Cancer cells
- start as normal body cells,
- get genetic mutations,
- divide uncontrollably, and
- run amok, causing disease.

In a healthy body, cell division allows for
- growth,
- the replacement of damaged cells, and
- development from an embryo into an adult.

In sexually reproducing organisms, eggs and sperm result from
- mitosis and
- meiosis.

Organisms reproduce their own kind, a key characteristic of life.

Cell division
- is reproduction at the cellular level,
- requires the duplication of chromosomes, and
- sorts new sets of chromosomes into the resulting pair of daughter cells.

Cell division is used
- for reproduction of single-celled organisms,
- growth of multicellular organisms from a fertilized egg into an adult,
- repair and replacement of cells, and
- sperm and egg production.
8.1 Cell division plays many important roles in the lives of organisms

- Living organisms reproduce by two methods.
  - **Asexual reproduction**
    - produces offspring that are identical to the original cell or organism and
    - involves inheritance of all genes from one parent.
  - **Sexual reproduction**
    - produces offspring that are similar to the parents, but show variations in traits and
    - involves inheritance of unique sets of genes from two parents.
8.2 Prokaryotes reproduce by binary fission

- Prokaryotes (bacteria and archaea) reproduce by binary fission ("dividing in half").
- The chromosome of a prokaryote is
  - a singular circular DNA molecule associated with proteins and
  - much smaller than those of eukaryotes.
- Binary fission of a prokaryote occurs in three stages:
  1. duplication of the chromosome and separation of the copies,
  2. continued elongation of the cell and movement of the copies, and
  3. division into two daughter cells.

8.3 The large, complex chromosomes of eukaryotes duplicate with each cell division

- Eukaryotic cells
  - have more genes, and
  - store most of their genes on multiple chromosomes within the nucleus.
- Eukaryotic chromosomes are composed of chromatin consisting of
  - one long DNA molecule and
  - proteins that help maintain the chromosome structure and control the activity of its genes.
- To prepare for division, the chromatin becomes
  - highly compact and
  - visible with a microscope.
Before a eukaryotic cell begins to divide, it duplicates all of its chromosomes, resulting in:
- two copies called *sister chromatids*
- joined together by a narrowed “waist” called the *centromere*.

When a cell divides, the sister chromatids:
- separate from each other, now called chromosomes, and
- sort into separate daughter cells.
8.4 The cell cycle multiplies cells

- The cell cycle is an ordered sequence of events that extends
  - from the time a cell is first formed from a dividing parent cell
  - until its own division.
- The cell cycle consists of two stages, characterized as follows:
  1. Interphase: duplication of cell contents
     - G₁—growth, increase in cytoplasm
     - S—duplication of chromosomes
     - G₂—growth, preparation for division
  2. Mitotic phase: division
     - Mitosis—division of the nucleus
     - Cytokinesis—division of cytoplasm
Mitosis progresses through a series of stages:
- prophase,
- metaphase,
- anaphase, and
- telophase.

Cytokinesis often overlaps telophase.

A mitotic spindle is
- Pull apart chromosomes,
- made of microtubules, and
- Made by centrosomes – found only in animal cells

Interphase
- Cytoplasm and organelles double,
- two centrosomes form,
- chromosomes duplicate in the nucleus during the S phase, and
- nucleoli are visible.
8.5 Cell division is a continuum of dynamic changes

- **Prophase**
  - Microtubules begin to emerge from centrosomes, forming the spindle.
  - In the nucleus
    - chromosomes coil and become compact and
    - nucleoli disappear.
8.5 Cell division is a continuum of dynamic changes

- **Metaphase**
  - Mitotic spindle is fully formed.
  - Chromosomes align at the cell equator.

- **Anaphase**
  - Sister chromatids separate at the centromeres.
  - Daughter chromosomes move to opposite poles of the cell by motor proteins and microtubules shorten.
  - The cell elongates

- **Telophase**
  - The cell continues to elongate.
  - The nuclear envelope forms around chromosomes at each pole.
  - Chromatin uncoils and nucleoli reappear.
  - The spindle disappears.

- **During cytokinesis**, the cytoplasm is divided into separate cells.

- The process of cytokinesis differs in animal and plant cells.
In animal cells, cytokinesis occurs as:
1. a cleavage furrow forms from a contracting ring of microfilaments and
2. the cleavage furrow deepens to separate the contents into two cells.

