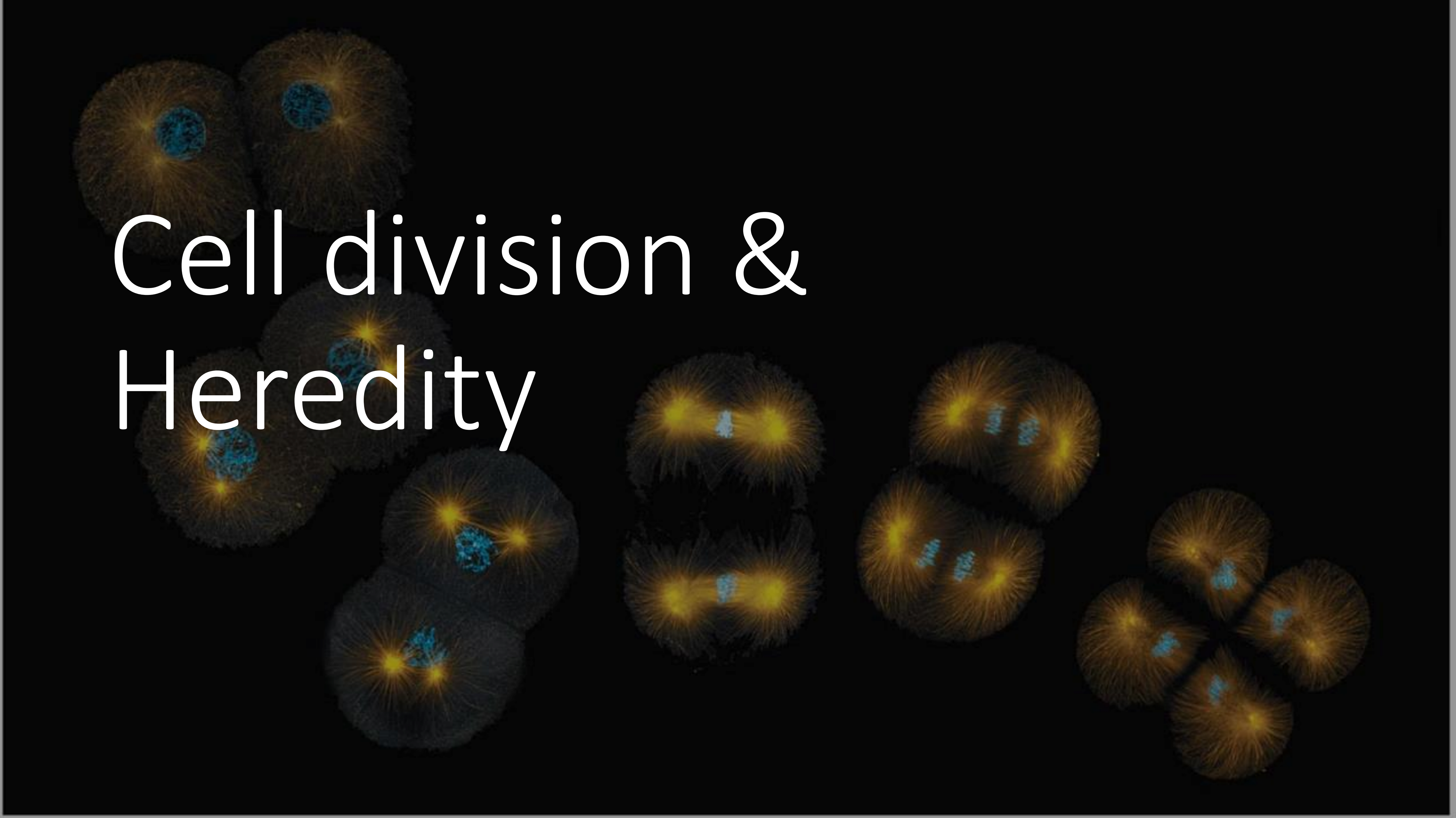
