

# **HUMAN BIOLOGY**

Seventeenth Edition

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## **Chapter 19** **Cell Division**

# 19.4 Meiosis <sub>1</sub>

## Learning Outcomes:

- List the stages of meiosis and describe what occurs in each stage.
- Explain how meiosis increases genetic variation.
- Differentiate between spermatogenesis and oogenesis with regard to occurrence and the number of functional gametes produced by each process.

# 19.4 Meiosis <sub>2</sub>

**Meiosis**—reduction division.

Has two consecutive cell divisions without an interphase in between.

Results in four daughter cells, each of which has one of each type of chromosome.

- The parent cell is **diploid ( $2n$ )**; the daughter cells are **haploid ( $n$ )**.

# 19.4 Meiosis <sub>3</sub>

## **Meiosis, concluded.**

Introduces genetic variation; each of the daughter cells is genetically different from the parent cell.

- Possesses new combinations of the genetic material.

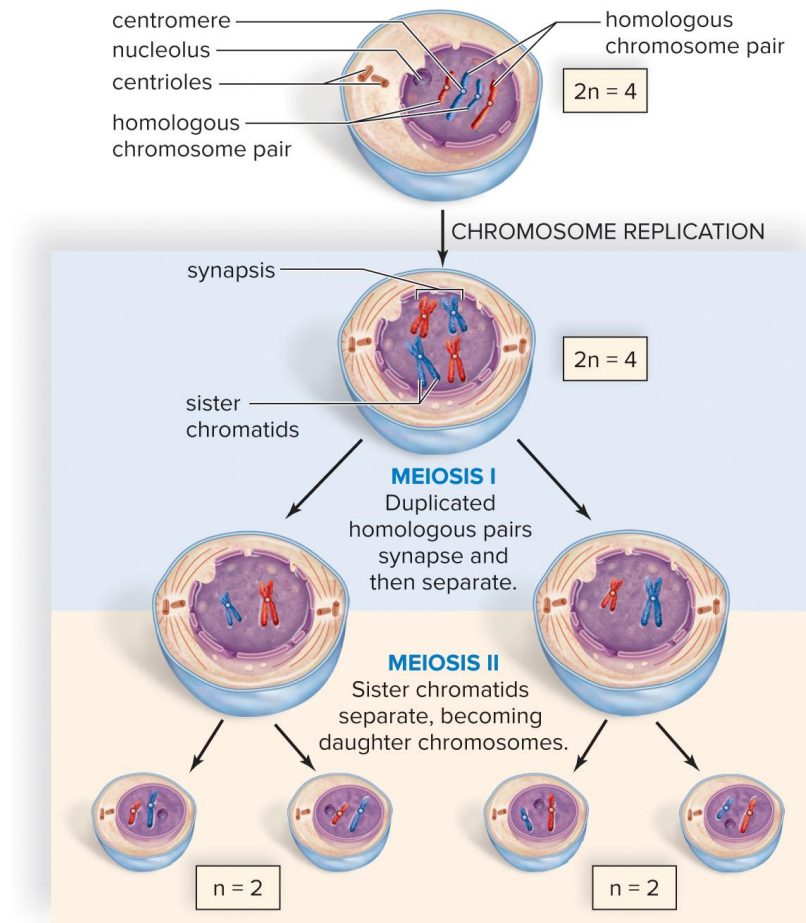
# Overview of Meiosis

At the start of meiosis, the parent cell is diploid ( $2n$ ), and the chromosomes occur in pairs.

The members of a pair are called **homologous chromosomes**, or **homologues**.

- They look alike and carry genes for the same traits.

# The Results of Meiosis (Figure 19.9)



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# Meiosis I

**Meiosis I** and **meiosis II**—the two cell divisions of meiosis.

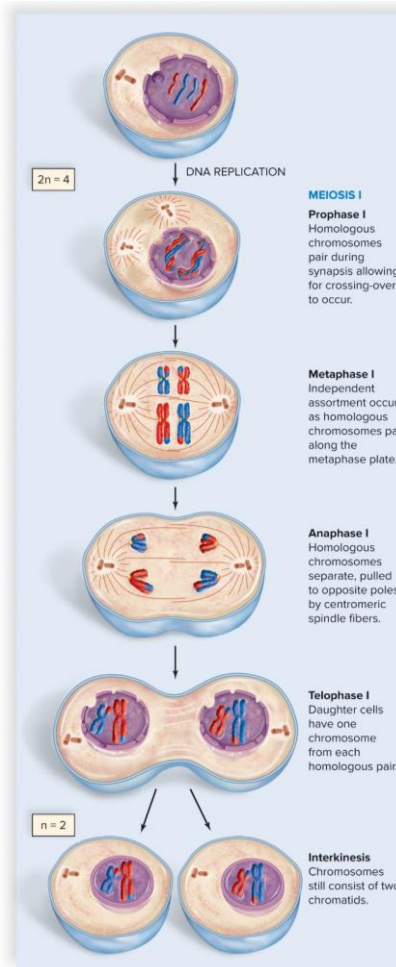
Prior to meiosis I, DNA has been replicated.

**Synapsis**—homologous chromosomes come together and line up side by side on the metaphase plate during meiosis I.

- Keeps the four chromatids close during the first two phases of meiosis I.

DNA does not replicate during **interkinesis**, the time between meiosis I and meiosis II.

# Meiosis I (Figure 19.10)



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# Meiosis II

During **meiosis II**, the centromeres divide.