In plant cells, cytokinesis occurs as:
1. a cell plate forms in the middle, from vesicles containing cell wall material,
2. the cell plate grows outward to reach the edges, dividing the contents into two cells,
3. each cell now possesses a plasma membrane and cell wall.
8.7 Anchorage, cell density, and chemical growth factors affect cell division

- The cells within an organism’s body divide and develop at different rates.
- Cell division is controlled by
  - the presence of essential nutrients,
  - **growth factors**, proteins that stimulate division,
  - **density-dependent inhibition**, in which crowded cells stop dividing, and
  - **anchorage dependence**, the need for cells to be in contact with a solid surface to divide.
8.8 Growth factors signal the cell cycle control system

- The **cell cycle control system** is a cycling set of molecules in the cell that
  - triggers and
  - coordinates key events in the cell cycle.
- Checkpoints in the cell cycle can
  - stop an event or
  - signal an event to proceed.

8.8 Growth factors signal the cell cycle control system

- There are three major checkpoints in the cell cycle.
  1. G₁ checkpoint
     - allows entry into the S phase or
     - causes the cell to leave the cycle, entering a nondividing G₀ phase.
  2. G₂ checkpoint, and
  3. M checkpoint.
- Research on the control of the cell cycle is one of the hottest areas in biology today.
8.9 CONNECTION: Growing out of control, cancer cells produce malignant tumors

- Cancer currently claims the lives of 20% of the people in the United States and other industrialized nations.
- Cancer cells escape controls on the cell cycle.
- Cancer cells
  - divide rapidly, often in the absence of growth factors,
  - spread to other tissues through the circulatory system, and
  - grow without being inhibited by other cells.
A tumor is an abnormally growing mass of body cells.
- Benign tumors remain at the original site.
- Malignant tumors spread to other locations, called metastasis.

Cancers are named according to the organ or tissue in which they originate.
- Carcinomas arise in external or internal body coverings.
- Sarcomas arise in supportive and connective tissue.
- Leukemias and lymphomas arise from blood-forming tissues.

Cancer treatments
- Localized tumors can be
  - removed surgically and/or
  - treated with concentrated beams of high-energy radiation.
- Chemotherapy is used for metastatic tumors.
In humans, somatic cells have
- 23 pairs of homologous chromosomes and
- one member of each pair from each parent.

The human sex chromosomes X and Y differ in size and genetic composition.

The other 22 pairs of chromosomes are autosomes with the same size and genetic composition.

Homologous chromosomes are matched in
- length,
- centromere position, and
- gene locations.

A locus (plural, loci) is the position of a gene.

Different versions of a gene may be found at the same locus on maternal and paternal chromosomes.
An organism’s **life cycle** is the sequence of stages leading
- from the adults of one generation
- to the adults of the next.

Humans and many animals and plants are diploid, with body cells that have
- two sets of chromosomes,
- one from each parent.

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**8.12 Gametes have a single set of chromosomes**

- Meiosis is a process that converts diploid nuclei to haploid nuclei.
  - **Diploid cells** have two homologous sets of chromosomes.
  - **Haploid cells** have one set of chromosomes.
  - Meiosis occurs in the sex organs, producing gametes—sperm and eggs.
- **Fertilization** is the union of sperm and egg.
- The **zygote** has a diploid chromosome number, one set from each parent.
8.12 Gametes have a single set of chromosomes

- All sexual life cycles include an alternation between
  - a diploid stage and
  - a haploid stage.
- Producing haploid gametes prevents the chromosome number from doubling in every generation.
8.13 Meiosis reduces the chromosome number from diploid to haploid

- **Meiosis** is a type of cell division that produces haploid gametes in diploid organisms.
- Two haploid gametes combine in fertilization to restore the diploid state in the zygote.

8.13 Meiosis reduces the chromosome number from diploid to haploid

- Meiosis and mitosis are preceded by the duplication of chromosomes. However,
  - meiosis is followed by two consecutive cell divisions and
  - mitosis is followed by only one cell division.
- Because in meiosis, one duplication of chromosomes is followed by two divisions, each of the four daughter cells produced has a haploid set of chromosomes.

