UNIT 2 CHAPTER 9

Sexual Reproduction and Meiosis

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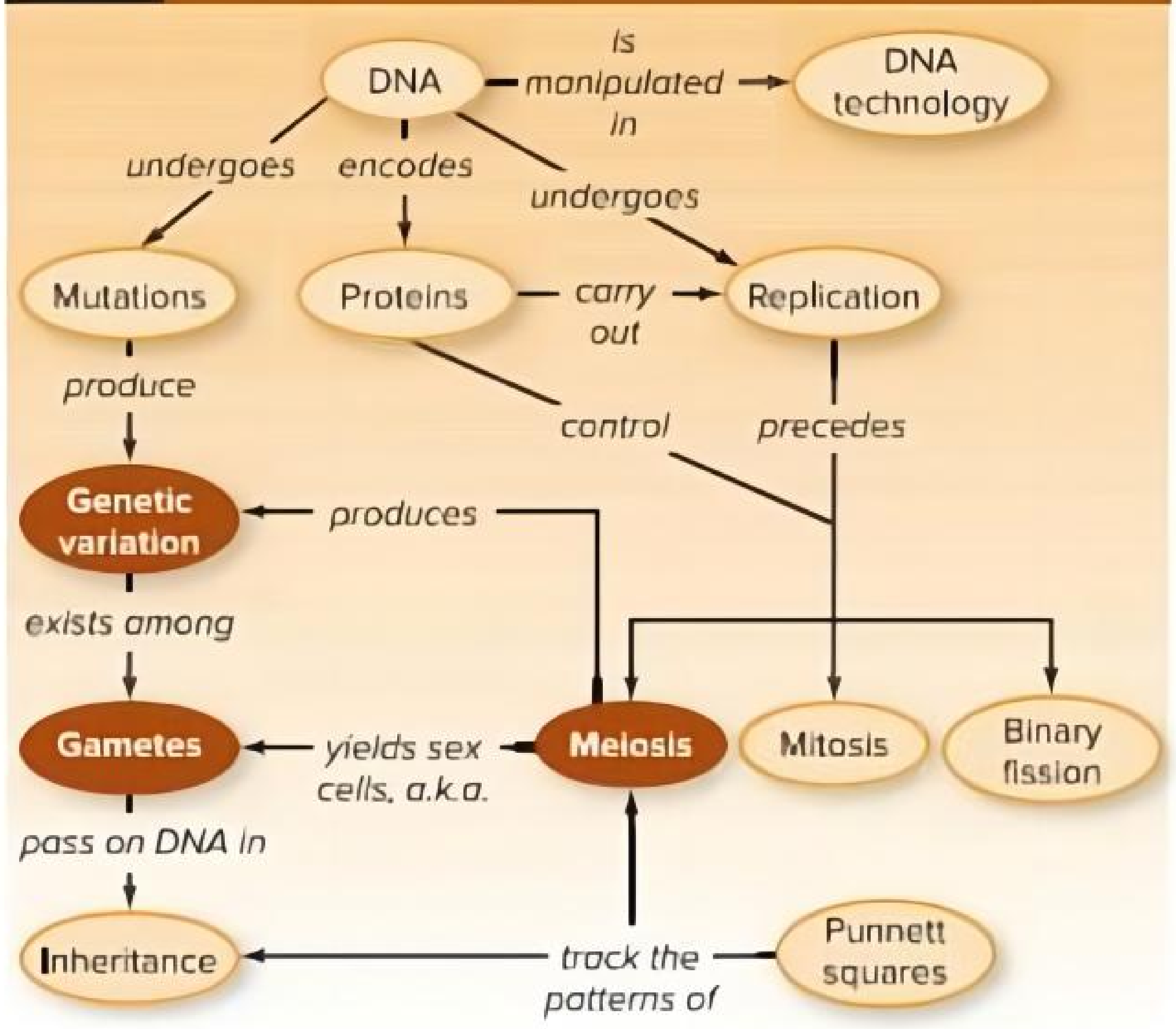
LEARNING OUTLINE (Chapter 9)

- 9.1 Why Sex?
- 9.2 Diploid Cells Contain Two Homologous Sets of Chromosomes
- 9.3 Meiosis Is Essential in Sexual Reproduction
- 9.4 In Meiosis,DNA Replicates Once,but the Nudeus Divides Twice
- 9.5 Meiosis Generates Enormous Variability
- 9.6 Mitosis and Meiosis Have Different Functions:A Summary
- 9.7 Errors Sometimes Occur in Meiosis

SURVEY THE LANDSCAPE
DNA, Inheritance, and Biotechnology



9.1 Why Sex?

- In fact, reproduction occurs in two main forms: asexual and sexual. In **asexual reproduction**, an organism **simply copies** its DNA and splits the contents of one cell into two. Some genetic material may mutate during DNA replication, but the offspring are virtually identical. Examples of asexual organisms include bacteria, archaea, and single-celled eukaryotes such. Many plants, fungi, and other multicellular organisms also reproduce asexually.

- **Sexual reproduction**, in contrast, requires two parents. The male parent contributes sperm cells, one of which fertilizes a female's egg cell to begin the next generation. Each time the male produces sperm, he scrambles the genetic information that he inherited from his own parents. A similar process occurs as the female produces eggs. The resulting variation among sex cells ensures that the offspring from two parents are genetically different from one another.

9.1 Why Sex?

- How did sexual reproduction evolve? Clues emerge from studies of reproduction and genetic exchange in diverse organisms. The earliest process that combines genes from two individuals appeared about 3.5 billion years ago. In conjugation, one bacterial cell uses an outgrowth called a sex pilus（菌毛） to transfer genetic material to another bacterium. This ancient form of bacterial gene transfer is still prevalent today.
- Attracting mates takes a lot of energy, as does producing and dispersing sperm and egg cells. Why does such a costly method of reproducing persist, and why is asexual reproduction comparatively rare?
- The mass production of identical offspring makes sense in habitats that never change, but conditions rarely remain constant in the real. Genetic variability increases the chance that at least some individuals will have a combination of traits that allows them to survive and reproduce, even if some poorly suited individuals die. **Asexual reproduction typically cannot create or maintain this genetic diversity, but sexual reproduction can.**

9.2 Diploid Cells Contain Two Homologous Sets of Chromosomes

- A sexually reproducing organism consists mostly of **diploid**(二倍体) cells (abbreviated 2n), which contain two full sets of chromosomes; one set is inherited from each parent. Each diploid human cell, for example, contains 46. Notice that the 46 chromosomes are arranged in 23 pairs; the mother and the father each contributed one member of each pair.
- Of the 23 chromosome pairs in a human cell,22 pairs consist of **autosomes(常染色体)**—chromosomes that are the same for both sexes. The remaining pair is made up of the two **sex chromosomes**, which determine whether an individual is female or male. Females have two X chromosomes, whereas males have one X and one Y chromosome.

