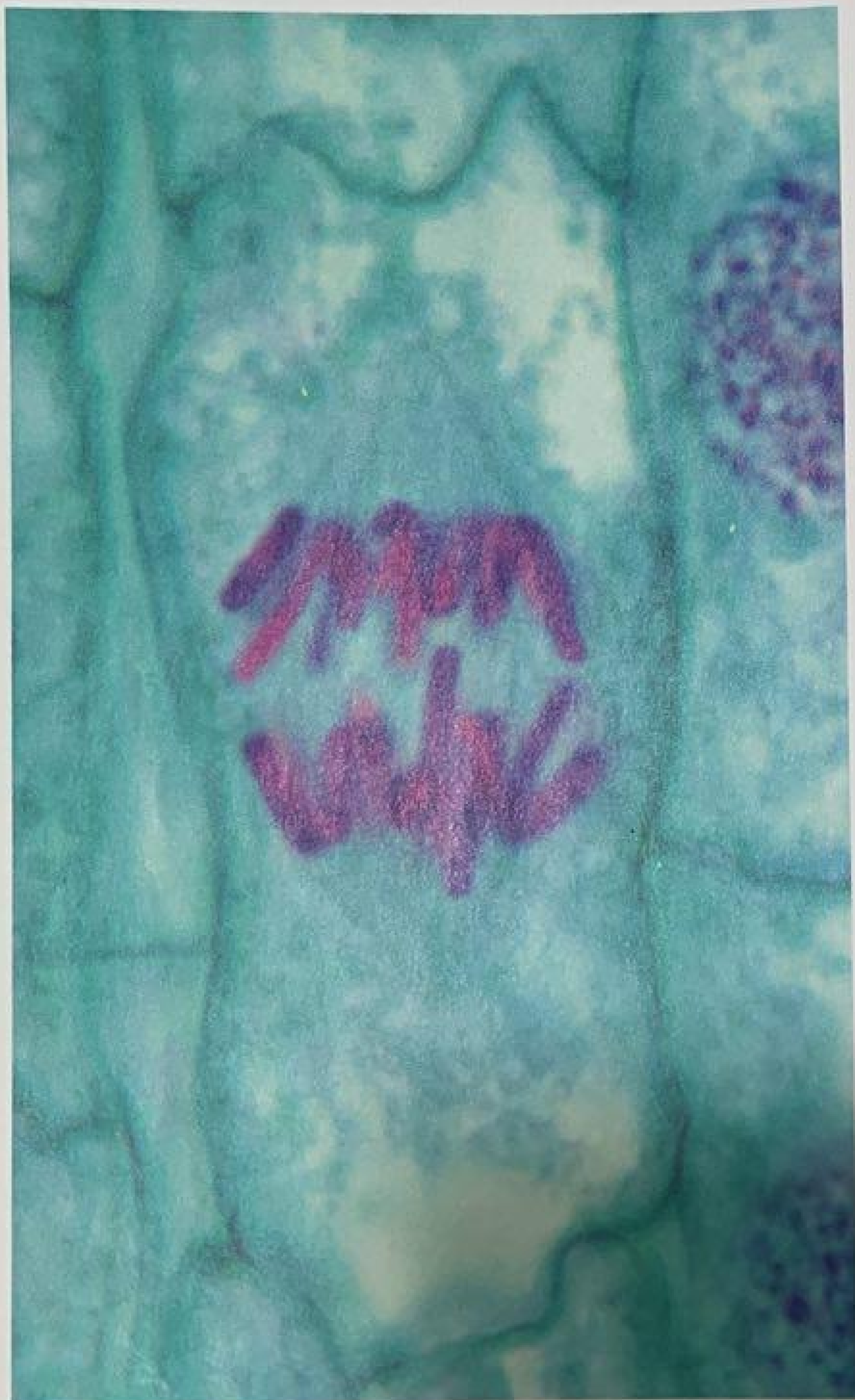
10

Cell Reproduction: Binary Fission and Mitosis

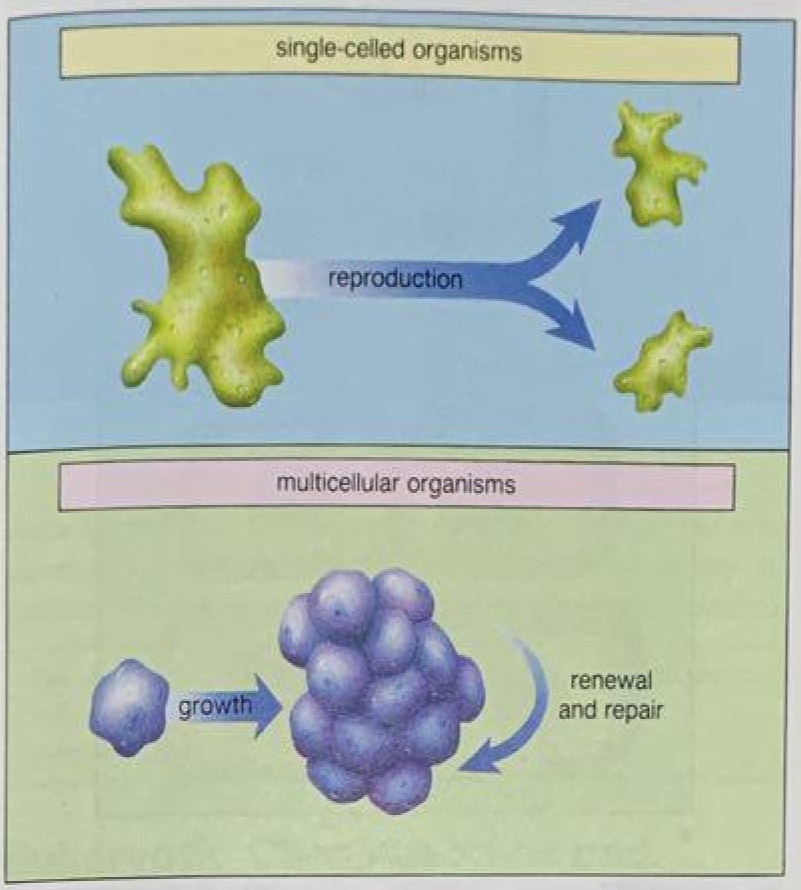


The mitotic spindle. During nuclear division, the chromosomes are attached to microtubules, which collectively assume the shape of a spindle. The spindle brings about the movement and distribution of a full set of daughter chromosomes to each of its poles.

Your study of this chapter will be complete when you can

1. relate binary fission and mitosis to the process of asexual reproduction among single-celled organisms and to growth and repair among multicellular forms;
2. list several benefits of binary fission and mitosis;
3. describe the prokaryotic chromosome and the process of binary fission;
4. describe a duplicated eukaryotic chromosome, and distinguish between the diploid and haploid number of chromosomes;
5. state the difference between chromatin and chromosome, and explain how they are related;
6. state the phases of the cell cycle, and describe what happens during each phase;
7. give evidence that the cell cycle is controlled, and contrast the behavior of normal cells with those of cancer cells;
8. draw a series of diagrams illustrating the stages of mitosis in animal cells, and tell what happens during each stage; describe cytokinesis in animal cells;
9. state at least one difference between animal and plant cell mitosis; describe cytokinesis in plant cells.

As we mentioned in the introductory chapter, the life cycle of all organisms includes reproduction. We have a tendency to think of reproduction in terms of multicellular organisms, even though reproduction always involves single cells. For example, all organisms begin life as a single cell—when that cell divides in single-celled organisms, it produces 2 new individuals that are like the parent. In other types of organisms, cell division is a part of the growth process that produces the multicellular form we recognize as the organism (fig. 10.1). Cell division is also important in multicellular forms for renewal and repair. For example, our own body is always producing new blood cells and skin cells to replace those that are worn out or damaged. In summary, then, simple cell division has these purposes:



Cell division occurs in single-celled organisms when they reproduce. Simple cell division is also involved in the growth and in the renewal and repair of multicellular forms.

