Cell Reproduction: Mitosis - 1

Growth and reproduction are two of the characteristics of life. The cell theory states **"All cells come from preexisting cells by a process of cell reproduction, or cell division".**

Mitotic cell division is the process by which all cells of a multicellular organism are formed. Cell division is also responsible for repair and replacement of cells and tissues during one's lifetime, and for asexual reproduction, a means of making more individuals common in protists, fungi, many plants and some animals.

We know that all cells of an individual have **exactly the same DNA**, and their DNA is found in structures called **chromosomes.** Each species has a fixed chromosome number, a number that does not change from generation to generation. The DNA must also stay the same from cell to cell within an organism, so that when cells divide, new cells formed will have exactly the same DNA as the original cell.

To ensure that chromosomes and DNA remain the same in new cells, the following must take place when cells divide:

- We must form two new cells from the original cell.
- Since each cell must have all of the genetic material for the organism, we must have a mechanism that exactly **duplicates** the DNA from the original cell and **distributes** the copied DNA equally to the new cells. The distribution of DNA into new nuclei during cell division is called **mitosis**. *(Duplication of DNA is a part of the discussion of structure and function of DNA.)*
- We must also separate the **cytoplasm,** and critical organelles, such as mitochondria and chloroplasts, of the original cell into the new cells formed so that the new cells can survive, grow and function. The separation of cytoplasm into new cells is called **cytokinesis**.

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In our discussion of cell reproduction, we shall focus on the processes of cell reproduction (mitosis and cytokinesis) in **eukaryotic** organisms. The process of cell division in **prokaryotic** organisms, **binary fission,** has similarities, but the single molecule of DNA and absence of a nucleus in the prokaryotic cell account for a number of differences in the "mechanics" of the process.

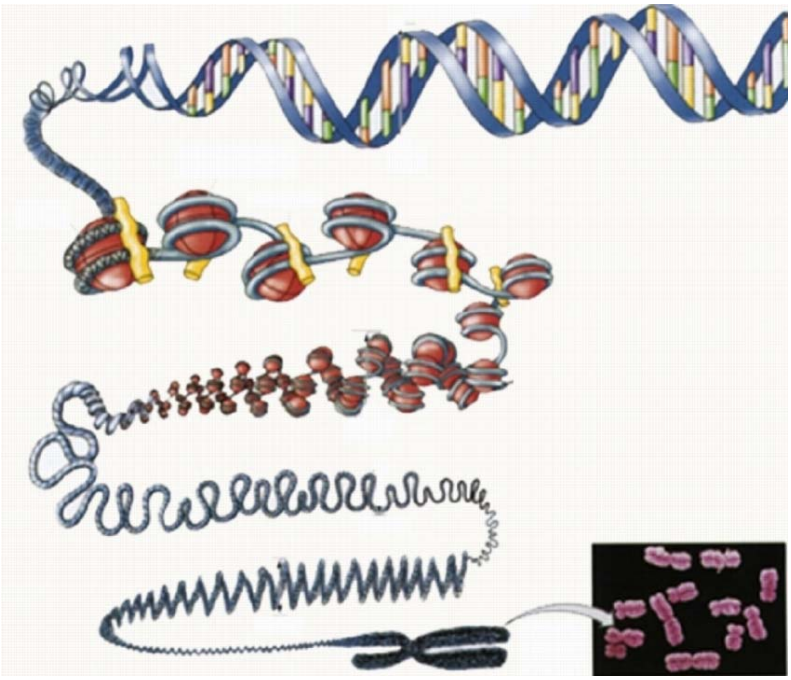
In addition, in sexually reproducing organisms, a variation of cell reproduction, called **meiosis,** occurs at one stage in the organism's life cycle (to form gametes in animals, or to start the gamete producing stage in plants). We will discuss the process of meiosis later.

Before discussing how cells divide, it's probably useful to discuss the structure of chromosomes and chromosome terms (of which there are a sufficiency).

