11

Cell Reproduction: Meiosis

Sexual reproduction requires the production of gametes, the sperm and egg. A sperm is penetrating a layer of cells that surrounds the much larger egg in this scanning electron micrograph. Each sperm is tipped with an acrosome, a cap that opens to release an enzyme that slices through the coating of the egg. (The acrosome is colored mauve.) Magnification, X6,000.

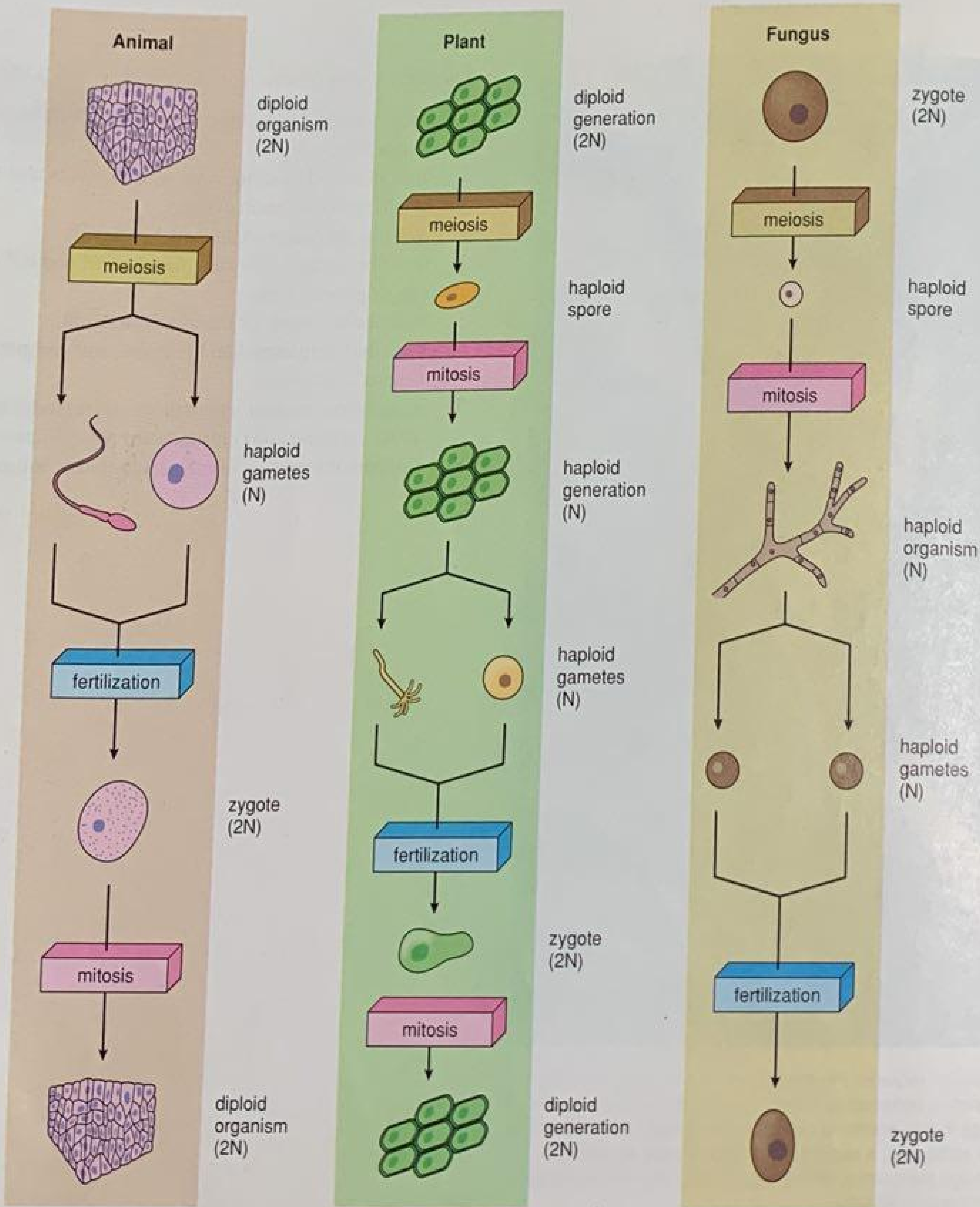
Your study of this chapter will be complete when you can

