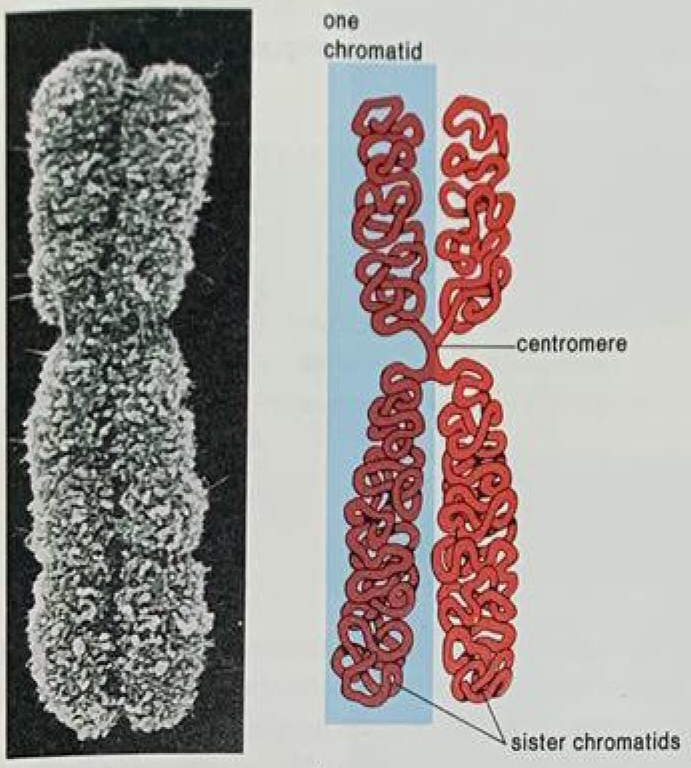


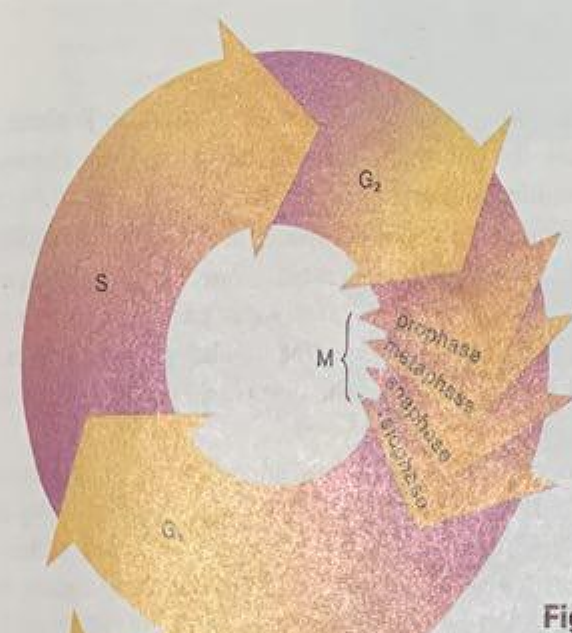
Figure 10.3
Duplicated chromosomes. DNA replication has occurred, and each chromosome is held together at a region called the centromere. ***a.*** Electron micrograph of highly coiled and compacted chromosome, typical of a nucleus about to divide. Magnification, X8,400. ***b.*** A chromosome that is not as condensed. One chromatid is indicated by the box. A duplicated chromosome contains 2 sister chromatids, each containing copies of the same genes.

DNA replicates prior to nuclear division, which consists of 4 stages.

Cell Cycle

By the 1870s, microscopy could provide detailed and accurate descriptions of chromosome movements during mitosis, but there was no knowledge of cellular events between divisions. Because there was little visible activity between divisions, the period of time was dismissed as a resting state termed **interphase.** When it was discovered in the 1950s that DNA replication occurs during interphase, the cell cycle concept was formulated.