Cells reproduce, and in that way new cells arise. In fact, new cells can only come from preexisting cells. This is a tenet of the cell theory we discussed on page 61. The organization of a cell is such that it is very unlikely that the coming together of biomolecules would spontaneously produce a new cell. Instead, only cell division produces new cells. Why can't a cell simply grow larger? What is the benefit of cell division in the first place? Recall that we previously considered these questions on page 65. A small cell has a more adequate plasma membrane-to-volume ratio than a large cell. Everything that enters and exits a cell must cross the plasma membrane, and as the cell increases in size, there comes a point when the plasma membrane surface area is not adequate to meet the needs of the cell. Cell division keeps the surface area-to-volume ratio favorable for the efficient survival of the cell.

Figure 10.1
Cell reproduction occurs in both single-celled organisms and in multicellular organisms. ***a.*** When a single-celled organism divides, reproduction occurs. This is a photograph of a paramecium dividing. Magnification, X200. ***b.*** Life begins as a single cell in multicellular organisms. When this cell divides, a multicellular organism results. This is a photograph of a slipper-shell mollusk embryo after only a single division has occurred. Magnification, X140.

a.

b.

> New cells only come from preexisting cells. When growing cells divide, they maintain a favorable surface area-to-volume relationship.

Another advantage of cell division that we have not considered previously concerns only multicellular organisms. Cell division allows cells to specialize for various functions, such as digestion, respiration, and excretion. Obviously, it would wreak havoc if these specialized cells didn't give rise to their own kind. In other words, intestinal cells give rise to intestinal cells, and kidney cells give rise to kidney cells. Another way that biologists like to say this is, "like begets like." By what mechanism does this occur? We have already considered that the nucleus, which contains the chromosomes, controls the cell. Cell division must have a way by which copies of the chromosomes are passed to newly formed cells. Indeed, this chapter is principally about the way in which copies of chromosomes are passed from parent cell to daughter cells so that the daughter cells receive a copy of each and every chromosome. In this way the daughter cells receive a complete copy of the genetic material, DNA.

> Cells always give rise to cells that are like themselves, that is, "like begets like." This occurs because the daughter cells receive a copy of the parent cell's genetic material.

Prokaryotic Chromosomes and Cell Division

Prokaryotic Chromosomes

Prokaryotes (i.e., bacteria) are single-celled organisms that lack a nucleus (p. 64). They have a single chromosome that is compacted into an electron-dense, irregularly shaped region called the **nucleoid,** which is not enclosed by a membrane. When stretched out, the chromosome is seen to be a circular loop attached to the inside of the plasma membrane. Its length may be about 500 times the length of the cell, which is why it needs to be compacted inside the cell.

The bacterial chromosome is not like the eukaryotic chromosome because it lacks associated proteins. It consists simply of the genetic material, DNA.

> The prokaryotic chromosome is a single loop of DNA that is compacted into a region called the nucleoid.

Cell Division

Cell division in prokaryotes is termed **binary fission** because division (fission) produces 2 (binary) daughter cells that are identical to the original parent cell. Before division takes place, the DNA is replicated so that there are 2 chromosomes attached to the inside of the plasma membrane. Following replication, the 2 chromosomes separate by an elongation of the cell that pushes the chromosomes apart. When the cell is approximately twice its original length, the plasma membrane grows inward and a cell wall forms, dividing the cell into 2 approximately equal portions (fig. 10.2).