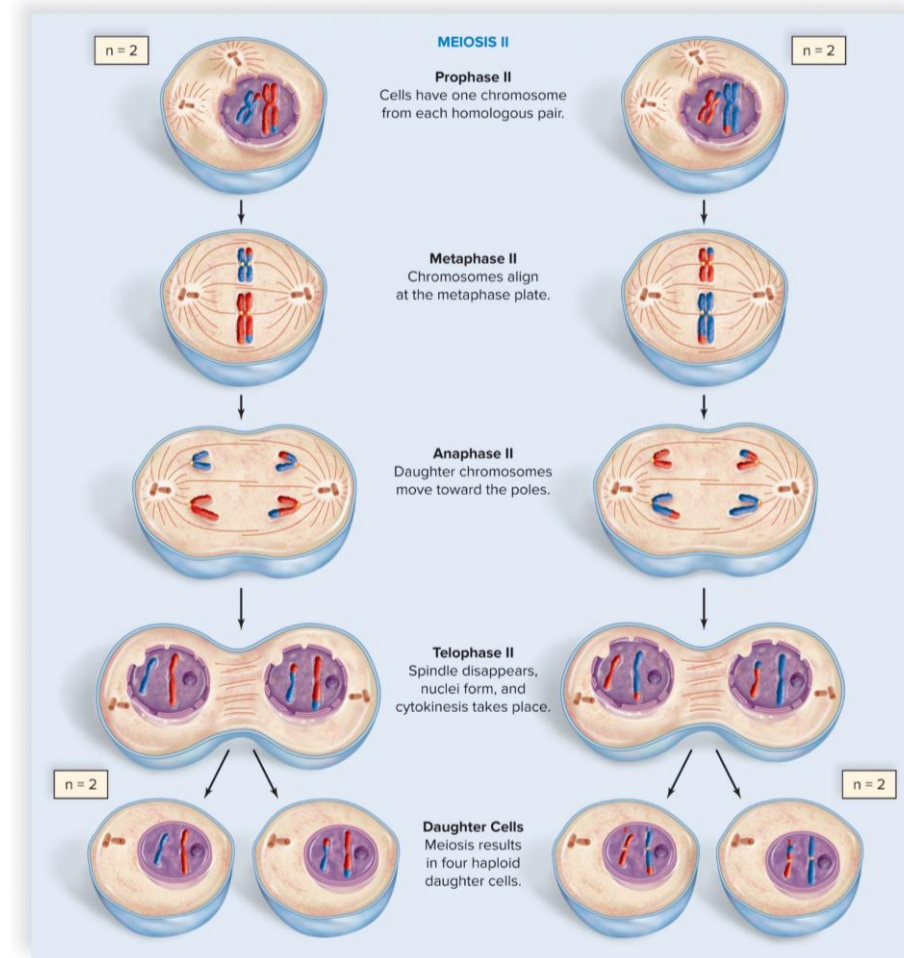
The sister chromatids separate and move toward opposite poles of the spindle.

- Sister chromatids are now called chromosomes.

The daughter cells mature into gametes (sperm and egg).

- Fertilization restores the diploid number of chromosomes in the zygote.

# Meiosis II (Figure 19.11)



[Access the text alternative for slide images.](#)

# Meiosis and Genetic Variation

## Meiosis and genetic variation.

- Meiosis ensures that offspring will be diploid and have a combination of genetic characteristics different from that of either parent.
- Both meiosis I and meiosis II have the same four stages of nuclear division as mitosis.

# Prophase I

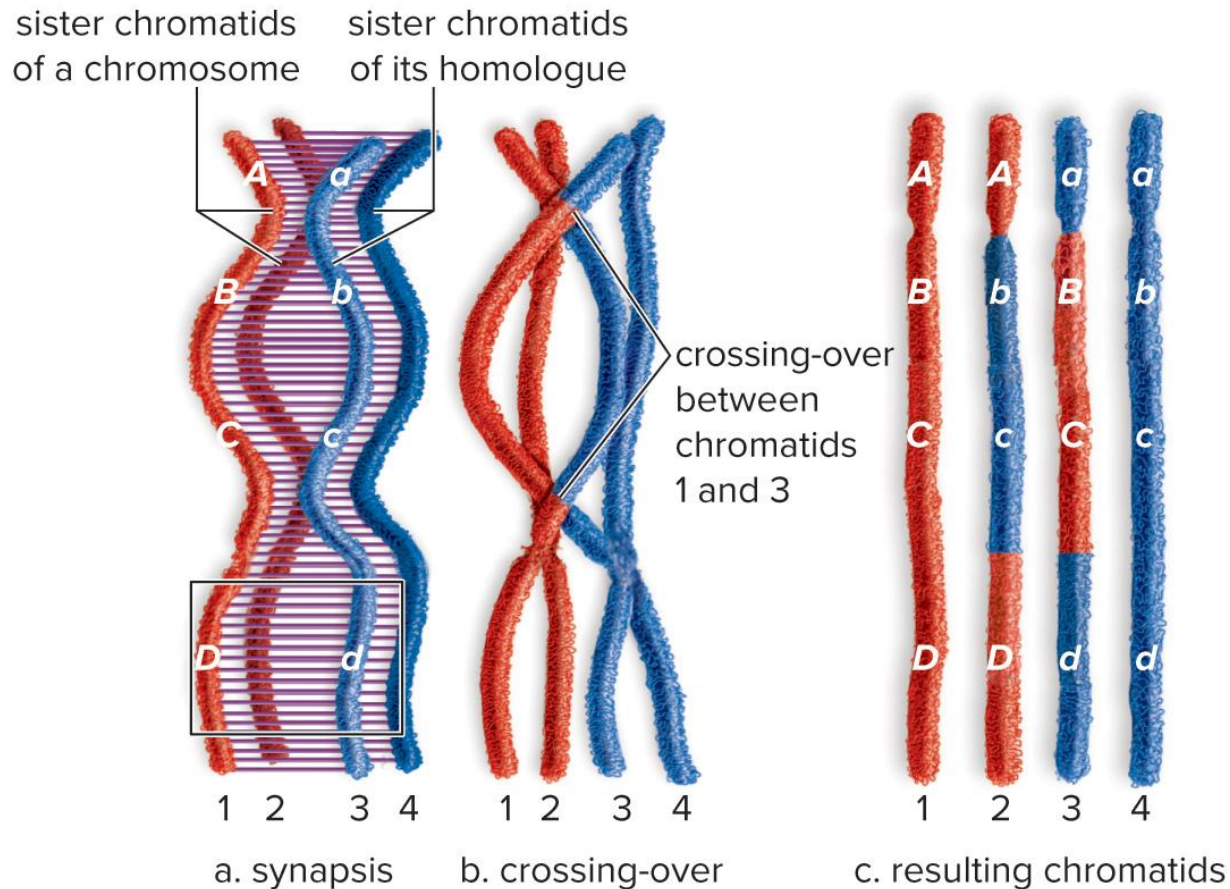
## Prophase I.

Synapsis occurs; homologous chromosomes line up side by side.

**Crossing-over**—an exchange of genetic material between the non-sister chromatids of the homologous pair.

- Produces chromatids that are no longer identical.

