The Biology Web (Home) General Biology 1 General Biology 2 Human Biology
Environmental Science

Chapter 11 - Mitosis

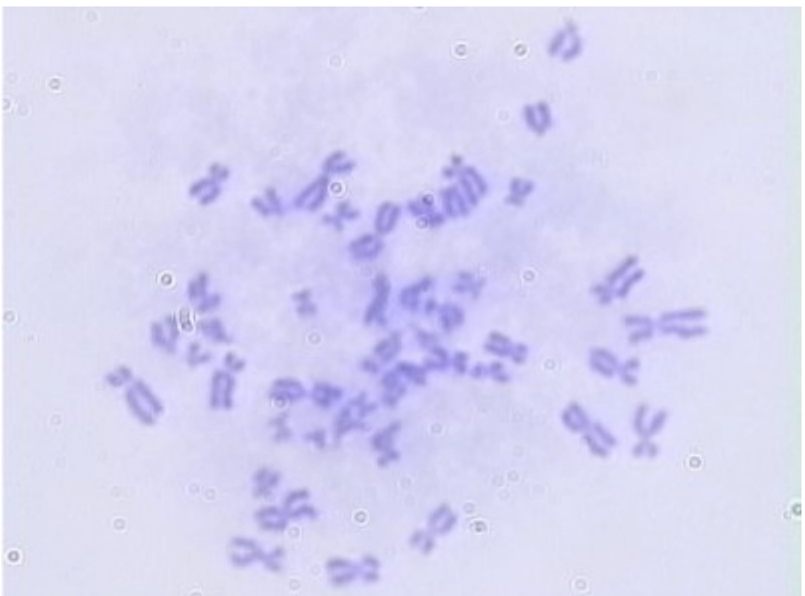
Introductory Concepts

Chromatin, Chromosomes

Chromatin is a mass of uncoiled DNA and associated proteins called ***histones***.

When cell division begins, DNA coils around the proteins forming visible structures called ***chromosomes***.

Below: Human chromosomes (female)



Haploid, Diploid

Diploid cells (2N) have two complete sets of chromosomes. The body cells of animals are diploid.

Haploid cells have one complete set of chromosomes. In animals, gametes (sperm and eggs) are haploid.

Homologous Chromosomes

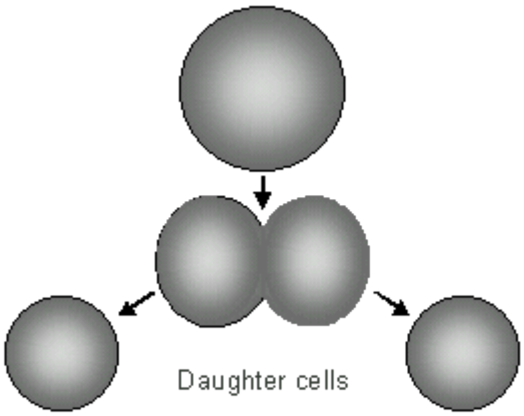
Diploid organisms have two copies of each chromosome (except the sex chromosomes). Each pair of chromosomes is ***homologous***. For example, the two #7 chromosomes are homologous. The homologue to the #3 chromosome would be the other #3 chromosome.

Genes

A small segment of DNA that contains the information necessary to construct a protein or part of a protein (polypeptide) is called a gene. Genes are the unit of inheritance.

Types of Cell Division

A cell divides by pinching into two. Each of two daughter cells produced contains genetic material inherited from the original (parent) cell.



Why Divide?

Single-celled organisms divide to reproduce.

Cell division in multicellular organisms enables the organism to grow larger while the cells remain small. A large surface:volume ratio is due to small cell size.

Organisms with many cells can have cells which are specialized for different functions and tasks. For example, red blood cells are specialized for carrying oxygen but neurons (nervous tissue) are specialized for conducting signals from one cell to another.

Some cells of multicellular organisms must divide to produce sex cells (gametes).

Mitosis

Mitosis produces two daughter cells that are identical to the parent cell. If the parent cell is haploid (N), then the daughter cells will be haploid. If the parent cell is diploid, the daughter cells will also be diploid.

N ® N

2N ® 2N

This type of cell division allows multicellular organisms to grow and repair damaged tissue.

Meiosis

Meiosis produces daughter cells that have one half the number of ***chromosomes*** as the parent cell.

2N ® N

Meiosis enables organisms to reproduce ***sexually***. Gametes (sperm and eggs) are haploid.

Meiosis is necessary in sexually-reproducing organisms because the fusion of two gametes (fertilization) doubles the number of chromosomes.

