**Stem Cell**

Primarily from Wikipedia, the free encyclopedia

([https://en.wikipedia.org/wiki/Cell\_(biology)](https://en.wikipedia.org/wiki/Cell_%28biology%29))

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**Abstract:** The cell is the basic structural, functional, and biological unit of all known organisms. Cells are the smallest units of life, and hence are often referred to as the building blocks of life. The study of cells is called [cell biology](https://en.wikipedia.org/wiki/Cell_biology), cellular biology, or cytology. Cells consist of [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm) enclosed within a [membrane](https://en.wikipedia.org/wiki/Cell_membrane), which contains many [biomolecules](https://en.wikipedia.org/wiki/Biomolecule) such as [proteins](https://en.wikipedia.org/wiki/Protein) and [nucleic acids](https://en.wikipedia.org/wiki/Nucleic_acid). Most plant and animal cells are only visible under a [light microscope](https://en.wikipedia.org/wiki/Light_microscope), with dimensions between 1 and 100 [micrometres](https://en.wikipedia.org/wiki/Micrometre). [Electron microscopy](https://en.wikipedia.org/wiki/Electron_microscopy) gives a much higher resolution showing greatly detailed cell structure. Organisms can be classified as [unicellular](https://en.wikipedia.org/wiki/Unicellular) or [multicellular](https://en.wikipedia.org/wiki/Multicellular). Most [unicellular organisms](https://en.wikipedia.org/wiki/Unicellular_organism) are classed as [microorganisms](https://en.wikipedia.org/wiki/Microorganism). The number of cells in plants and animals varies from species to species; it has been estimated that humans contain somewhere around 40 trillion (4×1013) cells. The human brain accounts for around 80 billion of these cells. Cells were discovered by [Robert Hooke](https://en.wikipedia.org/wiki/Robert_Hooke) in 1665, who named them for their resemblance to cells inhabited by [Christian monks](https://en.wikipedia.org/wiki/Christian_monasticism) in a monastery. [Cell theory](https://en.wikipedia.org/wiki/Cell_theory), first developed in 1839 by [Matthias Jakob Schleiden](https://en.wikipedia.org/wiki/Matthias_Jakob_Schleiden) and [Theodor Schwann](https://en.wikipedia.org/wiki/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.[[9]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-10) Cells emerged on Earth at least 3.5 billion years ago.

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**Keywords**: cell; biological unit; organism; biology; cytology; [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm); [membrane](https://en.wikipedia.org/wiki/Cell_membrane); [biomolecule](https://en.wikipedia.org/wiki/Biomolecule); [protein](https://en.wikipedia.org/wiki/Protein); [nucleic acid](https://en.wikipedia.org/wiki/Nucleic_acid); plant; animal; [unicellular](https://en.wikipedia.org/wiki/Unicellular); [multicellular](https://en.wikipedia.org/wiki/Multicellular); [microorganisms](https://en.wikipedia.org/wiki/Microorganism)

The cell is the basic structural, functional, and biological unit of all known organisms. Cells are the smallest units of life, and hence are often referred to as the building blocks of life. The study of cells is called [cell biology](https://en.wikipedia.org/wiki/Cell_biology), cellular biology, or cytology.[[1]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-etymonline1-1)

Cells consist of [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm) enclosed within a [membrane](https://en.wikipedia.org/wiki/Cell_membrane), which contains many [biomolecules](https://en.wikipedia.org/wiki/Biomolecule) such as [proteins](https://en.wikipedia.org/wiki/Protein) and [nucleic acids](https://en.wikipedia.org/wiki/Nucleic_acid).[[2]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Alberts2002-2) Most plant and animal cells are only visible under a [light microscope](https://en.wikipedia.org/wiki/Light_microscope), with dimensions between 1 and 100 [micrometres](https://en.wikipedia.org/wiki/Micrometre).[[3]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-3) [Electron microscopy](https://en.wikipedia.org/wiki/Electron_microscopy) gives a much higher resolution showing greatly detailed cell structure. Organisms can be classified as [unicellular](https://en.wikipedia.org/wiki/Unicellular) or [multicellular](https://en.wikipedia.org/wiki/Multicellular).[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) Most [unicellular organisms](https://en.wikipedia.org/wiki/Unicellular_organism) are classed as [microorganisms](https://en.wikipedia.org/wiki/Microorganism).

The number of cells in plants and animals varies from species to species; it has been estimated that humans contain somewhere around 40 trillion (4×1013) cells.[[5]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-cellcount-5) The human brain accounts for around 80 billion of these cells.[[6]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-JCN-7)

Cells were discovered by [Robert Hooke](https://en.wikipedia.org/wiki/Robert_Hooke) in 1665, who named them for their resemblance to cells inhabited by [Christian monks](https://en.wikipedia.org/wiki/Christian_monasticism) in a monastery.[[7]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Karp2009-8)[[8]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-9) [Cell theory](https://en.wikipedia.org/wiki/Cell_theory), first developed in 1839 by [Matthias Jakob Schleiden](https://en.wikipedia.org/wiki/Matthias_Jakob_Schleiden) and [Theodor Schwann](https://en.wikipedia.org/wiki/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.[[9]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-10) Cells emerged on Earth at least 3.5 billion years ago.[[10]](https://en.wikipedia.org/wiki/Cell_%28biology%29%22%20%5Cl%20%22cite_note-Origin1-11)[[11]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Origin2-12)[[12]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-RavenJohnson2002-13)

**Cell biology** (also **cellular biology** or **cytology**) is a branch of [biology](https://en.wikipedia.org/wiki/Biology) studying the [structure](https://en.wikipedia.org/wiki/Structural_biology) and [function](https://en.wikipedia.org/wiki/Physiology) of the [cell](https://en.wikipedia.org/wiki/Cell_%28biology%29), also known as the basic unit of [life](https://en.wikipedia.org/wiki/Life).[[1]](https://en.wikipedia.org/wiki/Cell_biology#cite_note-1) Cell biology encompasses both [prokaryotic](https://en.wikipedia.org/wiki/Prokaryote) and [eukaryotic cells](https://en.wikipedia.org/wiki/Eukaryote) and can be divided into many sub-topics which may include the study of [cell metabolism](https://en.wikipedia.org/wiki/Metabolism), [cell communication](https://en.wikipedia.org/wiki/Signaling_pathway), [cell cycle](https://en.wikipedia.org/wiki/Biological_life_cycle), [biochemistry](https://en.wikipedia.org/wiki/Biochemistry), and [cell composition](https://en.wikipedia.org/wiki/Cell_%28biology%29). The study of cells is performed using several techniques such as [cell culture](https://en.wikipedia.org/wiki/Cell_culture), various types of microscopy, and [cell fractionation](https://en.wikipedia.org/wiki/Cell_fractionation). These have allowed for and are currently being used for discoveries and research pertaining to how cells function, ultimately giving insight into understanding larger organisms. Knowing the components of cells and how cells work is fundamental to all [biological sciences](https://en.wikipedia.org/wiki/Biology) while also being essential for research in [biomedical](https://en.wikipedia.org/wiki/Bio-medical) fields such as [cancer](https://en.wikipedia.org/wiki/Cancer), and other diseases. Research in cell biology is interconnected to other fields such as [genetics](https://en.wikipedia.org/wiki/Genetics), [molecular genetics](https://en.wikipedia.org/wiki/Molecular_genetics), [biochemistry](https://en.wikipedia.org/wiki/Biochemistry), [molecular biology](https://en.wikipedia.org/wiki/Molecular_biology), [medical microbiology](https://en.wikipedia.org/wiki/Medical_microbiology), [immunology](https://en.wikipedia.org/wiki/Immunology), and [cytochemistry](https://en.wikipedia.org/wiki/Cytochemistry%22%20%5Co%20%22Cytochemistry).

## Cell types

Cells are of two types: [eukaryotic](https://en.wikipedia.org/wiki/Eukaryotic), which contain a [nucleus](https://en.wikipedia.org/wiki/Cell_nucleus), and [prokaryotic](https://en.wikipedia.org/wiki/Prokaryotic), which do not. Prokaryotes are [single-celled organisms](https://en.wikipedia.org/wiki/Unicellular_organism), while eukaryotes can be either single-celled or [multicellular](https://en.wikipedia.org/wiki/Multicellular_organism%22%20%5Co%20%22Multicellular%20organism).

**Prokaryotic cells**

[Prokaryotes](https://en.wikipedia.org/wiki/Prokaryote) include [bacteria](https://en.wikipedia.org/wiki/Bacteria) and [archaea](https://en.wikipedia.org/wiki/Archaea%22%20%5Co%20%22Archaea), two of the [three](https://en.wikipedia.org/wiki/Three_domain_system) [domains of life](https://en.wikipedia.org/wiki/Domain_%28biology%29). Prokaryotic cells were the first form of [life](https://en.wikipedia.org/wiki/Life) on Earth, characterized by having vital [biological processes](https://en.wikipedia.org/wiki/Biological_process) including [cell signaling](https://en.wikipedia.org/wiki/Cell_signaling). They are simpler and smaller than eukaryotic cells, and lack a [nucleus](https://en.wikipedia.org/wiki/Cell_nucleus), and other membrane-bound [organelles](https://en.wikipedia.org/wiki/Organelle). The [DNA](https://en.wikipedia.org/wiki/DNA) of a prokaryotic cell consists of a single [circular chromosome](https://en.wikipedia.org/wiki/Circular_prokaryote_chromosome) that is in direct contact with the [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm). The nuclear region in the cytoplasm is called the [nucleoid](https://en.wikipedia.org/wiki/Nucleoid%22%20%5Co%20%22Nucleoid). Most prokaryotes are the smallest of all organisms ranging from 0.5 to 2.0 μm in diameter.[[13]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-14)