Structure of Chromosomes

Chromosomes are composed of DNA and protein, a mixture called **chromatin**. During the normal metabolic activities of the cell the collective DNA, or chromatin, appears dense and grainy.

DNA is a thread-like double chain of nucleotides. The DNA coils around the histone proteins to form **nucleosomes.** Chromosomes continue to tightly coil and fold back on themselves prior to cell division. Chromosomes are visible only when tightly coiled.



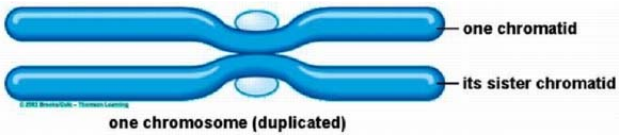
Each species has a characteristic number of chromosomes. Humans have 46 chromosomes; potatoes and chimpanzees have 48 chromosomes. The pea plant, important in Mendelian genetics has 14, the even more famous fruit fly has 8. Some ferns have chromosome numbers exceeding 1000. Chromosomes are self-duplicating and must do so prior to each cell division. There is an essential vocabulary associated with chromosome appearance before and after duplication.

Chromosome Terms before and after Duplication

- An unduplicated chromosome is **one chromosome.** A chromosome more or less consists of two arms that extend from a centralized region called the **centromere.**

one chromosome (unduplicated)

- When a chromosome duplicates, it becomes **one duplicated chromosome,** and the two copies remain attached to each other. It is still **one chromosome**. The two **exact** copies of the duplicated chromosome, which remain attached at the centromere region, are called **"sister" chromatids**. They are **identical** to each other. **(Remember this; it is essential!)**



one chromosome (duplicated)

- At the centromere region of the duplicated chromosome, there are structures (made of protein and DNA) called **kinetochores**. The kinetochores attach to microtubules of the spindle during mitosis.
- After the identical sister chromatids are separated during mitosis, each (called a "daughter" chromosome now) becomes a single unduplicated chromosome again.

Rule to remember: A chromatid must be attached to its identical chromatid and the two sister chromatids comprise one duplicated chromosome. **"Sister" chromatids are not two chromosomes.** They are one **duplicated** chromosome that consists of **two identical chromatids**. The only time you can use the word chromatid is when you have the two identical chromatids attached to each other.

The Cell Cycle

Mitosis is a part of the **cell cycle.** The cell cycle starts when a cell is formed and continues until it divides (or dies). Some cells never divide; others are specialized for division (especially in plants, where virtually all cell division occurs in specialized tissue called **meristem**). Cell division is a brief part of the life cycle; most of the life of a cell is spent in normal activities of growth and maintenance.

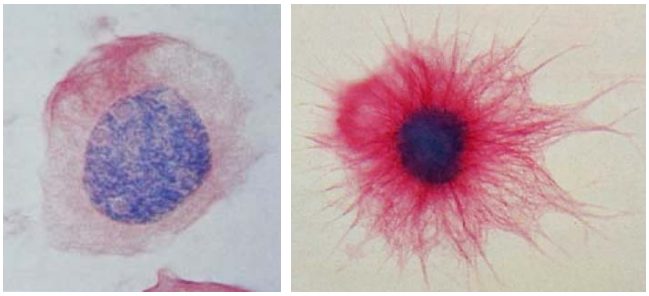
The cell cycle involves the following:

Interphase

Interphase is the period of time for normal cell activities, including:

- **Growth** (**G_1** or Gap)
  The newly formed cell does its normal activities.
- **DNA Duplication** (**S**)
  - DNA duplication (or synthesis) occurs.
  - Once started, DNA duplication cannot be reversed; the cell is committed to divide.
- **Preparation for Division** (**G_2**)
  - Proteins needed to do cell division are manufactured in preparation for mitosis and cytokinesis.
  - Cells can continue to grow and do their normal cell activities as well.
  - A G_2 checkpoint controls whether or not the cell will go into mitosis.

  Note: If a cell never divides, it stays in G_1 "permanently" a state called G_0 (or non-dividing state).

