplest unit of life and they are responsible for keeping an organism alive and functioning. Almost every different type of cell contains genetic material, a membrane and cytoplasm. The most basic categorization of Earth's organisms is determined by different types of cells. All cells can be divided into one of two classifications: prokaryotic cells and eukaryotic cells. Prokaryotic cells are found in bacteria and archaea. Eukaryotic cells are found in organisms from the domain Eukaryota which includes animals, plants, fungi and protists. Cell metabolism is the process by which individual cells process nutrient molecules. Metabolism has two distinct divisions: catabolism, in which the cell breaks down complex molecules to produce energy and reducing power, and anabolism, in which the cell uses energy and reducing power to construct complex molecules and perform other biological functions. Cells were discovered by Robert Hooke in 1665, who named them for their resemblance to cells inhabited by Christian monks in a monastery. Cell theory, first developed in 1839 by Matthias Jakob Schleiden and Theodor Schwann, states that all organisms are composed of one or more cells, that cells are the fundamental unit of structure and function in all living organisms, and that all cells come from pre-existing cells. Cells emerged on Earth at least 3.5 billion years ago. The study of cells is called cell biology or cellular biology.

Keywords: Cell; Photosynthesis; Mitochondria; Chloroplast; Nucleus; Genetics; Biology.

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INTRODUCTION

Cell, in biology, the basic membrane-bound unit that contains the fundamental molecules of life and of which all living things are composed. A single cell is often a complete organism, such as a bacterium or yeast.

Although cells are much larger than atoms, they are still very small. The smallest known cells are a group of tiny bacteria called mycoplasmas; some of these single-celled organisms are spheres as small as 0.2 µm in diameter (1µm = about 0.000039 inch), with a total mass of 10−14 gram—equal to that of 8,000,000,000 hydrogen atoms.

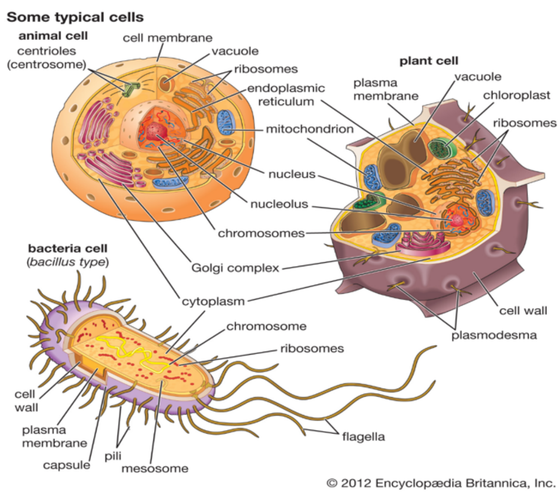

Figure 1: Animal Cell, Plant Cell & Bacteria Cell biology

Biology is the science of life. Its name is derived from the Greek words "bios" (life) and "logos" (study). Biologists study the structure, function, growth, origin, evolution and distribution of living organisms.

There are generally considered to be at least nine "umbrella" fields of biology, each of which consists of multiple subfields.

Biochemistry: the study of the material substances that make up living things

Botany: the study of plants, including agriculture

Cellular biology: the study of the basic cellular units of living things

Ecology: the study of how organisms interact with their environment

Evolutionary biology: the study of the origins and changes in the diversity of life over time