Cells grow and divide during a cycle that has 4 phases (fig. 10.4). The entire cell division phase, including both mitosis and cytokinesis, is termed the *M phase* (M = mitosis). The period of DNA replication is termed the *S phase* (S = synthesis) of the cycle. The proteins associated with DNA in eukaryotic chromosomes (see reading) are also synthesized during this phase. There are 2 other phases of the cycle. The period of time following the M phase and before the S phase begins is termed the *G_1 phase*, and the period of time following the S phase and before the M phase begins is termed the *G_2 phase*. At first, not much was known about these phases, and they were thought of as G = gap phases. Now we know that during the G_1 phase, the cell grows in size and the cellular organelles increase in number. During the G_2 phase, synthesis of various enzymes and other types of proteins occurs in preparation for mitosis. Some biologists today prefer the designation G = growth for these 2 G phases. In any case, interphase consists of G_1, S, and G_2 phases.



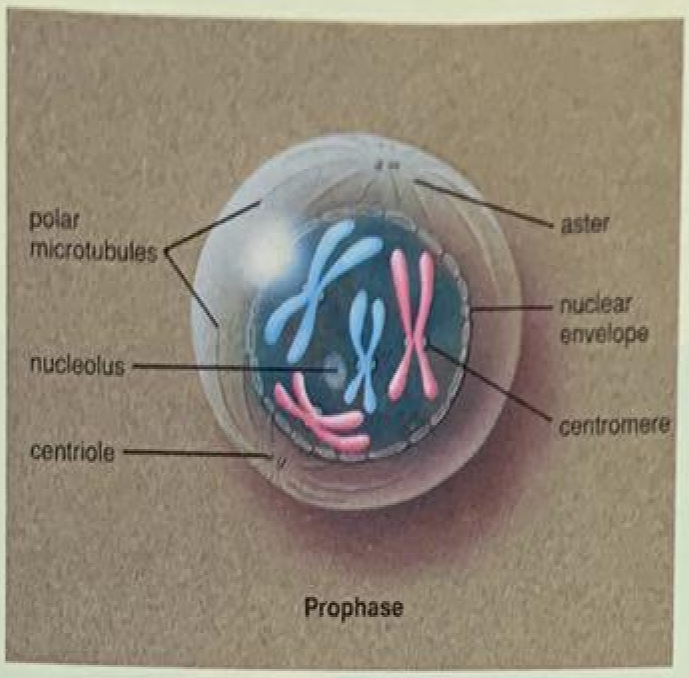
interphase

Phase	Main Events	*Vicia faba*	*Homo sapiens* (cultured fibroblasts)
G_1	organelles begin to double in number	4.9 hr	6.3 hr
S	replication of DNA	7.5	7.0
G_2	synthesis of proteins	4.9	2.0
M	mitosis	2.0	0.7
	Total:	19.3 hr	16.0 hr

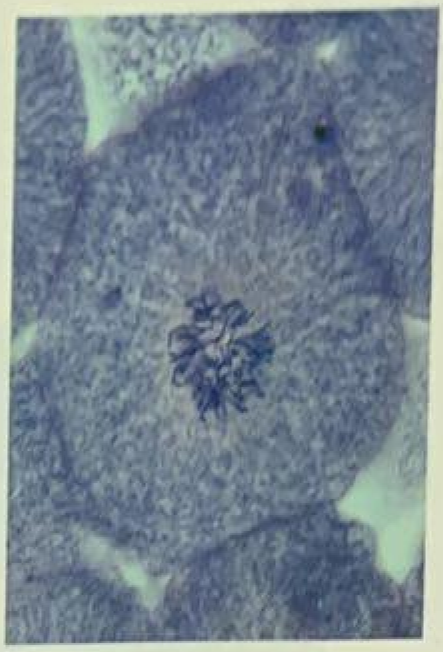
Figure 10.4
The cell cycle consists of 4 phases (G_1, S, G_2, and M for mitosis), which are indicated in the figure and described in the accompanying table. The length of the different phases varies both between species and between different cell types in the same individual. The approximate length of the phases for the broad bean (*Vicia faba*) and humans (*Homo sapiens*) are given. Many cells of the body do not participate in the cell cycle; they are in a nondividing "G_0" phase and are not preparing for DNA replication. Such cells are often specialized for a particular function.