Meiosis involves two divisions producing a total of four daughter cells.

Click here to go to the chapter on meiosis.

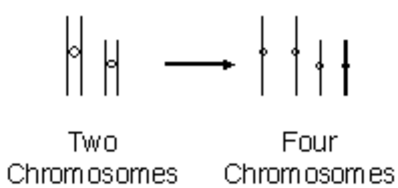
Chromosome Structure and Replication

A ***chromatid*** is a single DNA molecule.

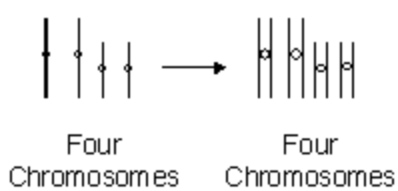
Double-stranded chromosomes have two chromatids; normally, each one is identical to the other. The point where the two chromatids are attached is called the ***centromere***.

Chromosome Doubling vs DNA Synthesis

Splitting chromosomes into two will double their number because each chromatid is identical.

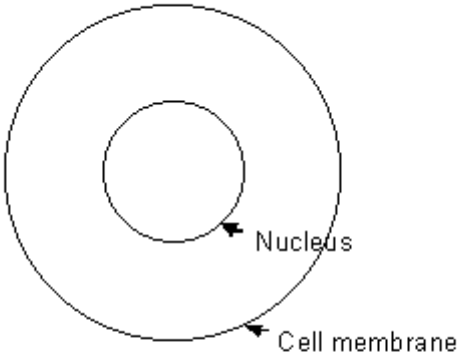


DNA replication occurs when a single-stranded chromosome produces a second chromatid.



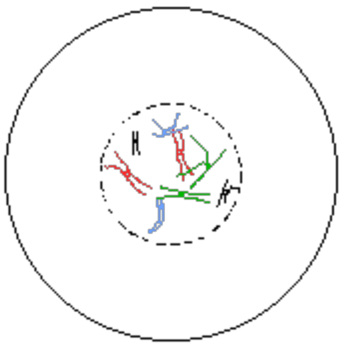
Click here to review DNA synthesis (replication).

Overview of the Cell Cycle



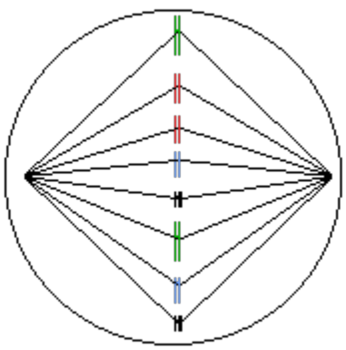
Interphase (G_1 and G_2)

Chromosomes are not visible because they are uncoiled



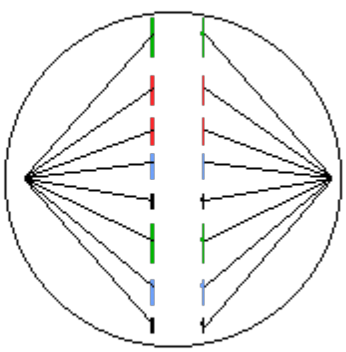
Prophase

The chromosomes coil.
The nuclear membrane disintegrates.
The spindle apparatus forms.



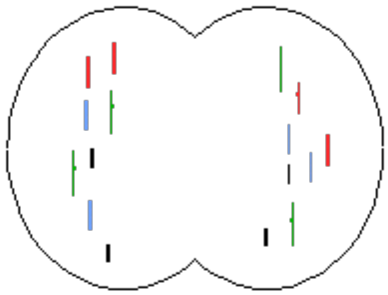
Metaphase

The chromosomes become aligned.



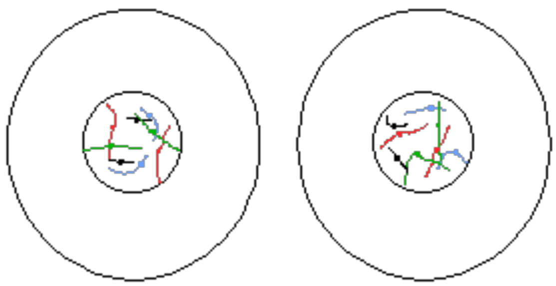
Anaphase

The chromatids separate (The number of chromosomes doubles).



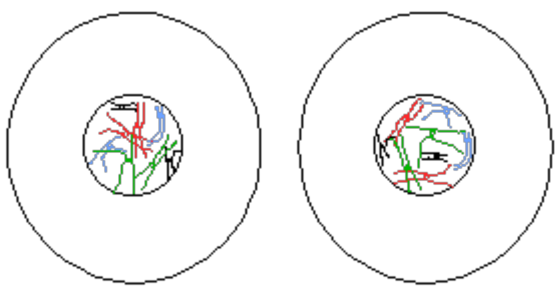
Telophase

The nuclear membrane reappears.
The chromosomes uncoil.
The spindle apparatus breaks down.
The cell divides into two.