Genetics: the study of heredity

Molecular biology: the study of biological molecules

Physiology: the study of the functions of organisms and their parts

Zoology: the study of animals, including animal behaviour

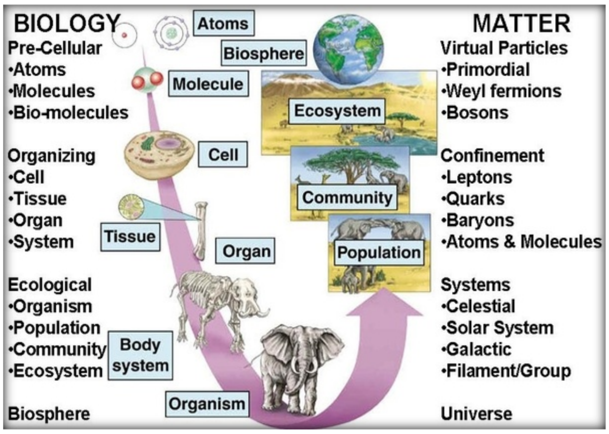

Figure 2: Biological Cycle

Cell biology: Cell biology (also called cytology, from the Greek κύτος, kytos, "vessel") is a branch of biology that studies the structure and function of the cell, which is the basic unit of life.

Cell biology is concerned with the physiological properties, metabolic processes, signalling pathways, life cycle, chemical composition and interactions of the cell with their environment. Research in cell biology is closely related to genetics, biochemistry, molecular biology, immunology and cytochemistry.

History of biology: Our fascination with biology has a long history. Even early humans had to study the animals they hunted and know where to find the plants they gathered for food. "The invention of agriculture was the first great advance of human civilization". Medicine has been important to us from earliest history as well. The earliest known medical texts are from China (2500 B.C.), Mesopotamia (2112 B.C.), and Egypt (1800 B.C.).

In classical times, Aristotle is often considered to be the first to practice scientific zoology. He is known to have performed extensive studies of marine life and plants. His student, Theophrastus, wrote one of the West's earliest known botanical texts in 300 B.C. on the structure, life cycle and uses of plants.

During the Renaissance, Leonardo da Vinci risked censure by participating in human dissection and making detailed anatomical drawings that are still considered among the most beautiful ever made. Binomial classification was inaugurated by Carolus Linnaeus in 1735, using Latin names to group species according to their characteristics.

Microscopes opened new worlds for scientists. In 1665, Robert Hooke, used a simple compound microscope to examine a thin sliver of cork. He observed that the "*plant tissue consisted of rectangular units that reminded him of the tiny rooms used by monks*". He called these units "cells." In 1676, Anton von Leeuwenhoek published the first drawings of living single celled organisms.

During 1859, Charles Darwin published "On the Origin of Species," the text that forever changed the world by showing that "*all living things are interrelated and that species were not separately created but arise from ancestral forms that are changed and shaped by adaptation to their environment*".

Gregor Mendel is now known as the father of genetics. His work was rediscovered in 1900 and further understanding of inheritance rapidly followed. Beginning with Watson and Crick explaining the structure and function of DNA in 1953, all fields of biology have expanded exponentially and touch every aspect of our lives.

Figure 3: From Top (Left to Right) - Aristotle – Theophrastus - Leonardo da Vinci - Carolus Linnaeus – Robert Hooke - Anton von Leeuwenhoek - Charles Darwin - Gregor Mendel - Watson and Crick

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Overview

All living cells possess a cell membrane. These membranes serve to contain and protect cell components from the surroundings as well as regulate the transport of material into and out of the cell. Cell membranes are the selectively permeable lipid bilayers inclusive of membrane proteins which delimits all prokaryotic and eukaryotic cells.

Table 1: Differences between Animal and Plant cell

S.No	Animal cell	Plant cell
1.	Animal cells are generally small in size.	Plant cells are larger than animal cells.
2.	Cell wall is absent.	The plasma membrane of plant cells is surrounded by a rigid cell wall of cellulose.
3.	Except the protozoan *Euglena* no animal cell possesses plastids.	Plastids are present.
4.	Vacuoles in animal cells are many and small.	Most mature plant cells have a large central sap vacuole.
5.	Animal cells have a single highly complex Golgi	Plant cells have many simpler units of and prominent Golgi apparatus. apparatus, called dictyosomes.
6.	Animal cells have centrosome and centrioles.	Plant cells lack centrosome and centrioles.