# Synapsis and Crossing-Over Increase Variability (Figure 19.12)



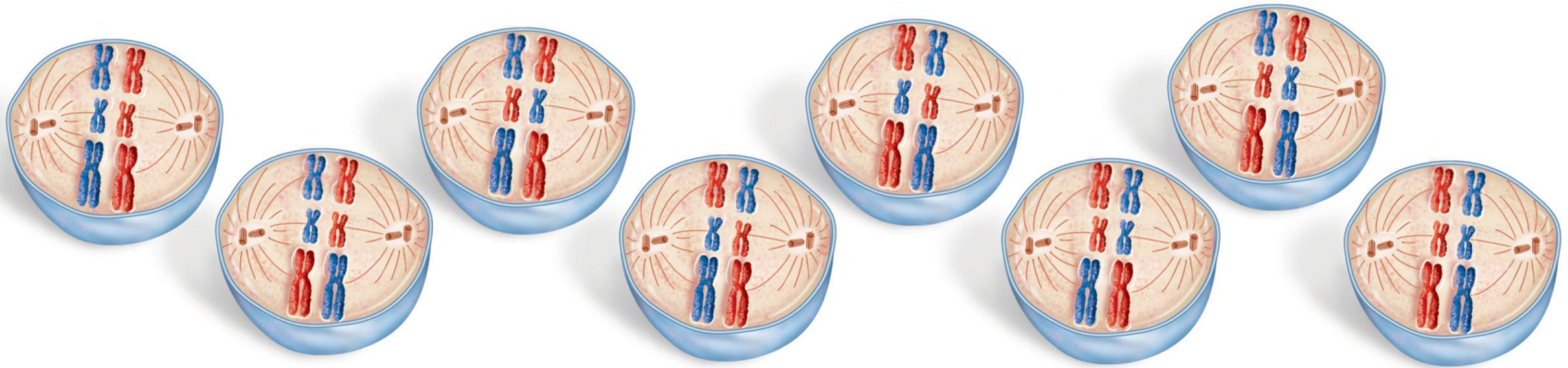
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# Metaphase I

During metaphase I, the homologous pairs align independently at the equator.

- The maternal or paternal member may be oriented toward either pole.

# Independent Alignment at Metaphase I Increases Variability (Figure 19.13)



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# Spermatogenesis and Oogenesis

Meiosis is a part of **spermatogenesis**, the production of sperm in males, and **oogenesis**, the production of eggs in females.

- Following meiosis, the daughter cells mature to become the gametes.

# Spermatogenesis <sup>1</sup>

## **Spermatogenesis.**

Is continual in the testes starting at puberty.

300,000 sperm are made per minute; over 400 million per day.

**Primary spermatocytes**—diploid ( $2n$ ).

- Divide during meiosis I to form two **secondary spermatocytes**, which are haploid ( $n$ ).

# Spermatogenesis <sup>2</sup>

## **Spermatogenesis, continued.**

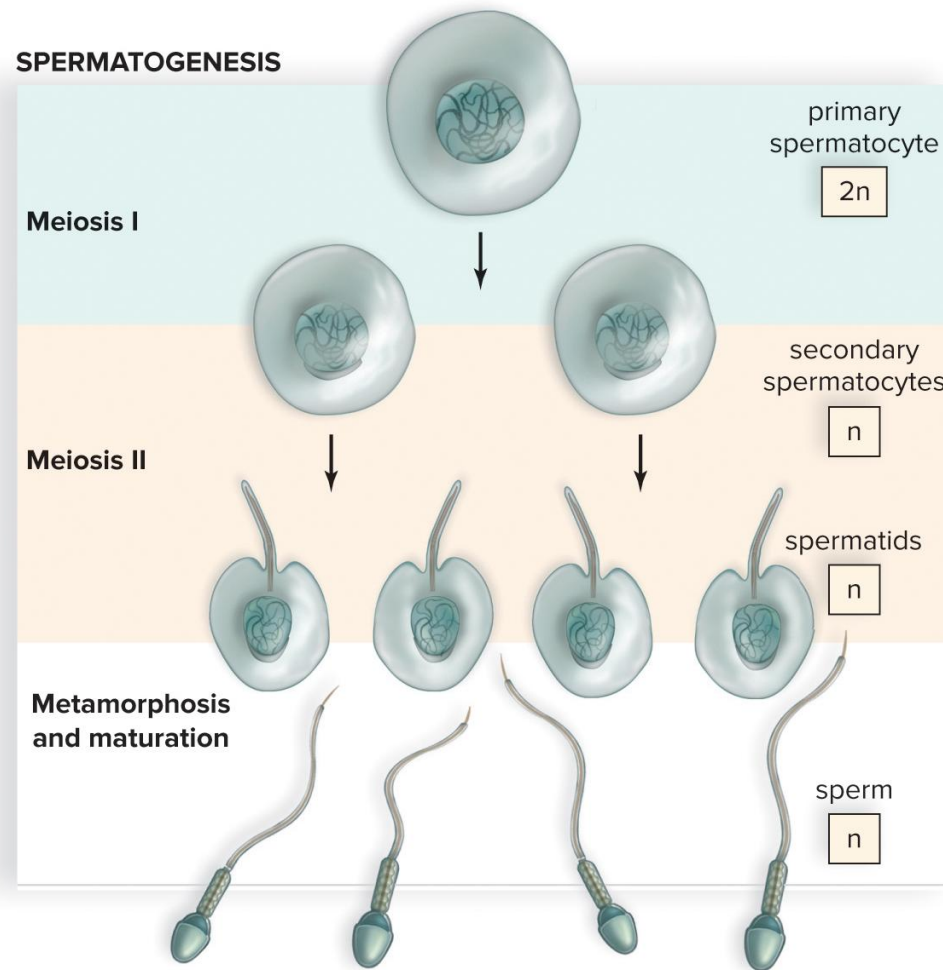
Secondary spermatocytes divide during meiosis II to produce four **spermatids**.

- The chromosomes in secondary spermatocytes are duplicated and consist of two chromatids, whereas those in spermatids consist of only one.

Spermatids mature into sperm (**spermatozoa**).

All four daughter cells become sperm.

# Spermatogenesis (Figure 19.14)



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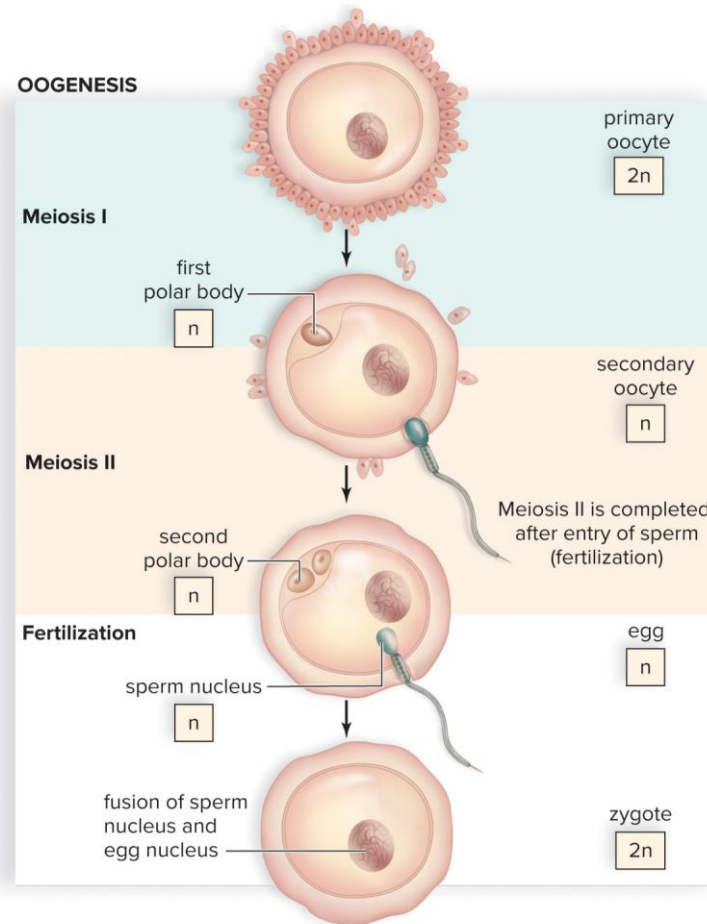
# Oogenesis <sub>1</sub>

Ovaries contain many immature follicles, which contain a primary oocyte arrested in prophase I.