G_1 Interphase

The chromosomes have one chromatid.



G_2 Interphase

The chromosomes have two chromatids.

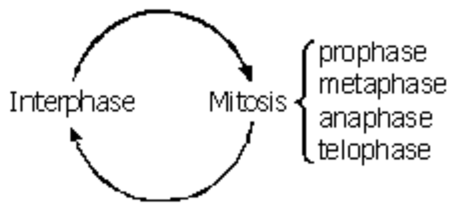
Mitosis Animation

The link below is an animation that shows chromosome movement during mitosis in a hypothetical species with 2N = 4.

Click here to begin the animation. After the screen opens, press Ctrl-F to view the animation in full screen mode.

The Cell Cycle

The cell cycle alternates between ***interphase*** and ***mitosis*** as diagrammed below.



Mitosis has these four phases: prophase, metaphase, anaphase, and telophase.

Prophase

During prophase, chromosomes begin condensing (forming) as DNA becomes coiled. The genes cannot function (produce mRNA and therefore protein) when the DNA is coiled. Coiling facilitates movement.

The nucleolus disappears.

The nuclear membrane becomes fragmented and disappears by the end of prophase.

A system of microtubules needed to move the chromosomes begins to form during prophase. The microtubules, also called ***spindle fibers***, form from an area of the cell called the ***centrosome***. During interphase, the cell has one centrosome but just before prophase, the centrosome duplicates, producing a second centrosome. During prophase, microtubules radiate from each centrosome. Some of the microtubules extend from one centrosome toward the other.

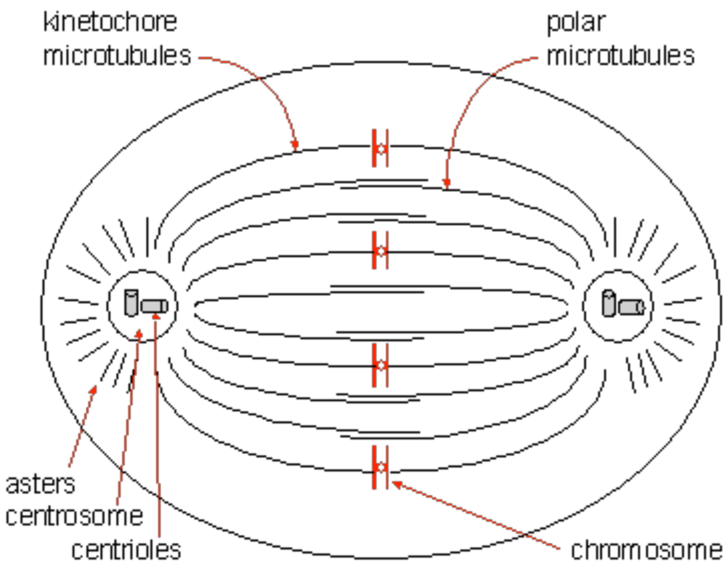
The entire complex of centrosomes and spindle fibers is called the spindle apparatus.

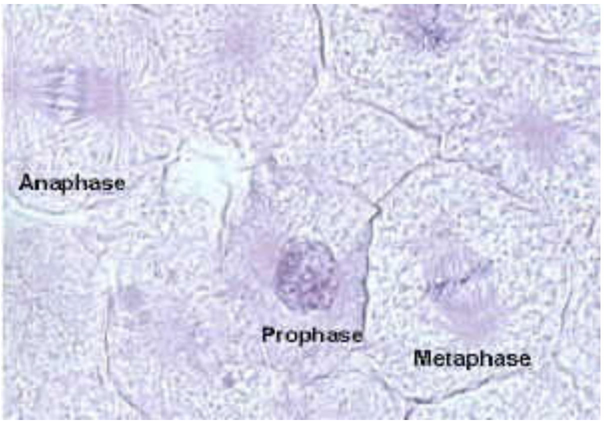
Each centrosome of an animal cell contains two ***centrioles***. Plant cells do not have centrioles but they do form spindle fibers.

Kinetochores and Kinetochore Microtubules

During prophase, protein plates called ***kinetochores*** form on the centromeres of each chromosome.

Kinetochore microtubules are spindle fibers that attach to the kinetochores and move the chromosomes to the center of the cell. The next phase (Metaphase) begins when the chromosomes become aligned in the center of the cell.