Roles of Cell Membrane

Functionally membranes take part in several cellular activities covering "motility, energy transduction in lower unicellular organisms to immunorecognition in higher eukaryotes". The most valuable function is segregation of the cell into compartments. "This functional diversity is due to the variability in lipid and protein composition of the membranes". The various functions can be summarized as given below.

Diffusion: Diffusion of small molecules such as carbon dioxide, oxygen (O_2), and water happens by passive transport.

Osmosis: Cell membrane is semipermeable thus it sets up an osmotic flow for solvent such as water, which can be transported across the membrane by osmosis.

Mediated Transport: Nutrients are moved across the membrane by special proteins called transport proteins or permeases which are quite specific, recognizing and transporting only a limited group of chemical substances, often even only a single substance.

Endocytosis: Endocytosis is the process in which cells absorb molecules by engulfing them small molecules and ions and macromolecules through active transport which requires ATP.

Exocytosis: The plasma membrane can extrude its contents to the surrounding medium to remove undigested residues of substances brought in by endocytosis, to secrete substances such as hormones and enzymes, and to transport a substance completely across a cellular barrier.

Cell adhesion: This is how cells and tissues hold together.

Cell signalling: This is the regulation of cellular behaviour by molecular signals from outside the cell.

Functions of cell organelles

Vacuole: It is present at the centre and is water-filled volume enclosed by a membrane known as the **tonoplast.** The function is to maintain the cell's turgor, pressure by controlling movement of molecules between the cytosol and sap, stores useful material and digests waste proteins and organelles.

Cell Wall: It is the extracellular structure surrounding plasma membrane. The cell wall is composed of cellulose, hemicellulose, pectin and in many cases lignin, is secreted by the protoplast on the outside of the cell membrane. The cell wall is divided into the primary cell wall and the secondary cell wall. The Primary cell wall: extremely elastic and the secondary cell wall forms around primary cell wall after growth are complete.

Plasmodesmata: Pores in the primary cell wall through which the plasmalemma and endoplasmic reticulum of adjacent cells are continuous.

Plastids: The plastids are chloroplasts, which contain chlorophyll and the biochemical systems for light harvesting and photosynthesis. A typical plant cell (e.g., in the palisade layer of a leaf) might contain as many as 50 chloroplasts. The other plastids are amyloplasts specialized for starch storage, elaioplasts specialized for fat storage, and chromoplasts specialized for synthesis and storage of pigments.

Parenchyma cells: These are living cells that have diverse functions ranging from storage and support to photosynthesis and are specialized for light penetration and focusing or regulation of gas exchange.

Collenchyma cells: Collenchyma cells are alive at maturity and have only a primary wall. Pectin and hemicellulose are the dominant constituents of collenchyma cell. The role of this cell type is to support the plant in axes still growing in length, and to confer flexibility and tensile strength on tissues.

Sclerenchyma cells: Sclerenchyma cells (from the Greek skleros, hard) are hard and tough cells with a function in mechanical support. They are of two broad types – sclereids or stone cells and fibres.

Nucleus: They are spherical body containing many organelles, including the nucleolus. The nucleus controls many of the functions of the cell (by controlling protein synthesis) and contains DNA (in chromosomes). The nucleus is surrounded by the nuclear membrane and possesses the nucleolus which is an organelle.

Golgi apparatus: It is a flattened, layered, sac-like organelle involved in packaging proteins and carbohydrates into membrane-bound vesicles for export from the cell.

Ribosome and Endoplasmic reticulum: Ribosomes are small organelles composed of RNA-rich cytoplasmic granules that are sites of protein synthesis and Endoplasmic reticulum are the sites of protein maturation and they can be divided into the following types:

a. **Rough endoplasmic reticulum**: Rough ER is covered with ribosomes that give it a rough appearance. Rough ER transport materials through the cell and produces proteins in sacks called cisternae (which are sent to the Golgi body, or inserted into the cell membrane).

b. **Smooth endoplasmic reticulum**: The space within the ER is called the ER lumen. Smooth ER transport materials through the cell. It contains enzymes and produces and digests lipids (fats) and membrane proteins; smooth ER buds off from rough ER, moving the newly made proteins and lipids to the Golgi body and membranes.