Figure 10.5
Prophase drawing (***a***) and micrograph (***b***) of whitefish (animal) embryonic cell. Magnification, X280. These events occur during prophase:

- chromatin condenses to (duplicated) chromosomes;
- nucleolus disappears;
- nuclear envelope fragments;
- centriole pairs migrate toward opposite poles;
- polar microtubules are assembling.



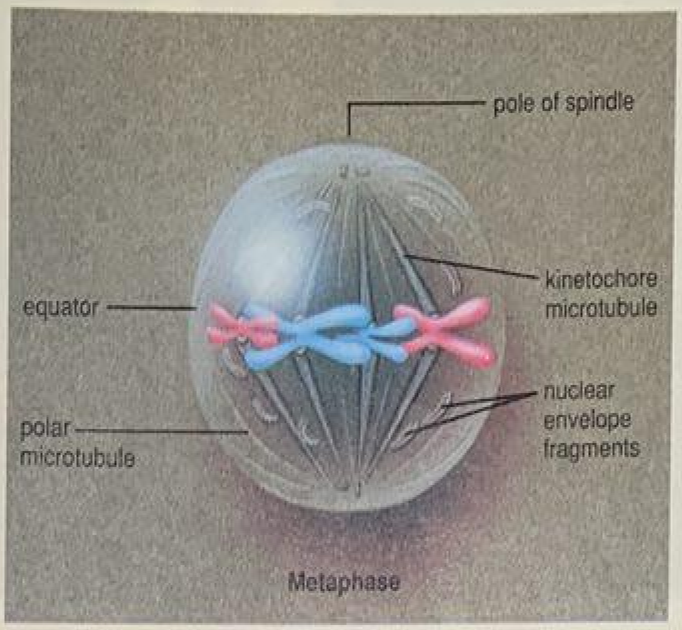
a.



b.

Figure 10.6
Metaphase drawing (***a***) and micrograph (***b***) of whitefish (animal) embryonic cell. Magnification, X280. These events occur during metaphase:

- nuclear envelope fragmentation is complete;
- spindle formation is completed;
- duplicated chromosomes are aligned at equator;
- kinetochore microtubules of sister chromatids point to opposite poles.

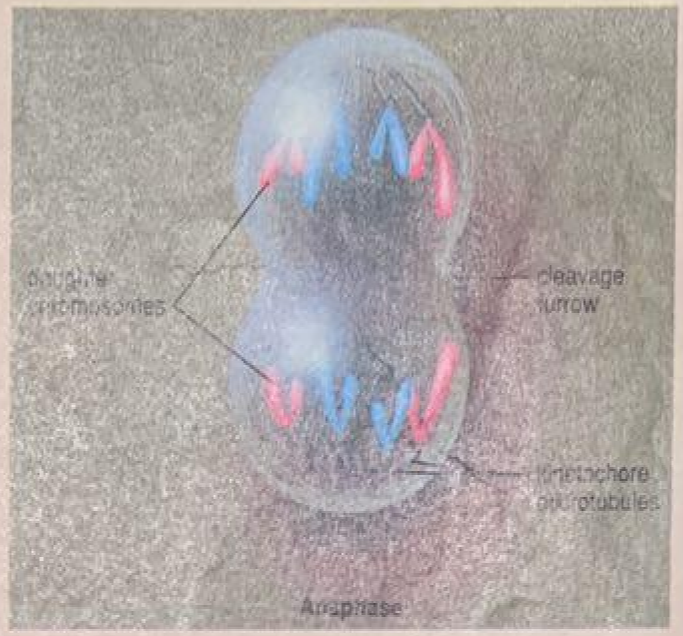


a.

b.