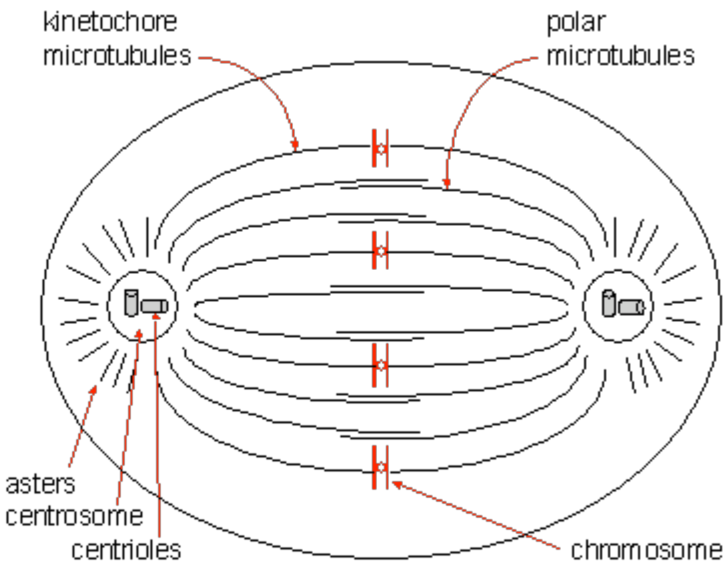


Click on the image above to enlarge it.

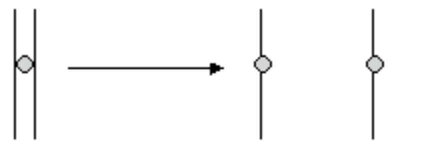
Metaphase

During metaphase, the chromosomes have moved to the center of the cell (diagram below, photograph above). This line of chromosomes is referred to as the metaphase plate.

The structures in the diagram below are referred to as the ***spindle apparatus***. Kinetochore microtubules are attached to the chromosomes. Polar microtubules are not attached to chromosomes but overlap each other. ***Asters*** are short microtubules that radiate from the centrosomes. The spindle apparatus can be seen on the drawing of a cell in metaphase below.



Metaphase ends when chromosomes split, thus doubling the number of chromosomes.



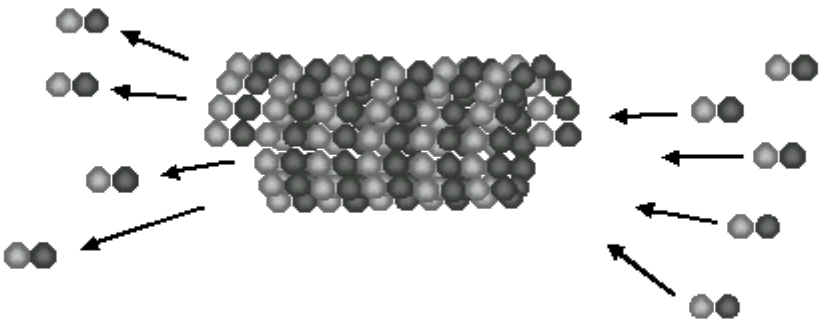
Anaphase

When the chromosomes split at the end of metaphase, the chromosome number is doubled. For example, the number of chromosomes and chromatids during each phase in a human cell is:

Phase	# Chromosomes	# Chromatids
Prophase	46	92
Metaphase	46	92
Anaphase	92	92
Telophase	92	92

Chromosome movement

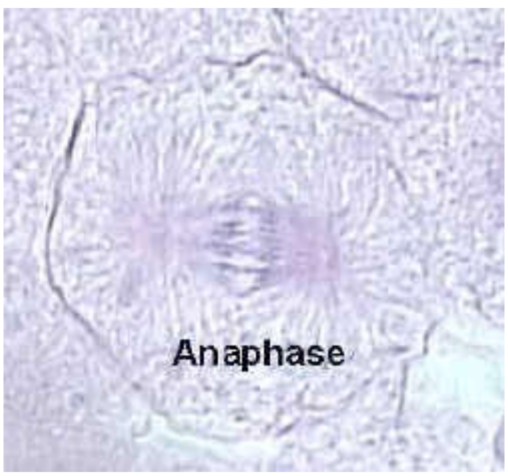
Microtubules lengthen and shorten by the addition or removal of tubulin dimers. Click here for details in the chapter on cells.



Kinetochore microtubules shorten in the region of the kinetochore, pulling the chromosomes apart.