**A prokaryotic cell has three regions:**

* Enclosing the cell is the [cell envelope](https://en.wikipedia.org/wiki/Cell_envelope) – generally consisting of a [plasma membrane](https://en.wikipedia.org/wiki/Plasma_membrane) covered by a [cell wall](https://en.wikipedia.org/wiki/Cell_wall) which, for some bacteria, may be further covered by a third layer called a [capsule](https://en.wikipedia.org/wiki/Bacterial_capsule). Though most prokaryotes have both a cell membrane and a cell wall, there are exceptions such as [*Mycoplasma*](https://en.wikipedia.org/wiki/Mycoplasma) (bacteria) and [*Thermoplasma*](https://en.wikipedia.org/wiki/Thermoplasma) (archaea) which only possess the cell membrane layer. The envelope gives rigidity to the cell and separates the interior of the cell from its environment, serving as a protective filter. The cell wall consists of [peptidoglycan](https://en.wikipedia.org/wiki/Peptidoglycan%22%20%5Co%20%22Peptidoglycan) in bacteria, and acts as an additional barrier against exterior forces. It also prevents the cell from expanding and bursting ([cytolysis](https://en.wikipedia.org/wiki/Cytolysis)) from [osmotic pressure](https://en.wikipedia.org/wiki/Osmotic_pressure) due to a [hypotonic](https://en.wikipedia.org/wiki/Hypotonicity) environment. Some eukaryotic cells ([plant cells](https://en.wikipedia.org/wiki/Plant_cell) and [fungal](https://en.wikipedia.org/wiki/Fungus) cells) also have a cell wall.
* Inside the cell is the [cytoplasmic region](https://en.wikipedia.org/wiki/Cytoplasm%22%20%5Co%20%22Cytoplasm) that contains the [genome](https://en.wikipedia.org/wiki/Genome) (DNA), ribosomes and various sorts of inclusions.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) The genetic material is freely found in the cytoplasm. Prokaryotes can carry [extrachromosomal DNA](https://en.wikipedia.org/wiki/Extrachromosomal_DNA) elements called [plasmids](https://en.wikipedia.org/wiki/Plasmid), which are usually circular. Linear bacterial plasmids have been identified in several species of [spirochete](https://en.wikipedia.org/wiki/Spirochete) bacteria, including members of the genus *[Borrelia](https://en.wikipedia.org/wiki/Borrelia%22%20%5Co%20%22Borrelia)* notably *[Borrelia burgdorferi](https://en.wikipedia.org/wiki/Borrelia_burgdorferi%22%20%5Co%20%22Borrelia%20burgdorferi)*, which causes Lyme disease.[[14]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-15) Though not forming a nucleus, the [DNA](https://en.wikipedia.org/wiki/DNA) is condensed in a [nucleoid](https://en.wikipedia.org/wiki/Nucleoid). Plasmids encode additional genes, such as [antibiotic resistance](https://en.wikipedia.org/wiki/Antibiotic_resistance) genes.
* On the outside, [flagella](https://en.wikipedia.org/wiki/Flagella) and [pili](https://en.wikipedia.org/wiki/Pilus%22%20%5Co%20%22Pilus) project from the cell's surface. These are structures (not present in all prokaryotes) made of proteins that facilitate movement and communication between cells.

**Eukaryotic cells**

[Plants](https://en.wikipedia.org/wiki/Plants), [animals](https://en.wikipedia.org/wiki/Animals), [fungi](https://en.wikipedia.org/wiki/Fungi), [slime moulds](https://en.wikipedia.org/wiki/Slime_mould), [protozoa](https://en.wikipedia.org/wiki/Protozoa), and [algae](https://en.wikipedia.org/wiki/Algae) are all [eukaryotic](https://en.wikipedia.org/wiki/Eukaryote). These cells are about fifteen times wider than a typical prokaryote and can be as much as a thousand times greater in volume. The main distinguishing feature of eukaryotes as compared to prokaryotes is [compartmentalization](https://en.wikipedia.org/wiki/Cellular_compartment): the presence of membrane-bound [organelles](https://en.wikipedia.org/wiki/Organelle) (compartments) in which specific activities take place. Most important among these is a [cell nucleus](https://en.wikipedia.org/wiki/Cell_nucleus),[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) an organelle that houses the cell's [DNA](https://en.wikipedia.org/wiki/DNA). This nucleus gives the eukaryote its name, which means "true kernel (nucleus)". Other differences include:

* The plasma membrane resembles that of prokaryotes in function, with minor differences in the setup. Cell walls may or may not be present.
* The eukaryotic DNA is organized in one or more linear molecules, called [chromosomes](https://en.wikipedia.org/wiki/Chromosome), which are associated with [histone](https://en.wikipedia.org/wiki/Histone%22%20%5Co%20%22Histone) proteins. All chromosomal DNA is stored in the [cell nucleus](https://en.wikipedia.org/wiki/Cell_nucleus), separated from the cytoplasm by a membrane.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) Some eukaryotic organelles such as [mitochondria](https://en.wikipedia.org/wiki/Mitochondria) also contain some DNA.
* Many eukaryotic cells are [ciliated](https://en.wikipedia.org/wiki/Cilium) with [primary cilia](https://en.wikipedia.org/wiki/Cilium#Primary_cilia). Primary cilia play important roles in chemosensation, [mechanosensation](https://en.wikipedia.org/wiki/Mechanosensation), and thermosensation. Each cilium may thus be "viewed as a sensory cellular [antennae](https://en.wikipedia.org/wiki/Antenna_%28biology%29) that coordinates a large number of cellular signaling pathways, sometimes coupling the signaling to ciliary motility or alternatively to cell division and differentiation."[[15]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Christenson2008-16)
* Motile eukaryotes can move using [motile cilia](https://en.wikipedia.org/wiki/Motile_cilia) or [flagella](https://en.wikipedia.org/wiki/Flagella). Motile cells are absent in [conifers](https://en.wikipedia.org/wiki/Conifers) and [flowering plants](https://en.wikipedia.org/wiki/Flowering_plants).[[16]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-raven-17) Eukaryotic flagella are more complex than those of prokaryotes.[[17]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-18)

## Subcellular components

All cells, whether [prokaryotic](https://en.wikipedia.org/wiki/Prokaryotic) or [eukaryotic](https://en.wikipedia.org/wiki/Eukaryotic), have a [membrane](https://en.wikipedia.org/wiki/Cell_membrane) that envelops the cell, regulates what moves in and out (selectively permeable), and maintains the [electric potential of the cell](https://en.wikipedia.org/wiki/Membrane_potential). Inside the membrane, the [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm) takes up most of the cell's volume. All cells (except [red blood cells](https://en.wikipedia.org/wiki/Red_blood_cell) which lack a cell nucleus and most organelles to accommodate maximum space for [hemoglobin](https://en.wikipedia.org/wiki/Hemoglobin)) possess [DNA](https://en.wikipedia.org/wiki/DNA), the hereditary material of [genes](https://en.wikipedia.org/wiki/Gene), and [RNA](https://en.wikipedia.org/wiki/RNA), containing the information necessary to [build](https://en.wikipedia.org/wiki/Gene_expression) various [proteins](https://en.wikipedia.org/wiki/Protein) such as [enzymes](https://en.wikipedia.org/wiki/Enzyme), the cell's primary machinery. There are also other kinds of [biomolecules](https://en.wikipedia.org/wiki/Biomolecule%22%20%5Co%20%22Biomolecule) in cells. This article lists these primary [cellular components](https://en.wikipedia.org/wiki/Cellular_component), then briefly describes their function.

**Membrane**

The [cell membrane](https://en.wikipedia.org/wiki/Cell_membrane), or plasma membrane, is a [biological membrane](https://en.wikipedia.org/wiki/Biological_membrane) that surrounds the cytoplasm of a cell. In animals, the plasma membrane is the outer boundary of the cell, while in plants and prokaryotes it is usually covered by a [cell wall](https://en.wikipedia.org/wiki/Cell_wall). This membrane serves to separate and protect a cell from its surrounding environment and is made mostly from a [double layer of phospholipids](https://en.wikipedia.org/wiki/Lipid_bilayer), which are [amphiphilic](https://en.wikipedia.org/wiki/Amphiphilic) (partly [hydrophobic](https://en.wikipedia.org/wiki/Hydrophobic) and partly [hydrophilic](https://en.wikipedia.org/wiki/Hydrophilic)). Hence, the layer is called a [phospholipid bilayer](https://en.wikipedia.org/wiki/Phospholipid_bilayer%22%20%5Co%20%22Phospholipid%20bilayer), or sometimes a fluid mosaic membrane. Embedded within this membrane is a macromolecular structure called the [porosome](https://en.wikipedia.org/wiki/Porosome%22%20%5Co%20%22Porosome) the universal secretory portal in cells and a variety of [protein](https://en.wikipedia.org/wiki/Protein) molecules that act as channels and pumps that move different molecules into and out of the cell.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) The membrane is semi-permeable, and selectively permeable, in that it can either let a substance ([molecule](https://en.wikipedia.org/wiki/Molecule) or [ion](https://en.wikipedia.org/wiki/Ion)) pass through freely, pass through to a limited extent or not pass through at all. Cell surface membranes also contain [receptor](https://en.wikipedia.org/wiki/Receptor_%28biochemistry%29#Transmembrane_receptors) proteins that allow cells to detect external signaling molecules such as [hormones](https://en.wikipedia.org/wiki/Hormone).

