Crossover events are the first source of genetic variation produced during meiosis. A single crossover event between homologous non-sister chromatids results in chromosomes that differ from the two parents. The recombinant sister chromatid has a combination of maternal and paternal genes that did not exist before the crossover (Figure 8.26). Crossover events can occur almost anywhere along the length of the chromosomes; therefore, each gamete produced will have unique combinations of both maternal and parental genes.

In humans, even though the X and Y allosomes are not considered homologous in that most of their genes differ, there is a small region of homology that allows the X and Y chromosomes to pair up during prophase I. There have also been documented cases where the SRY gene located on the Y chromosome has crossed over to the X chromosome. Recall that the SRY genes result in the development of testes. This has resulted in XX males who are phenotypically male, even though they have 2 X chromosomes.

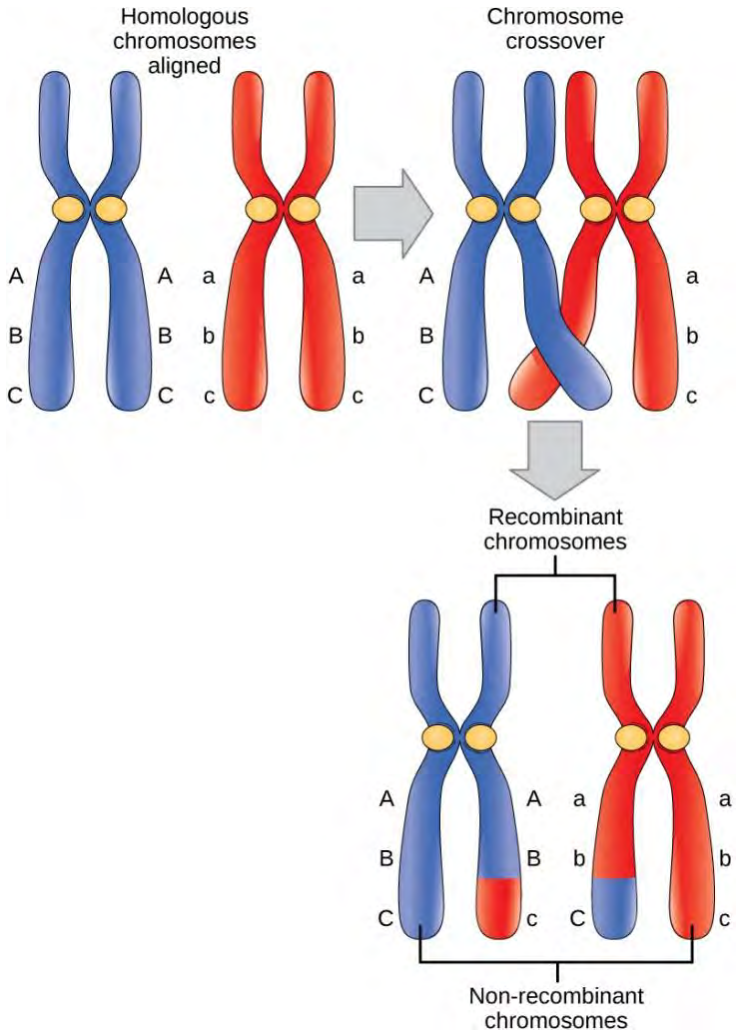

Figure 8.26 This illustration shows the effects of crossing over; the blue chromosome came from the individual's father, and the red chromosome came from the individual's mother. (credit: Clark et al./ Biology 2E OpenStax)

Prometaphase I

The key event in prometaphase I is the attachment of the microtubules to each sister chromatid's kinetochore proteins (Figure 8.25). The microtubules assemble from centrosomes at opposite poles of the cell and grow toward the middle of the cell. Homologous chromosomes are still held together at the chiasma. In addition, the nuclear membrane has broken down entirely.

Metaphase I

During metaphase I, the homologous chromosomes are arranged in the center of the cell, a region called the metaphase plate. Each tetrad is attached to microtubules from both poles. Within the tetrad, one homologous chromosome is attached at one pole, and the other homologous chromosome is attached to the opposite pole. The orientation or arrangement of each homologous pair on the metaphase plate is random.

This randomness of how the chromosomes align at the metaphase plate, called **independent assortment**, also generates genetic variation in offspring. Using humans as an example, the female provides one set of 23 maternal chromosomes via the egg or ova. The male provides the other set of 23 paternal chromosomes in the sperm which fertilizes the egg. In metaphase I, these pairs line up at the midway point between the two poles of the cell. The arrangement of the tetrads at the metaphase plate is random. This is because a microtubule is just as likely to attach to a maternal chromosome as it is to attach to a paternally inherited chromosome. Thus, any maternally inherited chromosome may face either pole. Likewise, any paternally inherited chromosome may also face either pole. The orientation of each tetrad is independent of the orientation of the other 22 tetrads.