Polar microtubules push against each other and thus, push the two centrosomes apart. This, in turn, also pulls the chromosomes apart.

The chromosomes move toward poles of cell.



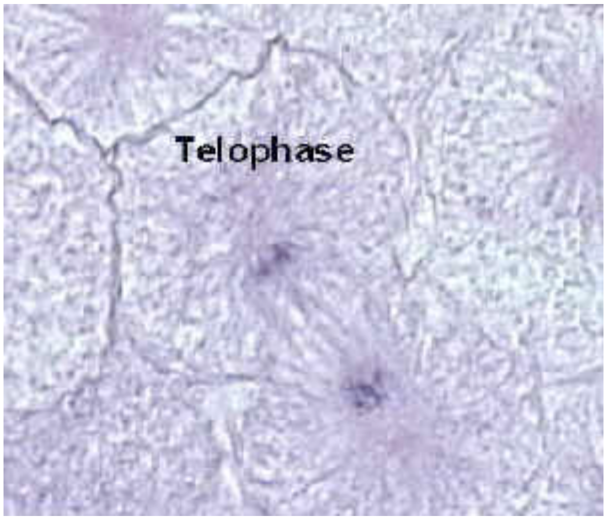
Cytokinesis (division of the cytoplasm) begins in anaphase. A cleavage furrow forms as actin filaments underneath the plasma membrane constrict in a band called the contractile ring. Two cells will be produced as this process continues.

Telophase

Telophase begins when chromosomes reach the poles of the daughter cells.

Many of the events in telophase are the reverse of prophase. The chromosomes uncoil, the nuclear membranes around daughter nuclei appear, the spindle apparatus breaks down, and the nucleolus reappears.

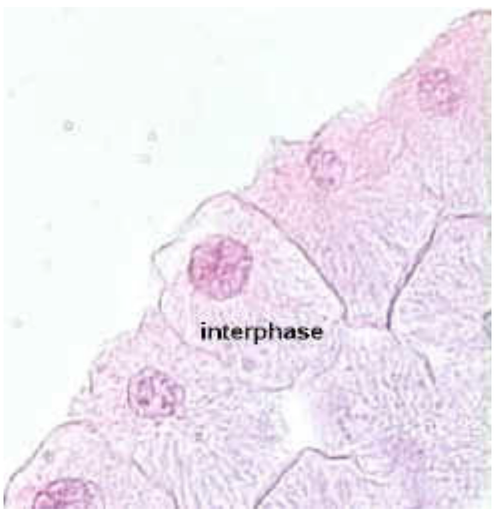
Cytokinesis is completed as telophase ends.



Interphase

This is the non-dividing phase.

During interphase, the nucleus is visible and the chromosomes are uncoiled and invisible.



Interphase includes G_1, S and G_2.

G_1

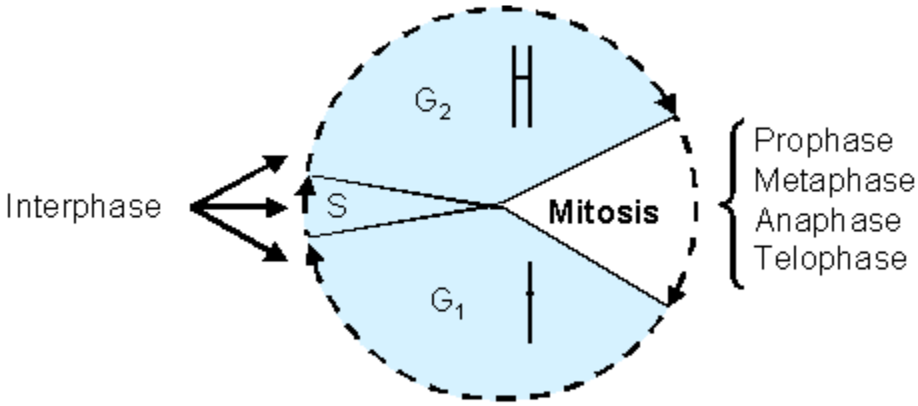
Each chromosome has one chromatid.
The cell grows in size.
Synthesis of organelles occurs.

S

This is when DNA synthesis occurs.

G_2

Each chromosome has two chromatids.
The synthesis of enzymes and other proteins in preparation for mitosis occurs during this period.