**Cytoskeleton**

The cytoskeleton acts to organize and maintain the cell's shape; anchors organelles in place; helps during [endocytosis](https://en.wikipedia.org/wiki/Endocytosis%22%20%5Co%20%22Endocytosis), the uptake of external materials by a cell, and [cytokinesis](https://en.wikipedia.org/wiki/Cytokinesis%22%20%5Co%20%22Cytokinesis), the separation of daughter cells after [cell division](https://en.wikipedia.org/wiki/Cell_division); and moves parts of the cell in processes of growth and mobility. The eukaryotic cytoskeleton is composed of [microtubules](https://en.wikipedia.org/wiki/Microtubule), [intermediate filaments](https://en.wikipedia.org/wiki/Intermediate_filament) and [microfilaments](https://en.wikipedia.org/wiki/Microfilament). In the cytoskeleton of a [neuron](https://en.wikipedia.org/wiki/Neuron) the intermediate filaments are known as [neurofilaments](https://en.wikipedia.org/wiki/Neurofilament%22%20%5Co%20%22Neurofilament). There are a great number of proteins associated with them, each controlling a cell's structure by directing, bundling, and aligning filaments.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) The prokaryotic cytoskeleton is less well-studied but is involved in the maintenance of cell shape, [polarity](https://en.wikipedia.org/wiki/Cell_polarity) and cytokinesis.[[19]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-20) The subunit protein of microfilaments is a small, monomeric protein called [actin](https://en.wikipedia.org/wiki/Actin). The subunit of microtubules is a dimeric molecule called [tubulin](https://en.wikipedia.org/wiki/Tubulin%22%20%5Co%20%22Tubulin). Intermediate filaments are heteropolymers whose subunits vary among the cell types in different tissues. But some of the subunit protein of intermediate filaments include [vimentin](https://en.wikipedia.org/wiki/Vimentin), [desmin](https://en.wikipedia.org/wiki/Desmin), [lamin](https://en.wikipedia.org/wiki/Lamin) (lamins A, B and C), [keratin](https://en.wikipedia.org/wiki/Keratin) (multiple acidic and basic keratins), neurofilament proteins (NF–L, NF–M).

**Genetic material**

Two different kinds of genetic material exist: [deoxyribonucleic acid](https://en.wikipedia.org/wiki/DNA) (DNA) and [ribonucleic acid](https://en.wikipedia.org/wiki/RNA) (RNA). Cells use DNA for their long-term information storage. The biological information contained in an organism is [encoded](https://en.wikipedia.org/wiki/Genetic_code) in its DNA sequence.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) RNA is used for information transport (e.g., [mRNA](https://en.wikipedia.org/wiki/MRNA)) and [enzymatic](https://en.wikipedia.org/wiki/Enzyme) functions (e.g., [ribosomal](https://en.wikipedia.org/wiki/Ribosome) RNA). [Transfer RNA](https://en.wikipedia.org/wiki/Transfer_RNA) (tRNA) molecules are used to add amino acids during protein [translation](https://en.wikipedia.org/wiki/Translation_%28biology%29).

Prokaryotic genetic material is organized in a simple [circular bacterial chromosome](https://en.wikipedia.org/wiki/Circular_bacterial_chromosome) in the [nucleoid region](https://en.wikipedia.org/wiki/Nucleoid_region%22%20%5Co%20%22Nucleoid%20region) of the cytoplasm. Eukaryotic genetic material is divided into different,[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) linear molecules called [chromosomes](https://en.wikipedia.org/wiki/Chromosome) inside a discrete nucleus, usually with additional genetic material in some organelles like [mitochondria](https://en.wikipedia.org/wiki/Mitochondria) and [chloroplasts](https://en.wikipedia.org/wiki/Chloroplasts) (see [endosymbiotic theory](https://en.wikipedia.org/wiki/Endosymbiotic_theory%22%20%5Co%20%22Endosymbiotic%20theory)).

A [human cell](https://en.wikipedia.org/wiki/Human_cell) has genetic material contained in the [cell nucleus](https://en.wikipedia.org/wiki/Cell_nucleus) (the [nuclear genome](https://en.wikipedia.org/wiki/Genome)) and in the mitochondria (the [mitochondrial genome](https://en.wikipedia.org/wiki/Mitochondrial_genome)). In humans the nuclear genome is divided into 46 linear DNA molecules called [chromosomes](https://en.wikipedia.org/wiki/Chromosome), including 22 [homologous chromosome](https://en.wikipedia.org/wiki/Homologous_chromosome) pairs and a pair of [sex chromosomes](https://en.wikipedia.org/wiki/Sex_chromosomes). The mitochondrial genome is a circular DNA molecule distinct from the nuclear DNA. Although the [mitochondrial DNA](https://en.wikipedia.org/wiki/Mitochondrial_DNA) is very small compared to nuclear chromosomes,[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) it codes for 13 proteins involved in mitochondrial energy production and specific tRNAs.

Foreign genetic material (most commonly DNA) can also be artificially introduced into the cell by a process called [transfection](https://en.wikipedia.org/wiki/Transfection%22%20%5Co%20%22Transfection). This can be transient, if the DNA is not inserted into the cell's [genome](https://en.wikipedia.org/wiki/Genome), or stable, if it is. Certain [viruses](https://en.wikipedia.org/wiki/Virus) also insert their genetic material into the genome.

**Organelles**

Organelles are parts of the cell which are adapted and/or specialized for carrying out one or more vital functions, analogous to the [organs](https://en.wikipedia.org/wiki/Organ_%28anatomy%29) of the human body (such as the heart, lung, and kidney, with each organ performing a different function).[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) Both eukaryotic and prokaryotic cells have organelles, but prokaryotic organelles are generally simpler and are not membrane-bound.

There are several types of organelles in a cell. Some (such as the [nucleus](https://en.wikipedia.org/wiki/Cell_nucleus) and [golgi apparatus](https://en.wikipedia.org/wiki/Golgi_apparatus%22%20%5Co%20%22Golgi%20apparatus)) are typically solitary, while others (such as [mitochondria](https://en.wikipedia.org/wiki/Mitochondria), [chloroplasts](https://en.wikipedia.org/wiki/Chloroplasts), [peroxisomes](https://en.wikipedia.org/wiki/Peroxisomes) and [lysosomes](https://en.wikipedia.org/wiki/Lysosomes%22%20%5Co%20%22Lysosomes)) can be numerous (hundreds to thousands). The [cytosol](https://en.wikipedia.org/wiki/Cytosol) is the gelatinous fluid that fills the cell and surrounds the organelles.

**Eukaryotic**

* **Cell nucleus**: A cell's information center, the [cell nucleus](https://en.wikipedia.org/wiki/Cell_nucleus) is the most conspicuous organelle found in a [eukaryotic](https://en.wikipedia.org/wiki/Eukaryotic) cell. It houses the cell's [chromosomes](https://en.wikipedia.org/wiki/Chromosomes), and is the place where almost all [DNA](https://en.wikipedia.org/wiki/DNA) replication and [RNA](https://en.wikipedia.org/wiki/RNA) synthesis ([transcription](https://en.wikipedia.org/wiki/Transcription_%28genetics%29)) occur. The nucleus is spherical and separated from the cytoplasm by a double membrane called the [nuclear envelope](https://en.wikipedia.org/wiki/Nuclear_envelope). The nuclear envelope isolates and protects a cell's DNA from various molecules that could accidentally damage its structure or interfere with its processing. During processing, [DNA](https://en.wikipedia.org/wiki/DNA) is [transcribed](https://en.wikipedia.org/wiki/Transcription_%28genetics%29), or copied into a special [RNA](https://en.wikipedia.org/wiki/RNA), called [messenger RNA](https://en.wikipedia.org/wiki/Messenger_RNA) (mRNA). This mRNA is then transported out of the nucleus, where it is translated into a specific protein molecule. The [nucleolus](https://en.wikipedia.org/wiki/Nucleolus) is a specialized region within the nucleus where ribosome subunits are assembled. In prokaryotes, DNA processing takes place in the [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm).[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4)
* **Mitochondria and chloroplasts**: generate energy for the cell. [Mitochondria](https://en.wikipedia.org/wiki/Mitochondrion) are self-replicating organelles that occur in various numbers, shapes, and sizes in the cytoplasm of all eukaryotic cells.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) [Respiration](https://en.wikipedia.org/wiki/Cellular_respiration) occurs in the cell mitochondria, which generate the cell's energy by [oxidative phosphorylation](https://en.wikipedia.org/wiki/Oxidative_phosphorylation), using [oxygen](https://en.wikipedia.org/wiki/Oxygen) to release energy stored in cellular nutrients (typically pertaining to [glucose](https://en.wikipedia.org/wiki/Glucose)) to generate [ATP](https://en.wikipedia.org/wiki/Adenosine_triphosphate). Mitochondria multiply by [binary fission](https://en.wikipedia.org/wiki/Binary_fission), like prokaryotes. Chloroplasts can only be found in plants and algae, and they capture the sun's energy to make carbohydrates through [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis).
* **Endoplasmic reticulum**: The [endoplasmic reticulum](https://en.wikipedia.org/wiki/Endoplasmic_reticulum) (ER) is a transport network for molecules targeted for certain modifications and specific destinations, as compared to molecules that float freely in the cytoplasm. The ER has two forms: the rough ER, which has ribosomes on its surface that secrete proteins into the ER, and the smooth ER, which lacks ribosomes.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) The smooth ER plays a role in calcium sequestration and release.
* **Golgi apparatus**: The primary function of the Golgi apparatus is to process and package the [macromolecules](https://en.wikipedia.org/wiki/Macromolecule) such as [proteins](https://en.wikipedia.org/wiki/Protein) and [lipids](https://en.wikipedia.org/wiki/Lipid) that are synthesized by the cell.
* **Lysosomes and peroxisomes**: [Lysosomes](https://en.wikipedia.org/wiki/Lysosome) contain [digestive enzymes](https://en.wikipedia.org/wiki/Digestive_enzyme) (acid [hydrolases](https://en.wikipedia.org/wiki/Hydrolase%22%20%5Co%20%22Hydrolase)). They digest excess or worn-out [organelles](https://en.wikipedia.org/wiki/Organelle), food particles, and engulfed [viruses](https://en.wikipedia.org/wiki/Virus) or [bacteria](https://en.wikipedia.org/wiki/Bacteria). [Peroxisomes](https://en.wikipedia.org/wiki/Peroxisome%22%20%5Co%20%22Peroxisome) have enzymes that rid the cell of toxic [peroxides](https://en.wikipedia.org/wiki/Peroxide). The cell could not house these destructive enzymes if they were not contained in a membrane-bound system.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4)
* **Centrosome**: the cytoskeleton organiser: The [centrosome](https://en.wikipedia.org/wiki/Centrosome) produces the [microtubules](https://en.wikipedia.org/wiki/Microtubules) of a cell – a key component of the [cytoskeleton](https://en.wikipedia.org/wiki/Cytoskeleton). It directs the transport through the [ER](https://en.wikipedia.org/wiki/Endoplasmic_reticulum) and the [Golgi apparatus](https://en.wikipedia.org/wiki/Golgi_apparatus). Centrosomes are composed of two [centrioles](https://en.wikipedia.org/wiki/Centrioles%22%20%5Co%20%22Centrioles), which separate during [cell division](https://en.wikipedia.org/wiki/Cell_division) and help in the formation of the [mitotic spindle](https://en.wikipedia.org/wiki/Mitotic_spindle). A single centrosome is present in the [animal cells](https://en.wikipedia.org/wiki/Animal_cell). They are also found in some fungi and algae cells.
* Vacuoles: [Vacuoles](https://en.wikipedia.org/wiki/Vacuole) sequester waste products and in plant cells store water. They are often described as liquid filled space and are surrounded by a membrane. Some cells, most notably [Amoeba](https://en.wikipedia.org/wiki/Amoeba_%28genus%29), have contractile vacuoles, which can pump water out of the cell if there is too much water. The vacuoles of plant cells and fungal cells are usually larger than those of animal cells.

