Inside the Living Cell

Study Guide for Instructors and Students

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How Cells Reproduce

DNA STRUCTURE

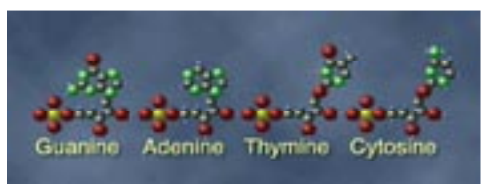
A good way to observe reproducing cells is to start with a sparse population of protozoa. A sample of water from a shallow pond, gutter, flowerpot, or ditch is a good source. Examine the sample through a microscope and look for microbes, specifically for dividing microbes.

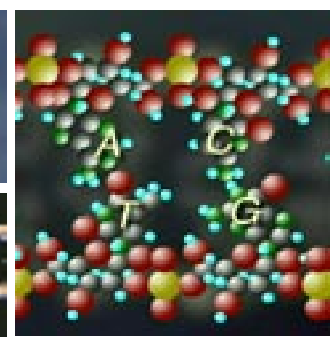
If you check back every twelve hours, or so, you'll see a rapid increase in the protozoa population – and each new individual looks exactly like the original cell. They are, in fact, its identical sisters.

This is because all of these cells have the same genes, those bits of DNA that determine a cell's attributes, its shape, its metabolic processes, even when and how it reproduces.

All of these genetic instructions are spelled out in a molecular code written on the incredibly long molecules of DNA located in a cell's nucleus.

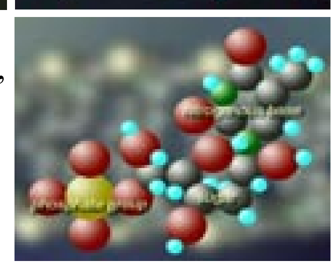
DNA is a long chain molecule made up of just four nucleotides, linked together. The four nucleotide building blocks are:





- Adenine
- Guanine
- Thymine
- Cytosine

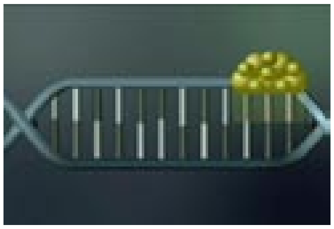
In cells, the DNA takes the shape of a twisted ladder.

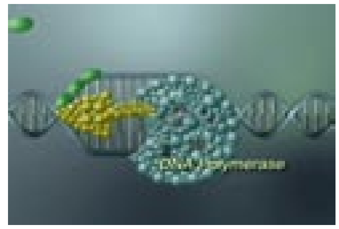


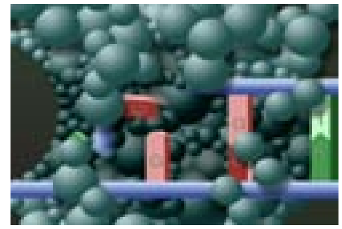
The building blocks all have the same molecular structure: a phosphate group, a sugar, and a nitrogenous base. (The nitrogen atoms are shown in green). The nitrogenous bases are slightly different in each of the four nucleotides.

Along the sides of the DNA ladder the nucleotides are bonded together with strong chemical bonds -- but weaker bonds that are easily broken hold the crosspieces. In these cross-links, Adenine will only bond with Thymine, and Guanine only with Cytosine.

The reason for this exclusive bonding arrangement is that Adenine and Thymine have two bonding sites, whereas Guanine and Cytosine have three.

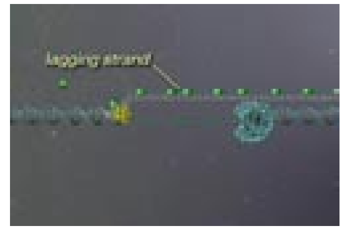




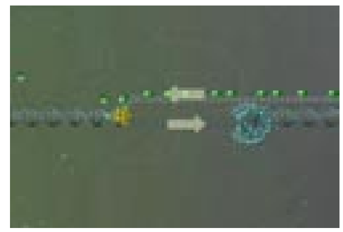


DNA REPLICATION

When cells divide, each one of their DNA molecules is copied so that each new generation of cells gets a complete and accurate set of working instructions.

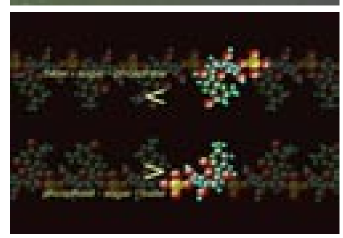


When it's time to replicate, a protein starts the process by landing on a particular set of nucleotides called the replication origin. These start-points are found all along the DNA strand.