Cells that permanently leave the cycle

Some cells remain permanently in G_1. Examples: skeletal muscle, nerve cells

Some cells remain permanently in G_2. Example: cardiac muscle

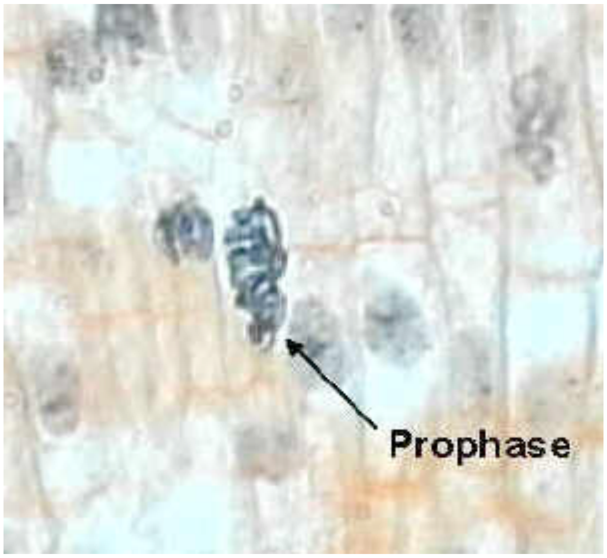
Below: Whitefish blastula X 400

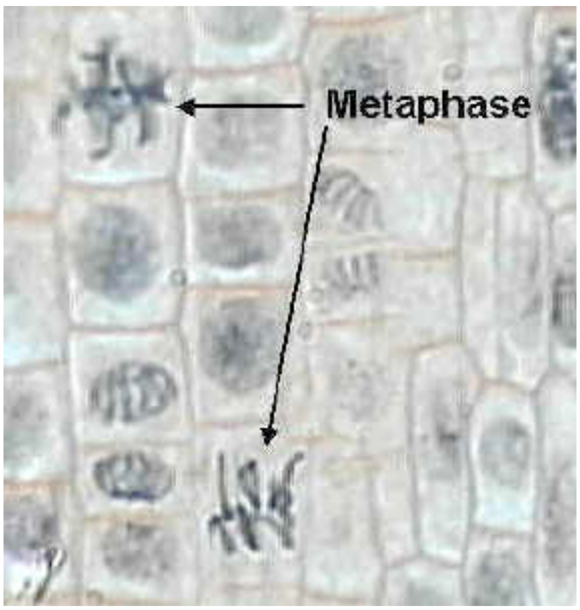
Mitosis in Plants

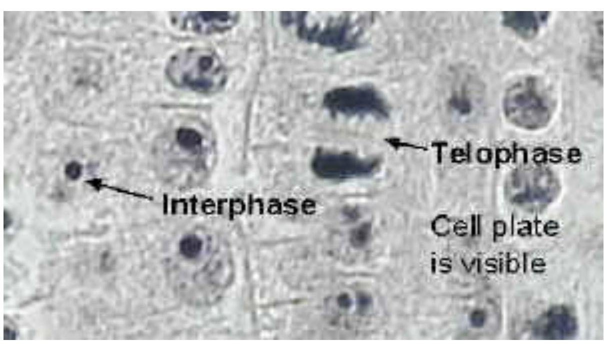
Plants form a spindle apparatus as animals do but plants lack centrioles.

Instead of furrowing, vesicles derived from the Golgi apparatus fuse at the equator to form a ***cell plate***. The vesicles contain materials necessary to construct a cell wall between the cells.

Mitosis in Allium (Onion)



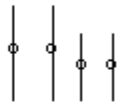


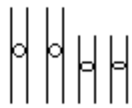


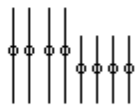
Practice

Click here for the answers to the questions below.

How many chromosomes are there in each of the three diagrams below? How many chromatids?

A 

B 

C 

If a parent cell had 6 chromosomes, how many during each phase listed below?

Phase	# Chromosomes	# Chromatids
prophase		
metaphase		
anaphase		
telophase		
G_1 interphase		
G_2 interphase		

If a cell had 4 chromosomes that were single-stranded, how many chromosomes and chromatids during each phase listed below?

Phase	# Chromosomes	# Chromatids
prophase		
metaphase		
anaphase		
telophase		

G_1 interphase		
G_2 interphase		

Draw each phase of mitosis (prophase, metaphase, anaphase, telophase) in a cell that has 2N = 4 chromosomes. Show the following in your drawings: chromosomes, kinetochore microtubules, and nuclear membrane.

Control of the cell cycle

Telomeres

Mammalian cells typically divide only about 50 times.

This limit is set by the presence of repeated sequences of DNA at the tips of the chromosomes called ***telomeres***.

In young cells, the sequence TTAGGG is repeated hundreds or thousands of times but each time the cell divides, it loses 50 to 200 of these repeats. Cells that have divided many times have fewer of these repeats left.