The primary oocyte, which is diploid ( $2n$ ), divides during meiosis I into two haploid cells:

- Secondary oocyte—receives almost all the cytoplasm.
  - Begins meiosis II but stops at metaphase II; doesn't complete it unless a sperm fertilizes it.
- First **polar body**—holds discarded chromosomes.

# Oogenesis (Figure 19.15)



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# Oogenesis <sub>2</sub>

The secondary oocyte (egg) leaves the ovary during ovulation and enters a uterine tube.

If it is fertilized, the oocyte is activated to complete the second meiotic division.

- Following meiosis II, there is one egg and two or possibly three polar bodies.
- The polar bodies disintegrate, which is a way to discard unnecessary chromosomes while keeping most of the cytoplasm in the egg.

# Significance of Meiosis

## Significance of meiosis.

One function is to keep the chromosome number constant from generation to generation.

Another is that it results in genetic recombination.

- Genetic recombination ensures that offspring will be genetically different from each other and their parents.
- Results from crossing-over and independent alignment of chromosomes.
- Generates the diversity needed to survive in changing conditions.

# Check Your Progress 19.4

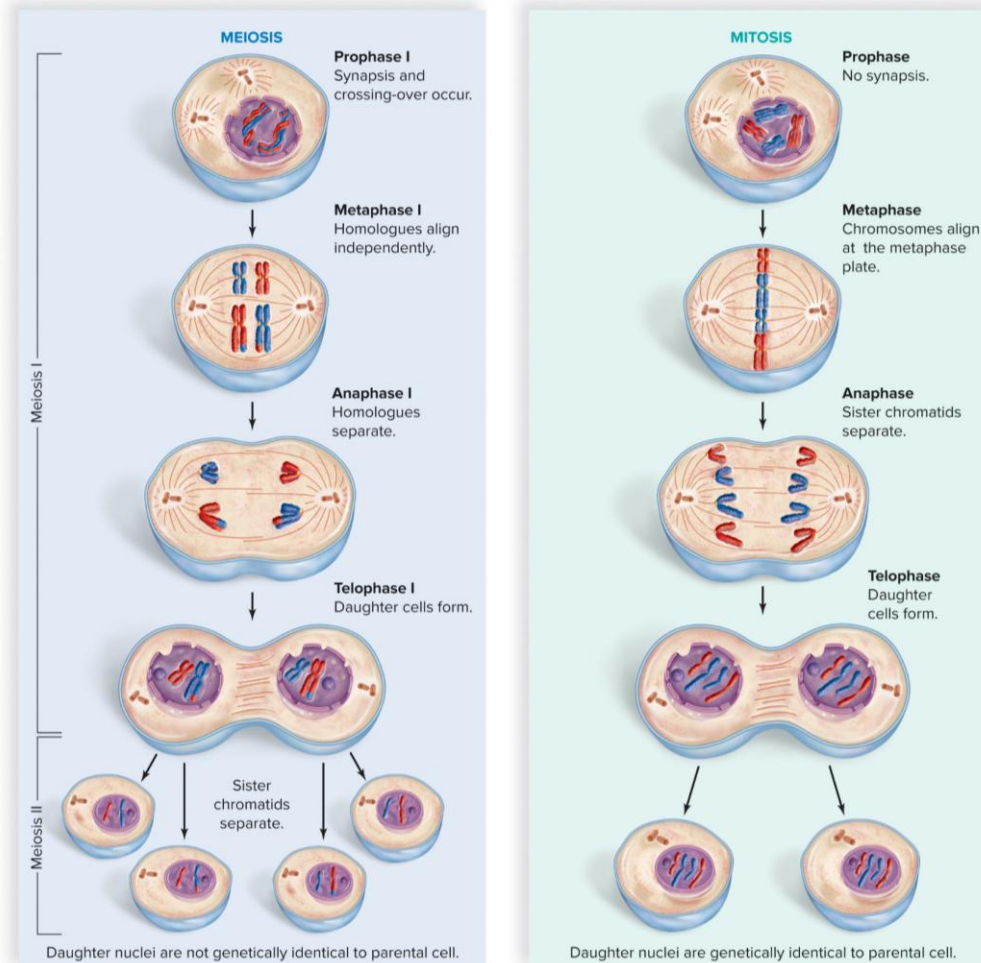
- Explain how, following meiosis, the chromosome number of the daughter cells compares to the chromosome number of the parent cell.
- Explain how meiosis reduces the likelihood that gametes will have the same combination of chromosomes and genes.
- Summarize the events during the two cell divisions of meiosis.
- Compare and contrast the stages of oogenesis and spermatogenesis.

# 19.5 Comparison of Meiosis and Mitosis

## Learning Outcomes:

- Distinguish between meiosis and mitosis with regard to the number of divisions and the number and chromosome content of the resulting cells.
- Contrast the events of meiosis I and meiosis II with the events of mitosis.

# A Comparison of Meiosis and Mitosis (Figure 19.16)



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# General Comparison <sub>1</sub>

## Comparison of meiosis and mitosis.

DNA replication takes place only once prior to both meiosis and mitosis.

- Meiosis requires two nuclear divisions, mitosis only one.

Meiosis produces four daughter cells, mitosis two.

Daughter cells of meiosis are haploid ( $n$ ); of mitosis, diploid.

# General Comparison <sub>2</sub>

## Comparison of meiosis and mitosis, continued.

- The daughter cells of meiosis are not genetically identical to each other or to the parent cell; the daughter cells of mitosis are.
- The specific differences between these nuclear divisions can be categorized according to **occurrence** and **process**.

# Occurrence

- Meiosis happens only in the reproductive organs and produces the gametes.
- Mitosis is more common; it occurs in all tissues during growth and repair.