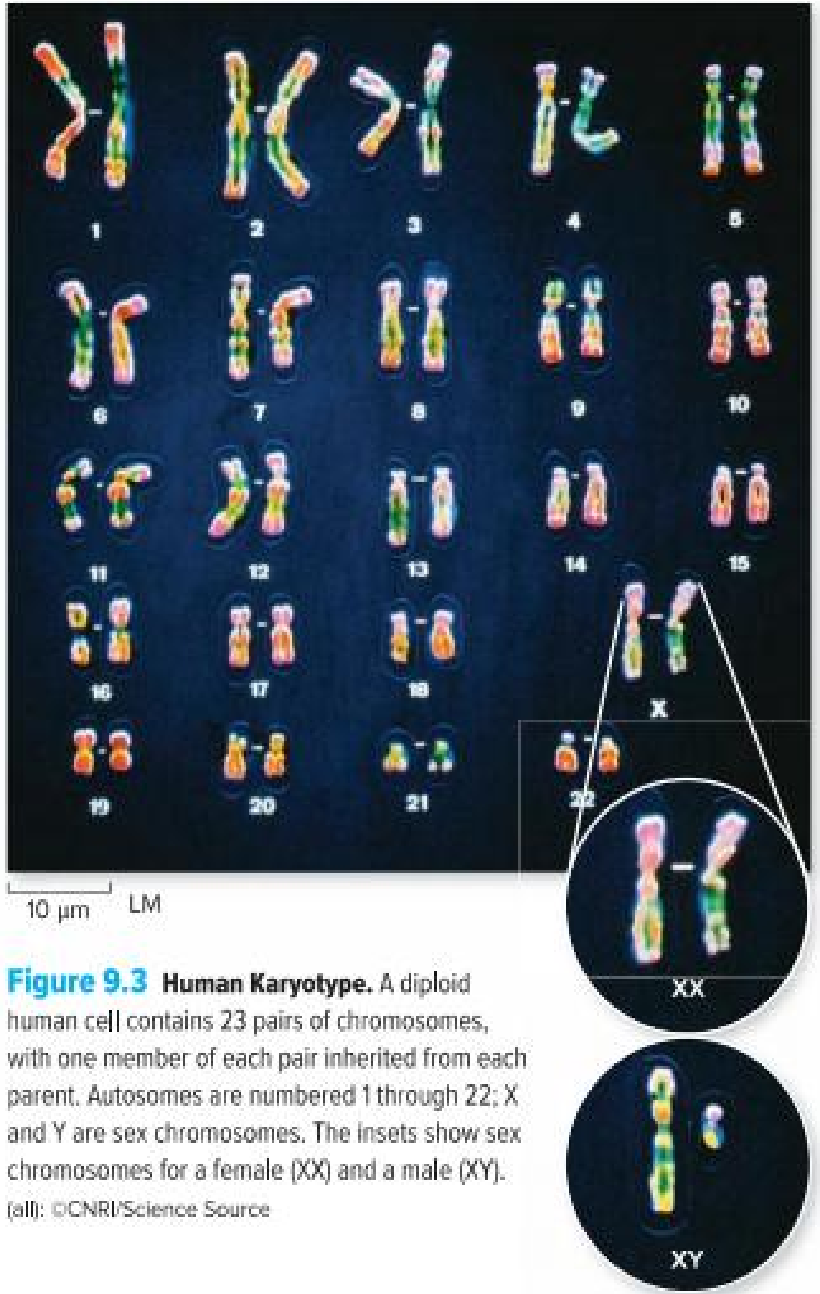


Figure 9.3 Human Karyotype. A diploid human cell contains 23 pairs of chromosomes, with one member of each pair inherited from each parent. Autosomes are numbered 1 through 22; X and Y are sex chromosomes. The insets show sex chromosomes for a female (XX) and a male (XY). (all): ©CNRI/Science Source

9.2 Diploid Cells Contain Two Homologous Sets of Chromosomes

- **Homologous chromosomes**(同源染色体)are not identical—after all, nobody has two identical parents! Instead the two homologs differ in the combination of alleles, or versions, of the genes they. Each allele of a gene encodes a different version of the same protein. A chromosome typically carries exactly one allele of each gene, so a person inherits one allele per gene from each parent. Depending on the parents chromosomes, the two alleles may be identical or different. Overall, however, the members of each homologous pair of chromosomes are at least slightly different from each other.
- Unlike the autosome pairs, the X and Y chromosomes are not homologous to each other. X is much larger than Y,and its genes are completely

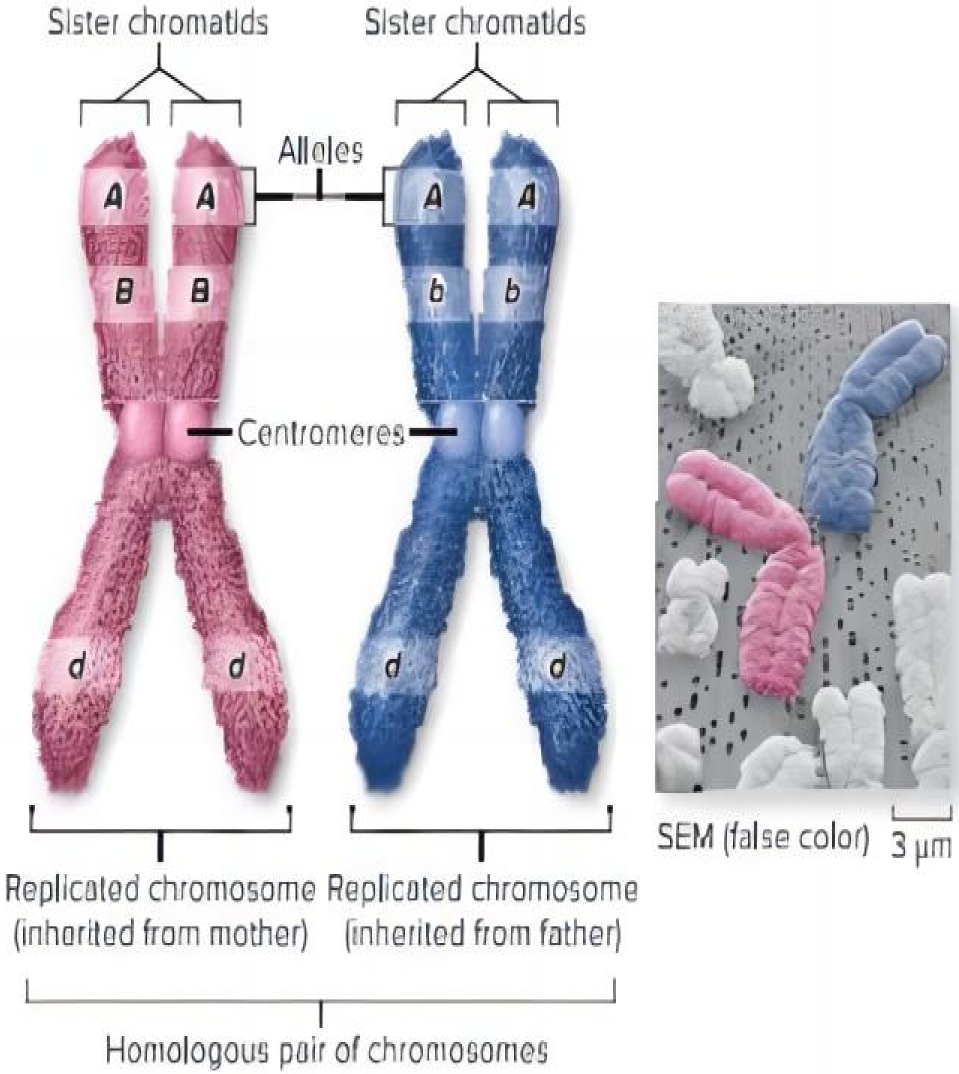


Figure 9.4 Homologous Pair. On these chromosomes, both alleles for gene *A* are the same, as are those for gene *D*. The two alleles for gene *B*, however, are different.

9.3 Meiosis Is Essential in Sexual Reproduction

- Sexually reproducing species range from humans to ferns(蕨类) to the mold(霉菌) that grows on bread.

A. Gametes Are Haploid Sex Cells (单倍体性细胞)

- Sexual reproduction poses a practical problem: maintaining the correct chromosome number. The most cells in the human body contain 46 chromosomes. If a baby arises from the union of a man‘s sperm and a woman’s egg, then why does the child not have 92 chromosomes per cell (46 from each parent)?And shouldn't cells in the next generation have184 chromosomes?

- In fact, **the chromosome number does not double with each generation**. The explanation is that sperm cells and egg cells are not diploid. Rather, they are haploid cells (abbreviated n):that is, they contain only one full set of genetic information instead of the two sets that characterize diploid cells.

9.3 Meiosis Is Essential in Sexual Reproduction

- These haploid cells, called gametes, are sex cells that combine to form a new offspring. Fertilization merges the gametes from two parents, creating a new cell: **the diploid zygote**(二倍体合子), which is the first cell of the new organism. The zygote has two full sets of chromosomes , one set from each parent. In most species, including plants and animals, the zygote begins dividing mitotically shortly after fertilization.
- Thus , the life of a sexually reproducing, multicellular organism requires two ways to package DNA into new cells. **Mitosis,** divides a eukaryotic cell's chromosomes into two identical daughter nuclei. Mitotic cell division produces the cells needed for growth development and tissue repair. **Meiosis ,** forms genetically variable nuclei, each containing half as many chromosomes as the organism's diploid cells.

9.3 Meiosis Is Essential in Sexual Reproduction

B. Specialized Germ Cells（生殖细胞） Undergo Meiosis

- **Only germ cells can undergo meiosis.** In humans and other animals, these specialized diploid cells occur only in the ovaries and testes（卵巢和睾丸）. Plants don't have the same reproductive organs as animals, but they do have specialized gamete-producing cells in flowers and other reproductive parts, such as pistils and stamens.
- The rest of the body‘s diploid cells, called somatic cells(体细胞), do not participate directly in reproduction. （Leaf cells, root cells, skin cells, muscle cells, and neurons） **Most somatic cells can divide mitotically, but they do not undergo meiosis**.
- At the beginning of human’s life cycle, we were a one-celled zygote with 46 chromosomes. That first cell then began dividing, generating identical copies of itself to form an embryo（胚胎）, then a fetus（胎儿）, an infant, a child, and eventually an adult. **Gametes are the only haploid cells in our life cycle; all other cells are diploid**. Sexual reproduction, however, can take many other forms as well. In some organisms, including plants, both the haploid and the diploid stages are multicellular.