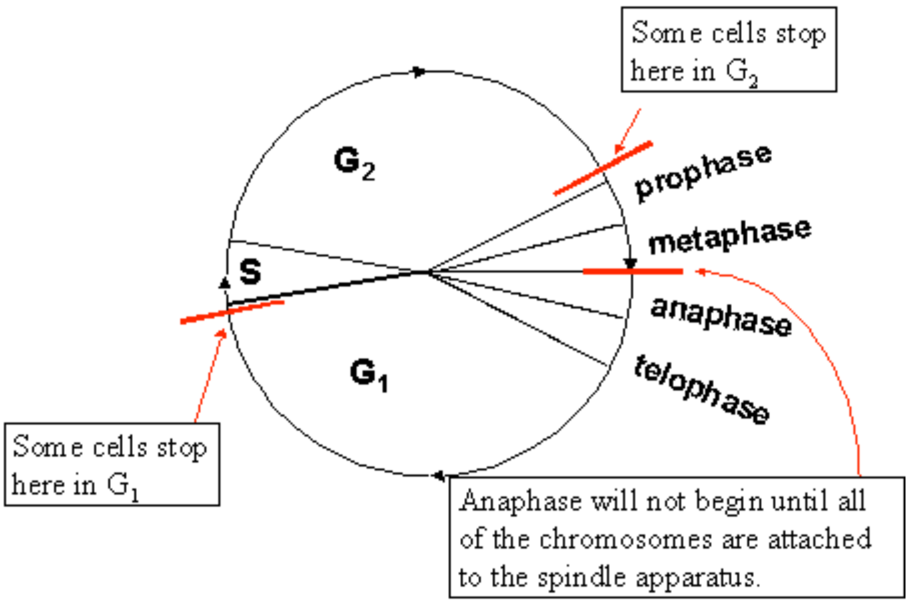
When the telomere is reduced to a certain size, the cell will no longer divide.

Telomeres are restored to their original length by an enzyme called ***telomerase***. This enzyme contains a single strand of RNA that is used to synthesize the telomeres.

Telomerase is usually found in cells involved in the production of gametes. It is not normally found in somatic cells.

Cyclin-Dependent Kinases

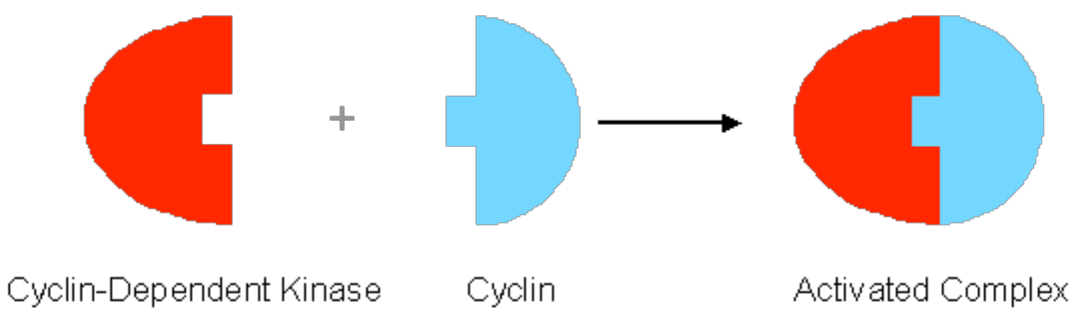
Some cells stop dividing in G_1; others stop in G_2.



Kinases are enzymes that activate proteins by transferring a phosphate group from ATP to the protein being activated. An activated protein is needed for the cell cycle to proceed from G_1 to S. Similarly, another activated protein is needed to move the cycle from G_2 to mitosis.

Kinases activate these proteins and thus stimulate the cell cycle to continue.

Kinases are normally inactive and must be activated before they can activate other proteins. Kinases become activated by combining with a protein called ***cyclin***.



The activated complex is involved in stimulating the cell cycle to resume.

The level of cyclin fluctuates (cycles). At low levels, kinases are not activated and the cell cycle is halted. At high levels, activation occurs and the cycle resumes.