8.13 Meiosis reduces the chromosome number from diploid to haploid

- **Meiosis I – Prophase I** – events occurring in the nucleus.
  - Chromosomes coil and become compact.
  - Homologous chromosomes come together as pairs by **synapsis**.
  - Each pair, with four chromatids, is called a tetrad.
  - Nonsister chromatids exchange genetic material by crossing over.
8.13 Meiosis reduces the chromosome number from diploid to haploid

- **Meiosis I – Metaphase I** – Tetrads align at the cell equator.
- **Meiosis I – Anaphase I** – Homologous pairs separate and move toward opposite poles of the cell.

8.13 Meiosis reduces the chromosome number from diploid to haploid

- **Meiosis I – Telophase I**
  - Duplicated chromosomes have reached the poles.
  - A nuclear envelope re-forms around chromosomes in some species.
  - Each nucleus has the haploid number of chromosomes.
Meiosis II follows meiosis I without chromosome duplication.

Each of the two haploid products enters meiosis II.

**Meiosis II – Prophase II**
- Chromosomes coil and become compact (if uncoiled after telophase I).
- Nuclear envelope, if re-formed, breaks up again.
8.13 Meiosis reduces the chromosome number from diploid to haploid

- **Meiosis II – Metaphase II** – Duplicated chromosomes align at the cell equator.

- **Meiosis II – Anaphase II**
  - Sister chromatids separate and
  - chromosomes move toward opposite poles.

- **Meiosis II – Telophase II**
  - Chromosomes have reached the poles of the cell.
  - A nuclear envelope forms around each set of chromosomes.
  - With cytokinesis, four haploid cells are produced.
Mitosis and meiosis both
- begin with diploid parent cells that
- have chromosomes duplicated during the previous interphase.

However the end products differ.
- Mitosis produces two genetically identical diploid somatic daughter cells.
- Meiosis produces four genetically unique haploid gametes.
Genetic variation in gametes results from
- independent orientation at metaphase I and
- random fertilization.
- Random fertilization – The combination of each unique sperm with each unique egg increases genetic variability.

Independent orientation at metaphase I
- Each pair of chromosomes independently aligns at the cell equator.
- There is an equal probability of the maternal or paternal chromosome facing a given pole.
- The number of combinations for chromosomes packaged into gametes is $2^n$ where $n$ = haploid number of chromosomes.
8.16 Homologous chromosomes may carry different versions of genes

- Separation of homologous chromosomes during meiosis can lead to genetic differences between gametes.
  - Homologous chromosomes may have different versions of a gene at the same locus.
  - One version was inherited from the maternal parent and the other came from the paternal parent.
  - Since homologues move to opposite poles during anaphase I, gametes will receive either the maternal or paternal version of the gene.
Genetic recombination is the production of new combinations of genes due to crossing over.

Crossing over is an exchange of corresponding segments between separate (nonsister) chromatids on homologous chromosomes.

- Nonsister chromatids join at a chiasma (plural, chiasmata), the site of attachment and crossing over.
- Corresponding amounts of genetic material are exchanged between maternal and paternal (nonsister) chromatids.
Figure 8.17B_3

Separation of chromatids at anaphase II and completion of meiosis

- Parental type of chromosome
- Recombinant chromosome
- Recombinant chromosome
- Parental type of chromosome
- Gametes of four genetic types

8.18 A karyotype is a photographic inventory of an individual’s chromosomes

- A **karyotype** is an ordered display of magnified images of an individual’s chromosomes arranged in pairs.

- **Karyotypes**
  - are often produced from dividing cells arrested at metaphase of mitosis and
  - allow for the observation of
    - homologous chromosome pairs,
    - chromosome number, and
    - chromosome structure.

- Blood culture
- Packed red and white blood cells
- Hypotonic solution
- Fixative
- Stain
- Fluid
- Centrifuge

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Trisomy 21
- involves the inheritance of three copies of chromosome 21 and
- is the most common human chromosome abnormality.

Trisomy 21, called Down syndrome, produces a characteristic set of symptoms, which include:
- mental retardation,
- characteristic facial features,
- short stature,
- heart defects,
- susceptibility to respiratory infections, leukemia, and Alzheimer’s disease, and
- shortened life span.

The incidence increases with the age of the mother.
8.20 Accidents during meiosis can alter chromosome number

- **Nondisjunction** is the failure of chromosomes or chromatids to separate normally during meiosis. This can happen during
  - meiosis I, if both members of a homologous pair go to one pole or
  - meiosis II if both sister chromatids go to one pole.
- Fertilization after nondisjunction yields zygotes with altered numbers of chromosomes.
8.21 CONNECTION: Abnormal numbers of sex chromosomes do not usually affect survival

- Sex chromosome abnormalities tend to be less severe, perhaps because of
  - the small size of the Y chromosome or
  - X-chromosome inactivation.