**Eukaryotic and prokaryotic**

* **Ribosomes**: The [ribosome](https://en.wikipedia.org/wiki/Ribosome) is a large complex of [RNA](https://en.wikipedia.org/wiki/RNA) and [protein](https://en.wikipedia.org/wiki/Protein) molecules.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) They each consist of two subunits, and act as an assembly line where RNA from the nucleus is used to synthesise proteins from amino acids. Ribosomes can be found either floating freely or bound to a membrane (the rough endoplasmatic reticulum in eukaryotes, or the cell membrane in prokaryotes).[[20]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-21)

## Structures outside the cell membrane

Many cells also have structures which exist wholly or partially outside the cell membrane. These structures are notable because they are not protected from the external environment by the [semipermeable cell membrane](https://en.wikipedia.org/wiki/Semipermeable_membrane%22%20%5Co%20%22Semipermeable%20membrane). In order to assemble these structures, their components must be carried across the cell membrane by export processes.

**Cell wall**

Many types of prokaryotic and eukaryotic cells have a [cell wall](https://en.wikipedia.org/wiki/Cell_wall). The cell wall acts to protect the cell mechanically and chemically from its environment, and is an additional layer of protection to the cell membrane. Different types of cell have cell walls made up of different materials; plant cell walls are primarily made up of [cellulose](https://en.wikipedia.org/wiki/Cellulose), fungi cell walls are made up of [chitin](https://en.wikipedia.org/wiki/Chitin) and bacteria cell walls are made up of [peptidoglycan](https://en.wikipedia.org/wiki/Peptidoglycan).

**Prokaryotic**

**Capsule**

A gelatinous [capsule](https://en.wikipedia.org/wiki/Bacterial_capsule) is present in some bacteria outside the cell membrane and cell wall. The capsule may be [polysaccharide](https://en.wikipedia.org/wiki/Polysaccharide) as in [pneumococci](https://en.wikipedia.org/wiki/Pneumococci%22%20%5Co%20%22Pneumococci), [meningococci](https://en.wikipedia.org/wiki/Meningococci) or [polypeptide](https://en.wikipedia.org/wiki/Polypeptide) as [*Bacillus anthracis*](https://en.wikipedia.org/wiki/Bacillus_anthracis) or [hyaluronic acid](https://en.wikipedia.org/wiki/Hyaluronic_acid) as in [streptococci](https://en.wikipedia.org/wiki/Streptococci). Capsules are not marked by normal staining protocols and can be detected by [India ink](https://en.wikipedia.org/wiki/India_ink#Uses_other_than_writing) or [methyl blue](https://en.wikipedia.org/wiki/Methyl_blue); which allows for higher contrast between the cells for observation.[[21]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-22):87

**Flagella**

[Flagella](https://en.wikipedia.org/wiki/Flagella) are organelles for cellular mobility. The bacterial flagellum stretches from cytoplasm through the cell membrane(s) and extrudes through the cell wall. They are long and thick thread-like appendages, protein in nature. A different type of flagellum is found in archaea and a different type is found in eukaryotes.

**Fimbriae**

A [fimbria](https://en.wikipedia.org/wiki/Fimbria_%28bacteriology%29%22%20%5Co%20%22Fimbria%20%28bacteriology%29) (plural fimbriae also known as a [pilus](https://en.wikipedia.org/wiki/Pilus), plural pili) is a short, thin, hair-like filament found on the surface of bacteria. Fimbriae are formed of a protein called [pilin](https://en.wikipedia.org/wiki/Pilin%22%20%5Co%20%22Pilin) ([antigenic](https://en.wikipedia.org/wiki/Antigenic)) and are responsible for the attachment of bacteria to specific receptors on human cells ([cell adhesion](https://en.wikipedia.org/wiki/Cell_adhesion)). There are special types of pili involved in [bacterial conjugation](https://en.wikipedia.org/wiki/Bacterial_conjugation).

## Cellular processes

## Replication

Cell division involves a single cell (called a *mother cell*) dividing into two daughter cells. This leads to growth in [multicellular organisms](https://en.wikipedia.org/wiki/Multicellular_organism%22%20%5Co%20%22Multicellular%20organism) (the growth of [tissue](https://en.wikipedia.org/wiki/Biological_tissue)) and to procreation ([vegetative reproduction](https://en.wikipedia.org/wiki/Vegetative_reproduction)) in [unicellular organisms](https://en.wikipedia.org/wiki/Unicellular_organism). [Prokaryotic](https://en.wikipedia.org/wiki/Prokaryote) cells divide by [binary fission](https://en.wikipedia.org/wiki/Binary_fission), while [eukaryotic](https://en.wikipedia.org/wiki/Eukaryote) cells usually undergo a process of nuclear division, called [mitosis](https://en.wikipedia.org/wiki/Mitosis), followed by division of the cell, called [cytokinesis](https://en.wikipedia.org/wiki/Cytokinesis%22%20%5Co%20%22Cytokinesis). A [diploid](https://en.wikipedia.org/wiki/Diploid) cell may also undergo [meiosis](https://en.wikipedia.org/wiki/Meiosis) to produce haploid cells, usually four. [Haploid](https://en.wikipedia.org/wiki/Haploid) cells serve as [gametes](https://en.wikipedia.org/wiki/Gamete) in multicellular organisms, fusing to form new diploid cells.

[DNA replication](https://en.wikipedia.org/wiki/DNA_replication), or the process of duplicating a cell's genome,[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) always happens when a cell divides through mitosis or binary fission. This occurs during the S phase of the [cell cycle](https://en.wikipedia.org/wiki/Cell_cycle).

In meiosis, the DNA is replicated only once, while the cell divides twice. DNA replication only occurs before [meiosis I](https://en.wikipedia.org/wiki/Meiosis_I). DNA replication does not occur when the cells divide the second time, in [meiosis II](https://en.wikipedia.org/wiki/Meiosis_II).[[22]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-23) Replication, like all cellular activities, requires specialized proteins for carrying out the job.[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4)

**DNA repair**

In general, cells of all organisms contain enzyme systems that scan their DNA for [damages](https://en.wikipedia.org/wiki/DNA_damage_%28naturally_occurring%29) and carry out [repair processes](https://en.wikipedia.org/wiki/DNA_repair) when damages are detected.[[23]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-24) Diverse repair processes have evolved in organisms ranging from bacteria to humans. The widespread prevalence of these repair processes indicates the importance of maintaining cellular DNA in an undamaged state in order to avoid cell death or errors of replication due to damages that could lead to [mutation](https://en.wikipedia.org/wiki/Mutation). [*E. coli*](https://en.wikipedia.org/wiki/Escherichia_coli) bacteria are a well-studied example of a cellular organism with diverse well-defined [DNA repair](https://en.wikipedia.org/wiki/DNA_repair) processes. These include: (1) [nucleotide excision repair](https://en.wikipedia.org/wiki/Nucleotide_excision_repair), (2) [DNA mismatch repair](https://en.wikipedia.org/wiki/DNA_mismatch_repair), (3) [non-homologous end joining](https://en.wikipedia.org/wiki/Non-homologous_end_joining) of double-strand breaks, (4) [recombinational repair](https://en.wikipedia.org/wiki/Homologous_recombination) and (5) light-dependent repair ([photoreactivation](https://en.wikipedia.org/wiki/Photolyase%22%20%5Co%20%22Photolyase)).

**Growth and metabolism**

Within the [nucleus](https://en.wikipedia.org/wiki/Cell_nucleus) of the cell (*light blue*), [genes](https://en.wikipedia.org/wiki/Gene) (DNA, *dark blue*) are [transcribed](https://en.wikipedia.org/wiki/Transcription_%28genetics%29) into [RNA](https://en.wikipedia.org/wiki/RNA). This RNA is then subject to post-transcriptional modification and control, resulting in a mature [mRNA](https://en.wikipedia.org/wiki/MRNA) (*red*) that is then transported out of the nucleus and into the [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm) (*peach*), where it undergoes [translation](https://en.wikipedia.org/wiki/Translation_%28genetics%29) into a protein. mRNA is translated by [ribosomes](https://en.wikipedia.org/wiki/Ribosome%22%20%5Co%20%22Ribosome) (*purple*) that match the three-base [codons](https://en.wikipedia.org/wiki/Codon%22%20%5Co%20%22Codon) of the mRNA to the three-base anti-codons of the appropriate [tRNA](https://en.wikipedia.org/wiki/Transfer_RNA%22%20%5Co%20%22Transfer%20RNA). Newly synthesized proteins (*black*) are often further modified, such as by binding to an effector molecule (*orange*), to become fully active.