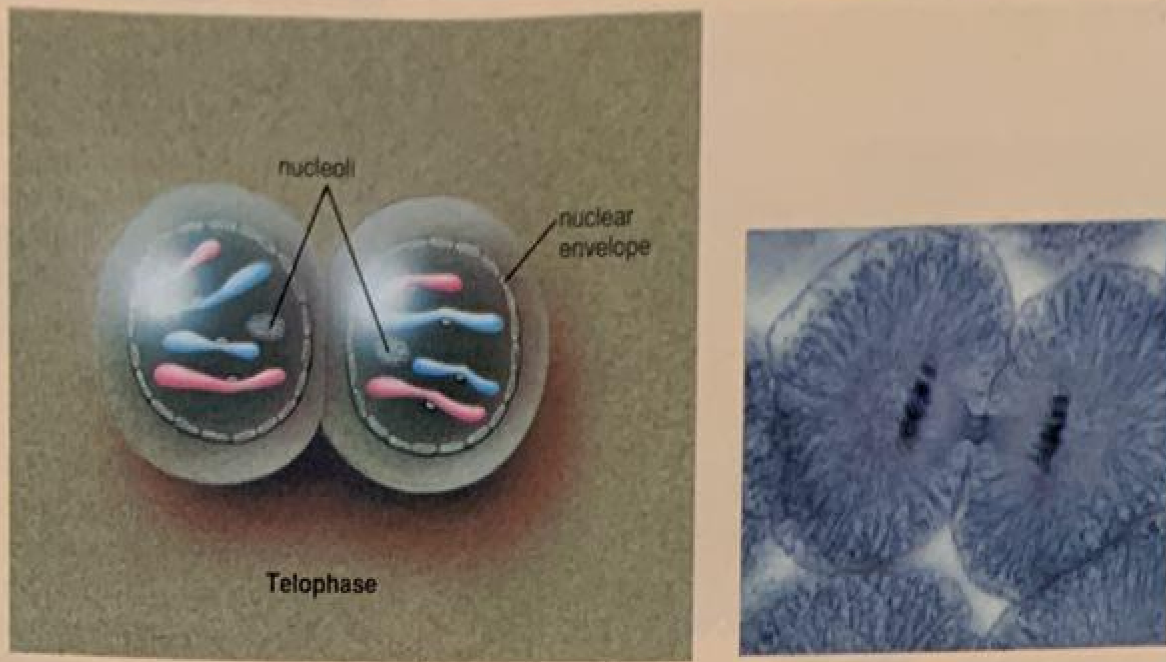
Figure 10.7
Anaphase drawing (***a***) and micrograph (***b***) of whitefish (animal) embryonic cell. Magnification, X500. These events occur during anaphase:

- centromeres divide;
- diploid set of daughter chromosomes move toward each pole;
- polar microtubules lengthen;
- cytokinesis begins.



a.

b.



a. b.

Figure 10.9
Telophase drawing (***a***) and micrograph (***b***) of whitefish (animal) embryonic cell. Magnification, X280. These events occur during telophase:

- chromosomes uncoil to chromatin;
- nuclear envelopes reform;
- nucleoli reappear;
- daughter nuclei are diploid;
- cytokinesis is nearly complete.

During prophase, chromatin condenses to form the chromosomes, which have no particular orientation.

Metaphase

As *metaphase* begins, the fragmentation of the nuclear envelope that began in prophase continues, and the polar microtubules now extend to the equator of the spindle (fig. 10.6). Specialized structures called *kinetochores* develop on either side of each centromere. Microtubules called *kinetochore microtubules* extend from the kinetochores to the poles. The chromatids of a chromosome dangle from the centromere, but the kinetochores are orientated so that the sister chromatids face opposite poles.

Metaphase is recognized by the alignment of the chromosomes at the equator of a fully formed spindle.

Anaphase

At the start of *anaphase*, the centromeres of the duplicated chromosomes divide (fig. 10.7). Daughter chromosomes, each having a single chromatid, begin to move toward opposite poles. The mechanism by which the centromeres divide is unknown, but it has been suggested that the centromeres are merely a region where the DNA did not replicate. Replication in this area would then allow the chromatids to separate.

There seem to be 2 processes that account for the movement of the daughter chromosomes toward opposite poles. A lengthening of the polar microtubules acts to push the chromosomes away from the equator, and a shortening of the kinetochore microtubules acts to pull the chromosomes toward the poles (fig. 10.8).