8.21 CONNECTION: Abnormal numbers of sex chromosomes do not usually affect survival

- The following table lists the most common human sex chromosome abnormalities. In general,
  - a single Y chromosome is enough to produce "maleness," even in combination with several X chromosomes, and
  - the absence of a Y chromosome yields "femaleness."
Table 8.21

<table>
<thead>
<tr>
<th>Sex Chromosomes</th>
<th>Syndrome</th>
<th>Origin of Egg or Sperm Formation</th>
<th>Frequency in Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>XY</td>
<td>Normal (male)</td>
<td>Normal</td>
<td>100%</td>
</tr>
<tr>
<td>XY</td>
<td>Male (normal male)</td>
<td>Normal</td>
<td>100%</td>
</tr>
<tr>
<td>XX</td>
<td>Female (normal female)</td>
<td>Normal</td>
<td>100%</td>
</tr>
<tr>
<td>XO</td>
<td>Female (nondisjunction)</td>
<td>Normal</td>
<td>100%</td>
</tr>
</tbody>
</table>

8.22 EVOLUTION CONNECTION: New species can arise from errors in cell division

- Errors in mitosis or meiosis may produce polyploid species, with more than two chromosome sets.
- The formation of polyploid species is
  - widely observed in many plant species but
  - less frequently found in animals.
Chromosome breakage can lead to rearrangements that can produce
- genetic disorders or,
- if changes occur in somatic cells, cancer.

These rearrangements may include
- a deletion, the loss of a chromosome segment,
- a duplication, the repeat of a chromosome segment,
- an inversion, the reversal of a chromosome segment, or
- a translocation, the attachment of a segment to a nonhomologous chromosome that can be reciprocal.

Chronic myelogenous leukemia (CML)
- is one of the most common leukemias,
- affects cells that give rise to white blood cells (leukocytes), and
- results from part of chromosome 22 switching places with a small fragment from a tip of chromosome 9.
1. Compare the parent-offspring relationship in asexual and sexual reproduction.

2. Explain why cell division is essential for prokaryotic and eukaryotic life.

3. Explain how daughter prokaryotic chromosomes are separated from each other during binary fission.

4. Compare the structure of prokaryotic and eukaryotic chromosomes.

5. Describe the stages of the cell cycle.
You should now be able to

6. List the phases of mitosis and describe the events characteristic of each phase.
7. Explain cytokinesis in animal and plant cells.
8. Explain how anchorage, cell density, and chemical growth factors control cell division.
9. Explain how cancerous cells are different from healthy cells.
10. Describe the functions of mitosis.
11. Explain how chromosomes are paired.
12. Distinguish between somatic cells and gametes and between diploid cells and haploid cells.

You should now be able to

13. Explain why sexual reproduction requires meiosis.
14. List the phases of meiosis I and meiosis II and describe the events characteristic of each phase.
15. Compare mitosis and meiosis noting similarities and differences.
16. Explain how genetic variation is produced in sexually reproducing organisms.
17. Explain how and why karyotyping is performed.
18. Describe the causes and symptoms of Down syndrome.

You should now be able to

19. Describe the consequences of abnormal numbers of sex chromosomes.
20. Define nondisjunction, explain how it can occur, and describe what can result.
21. Explain how new species form from errors in cell division.
22. Describe the main types of chromosomal changes. Explain why cancer is not usually inherited.
Figure 8.UN01

Genetically identical daughter cells

S (DNA synthesis)

G1

G2

Mitosis (division of the nucleus)

Cytokinesis (division of the cytoplasm)

Figure 8.UN02

Haploid gametes (n = 23)

Egg cell

Sperm cell

Meiosis

Fertilization

Human life cycle

Multicellular diploid adults (2n = 46)

Diploid zygote (2n = 46)

Mitosis

Figure 8.UN03

<table>
<thead>
<tr>
<th>Number of chromosomal duplications</th>
<th>Mitosis</th>
<th>Meiosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cell divisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of daughter cells produced</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of chromosomes in the daughter cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How the chromosomes line up during metaphase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genetic relationship of the daughter cells to the parent cell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functions performed in the human body</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>