# Process: Comparison of Meiosis I with Mitosis <sub>1</sub>

Events that distinguish meiosis I from mitosis.

- Homologous chromosomes pair and undergo crossing-over during prophase I of meiosis but not during mitosis.
- Paired homologous chromosomes align at the metaphase plate during metaphase I in meiosis; individual chromosomes align at the metaphase plate during metaphase in mitosis.

# Process: Comparison of Meiosis I with Mitosis <sub>2</sub>

Events that distinguish meiosis I from mitosis, continued.

- Homologous chromosomes (with centromeres intact) separate and move to opposite poles during anaphase I of meiosis.
- Centromeres split, and sister chromatids, now called chromosomes, move to opposite poles during anaphase in mitosis.

# Comparison of Meiosis I with Mitosis

## (Table 19.1)

**Table 19.1** Comparison of Meiosis I with Mitosis

Meiosis I	Mitosis
<i>Prophase I</i> Pairing of homologous chromosomes	<i>Prophase</i> No pairing of chromosomes
<i>Metaphase I</i> Homologous duplicated chromosomes at equator	<i>Metaphase</i> Duplicated chromosomes at equator
<i>Anaphase I</i> Homologous chromosomes separate.	<i>Anaphase</i> Sister chromatids separate, becoming daughter chromosomes, which move to the poles.
<i>Telophase I</i> Two haploid daughter cells	<i>Telophase</i> Two daughter cells, identical to the parent cell

# Process: Comparison of Meiosis II with Mitosis

- The events of meiosis II are like those of mitosis except that in meiosis II the nuclei are haploid.

# Comparison of Meiosis II with Mitosis (Table 19.2)

**Table 19.2** Comparison of Meiosis II with Mitosis

Meiosis II	Mitosis
<i>Prophase II</i> No pairing of chromosomes	<i>Prophase</i> No pairing of chromosomes
<i>Metaphase II</i> Haploid number of duplicated chromosomes at equator	<i>Metaphase</i> Duplicated chromosomes at equator
<i>Anaphase II</i> Sister chromatids separate, becoming daughter chromosomes, which move to the poles.	<i>Anaphase</i> Sister chromatids separate, becoming daughter chromosomes, which move to the poles.
<i>Telophase II</i> Four haploid daughter cells	<i>Telophase</i> Two daughter cells, identical to the parent cell

# Check Your Progress 19.5

- List the similarities and differences between meiosis I and mitosis.
- List the similarities and differences between meiosis II and mitosis.
- Explain why a close examination of metaphase can indicate whether a cell is undergoing mitosis or meiosis.

# 19.6 Chromosome Inheritance <sup>1</sup>

## Learning Outcomes:

- Explain how nondisjunction produces monosomy and trisomy chromosome conditions.
- Describe the causes and consequences of trisomy 21.
- List the major syndromes associated with changes in the number of sex chromosomes.
- Describe the effects of deletions, duplications, inversions, and translocations on chromosome structure.

# 19.6 Chromosome Inheritance <sup>2</sup>

Normally an individual possesses 22 pairs of autosomes and two sex chromosomes in their cells.

Each pair of these chromosomes carries genes for particular traits.

- These genes may be slightly different.
  - These gene variations are called **alleles**.
  - Changes in chromosome number or structure may change the combination of alleles for a trait.
    - This has a detrimental effect in most cases.

# Changes in Chromosome Number <sup>1</sup>

Some individuals are born with either too many or too few autosomes or sex chromosomes.

Caused by **nondisjunction** during meiosis I or meiosis II.

- During meiosis I, the homologous chromosomes fail to separate correctly.
- During meiosis II, the daughter chromosomes fail to separate.

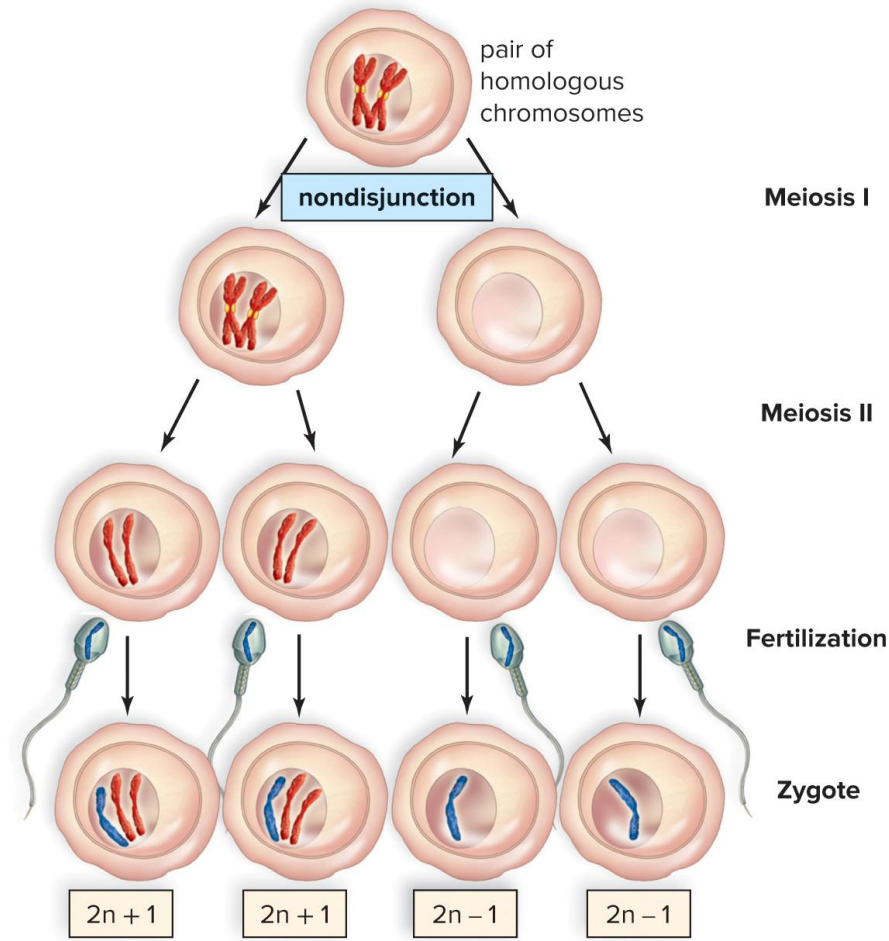
# Changes in Chromosome Number <sub>2</sub>

**Trisomy**—one type of chromosome is present in three copies ( $2n + 1$ ).

**Monosomy**—one type of chromosome is present in a single copy ( $2n - 1$ ).

- That is, if an egg with 22 chromosomes (versus 23) is fertilized with a normal sperm.