9.3 Meiosis Is Essential in Sexual Reproduction

C. Meiosis Halves（减半） the Chromosome Number and Scrambles(扰乱) Alleles

- No matter the species, meiosis has two main outcomes, First, **the resulting gametes contain half as many chromosomes as the rest of the body's cells.** They therefore ensure that the chromosome number does not double with every generation. The second function of meiosis is **to scramble genetic information**, so that two parents can generate offspring that are genetically different from the parents and from one another. **Genetic variability is one of the evolutionary advantages of sexual reproduction**.
- Although meiosis has unique functions, many of the events are similar to those of mitosis. Similarly, **interphase（间期）** occurs just before meiosis; the names of the phases of meiosis are similar to those in mitosis; and cytokinesis occurs after the genetic material is distributed.
- Despite these similarities, meiosis has two unique outcomes. First, **meiosis includes two divisions(两次分裂), which create four haploid cells from one specialized diploid cell**. Second, meiosis shuffles genetic information, **setting the stage for each haploid nucleus to receive a unique mixture of alleles**.

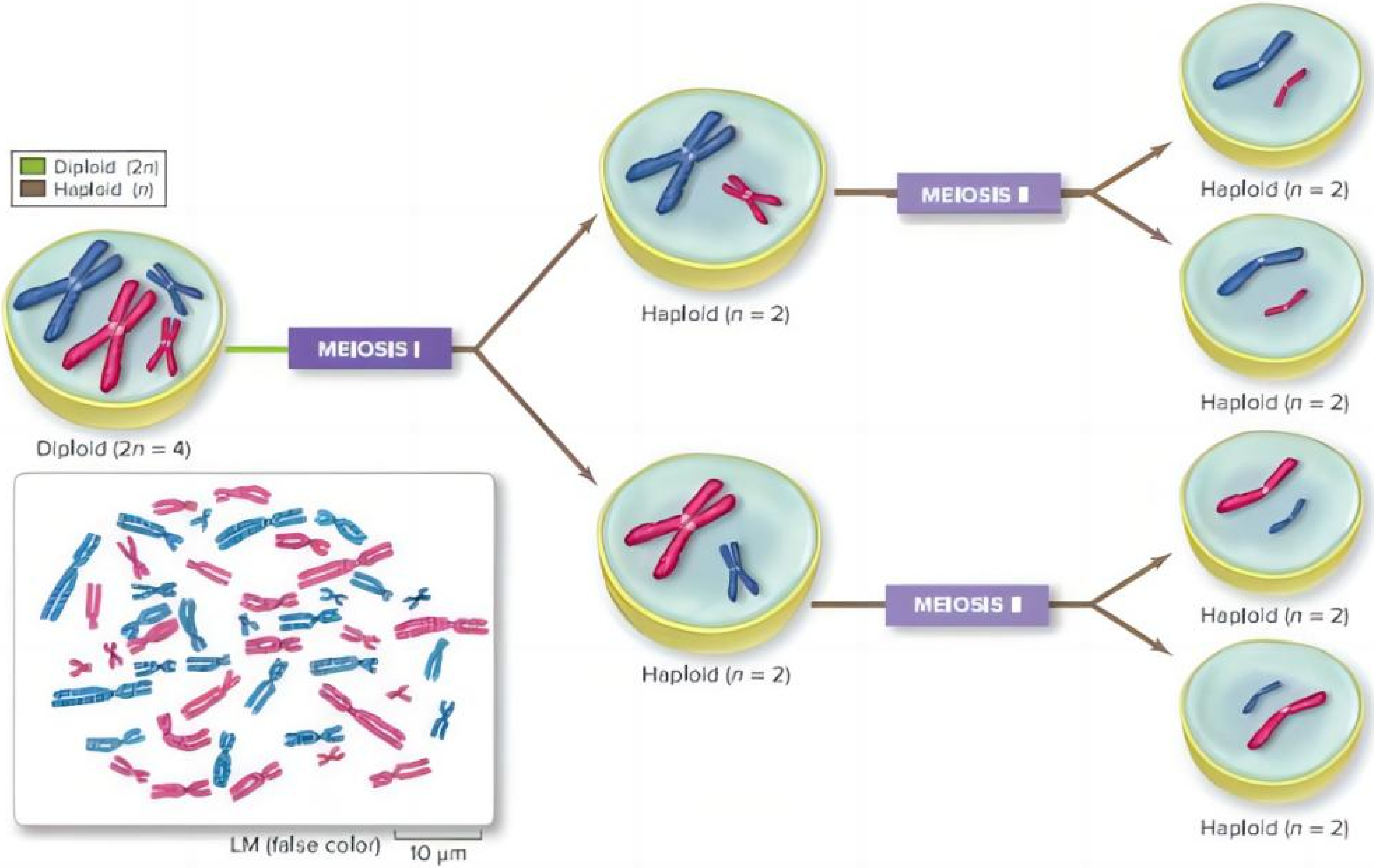


Figure 9.6 Summary of Meiosis. In meiosis, a diploid nucleus gives rise to four haploid nuclei with a mix of chromosomes from each parent. This illustration summarizes meiosis for a nucleus containing 4 chromosomes (2 homologous pairs). A diploid human cell, however, contains 46 chromosomes (23 homologous pairs, as shown in the inset).

Figure It Out

- A type of fish called a carp has gametes containing 52 chromosomes. How many chromosomes are in a carp's somatic cells?’

9.4 In Meiosis,DNA Replicates Once,but the Nudeus Divides Twice

- Before meiosis occurs, a diploid cell first undergoes interphase. The cell grows during interphase and produces many proteins, including those required for DNA replication. After all of the cell‘s DNA is copied, each chromosome consists of two identical sister chromatids(染色单体) attached at a centromere（着丝粒）. Finally, toward the end of interphase, the cell continues to grow and produce the enzymes and other proteins necessary to divide the cell.
- The cell is now ready for meiosis to begin. During meiosis I each chromosome physically aligns with its homolog（同源物）. The homologous pairs split into two nuclei toward the end of meiosis I. Meiosis II then partitions the genetic material into four haploid nuclei.

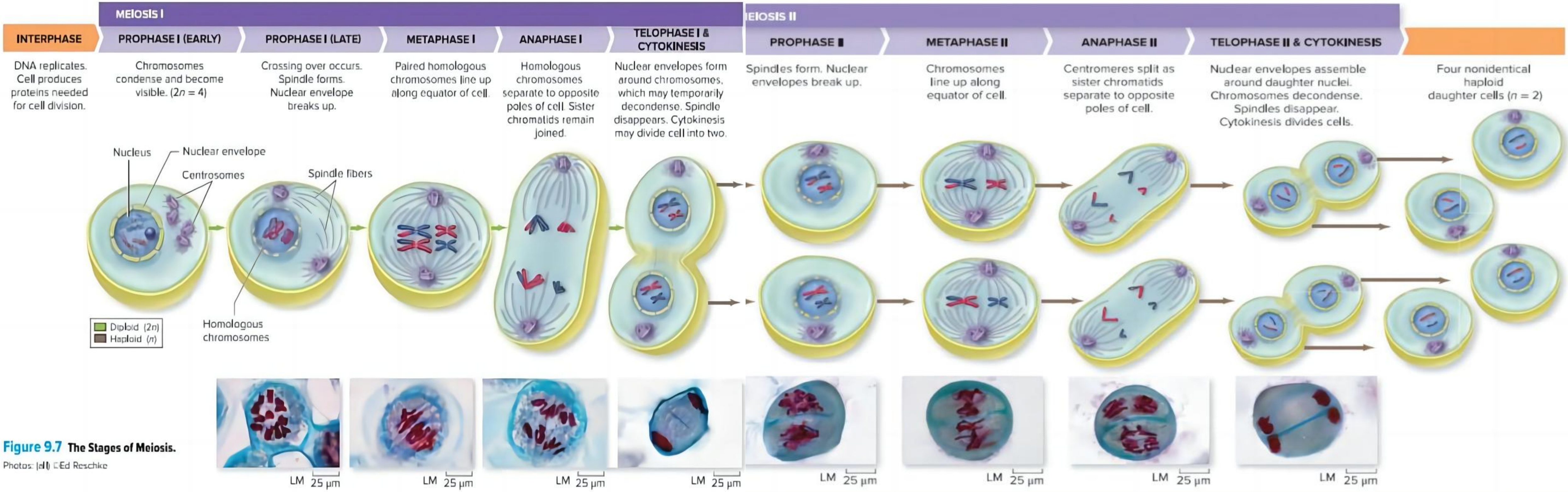


Figure 9.7 The Stages of Meiosis.