Between successive cell divisions, cells grow through the functioning of cellular metabolism. Cell metabolism is the process by which individual cells process nutrient molecules. Metabolism has two distinct divisions: [catabolism](https://en.wikipedia.org/wiki/Catabolism), in which the cell breaks down complex molecules to produce energy and [reducing power](https://en.wikipedia.org/wiki/Reducing_agent), and [anabolism](https://en.wikipedia.org/wiki/Anabolism), in which the cell uses energy and reducing power to construct complex molecules and perform other biological functions. Complex sugars consumed by the organism can be broken down into simpler sugar molecules called [monosaccharides](https://en.wikipedia.org/wiki/Monosaccharides) such as [glucose](https://en.wikipedia.org/wiki/Glucose). Once inside the cell, glucose is broken down to make adenosine triphosphate ([ATP](https://en.wikipedia.org/wiki/Adenosine_triphosphate)),[[4]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-NCBI-4) a molecule that possesses readily available energy, through two different pathways.

**Protein synthesis**

Cells are capable of synthesizing new proteins, which are essential for the modulation and maintenance of cellular activities. This process involves the formation of new protein molecules from [amino acid](https://en.wikipedia.org/wiki/Amino_acid) building blocks based on information encoded in DNA/RNA. Protein synthesis generally consists of two major steps: [transcription](https://en.wikipedia.org/wiki/Transcription_%28genetics%29) and [translation](https://en.wikipedia.org/wiki/Translation_%28genetics%29).

Transcription is the process where genetic information in DNA is used to produce a complementary RNA strand. This RNA strand is then processed to give [messenger RNA](https://en.wikipedia.org/wiki/Messenger_RNA) (mRNA), which is free to migrate through the cell. mRNA molecules bind to protein-RNA complexes called [ribosomes](https://en.wikipedia.org/wiki/Ribosome) located in the [cytosol](https://en.wikipedia.org/wiki/Cytosol), where they are translated into polypeptide sequences. The ribosome mediates the formation of a polypeptide sequence based on the mRNA sequence. The mRNA sequence directly relates to the polypeptide sequence by binding to [transfer RNA](https://en.wikipedia.org/wiki/Transfer_RNA) (tRNA) adapter molecules in binding pockets within the ribosome. The new polypeptide then folds into a functional three-dimensional protein molecule.

**Motility**

Unicellular organisms can move in order to find food or escape predators. Common mechanisms of motion include [flagella](https://en.wikipedia.org/wiki/Flagella) and [cilia](https://en.wikipedia.org/wiki/Cilia).

In multicellular organisms, cells can move during processes such as wound healing, the immune response and [cancer metastasis](https://en.wikipedia.org/wiki/Cancer_metastasis). For example, in wound healing in animals, white blood cells move to the wound site to kill the microorganisms that cause infection. Cell motility involves many receptors, crosslinking, bundling, binding, adhesion, motor and other proteins.[[24]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-25) The process is divided into three steps – protrusion of the leading edge of the cell, adhesion of the leading edge and de-adhesion at the cell body and rear, and cytoskeletal contraction to pull the cell forward. Each step is driven by physical forces generated by unique segments of the cytoskeleton.[[25]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Alberts2-26)[[26]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Ananthakrishnan-27)

**Navigation, control and communication**

In August 2020, scientists described one way cells – in particular cells of a slime mold and mouse pancreatic cancer–derived cells – are able to [navigate](https://en.wikipedia.org/wiki/Chemotaxis) efficiently through a body and identify the best routes through complex mazes: generating gradients after breaking down diffused [chemoattractants](https://en.wikipedia.org/wiki/Chemoattractant%22%20%5Co%20%22Chemoattractant) which enable them to sense upcoming maze junctions before reaching them, including around corners.[[27]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-28)[[28]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-29)[[29]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-30)

## Multicellularity

## Cell specialization/differentiation

Multicellular organisms are [organisms](https://en.wikipedia.org/wiki/Organism) that consist of more than one cell, in contrast to [single-celled organisms](https://en.wikipedia.org/wiki/Single-celled_organism).[[30]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-31)

In complex multicellular organisms, cells specialize into different [cell types](https://en.wikipedia.org/wiki/Cell_type) that are adapted to particular functions. In mammals, major cell types include [skin cells](https://en.wikipedia.org/wiki/Skin_cells), [muscle cells](https://en.wikipedia.org/wiki/Muscle_cells), [neurons](https://en.wikipedia.org/wiki/Neuron), [blood cells](https://en.wikipedia.org/wiki/Blood_cell), [fibroblasts](https://en.wikipedia.org/wiki/Fibroblast), [stem cells](https://en.wikipedia.org/wiki/Stem_cells), and others. Cell types differ both in appearance and function, yet are [genetically](https://en.wikipedia.org/wiki/Genetics) identical. Cells are able to be of the same [genotype](https://en.wikipedia.org/wiki/Genotype) but of different cell type due to the differential [expression](https://en.wikipedia.org/wiki/Regulation_of_gene_expression) of the [genes](https://en.wikipedia.org/wiki/Gene) they contain.

Most distinct cell types arise from a single [totipotent](https://en.wikipedia.org/wiki/Totipotent) cell, called a [zygote](https://en.wikipedia.org/wiki/Zygote), that [differentiates](https://en.wikipedia.org/wiki/Cellular_differentiation) into hundreds of different cell types during the course of [development](https://en.wikipedia.org/wiki/Development_%28biology%29). Differentiation of cells is driven by different environmental cues (such as cell–cell interaction) and intrinsic differences (such as those caused by the uneven distribution of [molecules](https://en.wikipedia.org/wiki/Molecule) during [division](https://en.wikipedia.org/wiki/Cell_division)).

**Origin of multicellularity**

Multicellularity has evolved independently at least 25 times,[[31]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Grosberg2007-32) including in some prokaryotes, like [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria), [myxobacteria](https://en.wikipedia.org/wiki/Myxobacteria), [actinomycetes](https://en.wikipedia.org/wiki/Actinomycetes), [*Magnetoglobus multicellularis*](https://en.wikipedia.org/wiki/Deltaproteobacteria) or *[Methanosarcina](https://en.wikipedia.org/wiki/Methanosarcina%22%20%5Co%20%22Methanosarcina)*. However, complex multicellular organisms evolved only in six eukaryotic groups: animals, fungi, brown algae, red algae, green algae, and plants.[[32]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-pmid21351878-33) It evolved repeatedly for plants ([Chloroplastida](https://en.wikipedia.org/wiki/Chloroplastida%22%20%5Co%20%22Chloroplastida)), once or twice for [animals](https://en.wikipedia.org/wiki/Animal), once for [brown algae](https://en.wikipedia.org/wiki/Brown_algae), and perhaps several times for [fungi](https://en.wikipedia.org/wiki/Fungi), [slime molds](https://en.wikipedia.org/wiki/Mycetozoa), and [red algae](https://en.wikipedia.org/wiki/Red_algae).[[33]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-34) Multicellularity may have evolved from [colonies](https://en.wikipedia.org/wiki/Colony_%28biology%29) of interdependent organisms, from [cellularization](https://en.wikipedia.org/wiki/Cellularization%22%20%5Co%20%22Cellularization), or from organisms in [symbiotic relationships](https://en.wikipedia.org/wiki/Symbiosis).

The first evidence of multicellularity is from [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria)-like organisms that lived between 3 and 3.5 billion years ago.[[31]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Grosberg2007-32) Other early fossils of multicellular organisms include the contested [Grypania](https://en.wikipedia.org/wiki/Grypania) spiralis and the fossils of the black shales of the [Palaeoproterozoic](https://en.wikipedia.org/wiki/Palaeoproterozoic) [Francevillian Group Fossil](https://en.wikipedia.org/wiki/Francevillian_Group_Fossil) B Formation in [Gabon](https://en.wikipedia.org/wiki/Gabon).[[34]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-35)

The evolution of multicellularity from unicellular ancestors has been replicated in the laboratory, in [evolution experiments](https://en.wikipedia.org/wiki/Experimental_evolution) using predation as the [selective pressure](https://en.wikipedia.org/wiki/Selective_pressure).[[31]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Grosberg2007-32)

**Origins**

The origin of cells has to do with the [origin of life](https://en.wikipedia.org/wiki/Abiogenesis), which began the [history of life](https://en.wikipedia.org/wiki/Timeline_of_evolution) on Earth.