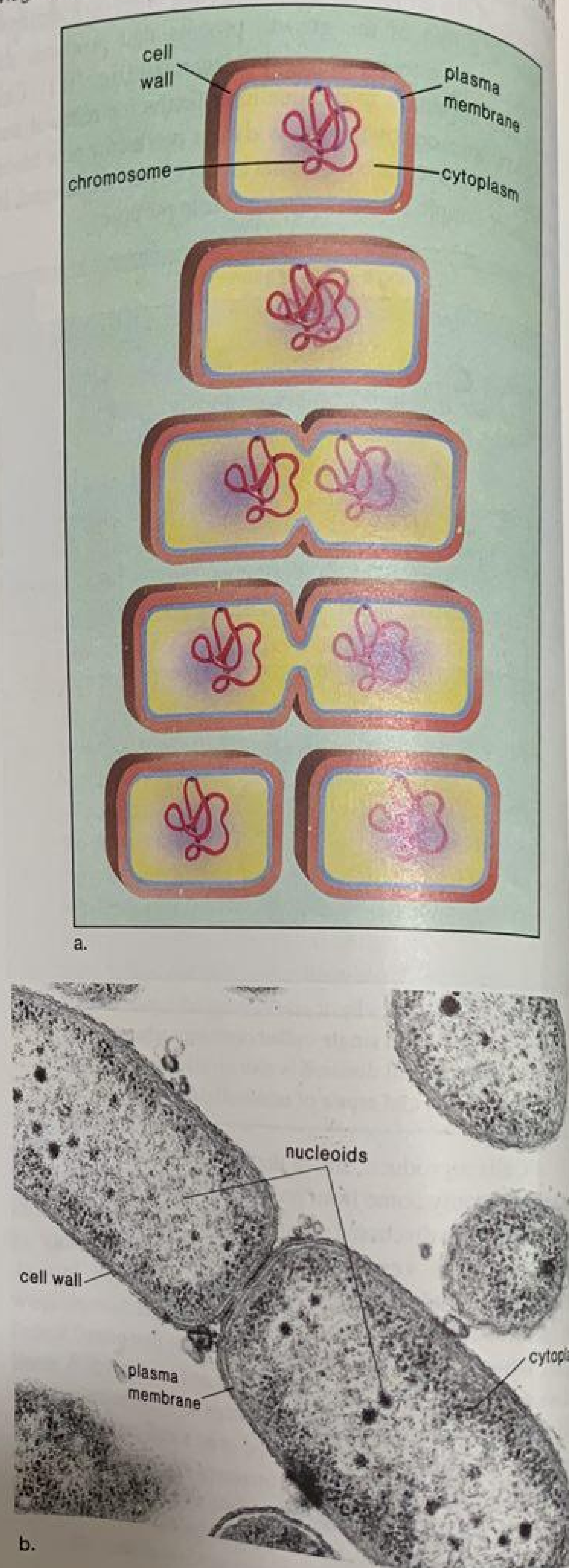


Figure 10.2
Binary fission in a prokaryote. ***a.*** The chromosome is a sing... DNA that is attached to the plasma membrane. After the DNA replicates and the cell divides, each daughter cell contains ... chromosome. ***b.*** Following division, each daughter cell has ... nucleoid, a region where the chromosome is compacted in the ... Magnification, X30,000.

Table 10.1
Diploid Chromosome Number of Some Eukaryotes

Type of Organism	Name of Organism	Chromosome Number
Fungi	*Aspergillus nidulans* (mold)	8
	Neurospora crassa (mold)	14
	Saccharomyces cerevisiae (yeast)	34
Plants	*Vicia faba* (broad bean)	12
	Zea mays (corn)	20
	Solanum tuberosum (potato)	48
	Nicotiana tabacum (tobacco)	48
Animals	*Felis domesticus* (cat)	38
	Equus caballus (horse)	64
	Gallus gallus (chicken)	78
	Pan troglodytes (chimp)	48
	Canis familiaris (dog)	78
	Rana pipiens (frog)	26
	Musca domestica (housefly)	12
	Homo sapiens (human)	46

Sometimes a prokaryotic cell has several nucleoids because several replications can be occurring at once. The third chromosome may begin at the site of the second, before the production of the second chromosome has even been completed.

Cell division in prokaryotes is by binary fission. DNA replicates before new plasma membrane and cell wall separate the cytoplasm.