Photos: (all) ©Ed Reschke

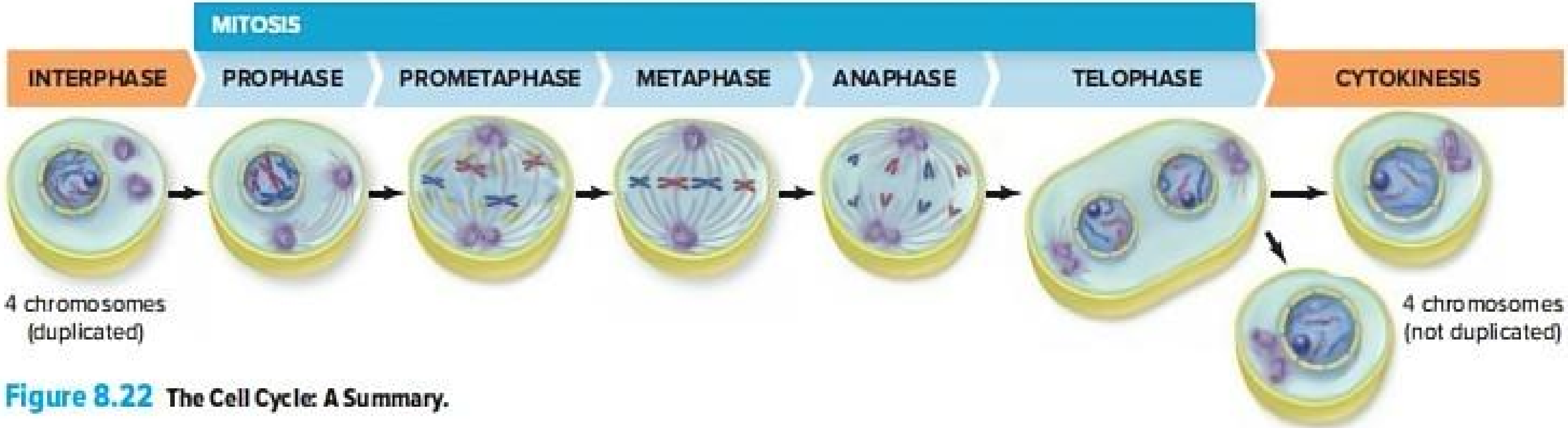


Figure 8.22 The Cell Cycle: A Summary.

9.4 In Meiosis,DNA Replicates Once,but the Nudeus Divides Twice

A. In Meiosis I, Homologous Chromosomes Pair Up and Separate

- Homologous pairs of chromosomes find each other and then split up during the first meiotic division.

- **Prophase I :** During prophase I, the replicated chromosomes condense. A spindle begins to form from microtubules(微管)assembled at the centrosomes(着丝粒), and spindle attachment points called kinetochores(着丝点)grow on each centromere. Meanwhile, the nuclear envelope(核膜)breaks up; once it is gone, the spindle fibers can reach the chromosomes. The events described so far resemble those of prophase of mitosis, but something unique happens during prophase I of meiosis: **The homologous chromosomes line up next to one another.**

- **Metaphase I:** In metaphase I, the spindle arranges the paired homologs down the center "equator“ of the cell. Each member of a homologous pair attaches to a spindle fiber stretching to one pole. The stage is therefore set for the homologous pairs to be separated.

- **Anaphase I**, **Telophase I and Cytokinesis :** Spindle fibers pull the homologous pairs apart in anaphase I, although the sister chromatids that make up each chromosome remain joined The chromosomes complete their movement to opposite poles in telophase I. Cytokinesis typically occurs after telophase I, splitting the original cell into 2.