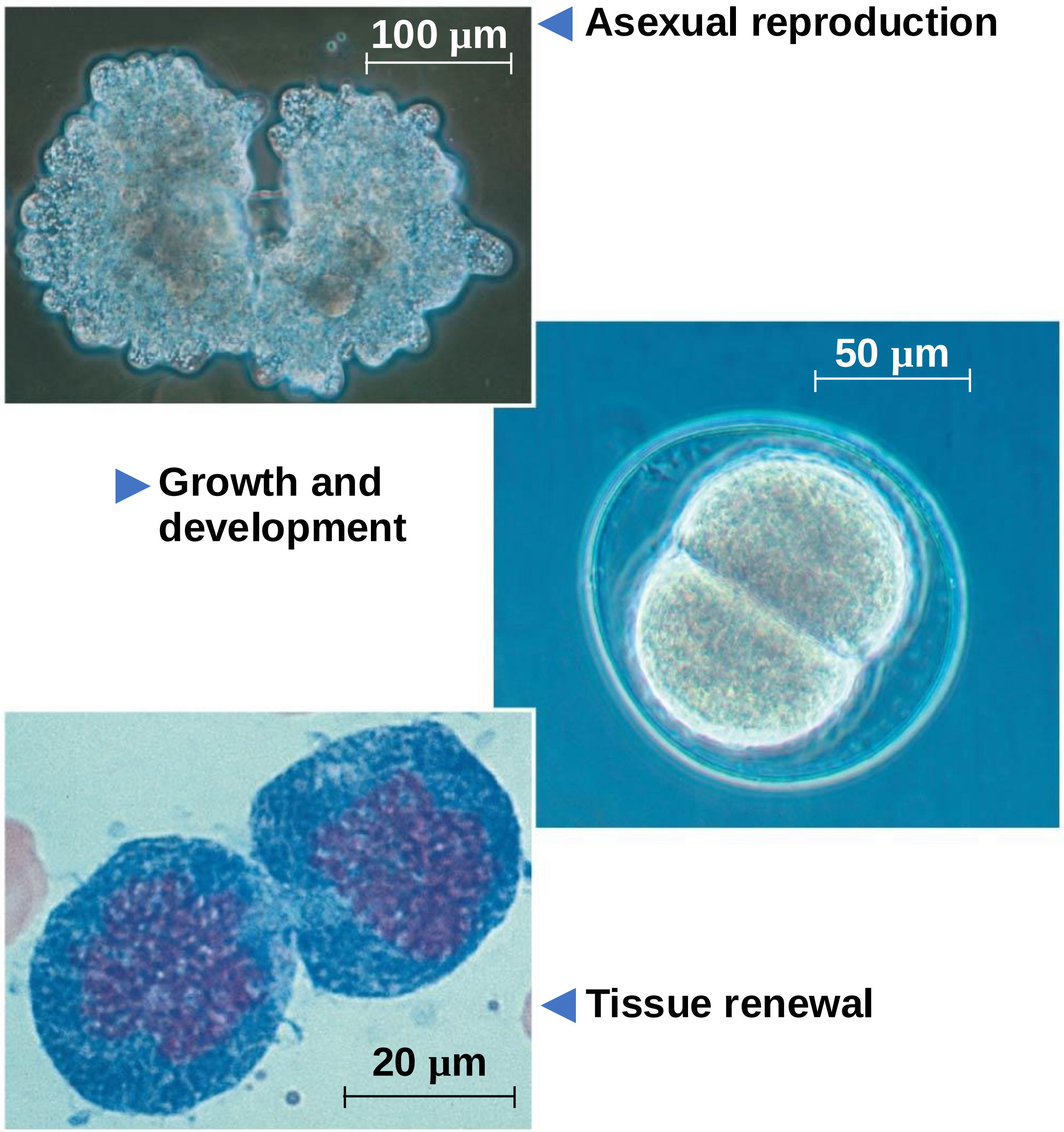
Cell division & Heredity