1. state in general the role of meiosis in plant, animal, and fungal life cycles;
2. give an overview of the process of meiosis and its stages, emphasizing the main events;
3. describe the stages of meiosis I in detail;
4. describe synapsis (bivalent formation), and tell how crossing-over occurs;
5. describe the stages of meiosis II in detail;
6. describe the mammalian life cycle, and compare spermatogenesis to oogenesis;
7. describe the manner in which sexual reproduction brings about variation and contributes to the evolutionary process;
8. compare the process of meiosis to that of mitosis.

Some organisms reproduce asexually, but on occasion even these also reproduce sexually. Both asexual and sexual reproduction support the cell theory because the new life begins as a single cell.

Gamete formation and fusion to form a zygote are integral parts of **sexual reproduction** (fig. 11.1). Obviously, if the gametes contained the same number of chromosomes as the body cells, the number of chromosomes would double with each new generation. Within a few generations the cells of the individual would be nothing but chromosomes! The early cytologists (biologists who study cells) realized this, and Pierre-Joseph van Beneden, a Belgian, was gratified to find in 1883 that the sperm and the egg of the worm *Ascaris* each contained only 2 chromosomes, while the cells of the embryo and the individual always have 4 chromosomes.

Figure 11.1
Life cycles of an animal, a plant, and a fungus. While meiosis always reduces the number of chromosomes, it occurs at a different point in each life cycle. Therefore, in animals, the haploid stage consists only of the gametes; in plants, there is both a diploid and haploid adult; in fungi, the adult is always haploid because the zygote undergoes meiosis.



Meiosis is the type of nuclear division that reduces the chromosome number from the diploid (2N) number to the haploid (N) number. Meiosis occurs at different points during the life cycle of various kinds of organisms (fig. 11.1). In animals, it occurs during the production of the gametes. In plants, meiosis produces spores that divide mitotically to become a haploid generation. It is this generation that produces the gametes. In fungi (and some algae) meiosis occurs directly after zygote formation, and the adult is always haploid. This haploid adult produces the gametes.

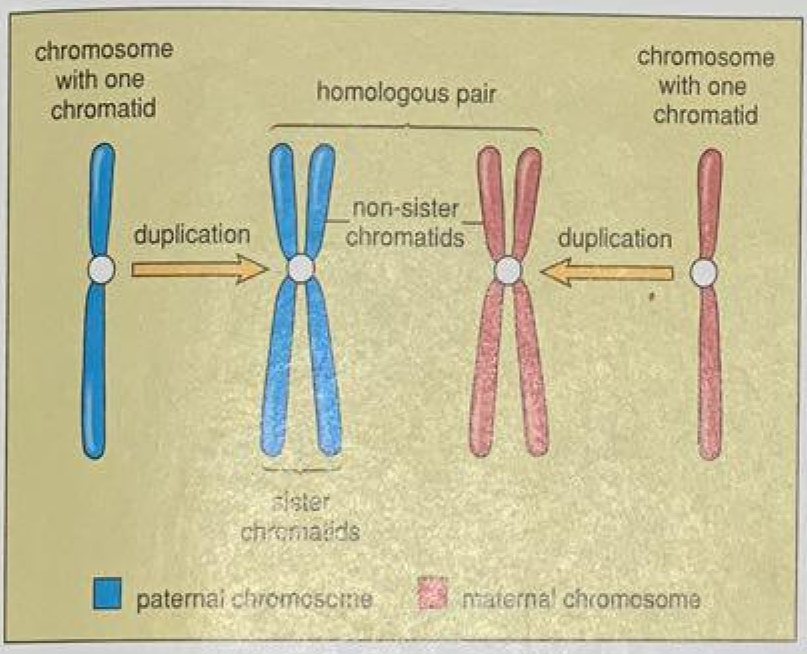
Notice in figure 11.1 that all 3 types of life cycles have both a diploid stage and a haploid stage. In animals, the adult is always diploid and the haploid stage consists only of the gametes. In plants, there is both a diploid adult and a haploid adult that produces the haploid gametes. In fungi (and some algae), the zygote is the only diploid stage and the adult, which is always haploid, produces the haploid gametes.