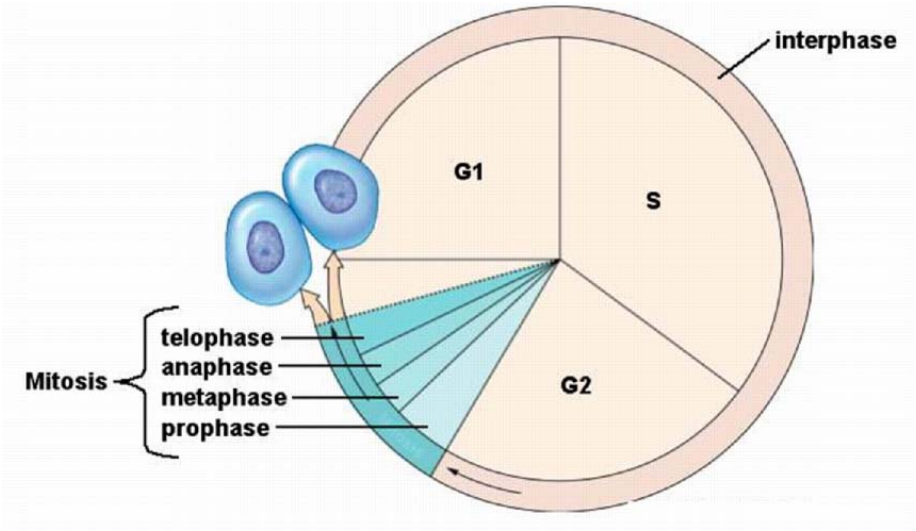


Interphase

Cell Division (or cell reproduction), which includes:

- **Mitosis**
  - Process of distributing the duplicated DNA equally to two new nuclei.
  - Mitosis is divided into 4 stages
    Prophase
    Metaphase
    Anaphase
    Telophase
- **Cytokinesis**
  - Process of separating the cytoplasm contents of the original cell into two new cells.

The events of the cell cycle are carefully regulated at checkpoints in the cycle. Cells that stay in G_0 for example, never receive the appropriate signal at the G_1 checkpoint to proceed into DNA synthesis. There are additional checkpoint signals in G_2 and during mitosis. One is at the start of anaphase.



The Stages of Mitosis

Mitosis is a continuum. Humans have decided to separate the process into stages for the convenience of our discussion. Some humans even separate the stages into sub-stages and intermediate stages.

Properly, mitosis refers to what happens to the chromosomes in the nucleus. Cytoplasmic division occurs during the accompanying cytokinesis.

The Spindle Complex

Since chromosomes are being distributed into new nuclei, a critical component of the process of mitosis is how the chromosomes are moved. Movement of chromosomes involves sets of microtubules, known as the **spindle apparatus**. Microtubules of the spindle complex extend from each pole of the cell and overlap each other at the equator of the cell. Poisons that affect microtubule function block cell division. Spindle formation is one of the events of prophase.

Prophase

Chromosome Condensation

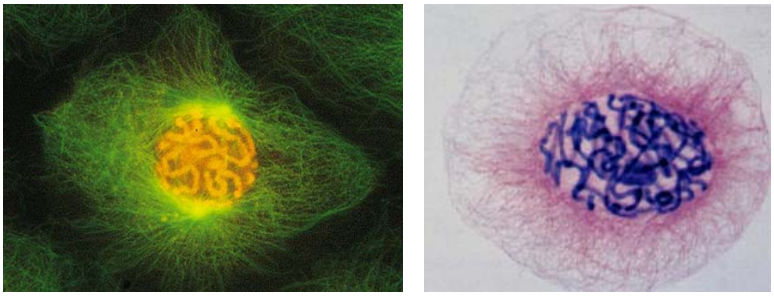
- Duplicated chromosomes start to condense and tightly coil to become visible as threadlike structures as prophase starts. Chromosomes continue to condense and become thicker as prophase progresses.
- The **nucleolus** region (an aggregation of chromosome bits and concentrated RNA and protein) of the nucleus will disassociate.
- The duplicated chromosomes are firmly attached at their centromeres throughout the condensation and coiling.