As the chromosomes reach the poles, cytokinesis begins.

Anaphase is recognized by the movement of chromosomes toward each pole of the spindle.

Telophase

As the microtubules disassemble during *telophase*, new nuclear envelopes form around the daughter chromosomes (fig. 10.9) Each daughter nucleus contains the same number and kinds of chromosomes as the original parent cell. Remnants of the polar microtubules are still visible between the 2 nuclei.

The chromosomes become more diffuse chromatin once again, and a nucleolus appears in each daughter nucleus. Cytokinesis is nearly complete, and soon there will be 2 individual daughter cells.

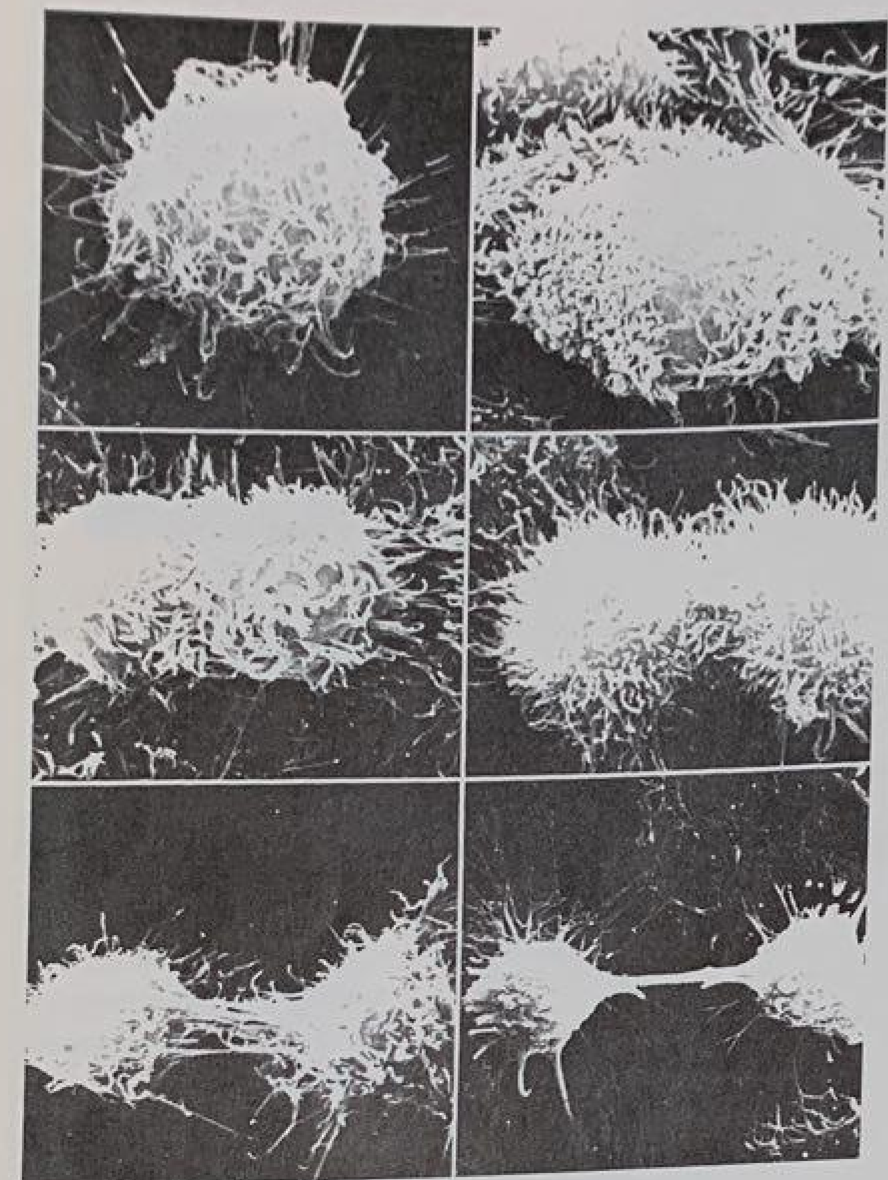
Telophase is recognized by 2 clusters of daughter chromosomes within newly forming daughter nuclei.