Meiosis is a special type of nuclear division that reduces the diploid (2N) number of chromosomes to the haploid (N) number of chromosomes. Meiosis occurs at different points in the life cycle of organisms.

Overview of Meiosis

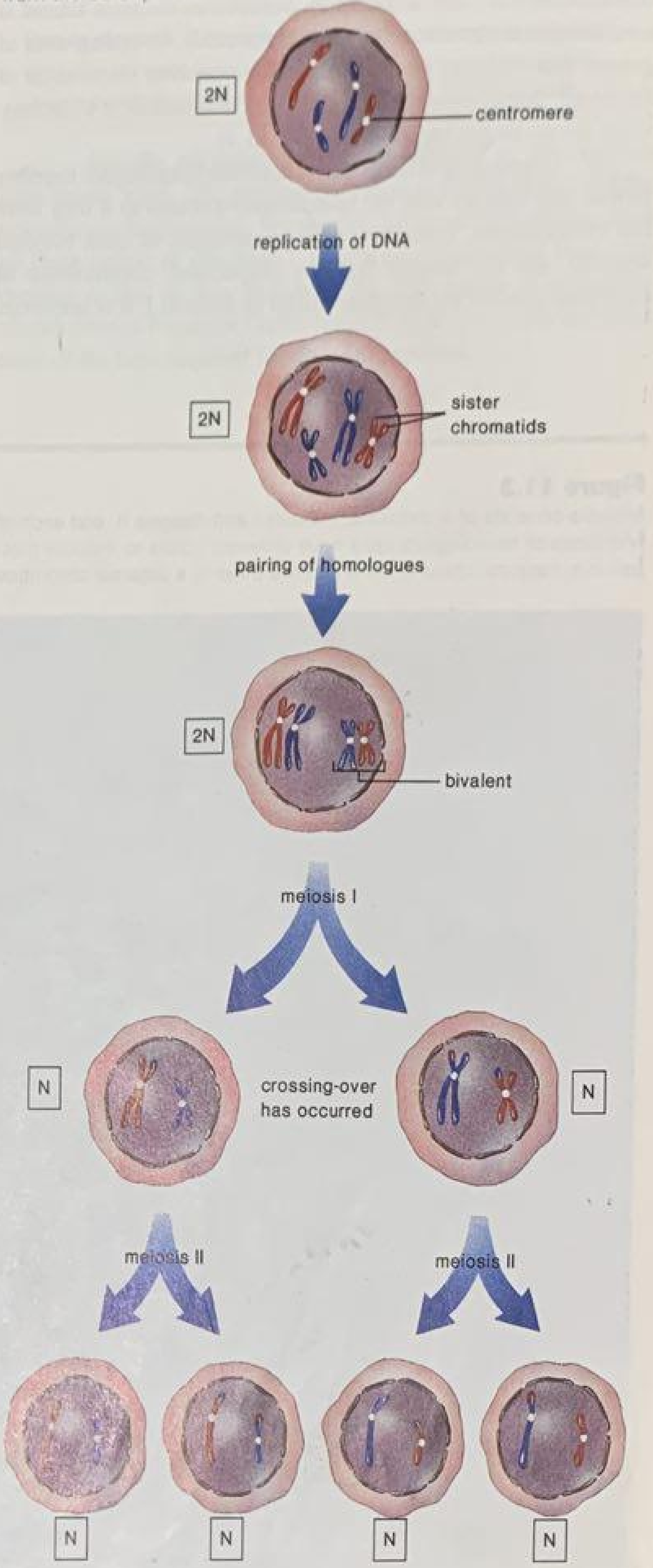
For the sake of simplicity, we presently will confine our discussion to meiosis in animals. Then, at the end of the chapter, we will discuss all 3 life cycles depicted in figure 11.1.