Mitochondria: These are spherical to rod-shaped organelles with a double membrane. The inner membrane is infolded many times, forming a series of projections (called cristae). The mitochondrion converts the energy stored in glucose into ATP (adenosine triphosphate) for the cell.

Chloroplasts: The chloroplast (chlor=green; plast=living) is most widely occurring chromoplast of the plants. It occurs mostly in the green algae and higher plants. The chloroplast contains the pigment chlorophyll a and chlorophyll b and DNA and RNA.

Photosynthesis: *Photosynthesis is a chemical reaction that takes place inside a plant, producing food for the plant to survive.*

Plants need food to respire, grow and reproduce. Unlike animals, plants can make their own food by the process of photosynthesis. Photosynthesis takes place in the part of the plant cell containing chloroplasts, these are small structures that contain chlorophyll. For photosynthesis to take place, plants need to take in carbon dioxide (from the air), water (from the ground) and light (usually from the sun).

Here is the word equation for photosynthesis:

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{sunlight}} \text{glucose} + \text{oxygen}$$

Equation 1: Photosynthesis chemical reaction

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow{\text{Light}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

DNA & RNA:

Living things like human and animal have **DNA (Deoxyribonucleic acid)**, a molecule containing the organism's instructions to develop, grow, live, and reproduce.

It is a primary macromolecule vital for all forms of life. It stands for ribonucleic acid. RNA allows the genetic flow of information in the cells. It begins with DNA and travels through the RNA to proteins.

DNA

A complex molecule found in the cell's nucleus.

It has a double-helix structure in eukaryotic cells.

It is present in all living organisms.

It contains genetic instructions necessary to develop and maintain life.

Its nucleic acid is deoxyribose.

Its nucleotides include adenine, cytosine, guanine, and thymine.

It is stable under alkaline conditions.

Its primary role is to store and transfer genetic information.

RNA

Its nucleic acid is ribose.

It is single-stranded and available in various shapes and types.

Its molecule can easily fold back on itself because of its single-stranded structure.

Its nucleotides include uracil, A, G, and C.

RNA is unstable in alkaline conditions.

Its primary function is to directly codes for amino acid and serves as a messenger between the DNA and ribosomes to create proteins.

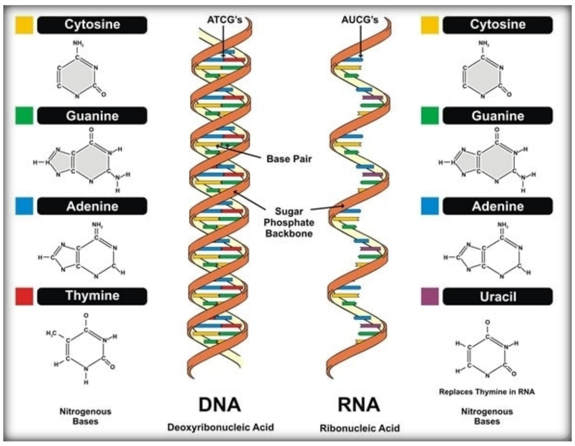


Figure 4: Comparison between DNA & RNA

Cell biology - cell cycle and division

Cell cycle refers to a sequence in actively dividing cells where the cells pass through several stages before ultimately dividing.

The stages of cell cycle include:

1. Two gap phases (G1 and G2)
2. The S phase (synthesis)
3. The M phase

At GI, the metabolic changes take place preparing the cell for the division process. At a given point known as the restriction point, the cell is committed to cell division and moves to the next phase.

