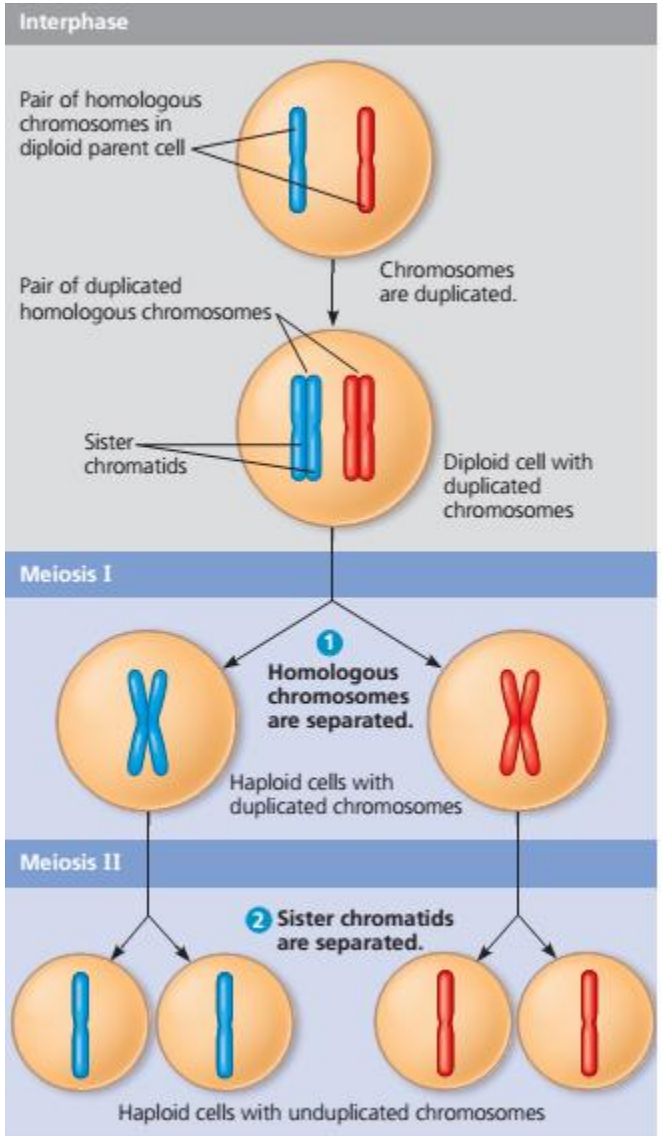
Meiosis

➔ One diploid nucleus divides by meiosis to produce four haploid nuclei.

In meiosis the nucleus divides twice. The first division produces two nuclei, each of which divides again to give a total of four nuclei. The two divisions are known as **meiosis I** and **meiosis II**. The cells produced by meiosis I have one chromosome of each type, so the halving of the chromosome number happens in the first division, not the second division. The two nuclei produced by meiosis l have the haploid number of chromosomes, but each chromosome still consists of two chromatids. These chromatids separate during meiosis II, producing four nuclei that have the haploid number of chromosomes, with each chromosome consisting of a single chromatid.

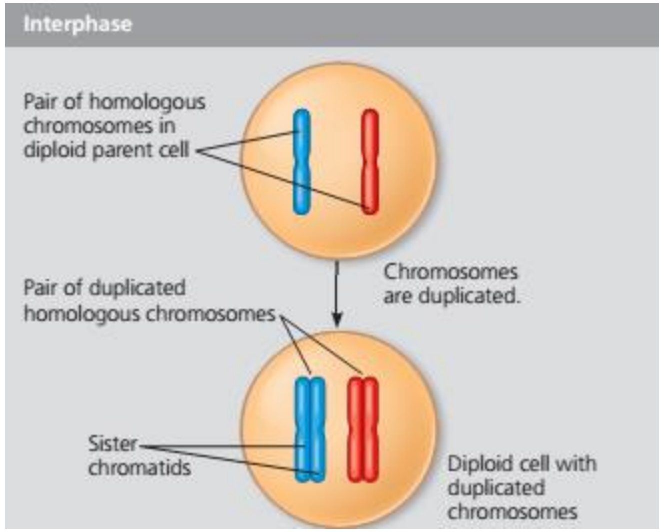
➔ The halving of the chromosome number allows a sexual life cycle with fusion of gametes.