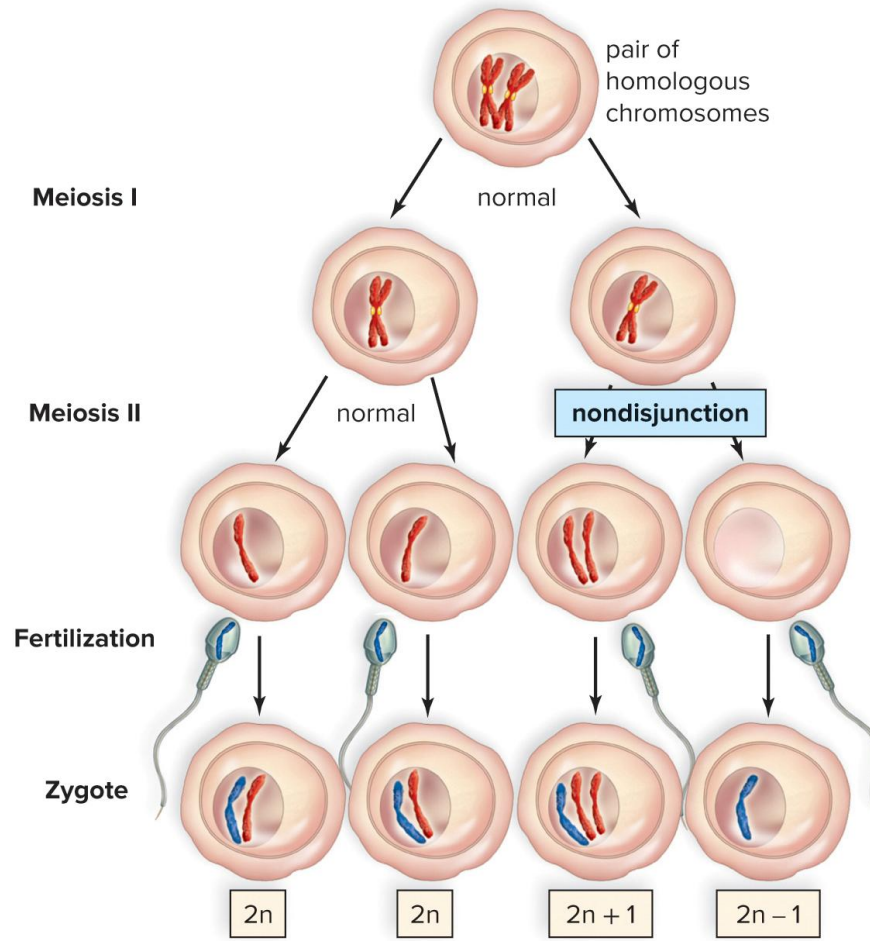
# Consequences of Nondisjunction During Meiosis I (Figure 19.17a)



a.

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# Consequences of Nondisjunction During Meiosis II (Figure 19.17b)



b.

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# Changes in Chromosome Number <sup>3</sup>

An abnormal number of autosomes causes a developmental abnormality.

Monosomy of all but the X chromosome is fatal.

Trisomy is usually fatal, though there are some exceptions.

- Among autosomal trisomies, only trisomy 21 (Down syndrome) has a chance of survival after birth.

# Changes in Chromosome Number <sup>4</sup>

The chances of survival are greater when trisomy or monosomy involves the sex chromosomes.

In normal XX females, one of the X chromosomes is called a **Barr body**, which is inactive.

- Female cells function with a single X chromosome just like males do.
  - This is most likely the reason that a zygote with one X chromosome (**Turner syndrome**) can survive.

# Changes in Chromosome Number <sup>5</sup>

Trisomy or monosomy of sex chromosomes, continued.

All extra X chromosomes become Barr bodies; so poly-X females and XXY males are survivable.

An extra Y chromosome, called **Jacobs syndrome (XYY)**, is survivable because the Y chromosome carries few genes.

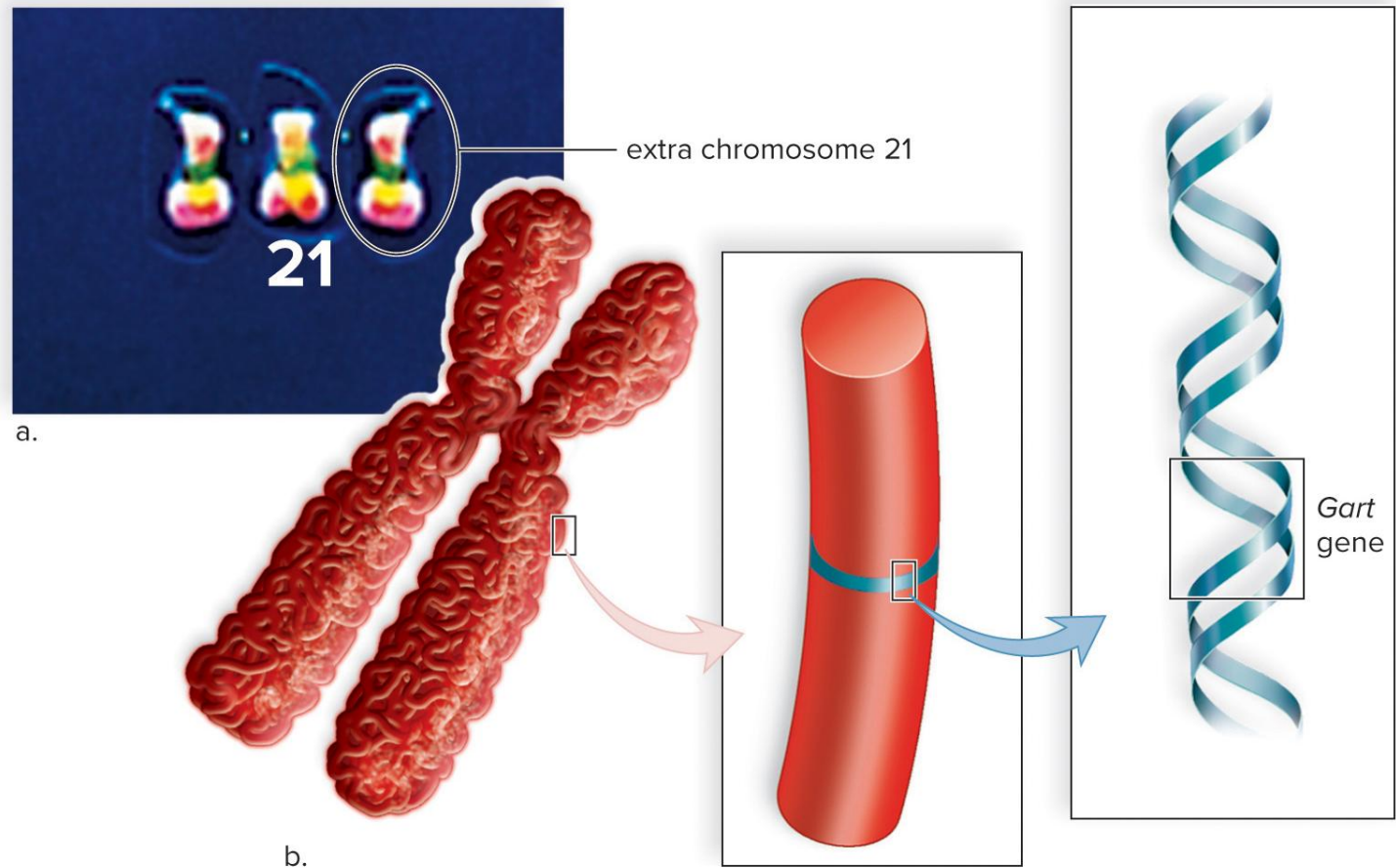
- Occurs from nondisjunction during meiosis II of spermatogenesis.