Eukaryotic Chromosomes and Cell Division

Eukaryotic Chromosomes

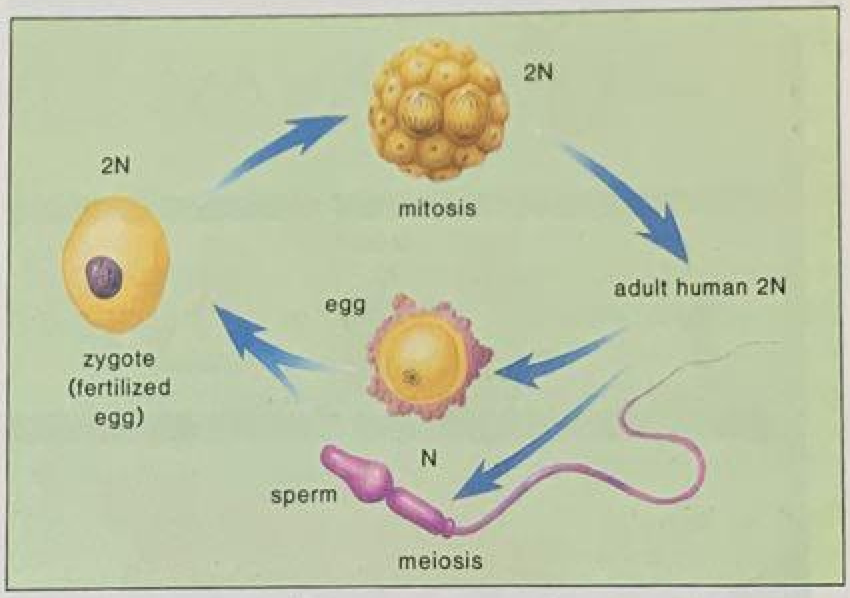
Eukaryotes have a true nucleus (see fig. 5.4) that is bounded by a double membrane called the nuclear envelope. The nuclear envelope contains pores that allow substances to pass between the nucleoplasm and the cytoplasm (see fig. 5.7). The DNA (and associated proteins) within a nucleus that is not undergoing division is a tangled mass of thin threads called **chromatin.** At the time of division, chromatin becomes highly coiled and condensed, and it is easy to see the individual **chromosomes.** The reading for this chapter describes the manner in which the coiling and condensation take place. In addition to chromatin, the nucleus contains at least one nucleolus that is attached to, and formed by, special regions of particular chromosomes. Recall that the nucleolus is involved in the production of ribosomes, which are found in the cytoplasm.

When the chromosomes are highly coiled and condensed at the time of cell division, it is possible to photograph and count them. Each species has a characteristic chromosome number (table 10.1); the chromosome number for humans is 46. This is called the full or **diploid (2N) number** of chromosomes that occurs in all cells of the body. The diploid number includes 2 chromosomes of each kind. Half the diploid number, called the **haploid (N) number** of chromosomes, contains only one of each kind of chromosome. In the life cycle of many animals only sperm and eggs have the haploid number of chromosomes.

Eukaryotic chromosomes are located within the nucleus of the cell.

Cell Division

Cell division in eukaryotes involves nuclear division and **cytokinesis,** which is division of the cytoplasm. The typical life cycle of animals includes 2 types of nuclear division:



Mitosis is nuclear division in which the chromosome number stays constant. A 2N nucleus divides to give daughter nuclei that are also 2N. Mitosis is the type of nuclear division that is involved in growth and in the repair of the body. **Meiosis** is nuclear division in which the chromosome number is halved. A 2N nucleus divides to give daughter nuclei that are N. Meiosis is the type of nuclear division involved in the production of **gametes,** the egg and sperm. When the sperm fertilizes the egg, the resulting zygote again has the 2N number of chromosomes.

Before nuclear division takes place, DNA replicates; therefore, each chromosome is duplicated and has 2 identical parts called **sister chromatids** (fig. 10.3). Sister chromatids are genetically identical; that is, they contain exactly the same genes. Sister chromatids are constricted and are attached to each other at a region called the **centromere.**

Nuclear division has 4 stages (prophase, metaphase, anaphase, and telophase), which will be considered in depth later in the chapter. During one of these stages, the centromeres divide, and in that way a duplicated chromosome gives rise to 2 daughter chromosomes. These chromosomes, which have only one chromatid, are distributed equally to the daughter cells. In this way, each daughter cell gets a complete copy of the organism's genetic material.

What's in a Chromosome?

When early investigators decided that the genes were on the chromosomes, they had no idea of chromosome composition. By the mid-1900s, it was known that chromosomes are made up of both DNA and protein. Only in recent years, however, have investigators been able to produce models suggesting how chromosomes are organized.