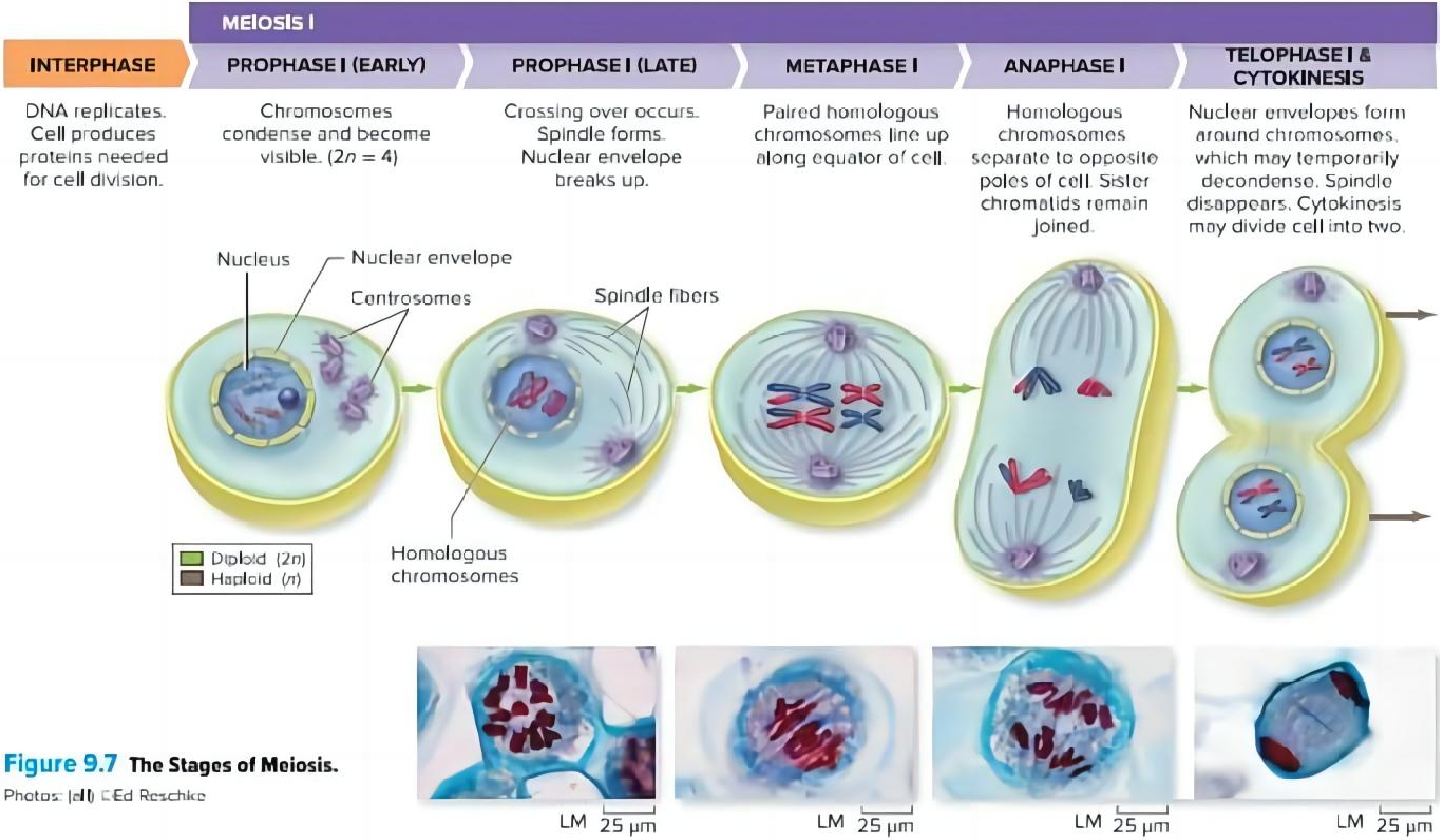


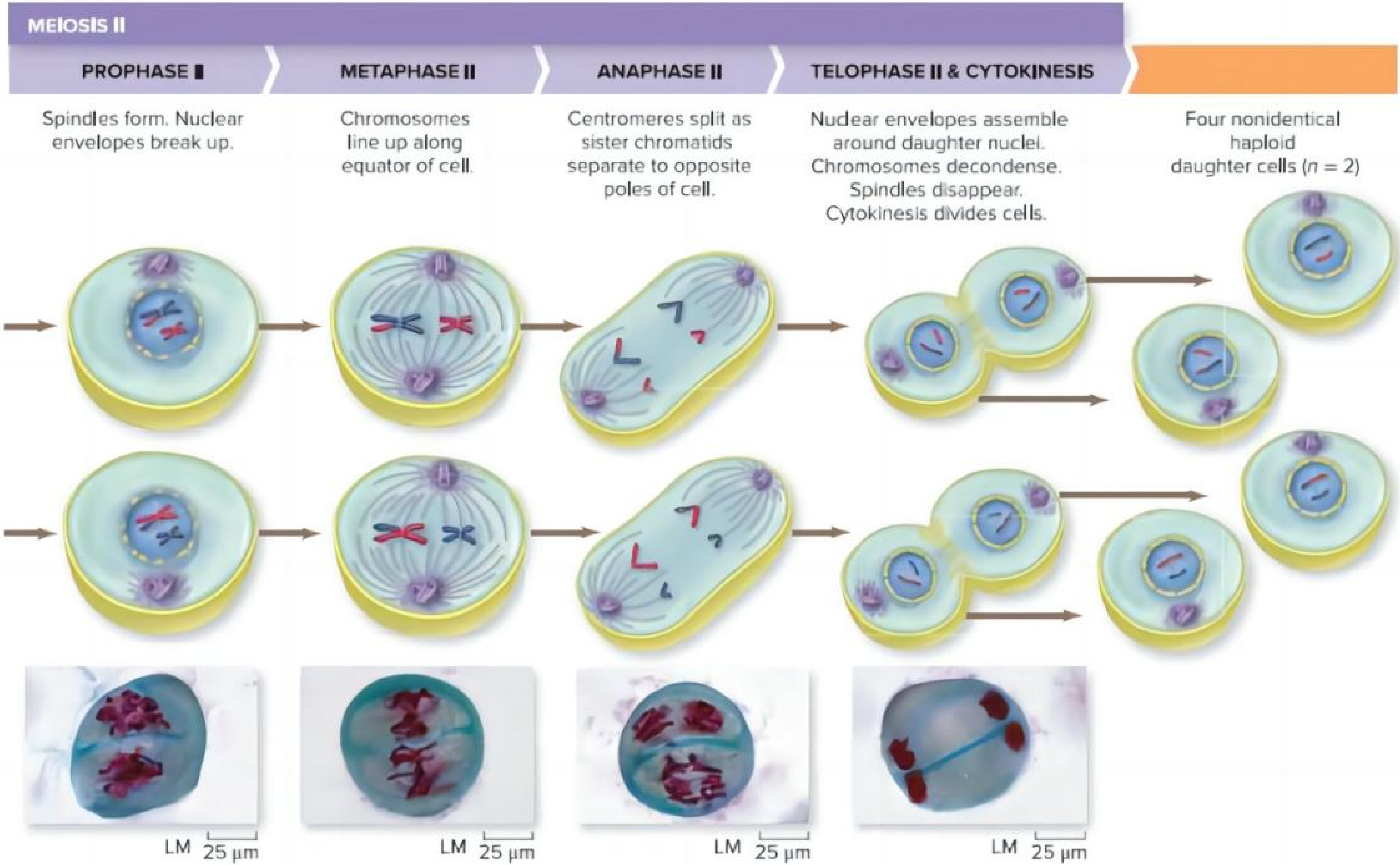
Figure 9.7 **The Stages of Meiosis.**

Photos: (all) ©Ed Reschke

9.4 In Meiosis,DNA Replicates Once,but the Nudeus Divides Twice

B.Meiosis Ⅱ Yields Four Haploid Nuclei

- A second interphase precedes meiosis II in many species. During this time, the chromosomes unfold into very thin threads. The cell produces proteins, but the DNA does not replicate a second time.
- Meiosis II strongly resembles mitosis. The process begins with prophase II, when the chromosomes again condense and become visible. In metaphase II, the spindle arranges the chromosomes down the center of each cell. In anaphase II, the centromeres split, and the separated sister chromatids move to opposite poles. In telophase II, nuclear envelopes form around the separated sets of chromosomes. Cytokinesis then separates the nuclei into individual cells. The overall result**: One diploid cell has divided into four haploid cells.**


MEIOSIS II
PROPHASE II
METAPHASE II
ANAPHASE II
TELOPHASE II & CYTOKINESIS
Spindles form. Nuclear envelopes break up.
Chromosomes line up along equator of cell.
Centromeres split as sister chromatids separate to opposite poles of cell.
Nuclear envelopes assemble around daughter nuclei. Chromosomes decondense. Spindles disappear. Cytokinesis divides cells.
Four nonidentical haploid daughter cells ($n = 2$)
LM 25 µm
LM 25 µm
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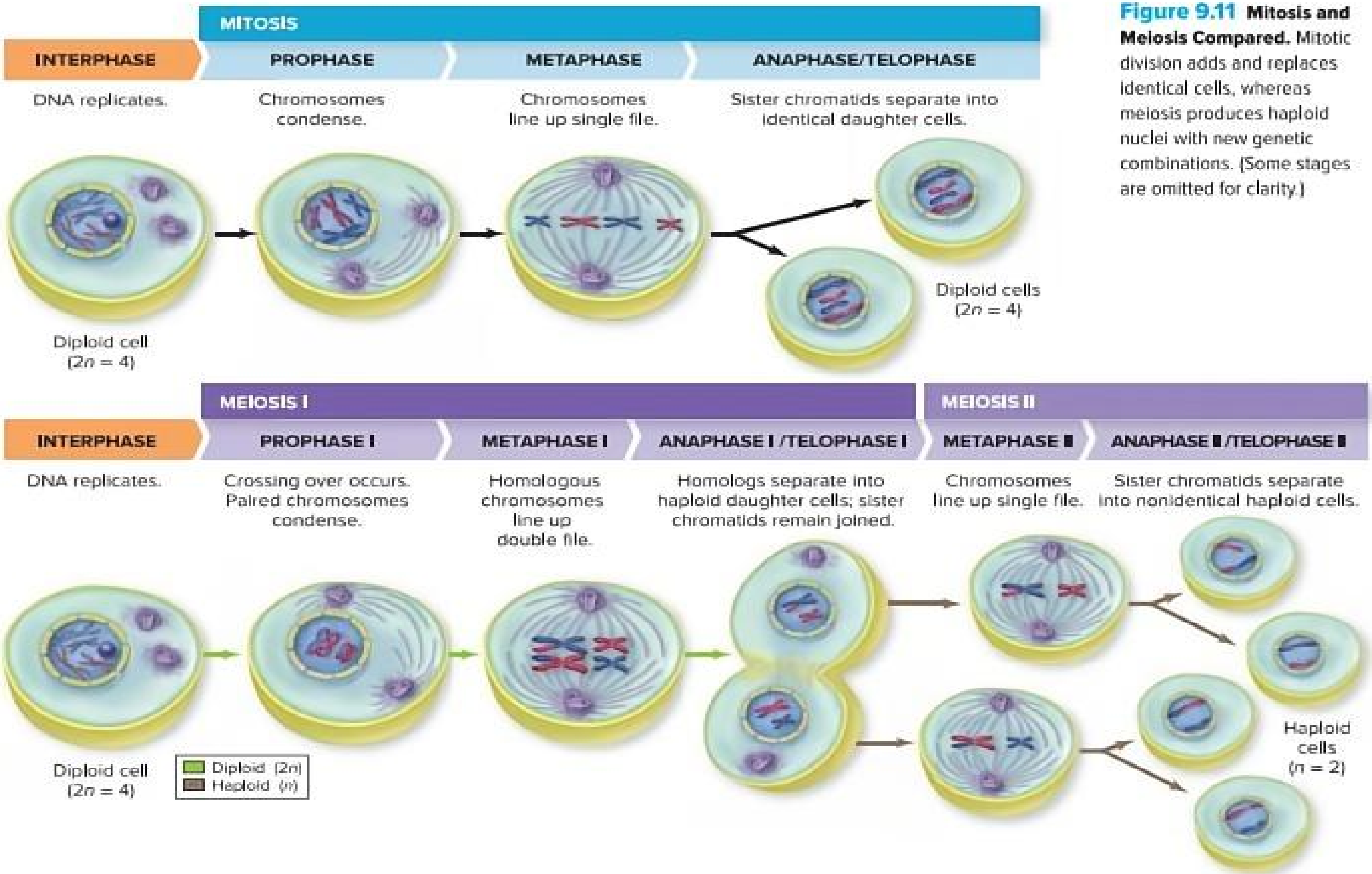


Figure 9.11 Mitosis and Meiosis Compared. Mitotic division adds and replaces identical cells, whereas meiosis produces haploid nuclei with new genetic combinations. (Some stages are omitted for clarity.)

Figure It Out

- A cell that is entering prophase I contains __ times as much DNA as one daughter cell at the end of meiosis.