Nuclear membrane

- The nuclear membrane degrades in later prophase into small vesicles, which can be used to synthesis new nuclear membrane material in the new cells.

Microtubule Organization

- Microtubules initiate **spindle** formation and determine the poles of the cell. The spindle apparatus will extend from the poles of the cell to the center of the cell surrounding the nuclear region and to the opposite pole of the cell.
- Some microtubules from each pole of the cell attach to each duplicated chromosome's **kinetochores** located in the centromere region.
- Other microtubules overlap each other from the poles through the equator region of the cell.
- In many cells, clusters of microtubules form around the **centriole pairs**, which replicated during interphase. Microtubules move centriole pairs to the respective poles of the dividing cell. These regions are sometimes called the **asters**. Centrioles are not essential to mitosis. Cells that lack centrioles still form the spindle complex. It's just a way to ensure that the new cells will have a pair of centrioles in their cytoplasm.

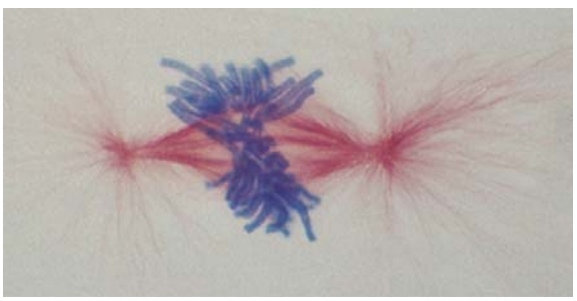
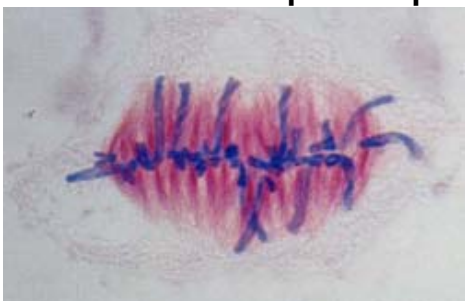


Prophase

Note: some researchers choose to call the events that include the degradation of the nuclear membrane and the attachment of the spindles to chromosomes **prometaphase.**

Metaphase

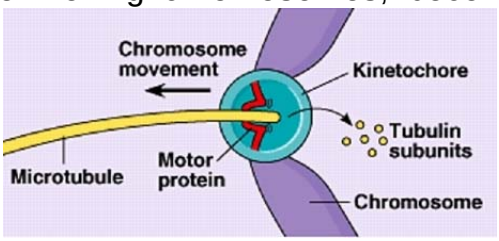
- The spindle apparatus moves the chromosomes to the equator of the cell, aligning the centromeres of each duplicated chromosome along the equator.
- Chromosomes are moved by a combination of pulling and pushing of spindle microtubules.
- The length of the spindle microtubules is regulated by the kinetochores to facilitate the alignment of centromeres at the equator.
- The ultimate alignment of chromosomes along the equator plane of the cell is metaphase, and the chromosomes are often called the **metaphase plate**.

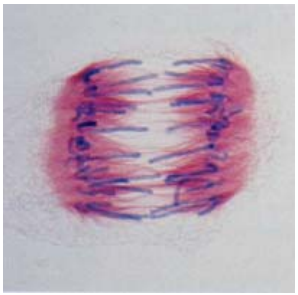
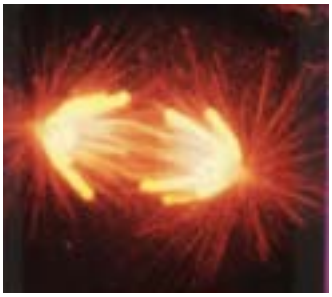
Metaphase

Anaphase

- Centromeres of each duplicated chromosome separate to start anaphase. You can't actually see this; the separating chromosomes are the first visual sign of anaphase.
  - Kinetochore motor proteins pull their chromosomes along the spindle microtubules from the equator to the poles of the cells. The microtubules disintegrate behind the moving chromosomes, becoming shorter.