**Origin of the first cell**

There are several theories about the origin of small molecules that led to life on the [early Earth](https://en.wikipedia.org/wiki/Early_Earth). They may have been carried to Earth on meteorites (see [Murchison meteorite](https://en.wikipedia.org/wiki/Murchison_meteorite)), created at [deep-sea vents](https://en.wikipedia.org/wiki/Hydrothermal_vent), or synthesized by lightning in a reducing atmosphere (see [Miller–Urey experiment](https://en.wikipedia.org/wiki/Miller%E2%80%93Urey_experiment)). There is little experimental data defining what the first self-replicating forms were. [RNA](https://en.wikipedia.org/wiki/RNA) is thought to be the earliest self-replicating molecule, as it is capable of both storing genetic information and catalyzing chemical reactions (see [RNA world hypothesis](https://en.wikipedia.org/wiki/RNA_world_hypothesis)), but some other entity with the potential to self-replicate could have preceded RNA, such as [clay](https://en.wikipedia.org/wiki/Abiogenesis#Clay_hypothesis) or [peptide nucleic acid](https://en.wikipedia.org/wiki/Peptide_nucleic_acid).[[35]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-OrgelLE-36)

Cells emerged at least 3.5 billion years ago.[[10]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Origin1-11)[[11]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-Origin2-12)[[12]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-RavenJohnson2002-13) The current belief is that these cells were [heterotrophs](https://en.wikipedia.org/wiki/Heterotroph). The early cell membranes were probably more simple and permeable than modern ones, with only a single fatty acid chain per lipid. Lipids are known to spontaneously form bilayered [vesicles](https://en.wikipedia.org/wiki/Vesicle_%28biology_and_chemistry%29) in water, and could have preceded RNA, but the first cell membranes could also have been produced by catalytic RNA, or even have required structural proteins before they could form.[[36]](https://en.wikipedia.org/wiki/Cell_%28biology%29#cite_note-37)

**Origin of eukaryotic cells**

The eukaryotic cell seems to have evolved from a [symbiotic community](https://en.wikipedia.org/wiki/Symbiosis) of prokaryotic cells. DNA-bearing organelles like the [mitochondria](https://en.wikipedia.org/wiki/Mitochondria) and the [chloroplasts](https://en.wikipedia.org/wiki/Chloroplasts) are descended from ancient symbiotic oxygen-breathing [proteobacteria](https://en.wikipedia.org/wiki/Proteobacteria%22%20%5Co%20%22Proteobacteria) and [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria%22%20%5Co%20%22Cyanobacteria), respectively, which were [endosymbiosed](https://en.wikipedia.org/wiki/Endosymbiotic_theory) by an ancestral [archaean](https://en.wikipedia.org/wiki/Archaea) prokaryote.

There is still considerable debate about whether organelles like the [hydrogenosome](https://en.wikipedia.org/wiki/Hydrogenosome%22%20%5Co%20%22Hydrogenosome) predated the origin of [mitochondria](https://en.wikipedia.org/wiki/Mitochondria), or vice versa: see the [hydrogen hypothesis](https://en.wikipedia.org/wiki/Hydrogen_hypothesis) for the origin of eukaryotic cells.

**Stem Cells**

In [multicellular organisms](https://en.wikipedia.org/wiki/Multicellular_organisms), stem cells are [undifferentiated](https://en.wikipedia.org/wiki/Cellular_differentiation) or partially differentiated [cells](https://en.wikipedia.org/wiki/Cell_%28biology%29) that can differentiate into various [types of cells](https://en.wikipedia.org/wiki/Types_of_cells) and [proliferate](https://en.wikipedia.org/wiki/Cell_proliferation) indefinitely to produce more of the same stem cell. They are the earliest type of cell in a [cell lineage](https://en.wikipedia.org/wiki/Cell_lineage).They are found in both [embryonic](https://en.wikipedia.org/wiki/Embryo) and adult organisms, but they have slightly different properties in each. They are usually distinguished from [progenitor cells](https://en.wikipedia.org/wiki/Progenitor_cells), which cannot divide indefinitely, and [precursor](https://en.wikipedia.org/wiki/Precursor_cell) or blast cells, which are usually committed to differentiating into one cell type.

In [mammals](https://en.wikipedia.org/wiki/Mammals), roughly 50–150 cells make up the [inner cell mass](https://en.wikipedia.org/wiki/Inner_cell_mass) during the [blastocyst](https://en.wikipedia.org/wiki/Blastocyst%22%20%5Co%20%22Blastocyst) stage of embryonic development, around days 5–14. These have stem-cell capability. [*In vivo*](https://en.wikipedia.org/wiki/In_vivo), they eventually differentiate into all of the body's cell types (making them [pluripotent](https://en.wikipedia.org/wiki/Pluripotent)). This process starts with the differentiation into the three [germ layers](https://en.wikipedia.org/wiki/Germ_layers) – the [ectoderm](https://en.wikipedia.org/wiki/Ectoderm), [mesoderm](https://en.wikipedia.org/wiki/Mesoderm) and [endoderm](https://en.wikipedia.org/wiki/Endoderm) – at the [gastrulation](https://en.wikipedia.org/wiki/Gastrulation) stage. However, when they are isolated and [cultured](https://en.wikipedia.org/wiki/Cell_culture) [*in vitro*](https://en.wikipedia.org/wiki/In_vitro), they can be kept in the stem-cell stage and are known as [embryonic stem cells](https://en.wikipedia.org/wiki/Embryonic_stem_cells) (ESCs).

[Adult stem cells](https://en.wikipedia.org/wiki/Adult_stem_cells) are found in a few select locations in the body, known as [niches](https://en.wikipedia.org/wiki/Stem-cell_niche), such as those in the [bone marrow](https://en.wikipedia.org/wiki/Bone_marrow) or [gonads](https://en.wikipedia.org/wiki/Gonads). They exist to replenish rapidly lost cell types and are [multipotent](https://en.wikipedia.org/wiki/Multipotent%22%20%5Co%20%22Multipotent) or unipotent, meaning they only differentiate into a few cell types or one cell type. In mammals, they include, among others, [hematopoietic stem cells](https://en.wikipedia.org/wiki/Hematopoietic_stem_cells), which replenish blood and immune cells, [basal cells](https://en.wikipedia.org/wiki/Basal_cells), which maintain the skin [epithelium](https://en.wikipedia.org/wiki/Epithelium), and [mesenchymal stem cells](https://en.wikipedia.org/wiki/Mesenchymal_stem_cells%22%20%5Co%20%22Mesenchymal%20stem%20cells), which maintain bone, [cartilage](https://en.wikipedia.org/wiki/Cartilage), muscle and fat cells. Adult stem cells are a small minority of cells; they are vastly outnumbered by the progenitor cells and terminally differentiated cells that they differentiate into.

Research into stem cells grew out of findings by Canadian biologists [Ernest McCulloch](https://en.wikipedia.org/wiki/Ernest_McCulloch), [James Till](https://en.wikipedia.org/wiki/James_Till) and Andrew J. Becker at the [University of Toronto](https://en.wikipedia.org/wiki/University_of_Toronto) in the 1960s. As of 2016, the only established [medical therapy using stem cells](https://en.wikipedia.org/wiki/Stem-cell_therapy) is [hematopoietic stem cell transplantation](https://en.wikipedia.org/wiki/Hematopoietic_stem_cell_transplantation), first performed in 1958 by French oncologist [Georges Mathé](https://en.wikipedia.org/wiki/Georges_Math%C3%A9). Since 1998 however, it has been possible to culture and differentiate human embryonic stem cells (in [stem-cell lines](https://en.wikipedia.org/wiki/Stem-cell_lines)). The process of isolating these cells has been [controversial](https://en.wikipedia.org/wiki/Stem_cell_controversy), because it typically results in the destruction of the embryo. Sources for isolating ESCs have been [restricted](https://en.wikipedia.org/wiki/Stem_cell_laws) in some European countries and Canada, but others such as the UK and China have promoted the research. [Somatic cell nuclear transfer](https://en.wikipedia.org/wiki/Somatic_cell_nuclear_transfer) is a [cloning](https://en.wikipedia.org/wiki/Cloning) method that can be used to create a cloned embryo for the use of its embryonic stem cells in stem cell therapy. In 2006, a Japanese team led by [Shinya Yamanaka](https://en.wikipedia.org/wiki/Shinya_Yamanaka) discovered a method to convert mature body cells back into stem cells. These were termed [induced pluripotent stem cells](https://en.wikipedia.org/wiki/Induced_pluripotent_stem_cells) (iPSCs).

In practice, stem cells are identified by whether they can regenerate tissue. For example, the defining test for bone marrow or [hematopoietic stem cells](https://en.wikipedia.org/wiki/Hematopoietic_stem_cell) (HSCs) is the ability to transplant the cells and save an individual without HSCs. This demonstrates that the cells can produce new blood cells over a long term. It should also be possible to isolate stem cells from the transplanted individual, which can themselves be transplanted into another individual without HSCs, demonstrating that the stem cell was able to self-renew.

Properties of stem cells can be illustrated [*in vitro*](https://en.wikipedia.org/wiki/In_vitro), using methods such as [clonogenic assays](https://en.wikipedia.org/wiki/Clonogenic_assay%22%20%5Co%20%22Clonogenic%20assay), in which single cells are assessed for their ability to differentiate and self-renew. Stem cells can also be isolated by their possession of a distinctive set of cell surface markers. However, *in vitro* culture conditions can alter the behavior of cells, making it unclear whether the cells shall behave in a similar manner [*in vivo*](https://en.wikipedia.org/wiki/In_vivo). There is considerable debate as to whether some proposed adult cell populations are truly stem cells.

[Embryonic stem cells](https://en.wikipedia.org/wiki/Embryonic_stem_cell) (ESCs) are the cells of the [inner cell mass](https://en.wikipedia.org/wiki/Inner_cell_mass) of a [blastocyst](https://en.wikipedia.org/wiki/Blastocyst), formed prior to [implantation](https://en.wikipedia.org/wiki/Implantation_%28human_embryo%29) in the uterus. In [human embryonic development](https://en.wikipedia.org/wiki/Human_embryonic_development) the [blastocyst](https://en.wikipedia.org/wiki/Blastocyst%22%20%5Co%20%22Blastocyst) stage is reached 4–5 days after [fertilization](https://en.wikipedia.org/wiki/Human_fertilization), at which time it consists of 50–150 cells. ESCs are [pluripotent](https://en.wikipedia.org/wiki/Pluripotent%22%20%5Co%20%22Pluripotent) and give rise during development to all derivatives of the three [germ layers](https://en.wikipedia.org/wiki/Germ_layer): [ectoderm](https://en.wikipedia.org/wiki/Ectoderm), [endoderm](https://en.wikipedia.org/wiki/Endoderm) and [mesoderm](https://en.wikipedia.org/wiki/Mesoderm). In other words, they can develop into each of the more than 200 cell types of the adult [body](https://en.wikipedia.org/wiki/Human_body) when given sufficient and necessary stimulation for a specific cell type. They do not contribute to the [extraembryonic membranes](https://en.wikipedia.org/wiki/Extraembryonic_membrane%22%20%5Co%20%22Extraembryonic%20membrane) or to the [placenta](https://en.wikipedia.org/wiki/Placenta).