A eukaryotic chromosome is more than 50% protein of 2 types: histones and nonhistones. The nonhistone proteins are acidic (have negatively charged R groups) and are only loosely associated with DNA. The functions of the nonhistone proteins are being studied, and some are known to be regulators of gene activity. Much more is known about the histone proteins, which are basic (have positively charged R groups) and bind strongly to the negatively charged phosphate groups of DNA.

There are 5 different primary types of histone molecules designated H1, H2A, H2B, H3, and H4, and all 5 types are found in all tissues of an organism. Remarkably, the amino acid sequences of H3 and H4 vary little between organisms. For example, H4 of peas is only 2 amino acids different from H4 of cattle. This similarity suggests that mutations in the histone proteins have been selected against during the evolutionary process and that the histones therefore have very important functions.

A human cell contains 46 chromosomes, and the length of the DNA in each is about 5 cm on the average. Therefore, a human cell contains a m of DNA. Yet all of this DNA is pa a nucleus that is about 5 µm in d The histones are responsible for pa the DNA so that it can fit into such space. First the DNA double helix is at intervals around a core of 8 histo ecules (2 copies each of H2A, H2B, H H4), giving the appearance of a s beads (fig. 10.A*b*). Each bead is c nucleosome, and the nucleosomes to be joined by "linker" DNA. This coiled tightly into a fiber that has 6 n somes per turn (fig. 10.A*c*)—the H1 h appears to mediate this coiling proc fiber loops back and forth (fig. 10.A*d* and can condense to give a highly pacted form (fig. 10.A*f*) character metaphase chromosomes.

An interphase nucleus shows d stained chromatin regions called he chromatin and lightly stained chroma gions called euchromatin (fig. 10.B) erochromatin is genetically inactive 10.A*e*). The mechanism of inactivati unknown, but it may involve methyla (adding methyl groups—CH_3—to the b of DNA). Euchromatin is genetically a (fig. 10.A*c*). It's believed that in this the nucleosomes allow access to the D so that a gene can be turned on and actively dictate protein synthesis in the