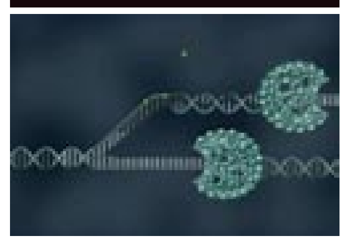


Next, helicase enzymes break the chemical bonds that hold the two strands together, opening up the DNA. This unzipped section of the DNA molecule is known as a replication fork.

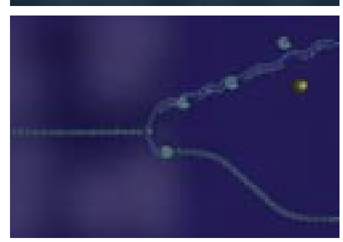
Special proteins -- (the green eggs) -- form temporary supports, preventing the freed strand from twisting up.



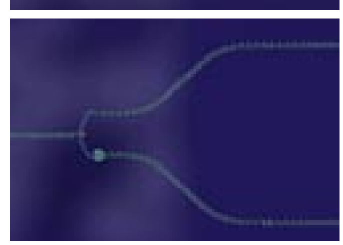
An enzyme lays down a "primer," which acts a start signal for replicating the leading strand.



With the DNA molecule open and ready for replication, the next enzymatic player arrives, DNA Polymerase. This is the enzyme that builds the complimentary strand, by adding on nucleotides gleaned from the cell's stockpile of loose building blocks. Adenine with Thymine, and Thymine with Adenine. Guanine with Cytosine and Cytosine with Guanine. DNA Polymerase starts building a new double stranded DNA molecule.

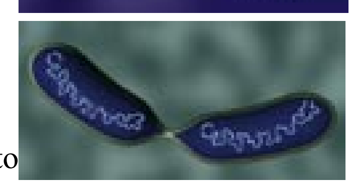


The other strand, ignored by DNA Polymerase, is called the lagging strand. Due to DNA's chemical make up, the leading and lagging strands run in opposite directions. To replicate the lagging strand a chemically different DNA polymerase enzyme is required, one that can run in the opposite direction. It clamps onto the primer and replicates the strand back to the previous completed section.



In this way, the lagging strand becomes a series of short sections that are then bonded together with the help of yet another enzyme, called Ligase.

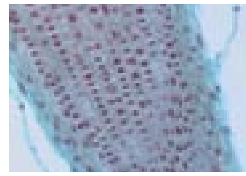
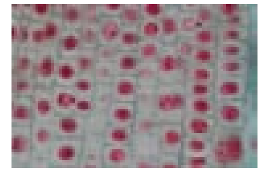
The process occurs all along the DNA strand until there are two new, perfectly copied DNA molecules.



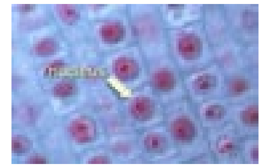
In the case of bacteria, which have no nucleus to contain their DNA, the cell just replicates one DNA molecule, its one chromosome. The two DNA replicants pull to opposite ends of the bacterium, and it pinches itself into two cells.

MITOSIS

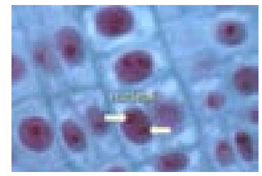
Human cells replicate all 46 DNA molecules, 23 inherited from each of our parents. With multiple chromosomes, correct sorting is essential. The various stages of chromosome sorting can be studied by looking at the lowly onion. Because onion roots grow fast, the root tip is a good place to look for rapidly dividing cells and chromosomes in various stages of sorting. These images are of thin sections of onion root tip tissue, stained with a dye that is picked up by DNA and its associated proteins making it visible.

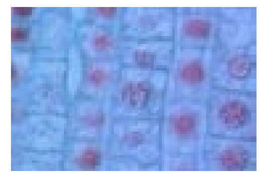
In the nucleus of these cells the DNA hasn't yet been replicated. It forms a tangled mass and is busily sending out its genetic instructions. The other obvious structures within the nucleus are the two nucleoli.

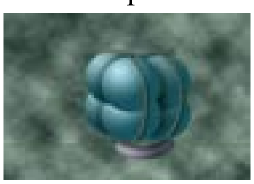


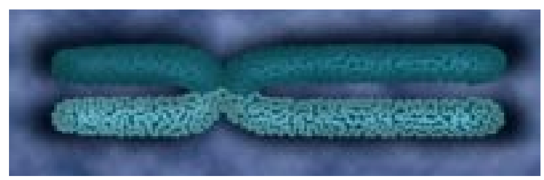
Here the nuclei look a little denser. Replication had evidently begun at the moment the onion root was sliced and stained. This is the beginning of the chromosome-sorting and distribution process known as Mitosis.