During embryonic development the cells of the inner cell mass continuously divide and become more specialized. For example, a portion of the ectoderm in the dorsal part of the embryo specializes as '[neurectoderm](https://en.wikipedia.org/wiki/Neurectoderm%22%20%5Co%20%22Neurectoderm)', which will become the future [central nervous system](https://en.wikipedia.org/wiki/Central_nervous_system). Later in development, [neurulation](https://en.wikipedia.org/wiki/Neurulation) causes the neurectoderm to form the [neural tube](https://en.wikipedia.org/wiki/Neural_tube). At the neural tube stage, the anterior portion undergoes [encephalization](https://en.wikipedia.org/wiki/Encephalization) to generate or 'pattern' the basic form of the brain. At this stage of development, the principal cell type of the CNS is considered a [neural stem cell](https://en.wikipedia.org/wiki/Neural_stem_cell).

The neural stem cells self-renew and at some point transition into [radial glial progenitor cells](https://en.wikipedia.org/wiki/Radial_glial_cell) (RGPs). Early-formed RGPs self-renew by symmetrical division to form a reservoir group of [progenitor cells](https://en.wikipedia.org/wiki/Progenitor_cell). These cells transition to a [neurogenic](https://en.wikipedia.org/wiki/Neurogenesis%22%20%5Co%20%22Neurogenesis) state and start to divide [asymmetrically](https://en.wikipedia.org/wiki/Asymmetric_cell_division) to produce a large diversity of many different neuron types, each with unique gene expression, morphological, and functional characteristics. The process of generating neurons from radial glial cells is called [neurogenesis](https://en.wikipedia.org/wiki/Neurogenesis%22%20%5Co%20%22Neurogenesis). The radial glial cell, has a distinctive bipolar morphology with highly elongated processes spanning the thickness of the neural tube wall. It shares some [glial](https://en.wikipedia.org/wiki/Glial%22%20%5Co%20%22Glial) characteristics, most notably the expression of [glial fibrillary acidic protein](https://en.wikipedia.org/wiki/Glial_fibrillary_acidic_protein) (GFAP). The radial glial cell is the primary neural stem cell of the developing [vertebrate](https://en.wikipedia.org/wiki/Vertebrate) CNS, and its cell body resides in the [ventricular zone](https://en.wikipedia.org/wiki/Ventricular_zone), adjacent to the developing [ventricular system](https://en.wikipedia.org/wiki/Ventricular_system). Neural stem cells are committed to the neuronal lineages ([neurons](https://en.wikipedia.org/wiki/Neuron), [astrocytes](https://en.wikipedia.org/wiki/Astrocyte), and [oligodendrocytes](https://en.wikipedia.org/wiki/Oligodendrocyte%22%20%5Co%20%22Oligodendrocyte)), and thus their potency is restricted.

Nearly all research to date has made use of mouse embryonic stem cells (mES) or human embryonic stem cells (hES) derived from the early inner cell mass. Both have the essential stem cell characteristics, yet they require very different environments in order to maintain an undifferentiated state. Mouse ES cells are grown on a layer of [gelatin](https://en.wikipedia.org/wiki/Gelatin) as an [extracellular matrix](https://en.wikipedia.org/wiki/Extracellular_matrix) (for support) and require the presence of [leukemia inhibitory factor](https://en.wikipedia.org/wiki/Leukemia_inhibitory_factor) (LIF) in serum media. A drug cocktail containing inhibitors to [GSK3B](https://en.wikipedia.org/wiki/GSK3B) and the [MAPK/ERK pathway](https://en.wikipedia.org/wiki/MAPK/ERK_pathway), called 2i, has also been shown to maintain pluripotency in stem cell culture. Human ESCs are grown on a feeder layer of mouse embryonic [fibroblasts](https://en.wikipedia.org/wiki/Fibroblasts) and require the presence of basic fibroblast growth factor (bFGF or FGF-2). Without optimal culture conditions or genetic manipulation, embryonic stem cells will rapidly differentiate.

A human embryonic stem cell is also defined by the expression of several transcription factors and cell surface proteins. The transcription factors [Oct-4](https://en.wikipedia.org/wiki/Oct-4), [Nanog](https://en.wikipedia.org/wiki/Homeobox_protein_NANOG), and [Sox2](https://en.wikipedia.org/wiki/Sox2) form the core regulatory network that ensures the suppression of genes that lead to differentiation and the maintenance of pluripotency. The cell surface antigens most commonly used to identify hES cells are the glycolipids [stage specific embryonic antigen 3](https://en.wikipedia.org/wiki/Stage_specific_embryonic_antigen_3) and 4, and the keratan sulfate antigens Tra-1-60 and Tra-1-81. The molecular definition of a stem cell includes many more proteins and continues to be a topic of research.

By using human embryonic stem cells to produce specialized cells like nerve cells or heart cells in the lab, scientists can gain access to adult human cells without taking tissue from patients. They can then study these specialized adult cells in detail to try to discern complications of diseases, or to study cell reactions to proposed new drugs.

Because of their combined abilities of unlimited expansion and pluripotency, embryonic stem cells remain a theoretically potential source for [regenerative medicine](https://en.wikipedia.org/wiki/Regenerative_medicine) and tissue replacement after injury or disease, however, there are currently no approved treatments using ES cells. The first human trial was approved by the US Food and Drug Administration in January 2009. However, the human trial was not initiated until October 13, 2010 in Atlanta for [spinal cord injury research](https://en.wikipedia.org/wiki/Spinal_cord_injury_research). On November 14, 2011 the company conducting the trial ([Geron Corporation](https://en.wikipedia.org/wiki/Geron_Corporation%22%20%5Co%20%22Geron%20Corporation)) announced that it will discontinue further development of its stem cell programs. Differentiating ES cells into usable cells while avoiding transplant rejection are just a few of the hurdles that embryonic stem cell researchers still face. Embryonic stem cells, being pluripotent, require specific signals for correct differentiation – if injected directly into another body, ES cells will differentiate into many different types of cells, causing a [teratoma](https://en.wikipedia.org/wiki/Teratoma%22%20%5Co%20%22Teratoma). Ethical considerations regarding the use of unborn human tissue are another reason for the lack of approved treatments using embryonic stem cells. Many nations currently have [moratoria](https://en.wikipedia.org/wiki/Moratorium_%28law%29) or limitations on either human ES cell research or the production of new human ES cell lines.

Embryonic stem cells (ESCs) have the ability to divide indefinitely while keeping their [pluripotency](https://en.wikipedia.org/wiki/Pluripotency%22%20%5Co%20%22Pluripotency), which is made possible through specialized mechanisms of [cell cycle](https://en.wikipedia.org/wiki/Cell_cycle) control. Compared to proliferating [somatic cells](https://en.wikipedia.org/wiki/Somatic_cell), ESCs have unique cell cycle characteristics—such as rapid cell division caused by shortened [G1 phase](https://en.wikipedia.org/wiki/G1_phase), absent [G0 phase](https://en.wikipedia.org/wiki/G2_phase), and modifications in [cell cycle checkpoints](https://en.wikipedia.org/wiki/Cell_cycle_checkpoint)—which leaves the cells mostly in [S phase](https://en.wikipedia.org/wiki/S_phase) at any given time. ESCs’ rapid division is demonstrated by their short doubling time, which ranges from 8 to 10 hours, whereas somatic cells have doubling time of approximately 20 hours or longer. As cells differentiate, these properties change: G1 and G2 phases lengthen, leading to longer cell division cycles. This suggests that a specific cell cycle structure may contribute to the establishment of pluripotency.

Particularly because G1 phase is the phase in which cells have increased sensitivity to differentiation, shortened G1 is one of the key characteristics of ESCs and plays an important role in maintaining undifferentiated [phenotype](https://en.wikipedia.org/wiki/Phenotype). Although the exact molecular mechanism remains only partially understood, several studies have shown insight on how ESCs progress through G1—and  potentially other phases—so rapidly.

The cell cycle is regulated by complex network of [cyclins](https://en.wikipedia.org/wiki/Cyclin), [cyclin-dependent kinases](https://en.wikipedia.org/wiki/Cyclin-dependent_kinase) (Cdk), [cyclin-dependent kinase inhibitors](https://en.wikipedia.org/wiki/Cyclin-dependent_kinase_inhibitor) (Cdkn), pocket proteins of the retinoblastoma (Rb) family, and other accessory factors. Foundational insight into the distinctive regulation of ESC cell cycle was gained by studies on mouse ESCs (mESCs). mESCs showed a cell cycle with highly abbreviated G1 phase, which enabled cells to rapidly alternate between M phase and S phase. In a somatic cell cycle, oscillatory activity of Cyclin-Cdk complexes is observed in sequential action, which controls crucial regulators of the cell cycle to induce unidirectional transitions between phases: [Cyclin D](https://en.wikipedia.org/wiki/Cyclin_D) and Cdk4/6 are active in the G1 phase, while [Cyclin E](https://en.wikipedia.org/wiki/Cyclin_E) and [Cdk2](https://en.wikipedia.org/wiki/Cyclin-dependent_kinase_2) are active during the late G1 phase and S phase; and [Cyclin A](https://en.wikipedia.org/wiki/Cyclin_A%22%20%5Co%20%22Cyclin%20A) and Cdk2 are active in the S phase and G2, while [Cyclin B](https://en.wikipedia.org/wiki/Cyclin_B%22%20%5Co%20%22Cyclin%20B) and [Cdk1](https://en.wikipedia.org/wiki/Cyclin-dependent_kinase_1) are active in G2 and M phase. However, in mESCs, this typically ordered and oscillatory activity of Cyclin-Cdk complexes is absent. Rather, the Cyclin E/Cdk2 complex is constitutively active throughout the cycle, keeping [retinoblastoma protein](https://en.wikipedia.org/wiki/Retinoblastoma_protein) (pRb) [hyperphosphorylated](https://en.wikipedia.org/wiki/Hyperphosphorylated) and thus inactive. This allows for direct transition from M phase to the late G1 phase, leading to absence of D-type cyclins and therefore a shortened G1 phase. Cdk2 activity is crucial for both cell cycle regulation and cell-fate decisions in mESCs; downregulation of Cdk2 activity prolongs G1 phase progression, establishes a somatic cell-like cell cycle, and induces expression of differentiation markers.