Cytokinesis in Animal Cells

Cytokinesis, or cytoplasmic cleavage, usually accompanies mitosis. A cleavage furrow, which is an indentation of the membrane between the 2 daughter nuclei, begins as anaphase draws to a close. The cleavage furrow deepens as a band of actin filaments, called the contractile ring, slowly constricts the cell at the equator. A narrow bridge between the 2 cells can be seen during telophase, and then the contractile ring completely separates the cytoplasm and there are 2 daughter cells (fig. 10.10).

Cytokinesis in animal cells is accomplished by a furrowing process.

Figure 10.10
Cytokinesis in an animal cell. The single cell becomes 2 daughter cells by a furrowing process.



Mitosis in Plant Cells

Figure 10.11 illustrates mitosis in plants. Note that there are exactly the same stages in plant cells as in animals cells. As mentioned previously, plant cells have a microtubule organizing center, but there are no centrioles or asters.

Certain plant tissue, called meristem tissue, retains the ability to divide throughout the lifetime of a plant. Meristem tissue is found in root and shoot tips and in stems, and it accounts for the ability of trees to grow larger each growing season.

Cytokinesis in Plant Cells

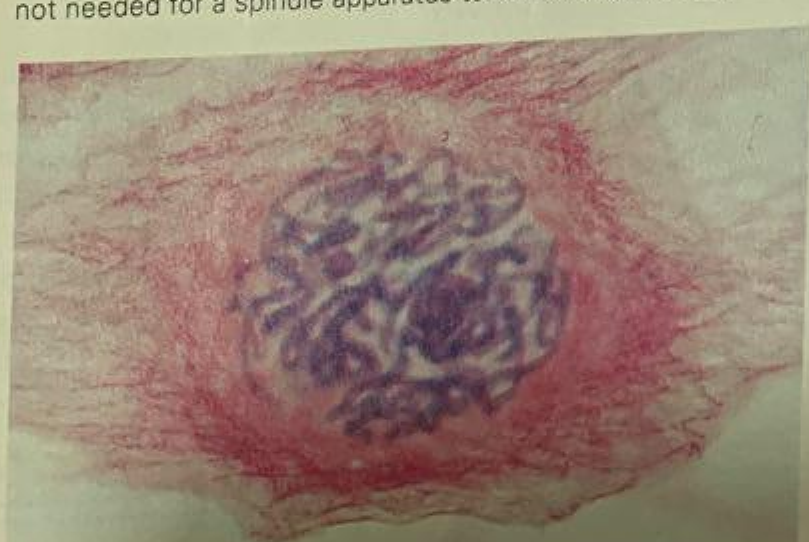
Cytokinesis in plant cells occurs by a process different from that seen in animal cells. The rigid cell wall that surrounds plant cells does not permit cytokinesis by furrowing. Instead, vesicles, largely derived from the Golgi apparatus, travel down the polar microtubules to the region of the equator. These vesicles fuse, forming a **cell plate.** Their membrane completes the plasma membrane for both cells (fig. 10.12). They also release polysaccharides that signal the formation of plant cell walls. These walls are later strengthened by the addition of cellulose fibrils.

> A spindle forms during mitosis in plant cells, but there are no centrioles or asters. Cytokinesis in plant cells involves the formation of a cell plate.

Importance of Binary Fission and Mitosis

Binary fission and mitosis are successful evolutionary adaptations that ensure daughter cells get equal amounts of genetic material and cytoplasm. Fission and mitosis differ chiefly in that binary fission does not utilize a spindle, whereas mitosis does utilize a spindle.