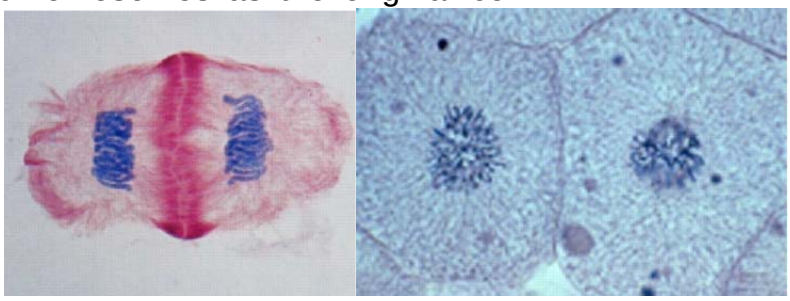
  - The overlapping polar microtubules lengthen moving the poles of the cell further apart, and, in animal cells elongating the cell.
  - Since sister chromatids are identical, each of the two clusters of chromosomes being pulled to the two poles of the cell has one copy of each original chromosome. As the chromosomes are pulled toward the poles, they begin to lengthen out.

Anaphase

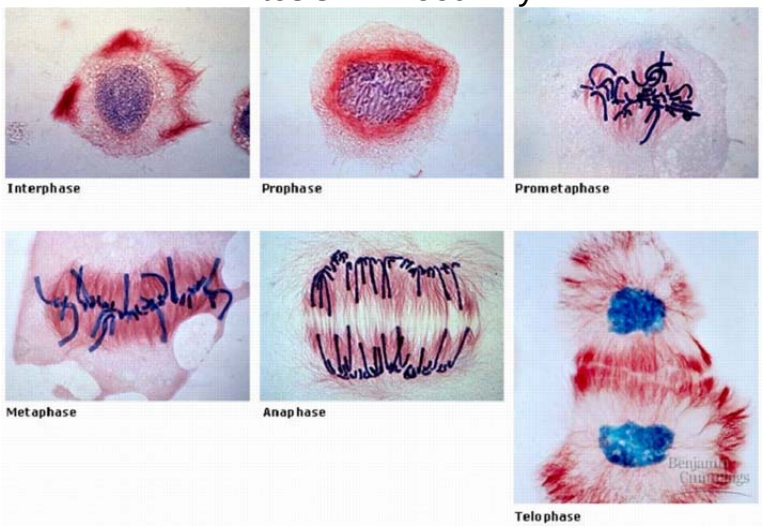
Telophase

- The spindle microtubules disperse and the spindle apparatus disappears.
- Chromosomes stretch back out and become indistinct as chromatin.
- Membrane vesicles form new nuclear membranes around each group of chromosomes (at the two poles).
- Each new nucleus has chromosomes identical to the original cell and the same number of chromosomes as the original cell.