In human ESCs (hESCs), the duration of G1 is dramatically shortened. This has been attributed to high mRNA levels of G1-related Cyclin D2 and Cdk4 genes and low levels of cell cycle regulatory proteins that inhibit cell cycle progression at G1, such as [p21CipP1](https://en.wikipedia.org/wiki/P21Cip1), p27Kip1, and p57Kip2. Furthermore, regulators of Cdk4 and Cdk6 activity, such as members of the Ink family of inhibitors (p15, p16, p18, and p19), are expressed at low levels or not at all. Thus, similar to mESCs, hESCs show high Cdk activity, with Cdk2 exhibiting the highest kinase activity. Also similar to mESCs, hESCs demonstrate the importance of Cdk2 in G1 phase regulation by showing that G1 to S transition is delayed when Cdk2 activity is inhibited and G1 is arrest when Cdk2 is knocked down. However unlike mESCs, hESCs have a functional G1 phase. hESCs show that the activities of Cyclin E/Cdk2 and Cyclin A/Cdk2 complexes are cell cycle-dependent and the Rb checkpoint in G1 is functional.

ESCs are also characterized by G1 checkpoint non-functionality, even though the G1 checkpoint is crucial for maintaining genomic stability. In response to [DNA damage](https://en.wikipedia.org/wiki/DNA_damage), ESCs do not stop in G1 to repair DNA damages but instead, depend on S and G2/M checkpoints or undergo apoptosis. The absence of G1 checkpoint in ESCs allows for the removal of cells with damaged DNA, hence avoiding potential mutations from inaccurate DNA repair. Consistent with this idea, ESCs are hypersensitive to DNA damage to minimize mutations passed onto the next generation.

Stem cell division and differentiation A: stem cell; B: progenitor cell; C: differentiated cell; 1: symmetric stem cell division; 2: asymmetric stem cell division; 3: progenitor division; 4: terminal differentiation. Adult stem cells, also called [somatic](https://en.wikipedia.org/wiki/Somatic_%28biology%29) (from Greek σωματικóς, "of the body") stem cells, are stem cells which maintain and repair the tissue in which they are found. They can be found in children, as well as adults.

Stem cells can also be taken from [umbilical cord blood](https://en.wikipedia.org/wiki/Umbilical_cord_blood) just after birth. Of all stem cell types, autologous harvesting involves the least risk. By definition, autologous cells are obtained from one's own body, just as one may bank his or her own blood for elective surgical procedures.

Pluripotent adult stem cells are rare and generally small in number, but they can be found in umbilical cord blood and other tissues. Bone marrow is a rich source of adult stem cells, which have been used in treating several conditions including liver cirrhosis, chronic limb ischemia and endstage heart failure. The quantity of bone marrow stem cells declines with age and is greater in males than females during reproductive years. Much adult stem cell research to date has aimed to characterize their potency and self-renewal capabilities. DNA damage accumulates with age in both stem cells and the cells that comprise the stem cell environment. This accumulation is considered to be responsible, at least in part, for increasing stem cell dysfunction with aging.

Adult stem cells have limitations with their potency; unlike [embryonic stem cells](https://en.wikipedia.org/wiki/Embryonic_stem_cell) (ESCs), they are not able to differentiate into cells from all three [germ layers](https://en.wikipedia.org/wiki/Germ_layers). As such, they are deemed [multipotent](https://en.wikipedia.org/wiki/Cell_potency%22%20%5Co%20%22Cell%20potency).

However, [reprogramming](https://en.wikipedia.org/wiki/Reprogramming) allows for the creation of pluripotent cells, [induced pluripotent stem cells](https://en.wikipedia.org/wiki/Induced_pluripotent_stem_cell) (iPSCs), from adult cells. These are not adult stem cells, but somatic cells (e.g. epithelial cells) reprogrammed to give rise to cells with pluripotent capabilities. Using genetic reprogramming with protein [transcription factors](https://en.wikipedia.org/wiki/Transcription_factors), pluripotent stem cells with ESC-like capabilities have been derived. The first demonstration of induced pluripotent stem cells was conducted by [Shinya Yamanaka](https://en.wikipedia.org/wiki/Shinya_Yamanaka) and his colleagues at [Kyoto University](https://en.wikipedia.org/wiki/Kyoto_University). They used the transcription factors [Oct3/4](https://en.wikipedia.org/wiki/Oct-4), [Sox2](https://en.wikipedia.org/wiki/Sox2), [c-Myc](https://en.wikipedia.org/wiki/C-Myc), and [Klf4](https://en.wikipedia.org/wiki/Klf4) to reprogram mouse fibroblast cells into pluripotent cells. Subsequent work used these factors to induce pluripotency in human fibroblast cells. [Junying Yu](https://en.wikipedia.org/wiki/Junying_Yu), [James Thomson](https://en.wikipedia.org/wiki/James_Thomson_%28cell_biologist%29), and their colleagues at the [University of Wisconsin–Madison](https://en.wikipedia.org/wiki/University_of_Wisconsin%E2%80%93Madison) used a different set of factors, Oct4, Sox2, Nanog and Lin28, and carried out their experiments using cells from human [foreskin](https://en.wikipedia.org/wiki/Foreskin). However, they were able to replicate [Yamanaka](https://en.wikipedia.org/wiki/Yamanaka)'s finding that inducing pluripotency in human cells was possible.

Induced pluripotent stem cells differ from embryonic stem cells. They share many similar properties, such as [pluripotency](https://en.wikipedia.org/wiki/Pluripotency%22%20%5Co%20%22Pluripotency) and differentiation potential, the expression of [pluripotency](https://en.wikipedia.org/wiki/Pluripotency%22%20%5Co%20%22Pluripotency) genes, [epigenetic](https://en.wikipedia.org/wiki/Epigenetic) patterns, [embryoid body](https://en.wikipedia.org/wiki/Embryoid_body) and [teratoma](https://en.wikipedia.org/wiki/Teratoma) formation, and viable [chimera](https://en.wikipedia.org/wiki/Chimera_%28genetics%29) formation, but there are many differences within these properties. The chromatin of iPSCs appears to be more "closed" or methylated than that of ESCs. Similarly, the gene expression pattern between ESCs and iPSCs, or even iPSCs sourced from different origins. There are thus questions about the "completeness" of [reprogramming](https://en.wikipedia.org/wiki/Reprogramming) and the somatic memory of induced pluripotent stem cells. Despite this, inducing somatic cells to be pluripotent appears to be viable.

As a result of the success of these experiments, [Ian Wilmut](https://en.wikipedia.org/wiki/Ian_Wilmut), who helped create the first cloned animal [Dolly the Sheep](https://en.wikipedia.org/wiki/Dolly_the_Sheep), has announced that he will abandon [somatic cell nuclear transfer](https://en.wikipedia.org/wiki/Somatic_cell_nuclear_transfer) as an avenue of research.

IPSCs has helped the field of medicine significantly by finding numerous ways to cure diseases. Since human IPSCc has given the advantage to make vitro models to study toxins and pathogenesis.

Furthermore, induced pluripotent stem cells provide several therapeutic advantages. Like ESCs, they are [pluripotent](https://en.wikipedia.org/wiki/Pluripotent%22%20%5Co%20%22Pluripotent). They thus have great differentiation potential; theoretically, they could produce any cell within the human body. Moreover, unlike ESCs, they potentially could allow doctors to create a pluripotent stem cell line for each individual patient. Frozen blood samples can be used as a valuable source of induced pluripotent stem cells. Patient specific stem cells allow for the screening for side effects before drug treatment, as well as the reduced risk of transplantation rejection. Despite their current limited use therapeutically, iPSCs hold create potential for future use in medical treatment and research.

The key factors controlling the cell cycle also regulate [pluripotency](https://en.wikipedia.org/wiki/Pluripotency). Thus, manipulation of relevant genes can maintain pluripotency and reprogram somatic cells to an induced pluripotent state. However, reprogramming of somatic cells is often low in efficiency and considered [stochastic](https://en.wikipedia.org/wiki/Stochastic).

With the idea that a more rapid cell cycle is a key component of pluripotency, reprogramming efficiency can be improved. Methods for improving pluripotency through manipulation of cell cycle regulators include: overexpression of Cyclin D/Cdk4, phosphorylation of [Sox2](https://en.wikipedia.org/wiki/SOX2) at S39 and S253, overexpression of Cyclin A and Cyclin E, knockdown of Rb, and knockdown of members of the [Cip/Kip](https://en.wikipedia.org/wiki/CIP/KIP) family or the Ink family. Furthermore, reprogramming efficiency is correlated with the number of cell divisions happened during the stochastic phase, which is suggested by the growing inefficiency of reprogramming of older or slow diving cells.

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3/25/2021