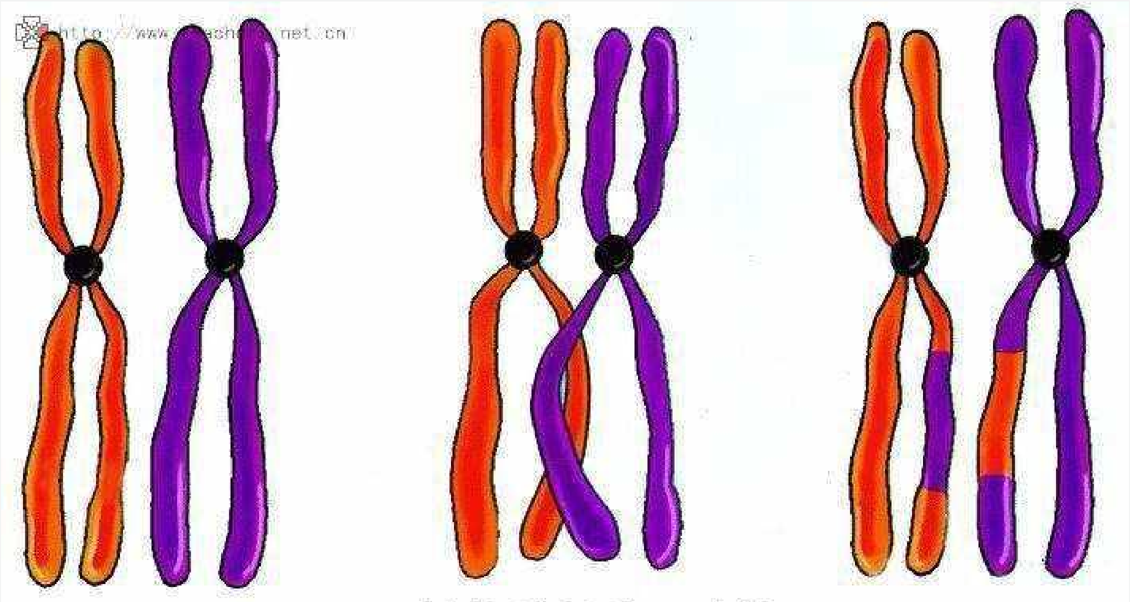
9.5 Meiosis Generates Enormous Variability

- By creating new combinations of alleles,meiosis generates astounding genetic variety among the offspring from just two parents. This section describes three mechanisms that account for this diversity.

A. Crossing Over Shuffles Alleles (交换扰乱等位基因)

- Crossing over is a process in which two homologous chromosomes exchange genetic material .During prophase I, the homologs align themselves precisely, gene by gene , in a process called synapsis (同源染色体联会) . The chromosomes are attached at a few points along their lengths, called chiasmata (交叉) (singular chiasma),where the homologs exchange chromosomal material.

Consider what takes place in your own ovaries or testes. You inherited one member of each homologous pair from your mother; the other came from your father. Crossing over means that pieces of these homologous chromosomes physically change places during meiosis.



9.5 Meiosis Generates Enormous Variability

A. Crossing Over Shuffles Alleles (交换扰乱等位基因)

- Suppose ,for instance, that one chromosome carries the genes that dictate hair color, eye color, and finger length. Perhaps the version you inherited from your father has the alleles that specify blond hair, blue eyes, and short fingers. The homolog from your mother is different; its alleles dictate black hair, brown eyes, and long fingers. Now,suppose that crossing over occurs between the homologous chromosomes. Afterward, one chromatid might carry alleles for blond hair, brown eyes ,and long fingers; another would specify black hair,blue eyes,and short fingers. These two chromatids are termed “recombinant”（重组） because they combine alleles from your two parents. The two chromatids that did not form chiasmata ,however, would remain unchanged and are termed “parental”（亲组）. Note that **although all of the alleles in your ovaries or testes came from your parents, half of the chromatids—the recombinant ones—now contain new allele combinations.**
- **The result of crossing over is four unique** chromatids in place of two pairs of identical chromatids. Each chromatid will end up in a separate haploid cell. Thus, crossing over ensures that each haploid cell will be genetically different from the others.

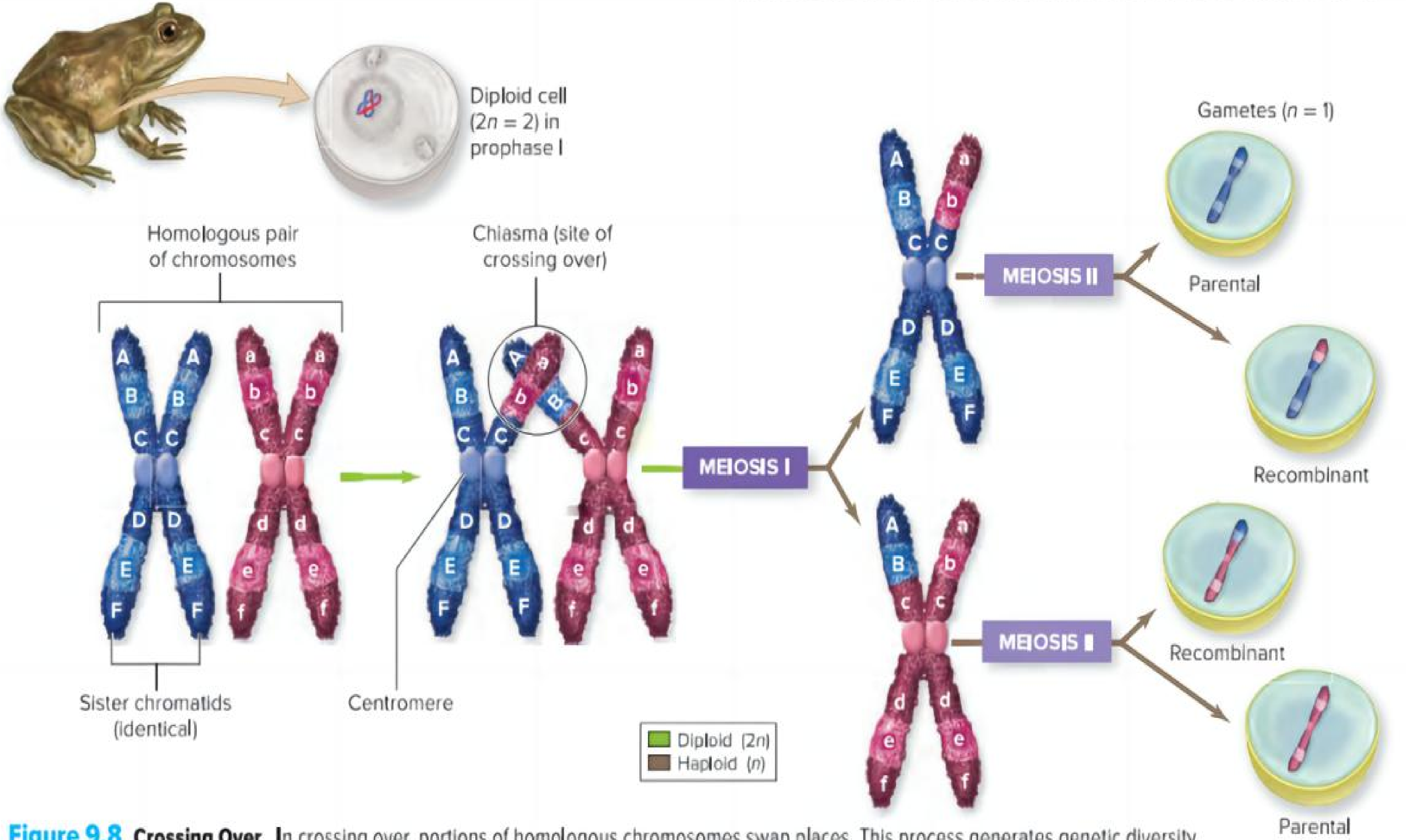


Figure 9.8 Crossing Over. In crossing over, portions of homologous chromosomes swap places. This process generates genetic diversity because each of the resulting chromatids has a unique combination of alleles. The capital and lowercase letters represent different alleles of six genes.

9.5 Meiosis Generates Enormous Variability

B. Homologous Pairs Are Oriented Randomly During Metaphase I

- Figure 9.9 reveals a second way that meiosis creates genetic variability. At metaphase I, pairs of homologous chromosomes line up at the cell's center. Examine the orientation of the chromosomes in the cell labeled "Alternative 1“. All of the blue chromosomes are on top, whereas the red homologs are on the bottom. In anaphase I, the chromosomes separate, and the resulting nuclei contain either all blue or all red chromosomes. The next time a cell in the same individual undergoes meiosis, the orientation of the chromosomes may be the same. or it may not be. **The arrangement of chromosomes at metaphase I is random**, and all four alternatives shown in figure 9.9 are equally probable. Most of the time, gametes will inherit a mix of genetic material from both parents. The number of possible arrangements is related to the chromosome number. For two pairs of homologs, each resulting gamete may have any of four(2^2) unique chromosome configurations.

For three pairs, as shown in figure 9.9, eight(2^3) unique configurations can occur in the gametes. Extending this formula to humans, with 23 chromosome pairs, each gamete contains one of 8,388,608 (2^{23}) possible chromosome combinations —all equally likely.