In each cell that undergoes meiosis, the arrangement of the tetrads is different. The number of variations depends on the number of chromosomes making up a set. Each tetrad has two possible orientations; thus, the potential number of alignments equals $2^{n,}$ where n is the number of chromosomes per set. Humans have 23 chromosome pairs, which results in over eight million (2^{23}) possibilities. This number does not include the variability previously created in the sister chromatids by crossing over. Given these two mechanisms, it is highly unlikely that any two haploid cells resulting from meiosis will have the same genetic composition (Figure 8.27).

Anaphase I

In anaphase I, the spindle fibers pull the linked homologous chromosomes apart. Once the homologous chromosomes are separated, one chromosome, in its duplicated state, is slowly pulled towards one pole while the other is pulled to the opposite pole. The sister chromatids that make up each chromosome remain tightly bound together at the centromere.

Telophase I

In telophase I, the separated chromosomes arrive at opposite poles. Other events that may occur in telophase depend on the species. In some organisms, including animal cells, the chromosomes decondense and the nuclear envelopes reform in telophase I. In other organisms, such as some protists, cytokinesis occurs without the reformation of the nuclei.

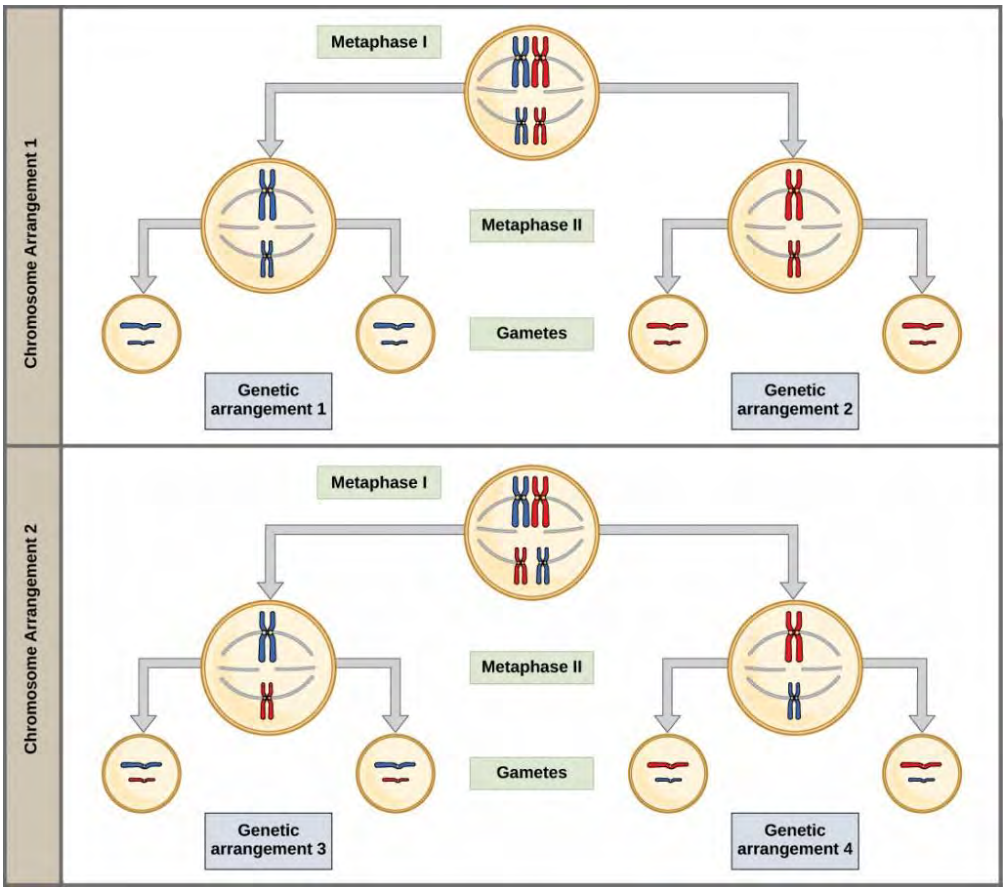

Figure 8.27 demonstrates independent assortment in metaphase I. (credit: Clark et al./ Biology 2E OpenStax)

Cytokinesis I

In nearly all species, cytokinesis I separate the cell contents by either a cleavage furrow in animals and some fungi, or a cell plate in plant cells. The cell plate will ultimately lead to the formation of a cell wall between the two new plant cells. At this point, each daughter cell is considered haploid; each cell contains only one set of chromosomes. Each of the chromosomes found in the daughter cells is in the duplicated state, meaning each chromosome consists of two sister chromatids that are still attached to each other. Although in interphase, the sister chromatids were exact copies of one another, they are no longer identical at this stage because of the process of crossing over.

In some species, cells enter a brief interphase, or **interkinesis**, before entering meiosis II. Interkinesis lacks an S phase, so chromosomes are not duplicated. The two haploid cells produced in meiosis I go through the events of meiosis II in synchrony. During meiosis II, the sister chromatids within the two daughter cells separate, forming four new haploid gametes. The mechanics of meiosis II are similar to mitosis, except that each dividing cell has only one set of homologous chromosomes, each consisting of two sister chromatids.