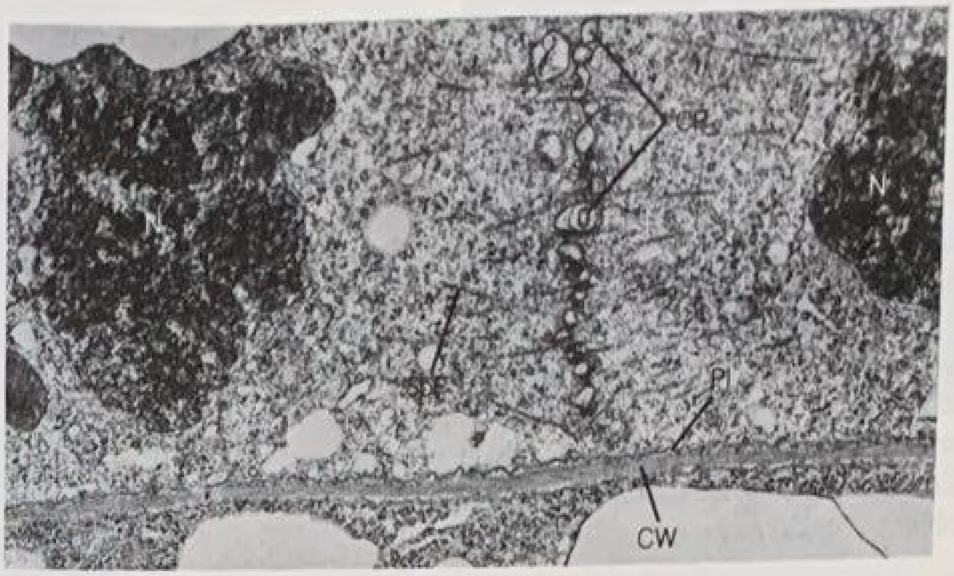
Figure 10.11
Mitosis in plant cells. Notice that there are no asters in plant cells because they lack centrioles. This is evidence that centrioles are not needed for a spindle apparatus to form. Magnification, X1,500.