The life cycles of living organisms can be sexual or asexual. In an asexual life cycle the offspring have the same chromosomes as the parent so are genetically identical. In a sexual life cycle there are differences between the chromosomes of the offspring and the parents, so there is genetic diversity . In eukaryotic organisms, sexual reproduction involves the process of fertilization. Fertilization is the union of sex cells, or gametes, usually from two different parents. Fertilization doubles the number of chromosomes each time it occurs. It would therefore cause a doubling of chromosome number every generation, if the number was not also halved at some stage in the life cycle. This halving of chromosome number happens during meiosis. Meiosis can happen at any stage during a sexual life cycle, but in animals it happens during the process of creating the gametes. Body cells are therefore diploid and have two copies of most genes.



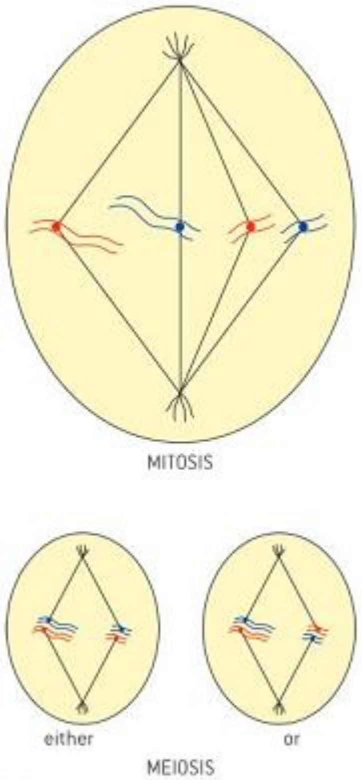
➔ DNA is replicated before meiosis so that all chromosomes consist of two sister chromatids

During the early stages of meiosis the chromosomes gradually shorten by supercoiling. As soon as they become visible it is clear that each chromosome consists of two chromatids. This is because all DNA in the nucleus is replicated during the interphase before meiosis, so each chromosome consists of two sister chromatids. Initially the two chromatids that make up each chromosome are genetically identical. This is because DNA replication is very accurate and the number of mistakes in the copying of the DNA is extremely small. We might expect the DNA to be replicated again between the first and the second division of meiosis, but it does not happen. This explains how the chromosome number is halved during meiosis. One diploid nucleus, in which each chromosome consists of two chromatids, divides twice to produce four haploid nuclei in which each chromosome consists of one chromatid.



➔ The early stages of meiosis involve pairing of homologous chromosomes and crossing over followed by condensation.

Firstly homologous chromosomes pair up with each other . Because DNA replication has already occurred, each chromosome consists of two chromatids and so there are four DNA molecules associated in each pair of homologous chromosomes. A pair of homologous chromosomes is bivalent and the pairing process is sometimes called synapsis. Soon after synapsis, a process called crossing over takes place. A junction is created where one chromatid in each of the homologous chromosomes breaks and rejoins with the other chromatid. Crossing over occurs at random positions anywhere along the chromosomes. At least one crossover occurs in each bivalent and there can be several. Because a crossover occurs at precisely the same position on the two chromatids involved, there is a mutual exchange of genes between the chromatids. As the chromatids are homologous but not identical, some alleles of the exchanged genes are likely to be different. Chromatids with new combinations of alleles are therefore produced.



▲ Figure 7 Comparison of attachment of chromosomes to spindle microtubules in mitosis and meiosis

➔ Orientation of pairs of homologous chromosomes prior to separation is random.

While pairs of homologous chromosomes are condensing inside the nucleus of a cell in the early stages of meiosis, spindle microtubules are growing from the poles of the cell. After the nuclear membrane has broken down, these spindle microtubules attach to the centromeres of the chromosomes. The attachment of the spindle microtubules is not the same as in mitosis. The principles are these:

- Each chromosome is attached to one pole only , not to both.
- The two homologous chromosomes in a bivalent are attached to different poles.
- The pole to which each chromosome is attached depends on which way the pair of chromosomes is facing. This is called the orientation.
- The orientation of bivalents is random, so each chromosome has an equal chance of attaching to each pole, and eventually of being pulled to it .
- The orientation of one bivalent does not affect other bivalents. The consequences of the random orientation of bivalents are discussed in the section on genetic diversity later in this topic.

➔ Separation of pairs of homologous chromosomes in the first division of meiosis halves the chromosome number.

The movement of chromosomes is not the same in the first division of meiosis as in mitosis. Whereas in mitosis the centromere divides and the two chromatids that make up a chromosome move to opposite poles, in meiosis the centromere does not divide and whole chromosomes move to the poles. Initially the two chromosomes in each bivalent are held together by **chiasmata**, but these slide to the end of the chromosomes and then the chromosomes can separate. This separation of homologous chromosomes is called **disjunction**. One chromosome from each bivalent moves to one of the poles and the other chromosome to the other pole. The separation of pairs of homologous chromosomes to opposite poles of the cell halves the chromosome number of the cell. It is therefore the first division of meiosis that is the reduction division. Because one chromosome of each type moves to each pole, both of the two nuclei formed in the first division of meiosis contain one of each type of chromosome, so they are both haploid.