The Key Roles of Cell Division

- The ability of organisms to produce more of their own kind distinguishes living things from nonliving matter
- The continuity of life is based on the reproduction of cells, or **cell division**
- In eukaryotic and procaryotic **unicellular organisms**, division of one cell reproduces the entire organism
- Multicellular eukaryotes depend on cell division for:
  - development from a fertilized egg
  - growth
  - repair

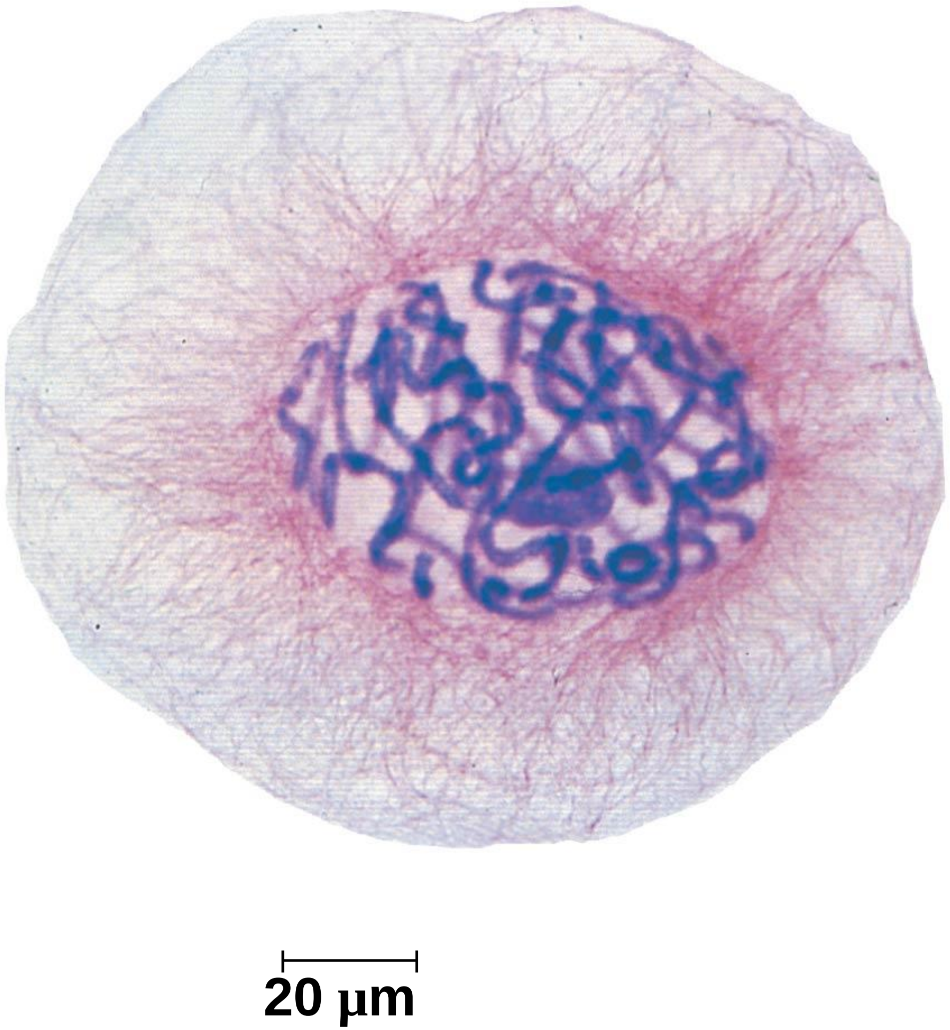


Most cell division results in genetically identical daughter cells

- Most cell division results in two daughter cells with identical genetic information, DNA
- The exception is meiosis, a special type of division that can produce sperm and egg cells

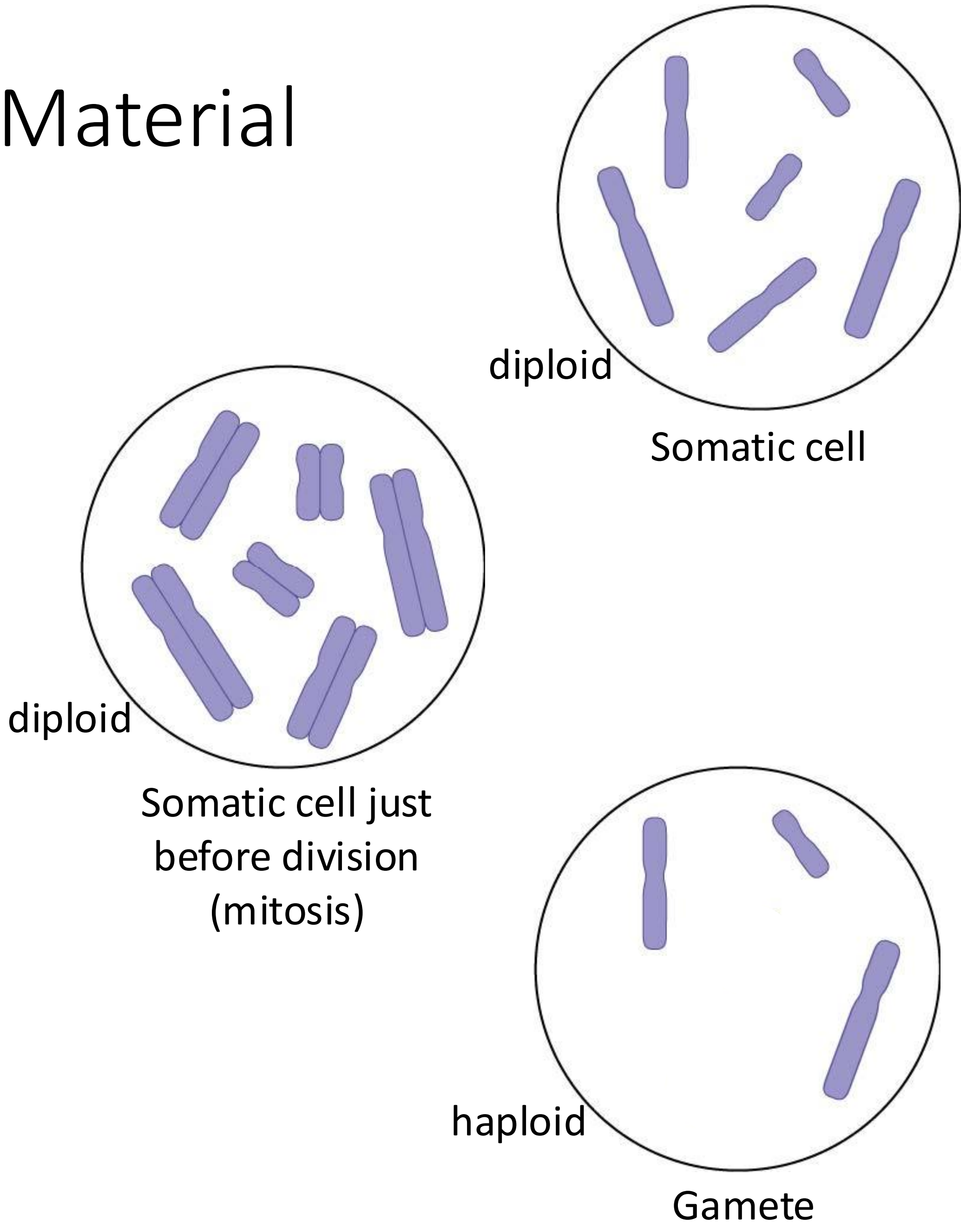
Cellular Organization of the Genetic Material