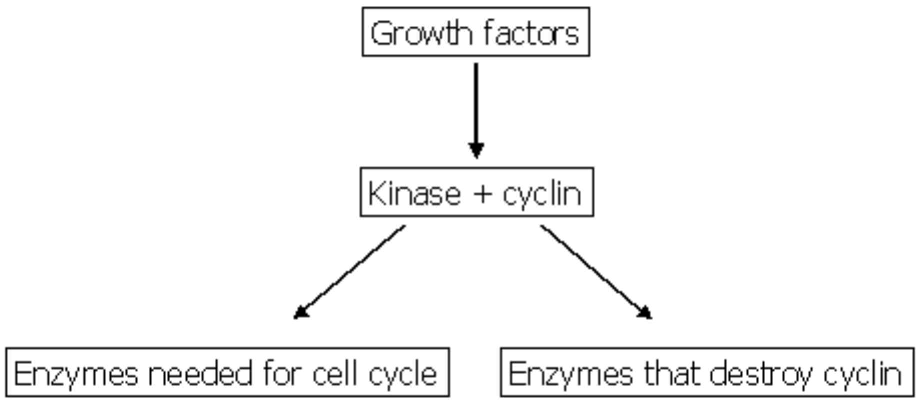
Growth Factors

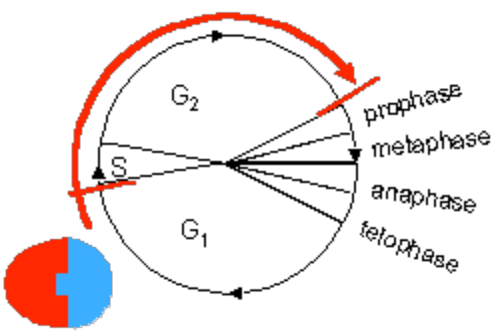
Growth factors are molecules that stimulate nearby cells to divide by promoting the binding of cyclin to kinase.

Under normal conditions, cyclin combines with kinase only when growth factors are present. For example, damaged tissue releases growth factors to stimulate cell division needed to repair the tissue.

S-Cyclin

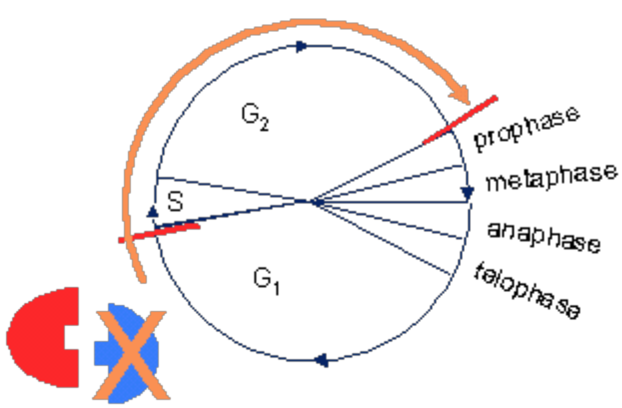
S-Kinase combines with S-cyclin and the resulting active complex stimulates DNA replication.





The "S" in S-kinase and S-cyclin refers to DNA synthesis.

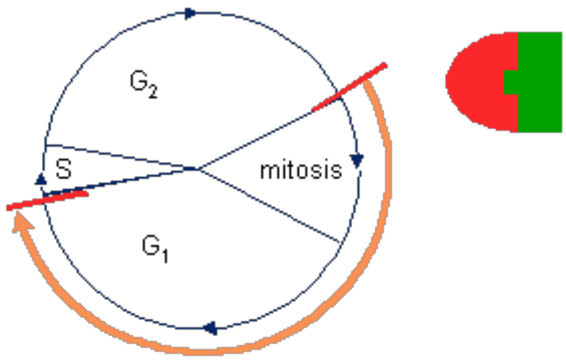
Enzymes triggered by the active kinase-cyclin complex then destroy the S-cyclin.



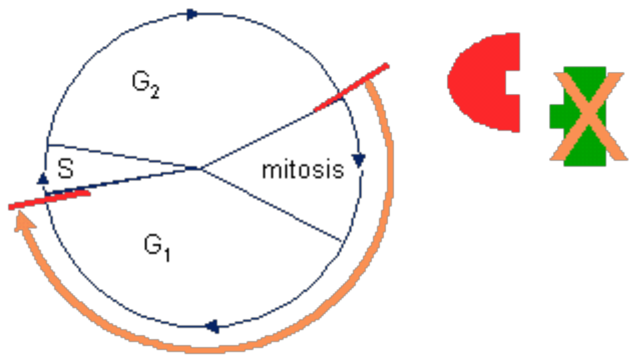
M-Cyclin

M-Kinase combines with M-cyclin and the active complex initiates several mitotic events:

1. chromosome condensation (coiling)
2. nuclear membrane disintegration
3. the synthesis of the spindle apparatus



The active kinase-cyclin complex also activates enzymes that destroy the M-cyclin.



Prokaryotes

Prokaryotic cells do not undergo mitosis. When the cell divides, the circular chromosome replicates itself (DNA synthesis) and the cell pinches into two.

This process is called ***binary fission***.

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