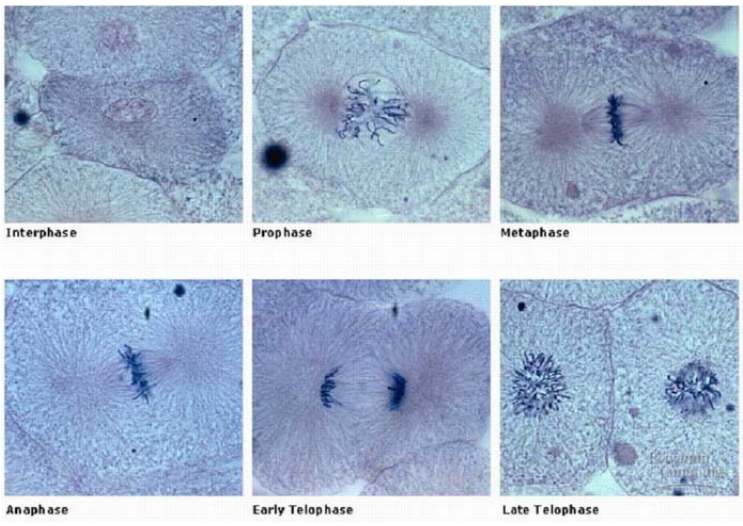


Telophase

Mitosis in Blood Lily



Mitosis in Whitefish Blastula



Cytokinesis: Separation of the Cytoplasmic Contents

Mitosis describes events of chromosomes and nuclei. Most cells accompany mitosis with **cytokinesis**, the separation of the cytoplasm of the original cell into two new cells. This is not always the case. Some organisms (including many fungi and algae) are "multinucleate", they just have one cell body with many nuclei. Some animal tissues are also multinucleate.

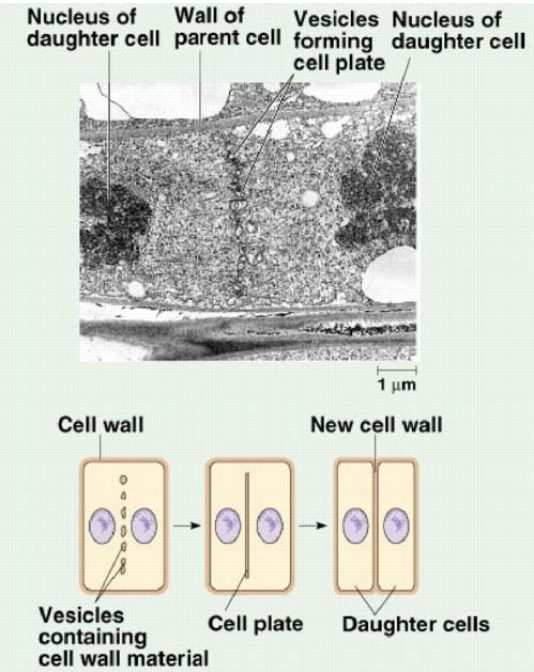
Cytokinesis coincides with the events of telophase or occurs immediately after, so that at the completion of mitosis, the original cell is separated into two cells, each with a nucleus and DNA identical to that of the original cell. Although the end result of cytokinesis is always two new cells, the mechanism of separation is different in plants and animals, so we shall discuss them separately.

Cytokinesis in Plant Cells

Each cell of a plant is surrounded by a rigid cell wall. During cytokinesis, new wall material must be synthesized along with plasma membrane. The formation of the new cell walls is called **cell plate formation**.

Cell plate formation involves making a cross wall at the equator of the original cell. Golgi vesicles containing wall material fuse along microtubules forming a disk-like structure called the **phragmoplast** or **cell plate**. As cellulose and other fibers are deposited, the cell plate is formed creating a boundary and new cell wall between the two new cells.

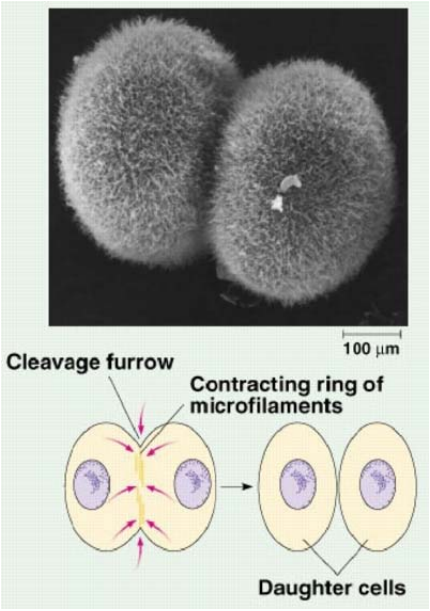
Membrane material from the original cell fuses to each side of the cell plate forming new cell membranes on the dividing sides of the original cell.



Cytokinesis in Plant Cells

Cytokinesis in Animal Cells
The cells of animals lack cell walls. Cytokinesis in animal cells is started with the formation of a **cleavage furrow**, a depression or pinching in of the plasma membrane.