In a diploid cell, chromosomes come in pairs called **homologous chromosomes, or homologues.** Homologues are the same kind of chromosomes: they look alike, and they also carry genes for the same traits. One member of each pair was contributed by the male gamete, and the other was contributed by the female gamete:



Meiosis requires 2 nuclear divisions and produces 4 haploid daughter cells, each having one of each kind of chromosome and therefore half the total number of chromosomes present in the diploid parent nucleus. Figure 11.2 provides an overview of meiosis, indicating its 2 nuclear divisions, *meiosis I* and *meiosis II*.

Figure 11.2
Overview of meiosis. The number of chromosomes in each nucleus can be determined by counting the number of centromeres. Following meiosis I there are 2 haploid daughter cells; following meiosis II there are 4 haploid daughter cells. Notice that no 2 daughter cells are alike because of crossing-over. The blue chromosomes were inherited from one parent and the red chromosomes were inherited from the other parent.



Prior to meiosis, DNA replication has occurred; therefore, each chromosome has 2 sister chromatids. Meiosis I reduces the number of chromosomes, and meiosis II produces daughter chromosomes.

During meiosis I, something new happens that does not occur in mitosis. The homologues actually come together and pair, forming a so-called **bivalent.** It is a bivalent because there are 2 chromosomes in close association. Sometimes the term **tetrad** is used because the bivalent contains 4 chromatids. **Crossing-over** of genetic material may occur between the nonsister chromatids of the tetrad. Due to crossing-over, the sister chromatids of a chromosome are no longer identical (see fig. 11.4).

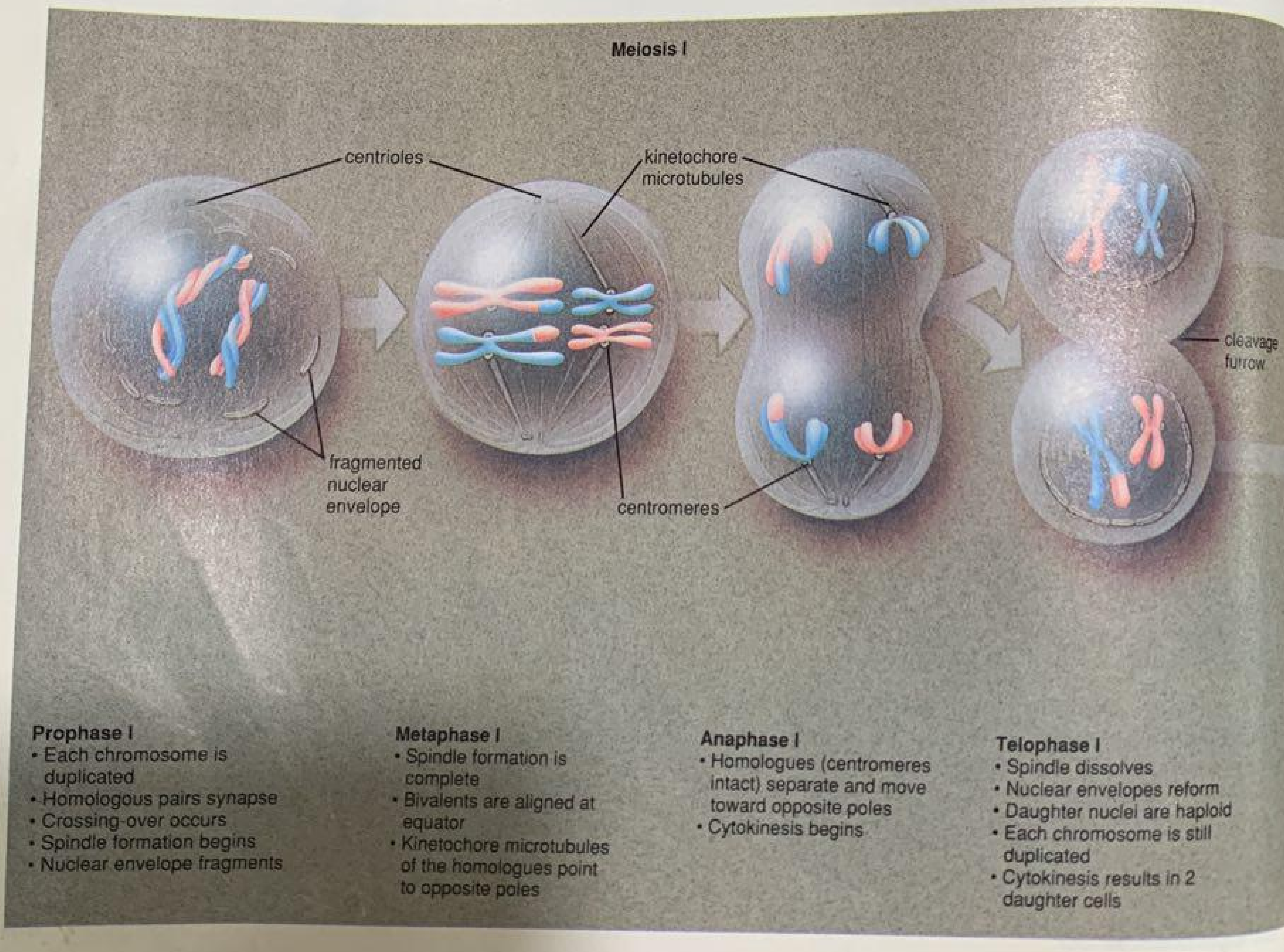
Crossing-over temporarily holds the homologues together so that they interact with the spindle microtubules as if they were one chromosome. Eventually, the homologues of each bivalent separate, and this assures that one (duplicated) chromosome of each kind reaches the daughter nuclei of meiosis I. It is important for daughter nuclei to have one member from each pair of homologous chromosomes because only in that way can there be one copy of each kind of gene in the daughter nuclei.