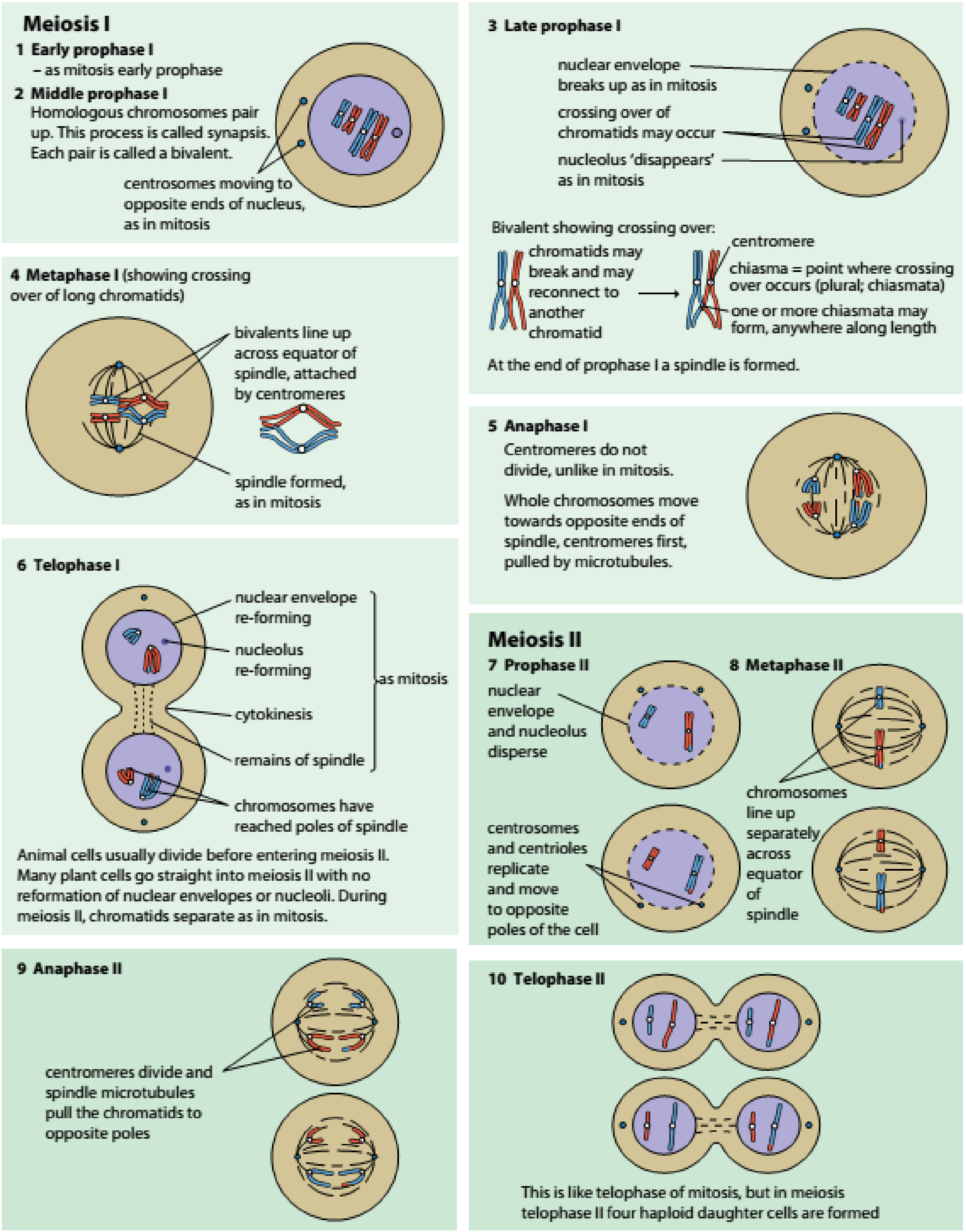


Figure 16.8 Meiosis and cytokinesis in an animal cell. Compare this process with nuclear division by mitosis, shown in