# Down Syndrome: An Autosomal Trisomy

**Down syndrome (trisomy 21)**—the most common autosomal trisomy.

- Three copies of chromosome 21.
- A woman over 40 is more likely to have a Down syndrome child.
- Characteristics: short stature; eyelid fold; flattened facial profile; stubby fingers; a wide gap between the first and second toes; a large, fissured tongue; a round head; a palm crease known as the single transverse palmar crease (STPC).
- Individuals may experience developmental delays and intellectual disability, which vary in severity.

# Down Syndrome (Figure 19.18)



# Changes in Sex Chromosome Number <sup>1</sup>

- Nondisjunction during oogenesis or spermatogenesis can result in gametes that have too few or too many sex chromosomes.
- **Syndrome**—a group of symptoms that always occur together.

# Changes in Sex Chromosome Number <sub>2</sub>

The presence of a Y chromosome, not the number of X chromosomes, determines maleness.

- The *SRY* gene produces a hormone called **testis-determining factor**, which is important in the development of male sex organs.

# Turner Syndrome

## **Turner syndrome (XO).**

- Are female; has only one X chromosome.
- physical features: short stature, broad chest, and folds of skin on the back of the neck.
- The ovaries, uterine tubes, and uterus are very small and underdeveloped; they do not undergo puberty or menstruate, and their breasts do not develop.
- Do not have an intellectual disability and can lead healthy lives if they receive hormone supplements.

# Klinefelter Syndrome <sup>1</sup>

## **Klinefelter syndrome (47, XXY).**

- Are male, with two X chromosomes and one Y chromosome.
- Symptoms and characteristics: testes and prostate gland are underdeveloped and facial hair is lacking; may exhibit breast development; have large hands and feet; have very long arms and legs.
- Slow to learn but do not have an intellectual disability unless they inherit more than two X chromosomes.

# Klinefelter Syndrome <sup>2</sup>

## **Klinefelter syndrome (47, XXY), continued.**

Have an increased risk of breast cancer, osteoporosis, and lupus.

Typically do not need medical treatment, but testosterone therapy helps increase muscle strength, sex drive, and concentration ability.

- Testosterone treatment does not reverse the sterility due to incomplete testicle development.

# Females with Poly-X Syndrome

## **Female poly-X syndrome.**

More than two X chromosomes and extra Barr bodies.

No distinctive appearance aside from being tall and thin.

- May experience delayed motor and language development, but no intellectual disabilities.
- Their children usually have a normal karyotype.

Females with more than three X chromosomes are rare.

# Jacobs Syndrome

## **Jacobs syndrome (XYY).**

- Can only result from nondisjunction during spermatogenesis.
- Males with this syndrome are usually taller than average, have persistent acne, and tend to experience speech and reading problems, but they are fertile and may have children.

# Changes in Chromosome Structure <sup>1</sup>

Changes in chromosome structure.

Environmental agents such as radiation, organic chemicals, or viruses can cause chromosomes to break.

- Ordinarily, when breaks occur the two broken ends reunite.
- But sometimes the broken ends do not rejoin in the same pattern as before.

# Changes in Chromosome Structure <sup>2</sup>

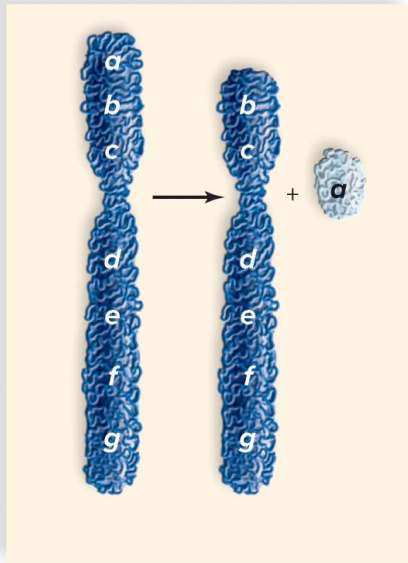
Changes in chromosome structure, continued.

Include **deletions, duplications, inversions, and translocations** of chromosome segments.

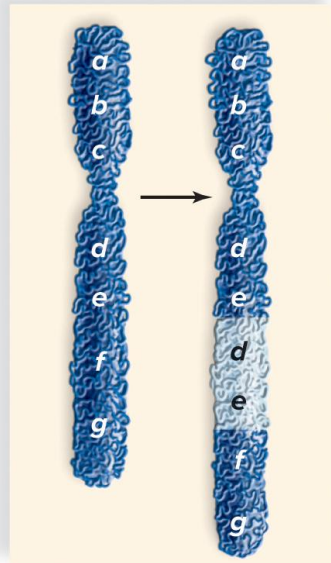
**Deletion**—a part of a chromosome breaks off.

- Even when only one member of a pair of chromosomes is affected, a deletion often causes abnormalities.