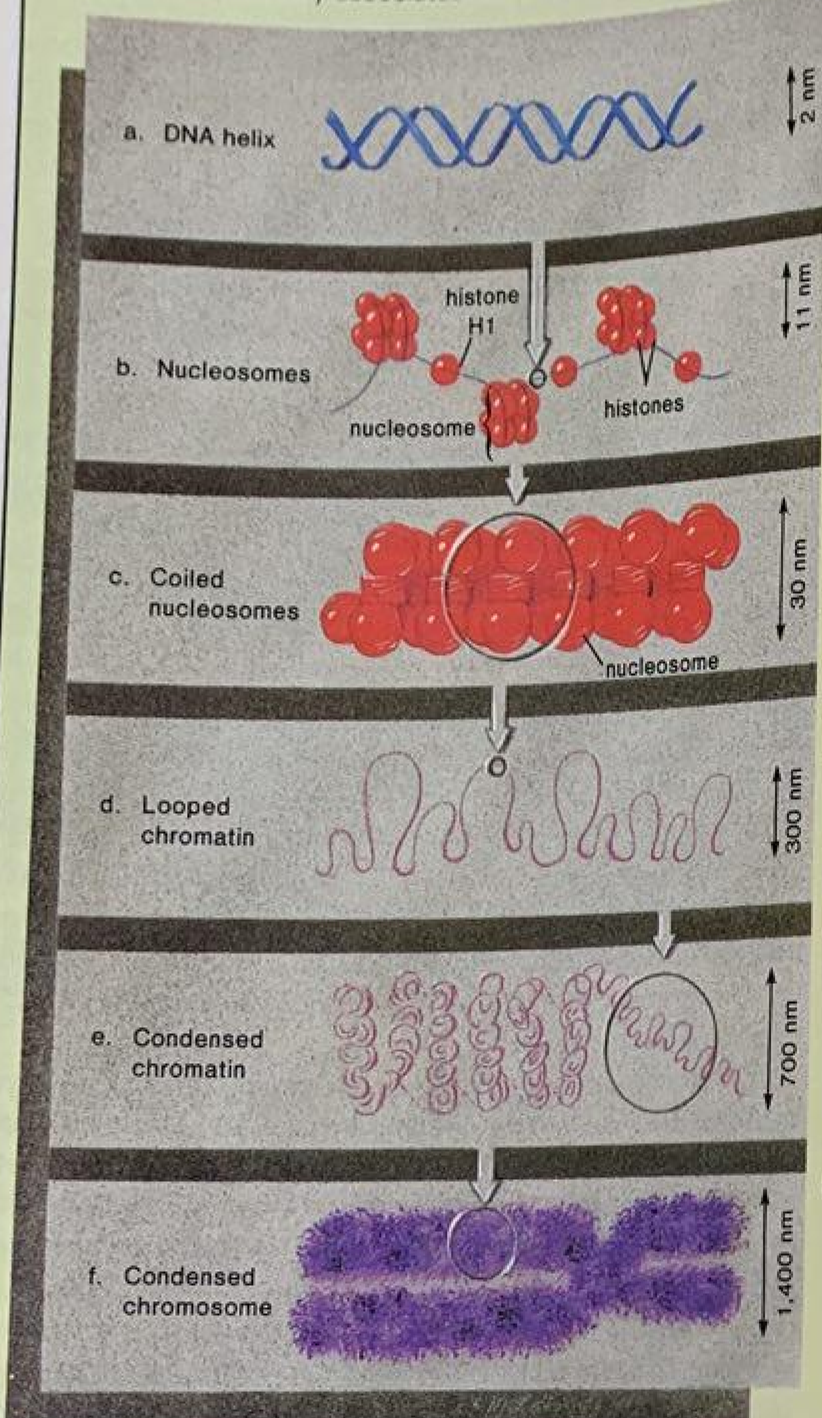


Figure 10.A
Levels of chromosome structure. Each drawing has a scale giving a measurement of length for that drawing. Notice each measurement represents an ever-increasing length; therefore, it would take a much higher magnification to see the structure in (*a*) compared to (*f*).

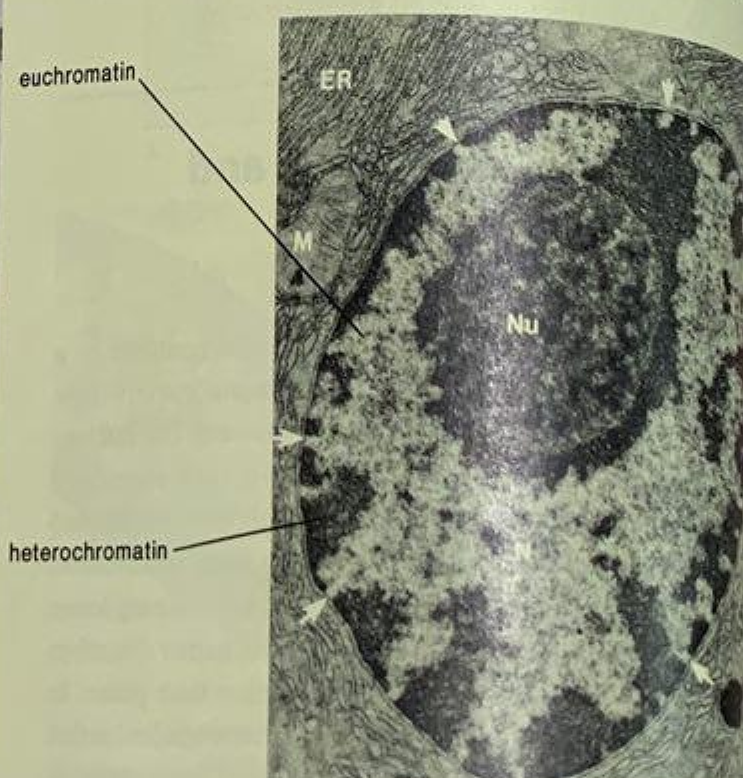


Figure 10.B
Eukaryotic nucleus. The nucleus contains chromatin, DNA at 2 different levels of coiling and condensation. Euchromatin is at the level of coiled nucleosomes (30 nm), and heterochromatin is at the level of condensed chromatin (700 nm). Arrows indicate nuclear pores. Magnification, X10,000.