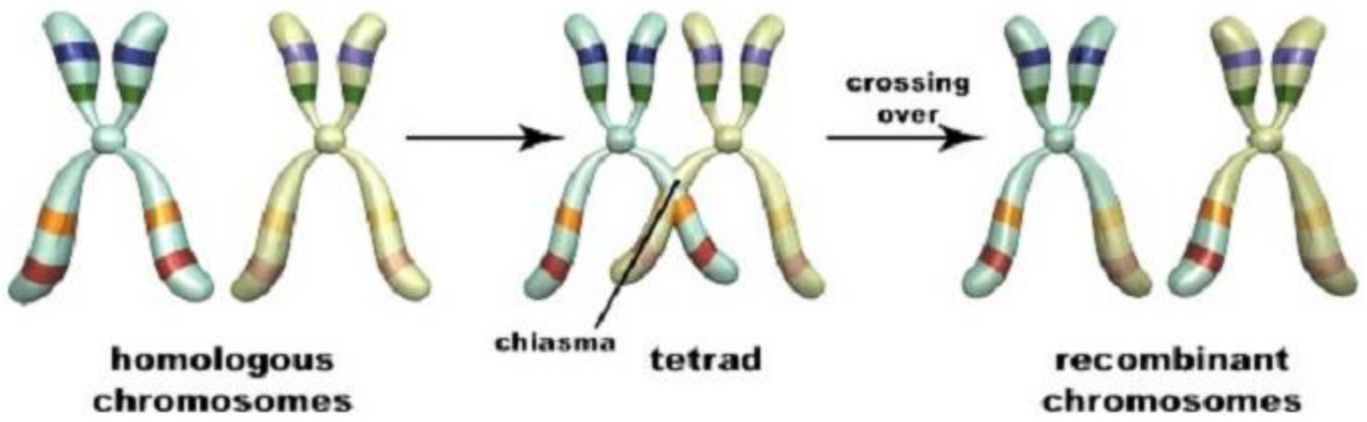
➔ Crossing over and random orientation promotes genetic variation.

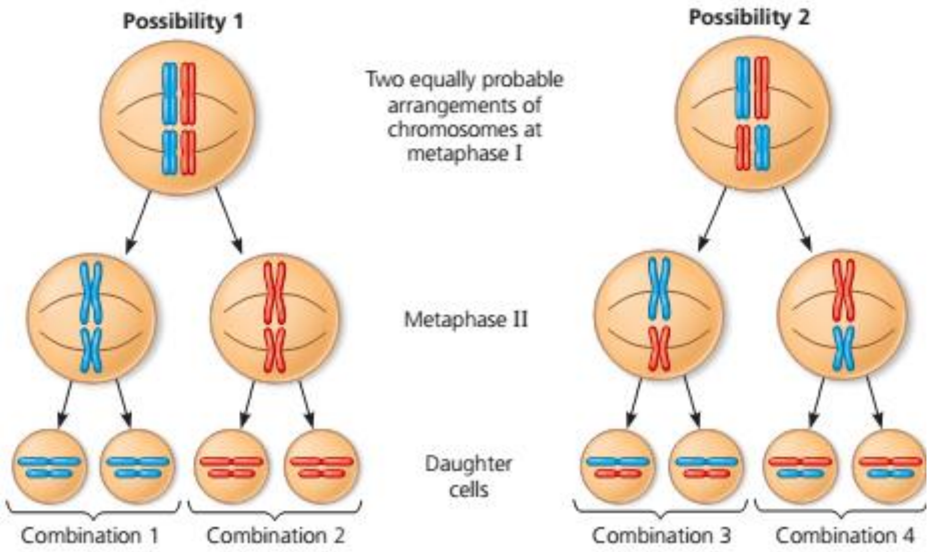
When two parents have a child, they know that it will inherit an unpredictable mixture of characteristics from each of them. Much of the unpredictability is due to meiosis. Every gamete produced by a parent has a new combination of alleles – meiosis is a source of endless genetic variation. Apart from the genes on the X and Y chromosomes, humans have two copies of each gene. In some cases the two copies are the same allele and there will be one copy of that allele in every gamete produced by the parent. There are likely to be thousands of genes in the parent's genome.