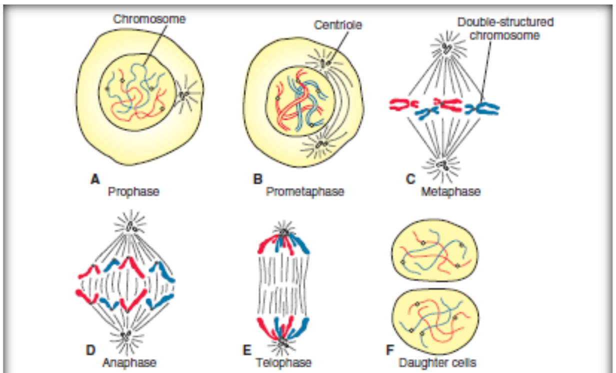
S - The S phase involves DNA synthesis. It is during this phase that the replication of genetic material starts with each of the chromosome having two chromatic sisters.

G2 - During this phase, there are metabolic changes that assemble the necessary cytoplasmic materials for the mitosis process and splitting of the mother cell.

M - The M phase is where nuclear division takes place and followed by the division of the cell.

Mitosis

Mitosis is the process whereby one cell divides, giving rise to two daughter cells that are genetically identical to the parent cell.



Various stages of mitosis. In prophase, chromosomes are visible as slender threads. Doubled chromatids become clearly visible as individual units during metaphase. At no time during division do members of a chromosome pair unite. *Blue*, paternal chromosomes; *red*, maternal chromosomes.

Figure 5: Various Stages of Mitosis

Each daughter cell receives the complete complement of 46 chromosomes. Before a cell enters mitosis, each chromosome replicates its deoxyribonucleic acid (DNA). During this replication phase chromosomes are extremely long, they are spread diffusely through the nucleus, and they cannot be recognized with the light microscope. With the onset of mitosis, the chromosomes begin to coil, contract, and condense; these events mark the beginning of prophase. Each chromosome now consists of two parallel subunits, chromatids, that are joined at a narrow region common to both called the centromere. Throughout prophase, the chromosomes continue to condense, shorten, and thicken, but only at prometaphase do the chromatids become distinguishable. During metaphase, the chromosomes line up in the equatorial plane, and their doubled structure is clearly visible. Each is attached by microtubules extending from the centromere to the centriole, forming the mitotic spindle. Soon, the centromere of each chromosome divides, marking the beginning of anaphase, followed by migration of chromatids to opposite poles of the spindle. Finally, during telophase, chromosomes uncoil and lengthen, the nuclear envelope reforms, and the cytoplasm divides. Each daughter cell receives half of all doubled chromosome material and thus maintains the same number of chromosomes as the mother cell.

MEIOSIS

Meiosis is the cell division that takes place in the germ cells to generate male and female gametes, sperm and egg cells, respectively.

Meiosis requires two cell divisions, meiosis I and meiosis II, to reduce the number of chromosomes to the haploid number of 23. As in mitosis, male and female germ cells (spermatocytes and primary oocytes) at the beginning of meiosis I replicate their DNA so that each of the 46 chromosomes is duplicated into sister chromatids. In contrast to mitosis, however, homologous chromosomes then align themselves in pairs, a process called synapsis. The pairing is exact and point for point except for the XY combination. Homologous pairs then separate into two daughter cells, thereby reducing the chromosome number from diploid to haploid. Shortly thereafter, meiosis II separates sister chromatids. Each gamete then contains 23 chromosomes.

Crossover : Crossovers, critical events in meiosis I, are the interchange of chromatid segments between paired homologous chromosomes. Segments of chromatids break and are exchanged as homologous chromosomes separate. As separation occurs, points of interchange are temporarily united and form an X-like structure, a chiasma. The approximately 30 to 40 cross- overs (one or two per chromosome) with each meiotic I division are most frequent between genes that are far apart on a chromosome.