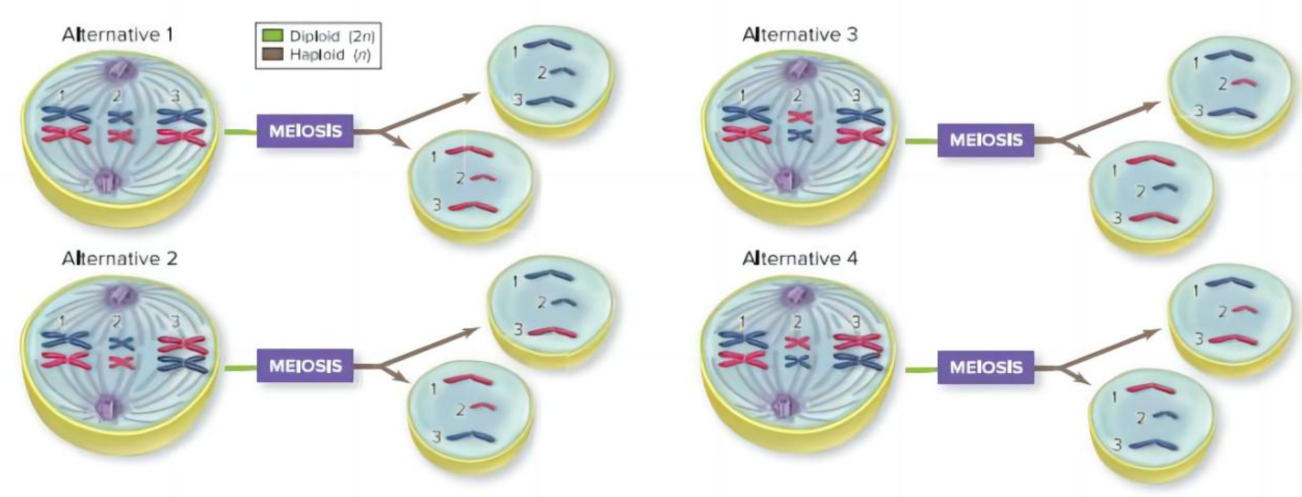


Figure 9.9 Random Orientation. A germ cell containing three homologous pairs of chromosomes can generate eight genetically different gametes. Note that this number does not include the effects of crossing over.

9.5 Meiosis Generates Enormous Variability

C. Fertilization Multiplies the Diversity

- We have already seen that every diploid cell undergoing meiosis is likely to produce haploid nuclei with different combinations of chromosomes. Furthermore, it takes two to reproduce. In one mating, any of a woman's 8,388,608 possible egg cells can combine with any of the 8,388,608 possible sperm cells of a partner. One couple could therefore theoretically create more than 70 trillion($8,388,608^2$) genetically unique individuals! And this enormous number is an underestimate, because it does not take into account the additional variation from crossing over.
- With so much potential variability, the chance of two parents producing genetically identical children seems exceedingly small. How do the parents of identical twins defy the odds? The answer is that identical twins result from just one fertilization event. The resulting zygote or embryo splits in half, creating separate, identical babies. Identical twins are called monozygotic because they derive from one zygote. In contrast, nonidentical (fraternal)twins occur when two sperm cells fertilize two separate egg cells. The twins are there-fore called dizygoric.

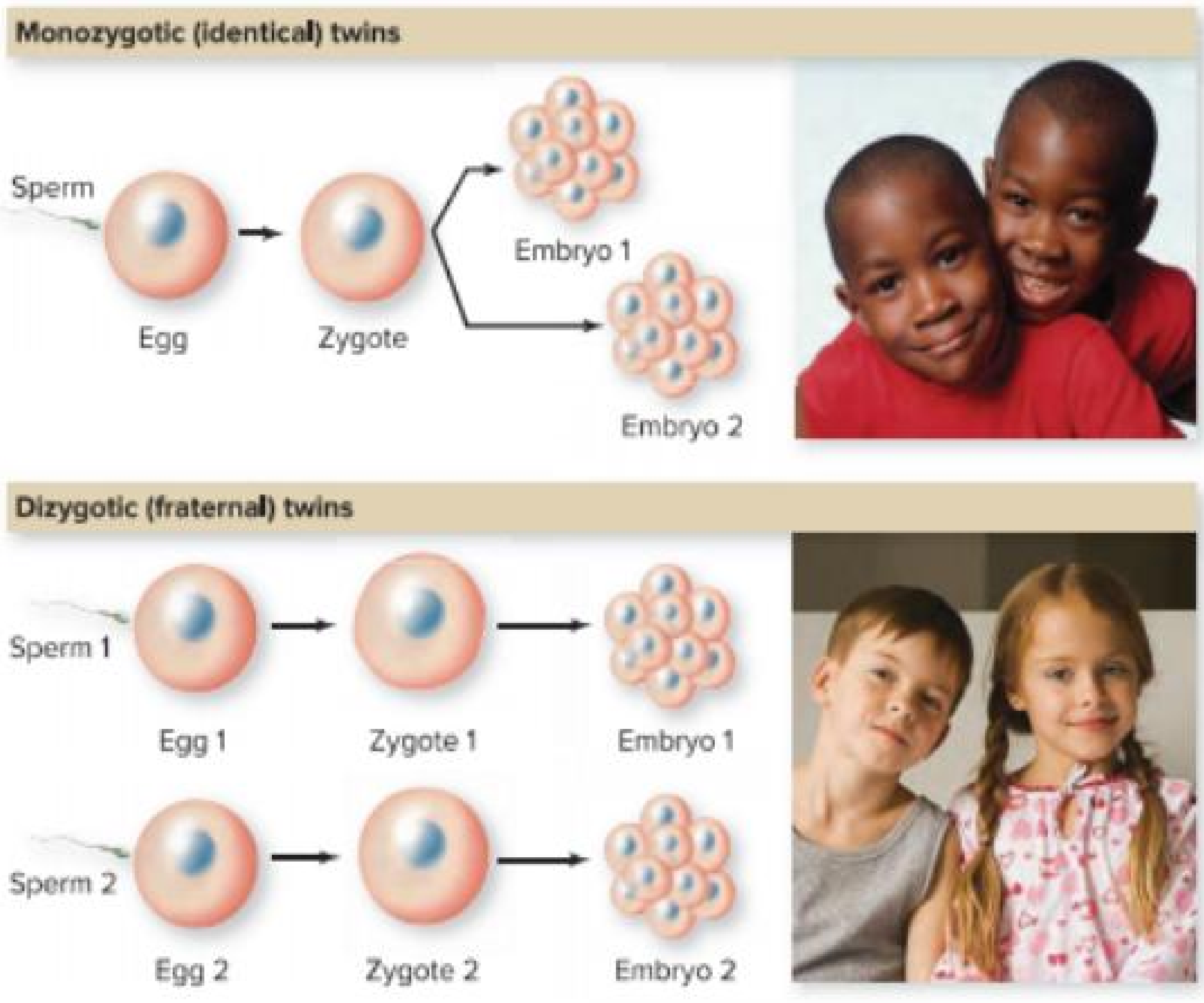


Figure 9.10 **Two Ways to Make Twins.** Monozygotic twins are genetically identical because they come from the same zygote. Dizygotic (fraternal) twins are no more alike than nontwin siblings because they start as two different zygotes.

How many pairs of twins ?





9.6 Mitosis and Meiosis Have Different Functions:A Summary

- Mitosis and meiosis are both mechanisms that divide a eukaryotic cell's genetic material.
- The two processes share many events, as revealed by the similar names of the stages.
- The cell copies its DNA during an interphase stage that precedes both mitosis and meiosis, after which the chromosomes condense.
- Moreover, spindle fibers orchestrate the movements of the chromosomes in both mitosis and meiosis.