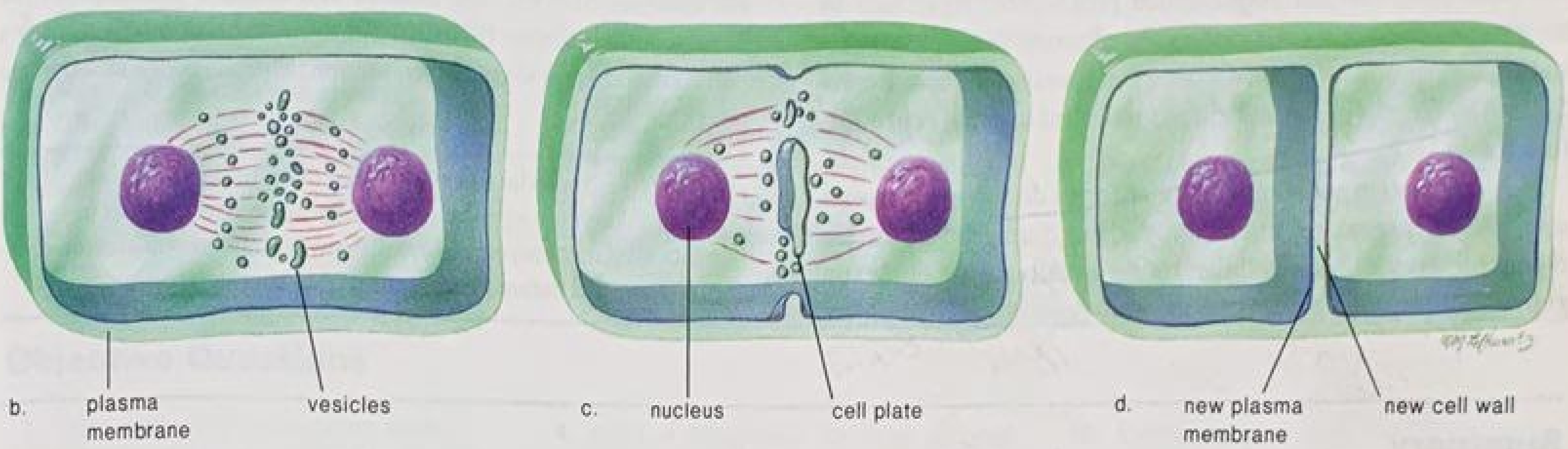
a. Prophase

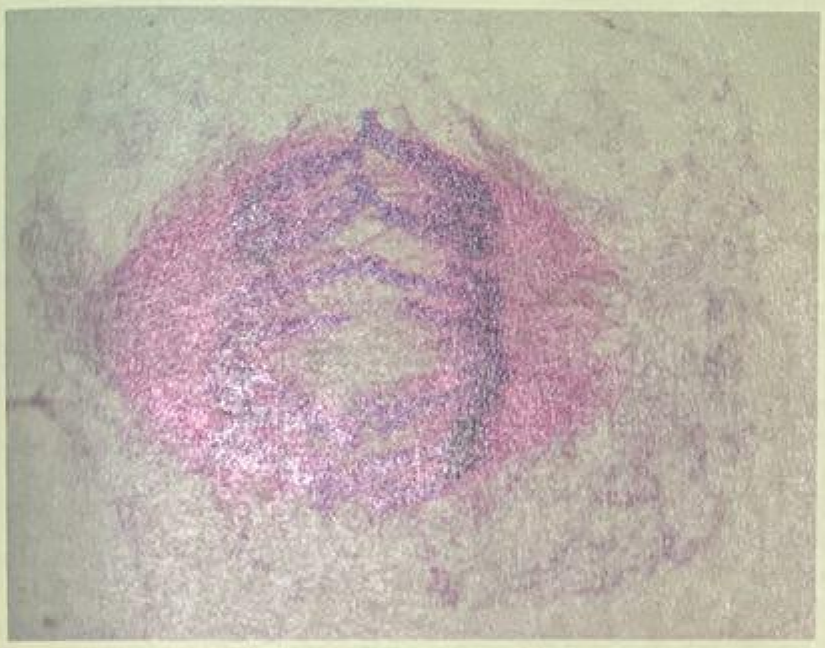
b. Metaphase

Figure 10.12
Cytokinesis in a plant cell involves the formation of a cell plate. ***a.*** Electron micrograph showing the stage that corresponds to (***c***). CP = cell plate; CW = cell wall; Pl = plasma membrane; N = nucleus; SpF = spindle fiber. Magnification, X20,000. ***b.*** Vesicles containing polysaccharides are at the center of the cell. ***c.*** The cell plate forms at the cell equator and extends to the plasma membrane. ***d.*** Daughter cell plasma membranes are complete, and the cell wall has formed.

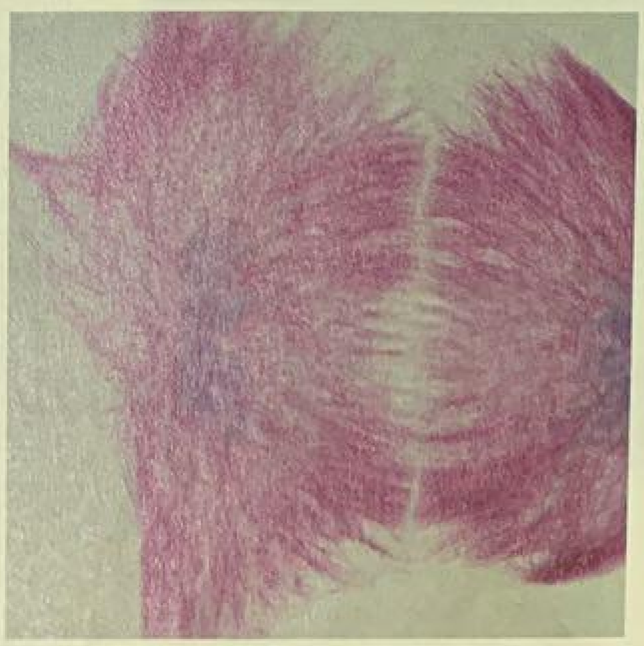


a.





c. Anaphase



d. Telophase