As a result of meiotic divisions

Genetic variability is enhanced through

crossover, which redistributes genetic material

random distribution of homologous chromosomes to the daughter cells

Each germ cell contains a haploid number of chromosomes, so that at fertilization the diploid number of 46 is restored.

Polar Bodies

Also, during meiosis, one primary oocyte gives rise to four daughter cells, each with 22 plus 1 X chromosomes. Only one of these develops into a mature gamete, however, the oocyte; the other three, the polar bodies, receive little cytoplasm and degenerate during subsequent development. Similarly, one primary spermatocyte gives rise to four daughter cells, two with 22 plus 1 X Chromosomes and two with 22 plus 1 Y Chromosomes. In contrast to oocyte formation, however, all four develop into mature gametes.

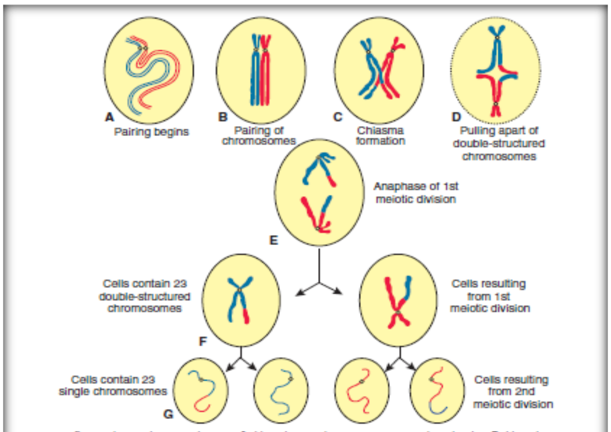
Chromosome - A molecule of DNA wrapped around histones that becomes visible during prophase of cell division.

Chromatid - A replicated chromosome: each strand of the 'X' is a chromatid.

Diploid - Cells that have two copies of each chromosome in their nuclei.

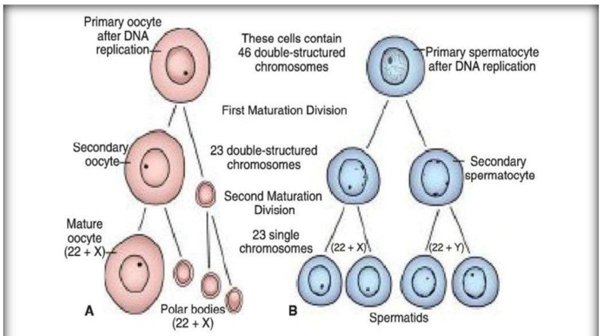
Haploid - Cells that have one copy of each chromosome in their nuclei.

Homologous Chromosomes - Chromosomes that have the same genes in the same places. For each homologous pair, one comes from the mother, the other from the father.



First and second meiotic divisions. **A.** Homologous chromosomes approach each other. **B.** Homologous chromosomes pair, and each member of the pair consists of two chromatids. **C.** Intimately paired homologous chromosomes interchange chromatid fragments (crossover). Note the chiasma. **D.** Double-structured chromosomes pull apart. **E.** Anaphase of the first meiotic division. **F,G.** During the second meiotic division, the double-structured chromosomes split at the centromere. At completion of division, chromosomes in each of the four daughter cells are different from each other.

Figure 6: Stages of Meiotic Divisions



Events occurring during the first and second maturation divisions. **A.** The primitive female germ cell (primary oocyte) produces only one mature gamete, the mature oocyte. **B.** The primitive male germ cell (primary spermatocyte) produces four spermatids, all of which develop into spermatozoa.

Figure 7: Gametogenesis: Conversion of Germ Cells into Male and Female Gametes

Common cell biology techniques

Some of the more commonly used cell biology techniques – it is by no means exhaustive.