This is caused by a ring of microfilaments (the **contractile ring**), composed of the protein, actin, which forms across the middle of the cell after the chromatids are separated in anaphase. This ring contracts, pinching the membrane toward the center of the cell, which eventually pinches the cell in two. The additional membrane surface needed is supplied by membrane made during interphase.



Cytokinesis in Animal Cells

When and Where does Mitosis Occur? Cell Division in Perspective
Growth
All growth (increase in numbers of cells) in individual organisms takes place by mitosis, from the fertilized egg (zygote) to death.

Replacement
Many cells are routinely replaced in organisms. This replacement of cells is done by mitosis. For examples, we replace the cells that line our digestive tract every one to three days.

Repair and Maintenance
Mitosis is used for repair and replacement of damaged cells or tissues, whenever possible. This includes regeneration of lost parts for some organisms.

Non-Sexual (Asexual) Reproduction

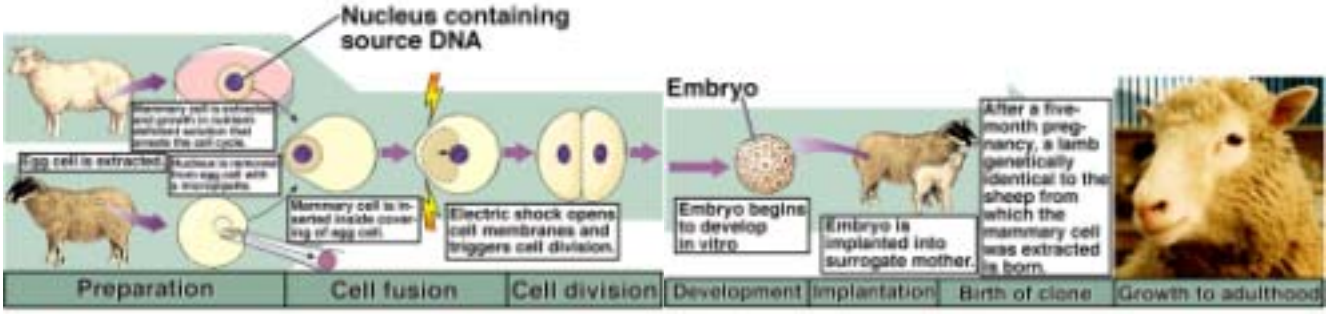
Mitosis is used for all asexual reproduction or **propagation**. This is especially common in plants, fungi and protists. Animals less commonly reproduce asexually. There are many claims for the world's largest organism based on the ability to make more. Asexual reproduction produces offspring genetically identical to the original parent, as would be expected of any mitosis.

Asexual Reproduction in Yeast, Protist and Hydra (an Animal)

Cloning, a method of producing genetically identical offspring, uses mitosis, precisely because mitosis duplicates the DNA exactly. Cloning is quite easy to do with many plants; they are easily propagated non-sexually anyway. Many of the agricultural products originate from cloned individuals, such as navel oranges.

Tissue culture is also a popular way of cloning plants. Most cells of plants retain the ability to "dedifferentiate" and become embryonic-like. Most animal cells, once specialized (or differentiated), cannot do so.

In many animals, cloning takes on a different meaning. The new organism takes a nucleus from the "parent", but the nucleus is injected into an egg cell from that species, from which the egg cell nucleus has been removed. The "clone" is then implanted into a surrogate mother for development. Dolly, the sheep, is our most famous mammal clone to date, because she was the first. Dolly is essentially genetically identical to the individual from whom the nucleus was removed, but the cytoplasm of the donor egg cell has some influence on early development and especially in mitochondria.



The successful "cloning" of mammals has resulted in a flurry of research, and speculation about cloning humans. This is one of the biological issues that has serious ethical consequences. One of the reasons each of us should learn as much as possible about biology is to make informed decisions about the ethical applications of research. Cloning is discussed more extensively in the DNA unit.