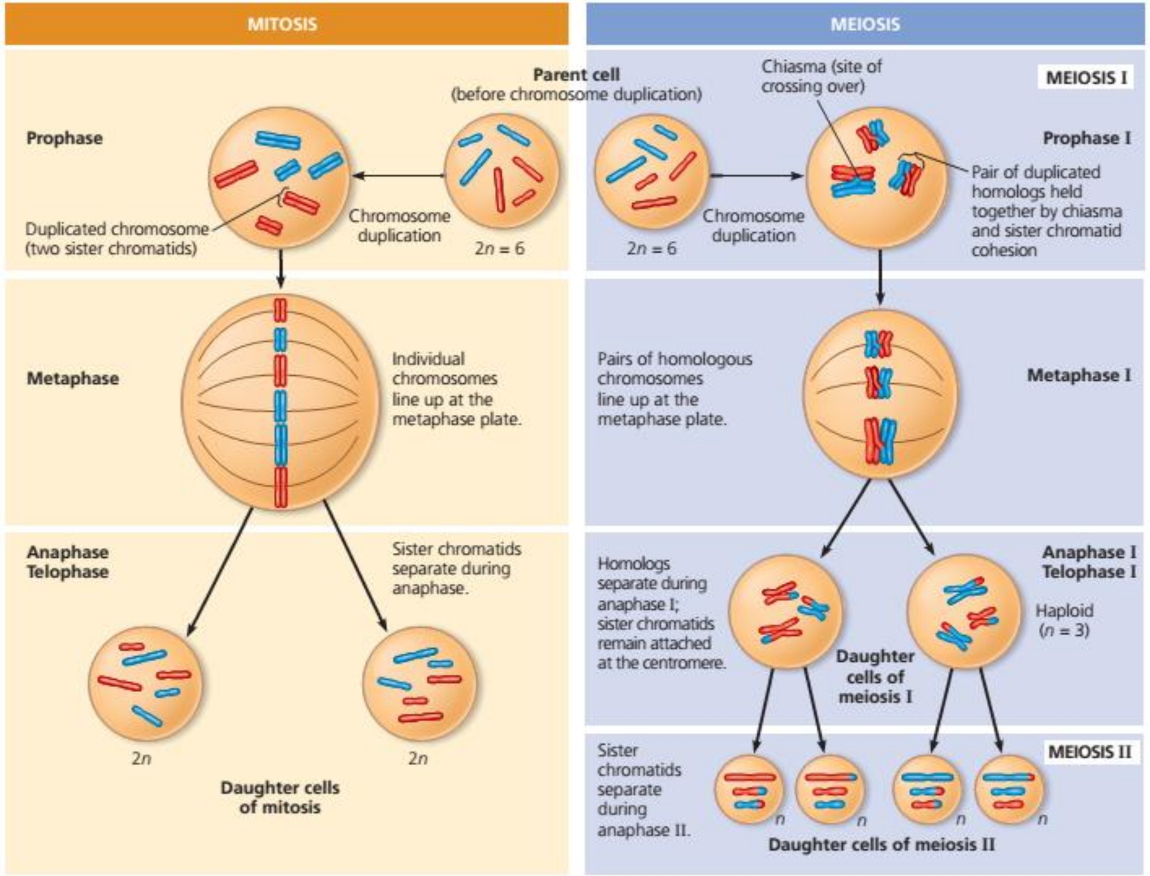
There are two processes in meiosis that generate diversity :

1- Random orientation of bivalents: In metaphase I the orientation of bivalents is random and the orientation of one bivalent does not influence the orientation of any of the others. For humans with a haploid number of 23, chromosome combinations in a cell produced by meiosis, amounts to 23^2 or over 8 million combinations.

2. Crossing over: Without crossing over in prophase I, combinations of alleles on chromosomes would be forever linked together . For example, if one chromosome carried the combination CD and another carried cd, only these combinations could occur in gametes. Crossing over allows linked genes to be reshuffled, to produce new combinations such as Cd and cD. It increases the number of allele combinations that can be generated by meiosis so much that it is effectively infinite.







Property	**Mitosis** (occurs in both diploid and haploid cells)	**Meiosis** (can only occur in diploid cells)
DNA replication	Occurs during interphase, before mitosis begins	Occurs during interphase before meiosis I but not before meiosis II
Number of divisions	One, including prophase, prometaphase, metaphase, anaphase, and telophase	Two, each including prophase, metaphase, anaphase, and telophase
Synapsis of homologous chromosomes	Does not occur	Occurs during prophase I along with crossing over between nonsister chromatids; resulting chiasmata hold pairs together due to sister chromatid cohesion
Number of daughter cells and genetic composition	Two, each genetically identical to the parent cell, with the same number of chromosomes	Four, each haploid (n); genetically different from the parent cell and from each other
Role in animals, fungi, and plants	Enables multicellular animal, fungus, or plant (gametophyte or sporophyte) to arise from a single cell; produces cells for growth, repair, and, in some species, asexual reproduction; produces gametes in the plant gametophyte	Produces gametes (in animals) or spores (in fungi and in plant sporophytes); reduces number of chromosome sets by half and introduces genetic variability among the gametes or spores