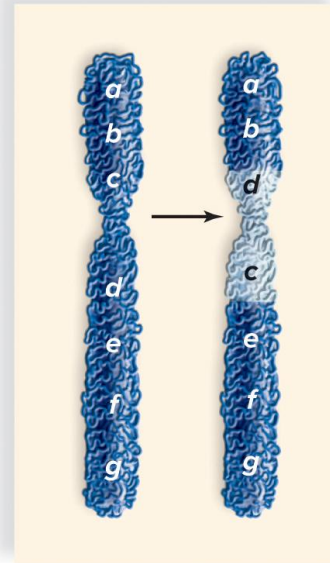
# The Various Types of Chromosomal Mutations (Figure 19.19)



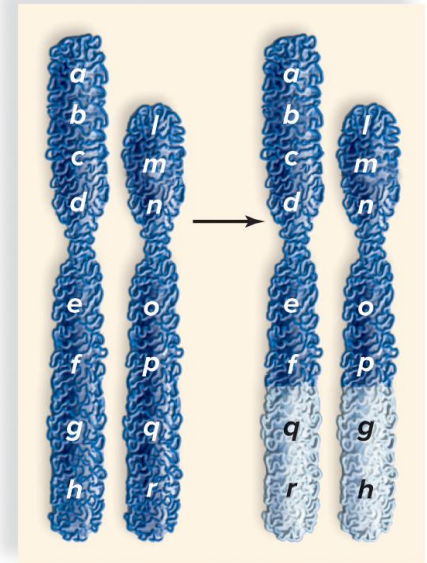
a. Deletion



b. Duplication



c. Inversion



d. Translocation

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# Changes in Chromosome Structure <sup>3</sup>

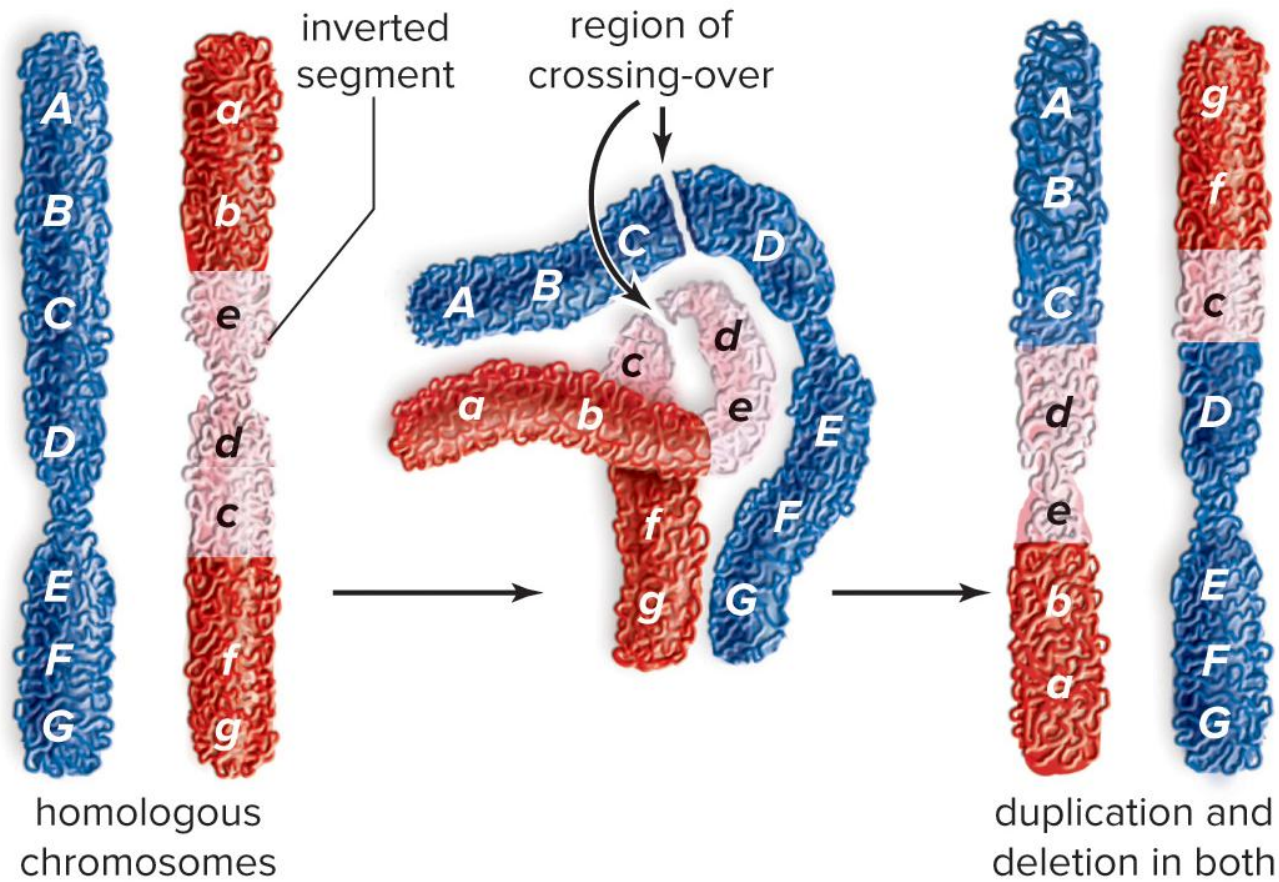
Changes in chromosome structure, concluded.

**Duplication**—the presence of a chromosomal segment more than once in the same chromosome.

**Inversion**—a segment of a chromosome is inverted.

- Most do not present problems because all of the genes are present.

# A Chromosomal Inversion (Figure 19.20)



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# Changes in Chromosome Structure <sup>4</sup>

**Translocation**—the movement of a segment from one chromosome to another nonhomologous chromosome.

- In 5% of cases, a translocation that occurred in a previous generation between chromosomes 21 and 14 is the cause of Down syndrome.

# Human Syndromes <sup>1</sup>

## Deletion syndromes.

**Williams syndrome**—chromosome 7 loses an end piece.

- Turned-up nose, wide mouth, small chin, and large ears.
- Often have learning disabilities but excellent verbal and musical abilities.
- The gene for elastin is missing; this affects the cardiovascular system and causes skin to age prematurely.
- Other characteristics: friendly and outgoing in temperament; anxiety, phobias, hyperactivity, and difficulty with attention and concentration.

# Human Syndromes <sub>2</sub>

## **Deletion syndromes, continued.**

**Cri du chat (“cat’s cry”) syndrome**—chromosome 5 is missing an end piece.

- Small head, intellectual disabilities, facial abnormalities.
- Abnormal development of the glottis and larynx results in a cry that resembles that of a cat.

# Human Syndromes <sup>3</sup>

## **Translocation syndromes.**

When someone inherits both translocated chromosomes, they have the normal amount of genetic material, so are healthy.

- Unless the chromosome exchange broke an allele into two pieces.

When someone inherits only one of them, they will have only one copy of certain alleles and three copies of other alleles.

# Human Syndromes <sup>4</sup>

## Translocation syndromes, continued.

Alagille syndrome—a translocation between chromosomes 2 and 20.

- Exhibit a combination of heart defects called **tetralogy of Fallot**.
- **Clubbing** (widening of the fingertips) may also occur.

Translocations can also cause cancer.

# Check Your Progress 19.6

- Explain what causes an individual to have an abnormal number of chromosomes.
- Describe the specific chromosome abnormality of a person with Down syndrome.
- Distinguish between a translocation and an inversion.
- Describe the nondisjunction events that would cause Turner and Jacobs syndromes.



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