The separation process has no restrictions; either homologue of a homologous pair may occur in a daughter nucleus with either homologue of any other pair.

> Meiosis I is a form of nuclear division that results in cells that have only one copy of each kind of chromosome. Each homologous pair separates independently of all other pairs.

At the completion of meiosis I, the chromosomes in the daughter nuclei still consist of sister chromatids. Therefore, DNA replication does not occur between meiosis I and meiosis II. During meiosis II, the centromeres divide and a haploid set of daughter chromosomes moves toward each pole of the spindle. At the completion of meiosis II, there are 4 daughter cells, each with the haploid number of chromosomes.

Figure 11.3
Meiosis consists of 2 divisions, meiosis I and meiosis II, and each of these has 4 stages. Members of homologous pairs have different colors to indicate that one member of each pair is a maternal chromosome and the other is a paternal chromosome.



During meiosis II, the centromeres holding sister chromatids together divide and daughter chromosomes move toward each pole. At the completion of meiosis there are 4 daughter cells each with the haploid number of chromosomes.

Meiosis I

Meiosis I is divided into the same 4 stages as mitosis, but the prophase stage is much more complicated (fig. 11.3).

Prophase I

During prophase I, replication has already occurred and the chromosomes consist of sister chromatids held together at a centromere. Only because of replication will there be tetrads permitting crossing-over between the nonsister chromosomes.

Before crossing-over occurs, each one of these duplicated but still extended chromosomes begins to pair with its homologue. During this process, called **synapsis,** the homologues line up side by side, and a nucleoprotein lattice (called the synaptomenal complex) appears between them (fig. 11.4). This lattice holds the members of a bivalent together in such a way that the DNA of the nonsister chromatids is aligned. Now crossing-over, an exchange of genetic material between nonsister chromatids, can occur. The lattice then begins to break down, and the homologues begin to move apart, but not too far apart because they are held together by **chiasmata** (chiasma sing.), regions where the nonsister chromatids are still attached due to crossing-over (fig. 11.5).

During prophase I, synapsis occurs and a nucleoprotein lattice develops between homologues. This close association assists crossing-over between nonsister chromatids of the bivalent.

Spindle microtubules begin to appear as the centriole pairs move apart. The nuclear envelope is fragmenting, and the nucleolus is disappearing. We should also mention that throughout all these events of prophase I, the chromosomes have been condensing so that by now they have the appearance of metaphase chromosomes. Prophase I is the longest stage of meiosis and takes most of the time required for the entire process.