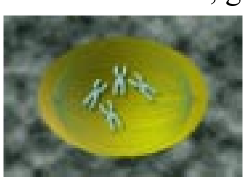
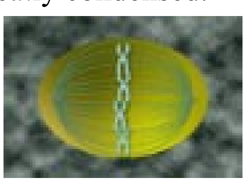
Before sorting can begin, the extremely long, entangled DNA molecules must be condensed for easier management. Condensation into visible chromosomes has just occurred in this sample (right). The first appearance of the condensed chromosomes, seen during Mitosis, is called Prophase.

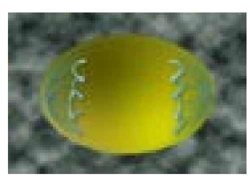
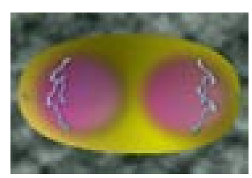




In Prophase each long DNA molecule is wrapping around disc-shaped proteins called histones. These bundles of DNA and histone proteins are called nucleosomes. The condensed DNA then curls and super-twists until it is tightly packed, now about one one-thousandth of its former length. Each replicated DNA molecule makes up one side of the visible chromosome, called a chromatid. The two chromatids are actually the two replicated DNA molecules, greatly condensed.

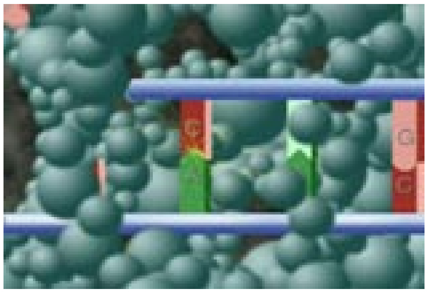



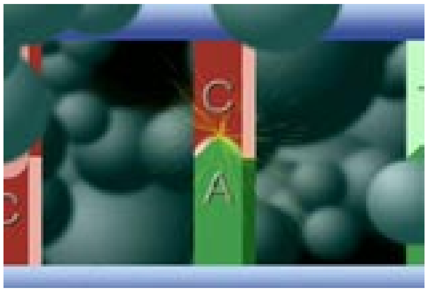

In the onion cells other changes have occurred. The two nucleoli have vanished, along with the nuclear membrane. At this stage, a basket of fibers has surrounded the chromosomes. Microtubules, the cell's muscles, are attaching to individual chromosomes. The chromosomes line up in a stage of Mitosis known as Metaphase. Guided by the fibers and microtubules, the chromatids are pulled apart -- Anaphase. In the final stage of Mitosis -- Telophase, the chromatids clump together at opposite ends of the cell. Mitosis has completed its function; it has separated the replicated chromatids into two identical groups, each with full instructions for becoming a new onion cell.

The final division of the cell is called Cytokinesis. In plant cells, islands of membrane lay down two new cell walls, permanently dividing the daughters. In animal cells, Cytokinesis special proteins pinch off the two daughters.

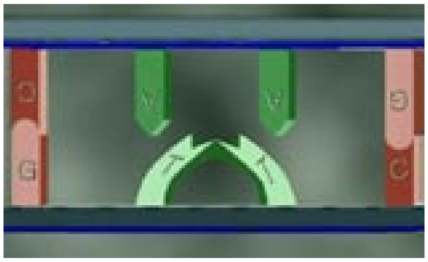
MUTATION and DNA REPAIR



During the copying of the DNA strands, an occasional mistake does occur. Running along at a hundred pairings per second, an incorrect nucleotide can get jammed into the strand. DNA Polymerase is quick to chemically recognize such mistakes. It backs up, rejects the mismatch, and substitutes the correct nucleotide.



Even so, reactive chemicals and radiation can create glitches in the DNA code. Ultraviolet radiation can bond two Thymine nucleotides to each other forming a Thymine dimer, disrupting the DNA code.



Special proofreading enzymes cruise the DNA looking for these problems. The proofreading enzyme cuts out the section containing the Thymine dimer, and DNA polymerase builds a new matching strand.

But knowing how DNA is replicated and parceled out to the next cell generation by Mitosis poses some interesting questions. If exactly the same genes are passed on to each new generation of cells, how is it that an animal starts out as a single cell, and over its embryological development, winds up with around 200 different kinds of cells?

Cell differentiation during embryological development is one of the new frontiers of biology, and a good topic for class discussion.