Cell / Tissue Culture - Cell and tissue culture is a powerful tool which provides an almost limitless supply of test material for researchers to use without resorting to using whole organisms. In addition, the controlled conditions in cell and tissue culture allows researchers to carry out experiments with a lower number of variables which may affect the outcome of the test. Cell culture may use cells removed directly from an organism (primary culture), or it may use lines of cultured cancer cells. The benefit of the latter approach is that cancer cells continue to divide, while primary cultures cease dividing after a few cycles.

Microscopy – the basic tool of cell biology is microscopy. Recent advances in imaging technology has allowed an unprecedented amount of information to be gleaned from microscopic analysis. Types of microscopic techniques which are used include:

Brightfield – traditional microscopy, where cells are illuminated by visible light. Brightfield microscopy gives a general picture of cell function, although that information is not very detailed or specific. As animal cells lack cell walls, brightfield microscopy may use special techniques such as phase contrast to show cellular structures in more detail.

Electron Microscopy – uses a focused beam of electrons instead of light. Electron microscopy permits a much higher magnification of specimens than light microscopy and is useful in obtaining detailed information about sub-cellular structures. Electron microscopy requires extensive processing and so can only be performed on fixed specimens. Transmission electron microscopy provides a cross section of a specimen, while scanning electron microscopy gives a three-dimensional image of the surface of a specimen.

Fluorescence Microscopy – uses fluorescent materials to indicate structures in a specimen. Fluorescence occurs when light of one wavelength "excites" a material and causes it to emit light of a different wavelength. Most fluorescent materials give off visible light after excitation by ultraviolet light. Structures may be naturally fluorescent (autofluorescence) or they may be labelled with a compound which is fluorescent (e.g. DAPI is a dye which binds onto DNA. The DNA and nuclei of cells stained with DAPI emit a blue light under ultraviolet light).

Immunofluorescence – antibodies are proteins made by the immune system which bind onto specific parts of proteins. Antibodies can be raised against any protein in the cell. If these antibodies are attached to a fluorescent tag, the tag will only show up where that antibody attached (i.e. where the target protein is found in the cell). Immunofluorescence allows very specific targeting of cellular structures.

RNA Interference – RNA interference uses short sequences of RNA which are complementary to the mRNA which carries to instructions to translate proteins from the DNA to the ribosomes. The interfering RNA binds to the target sequence, preventing it from being translated.

Time-lapse Microscopy – many cellular processes (e.g. mitosis) occur over a period which is not practical for direct observation. Imaging cells over a period (e.g. a photograph is taken every 20 minutes for 24 hours) allows us to combine these images in a "movie" which compresses a long time period into a shorter one.

APPLICATIONS OF CELL BIOLOGY

1. Studies of the cell structure, a very integral part of Cell Biology, is essential in Biotechnology research as the latter involves knowledge of cell structure of living cells in order to carry out cell therapeutics and related genetic studies
2. Cell and tissue culturing, an essential unit of cell biology inculcates knowledge and practice of the fundamental techniques involved in the growth of the cell type of interest. This is applied in biotechnology to nature cells of interest in preparation for Genetic studies.
3. Cell division in Cell Biology, is crucial in Biotechnological studies, when monitoring growth of Cancer cells for therapeutic purposes.
4. Cell physiology, studied in Cell Biology, helps Biotechnologists to understand the concept of Cell transport which they apply in Mutation studies to confirm how wild strains and mutants behave physiologically.
5. Biotechnologists apply the concept of Cell Death (a unit in Cell Biology) to study the effects of external and internal forces influencing the cell's life-maintaining signals, this therefore helps them know and appreciate the concept of cell apoptosis (programmed cell death)

CONCLUSION

Cell biology is an important discipline that has allowed for viewing and studying of cells for decades now. It has become particularly important to differentiate and determine different types of cells, cell processes as well as understanding of various diseases and illnesses associated with cell malfunctioning.

With advancements in various cell biology techniques, it is becoming easier to learn more about cells and cell processes for effective intervention where necessary.

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