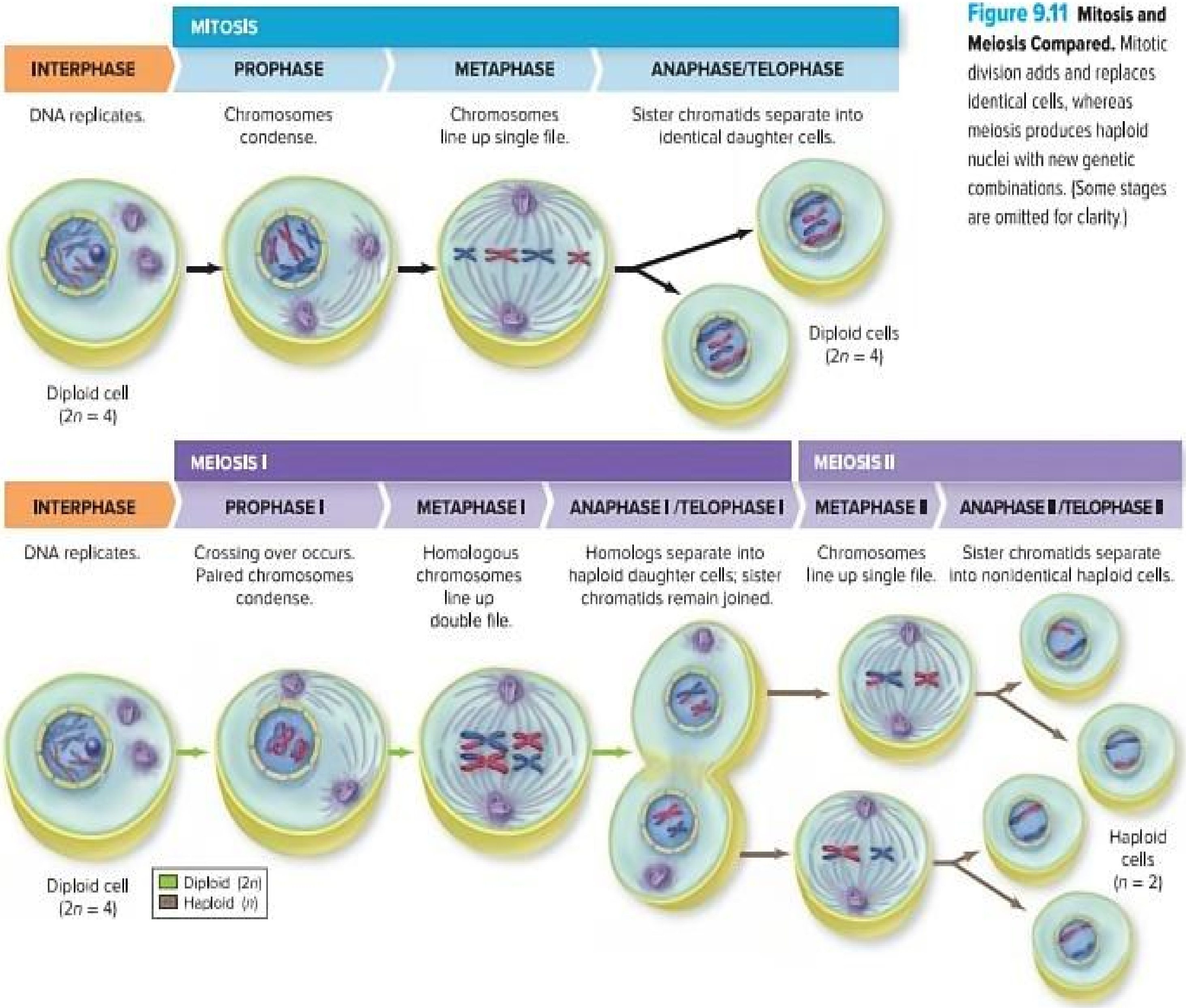


Figure 9.11 Mitosis and Meiosis Compared. Mitotic division adds and replaces identical cells, whereas meiosis produces haploid nuclei with new genetic combinations. (Some stages are omitted for clarity.)

9.6 Mitosis and Meiosis Have Different Functions: A Summary

- However, the two processes also differ in many ways:

✓ Mitosis occurs in somatic cells throughout the body, and it occurs throughout the life cycle. In contrast, meiosis occurs only in germ cells and only at some stages of life .

✓ Homologous chromosomes align with each other during meiosis but not mitosis. This alignment allows for crossing over, which also occurs only in meiosis.

✓ Following mitosis, cytokines is occurs once for every DNA replication event. The product of mitotic division is therefore two daughter cells. In meiosis, cytokines is occurs twice, although the DNA has replicated only once. One cell therefore yields four daughter cells.

✓ After mitosis, the chromosome number in the two daughter cells is the same as in the parent cell. Depending on the species, either haploid or diploid cells can divide mitotically. In contrast, only diploid cells divide by meiosis, producing four haploid daughter cells.

✓ Mitotic division yields identical daughter cells for growth, repair, and asexual reproduction. Meiotic division generates genetically variable daughter cells used in sexual reproduction. The variation among gametes results from crossing over and the random orientation of chromosome pairs during metaphase I.

9.7 Errors Sometimes Occur in Meiosis

- We have already seen that DNA replication errors can cause mutations ;these mistakes may occur during interphase preceding either mitosis or meiosis. Other types of errors can occur when a nucleus divides, producing daughter cells with extra or missing DNA. These errors may have especially serious consequences if they occur during gamete production.

A Cells May Inherit Too Many or Too Few Chromosomes

- An error in meiosis, such as the failure of the spindle to form properly, can produce a polyploid (多倍体) cell with one or more complete sets of extra chromosomes (polyploid means “many sets”).For example, if a sperm with the normal 23 chromosomes fertilizes an abnormal egg cell with two full sets (46),the resulting zygote will have three copies of each chromosome (69 total),a type of polyploidy called triploidy (三倍体) . Most human polyploids fail to live past the very early stages of development.
- Polyploidy is an important force in plant evolution. In contrast to humans, about 30%of flowering plant species tolerate polyploidy well, and many crop plants are polyploids. The durum wheat in pasta, for example , is tetraploid (it has four sets of seven chromosomes),and the wheat in bread is hexaploid, with six sets of seven chromosomes.

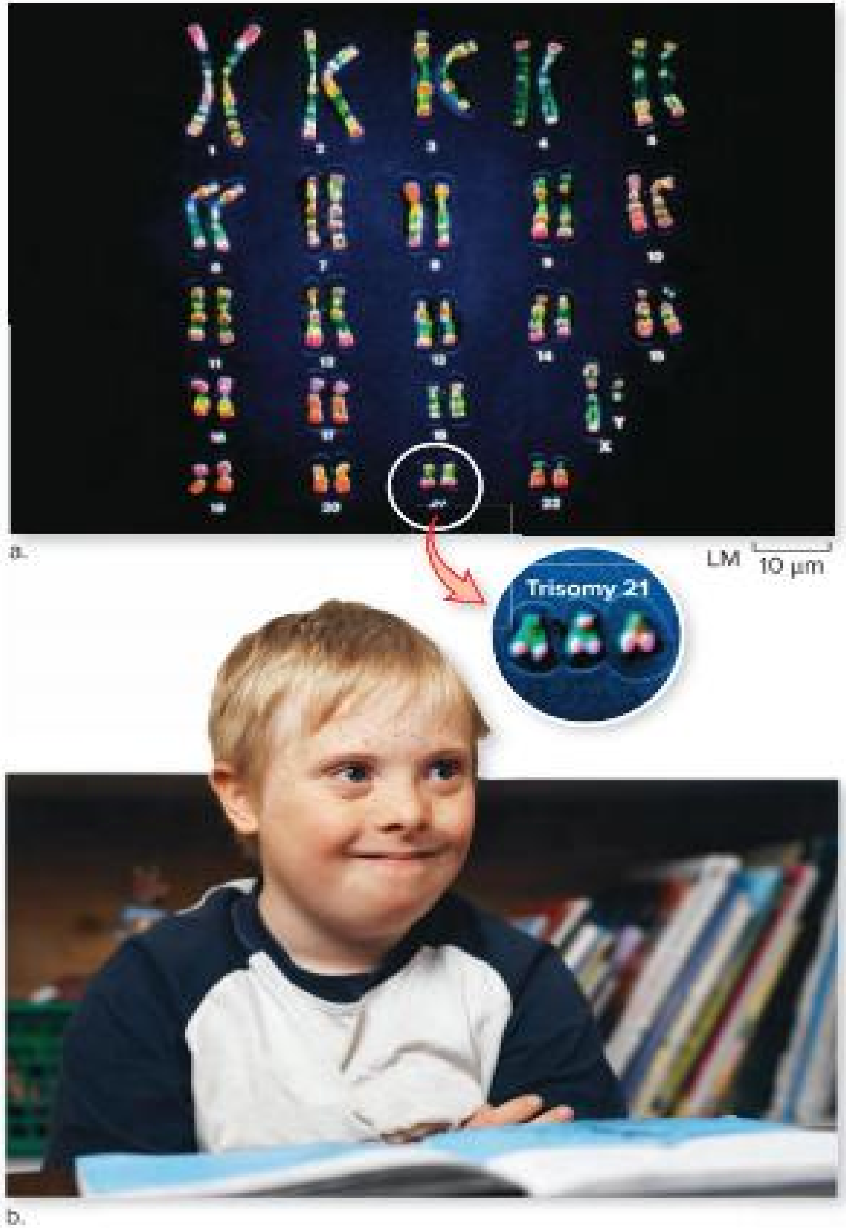


Figure 9.13 **Trisomy 21.** (a) A normal human karyotype reveals 46 chromosomes, in 23 pairs. (b) A child with three copies of chromosome 21 has Down syndrome.

9.7 Errors Sometimes Occur in Meiosis

B. Changes in Chromosome Structure May Be Harmful

- Parts of a chromosome may be deleted, duplicated, inverted, or even moved to a new location. These structural abnormalities may have many causes , ranging from radiation expo-sure to errors in crossing over. Because each chromosome includes hundreds or thousands of genes , even small changes in a chromosome's structure can affect an organism.

Home Work

- 1. what ways are mitosis and meiosis similar?
- 2. what ways are mitosis and meiosis different?