- All the DNA in a cell constitutes the cell's **genome**
- A genome can consist of a single DNA molecule (common in prokaryotic cells) or a number of DNA molecules (common in eukaryotic cells)
- DNA molecules in a cell are packaged into **chromosomes**



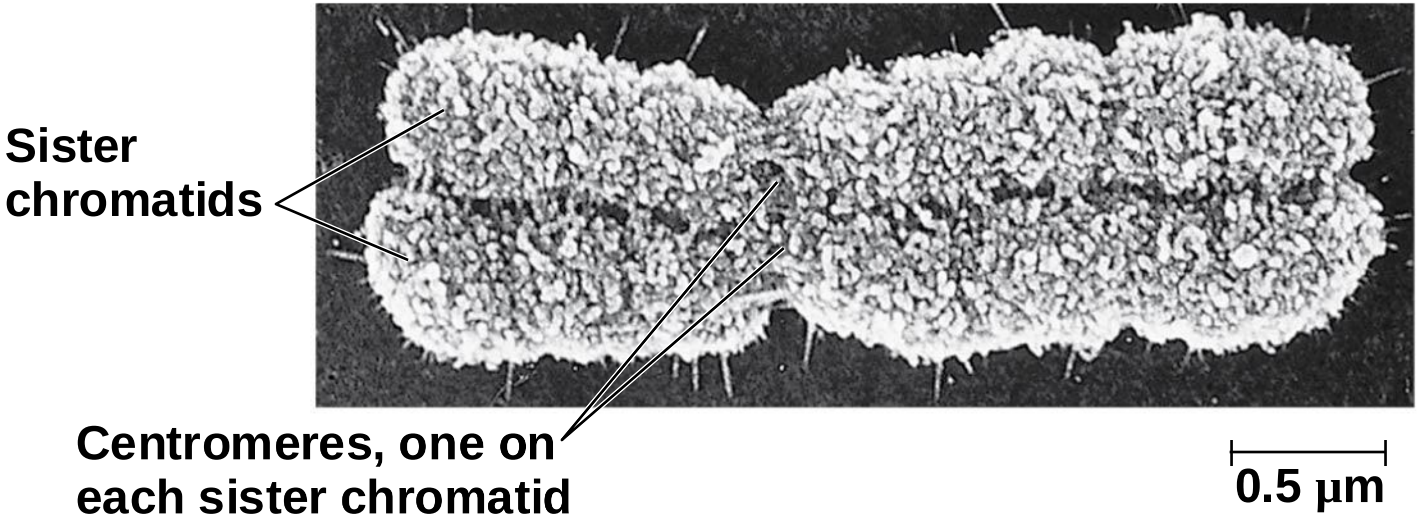
Cellular Organization of the Genetic Material

- Eukaryotic chromosomes consist of **chromatin**, a complex of DNA and protein that condenses during cell division
- Every eukaryotic species has a characteristic number of chromosomes in each cell nucleus
- **Somatic cells** (non-reproductive cells) have two sets of chromosomes – diploid
- **Gametes** (reproductive cells: sperm and eggs) have half as many chromosomes as somatic cells - haploid



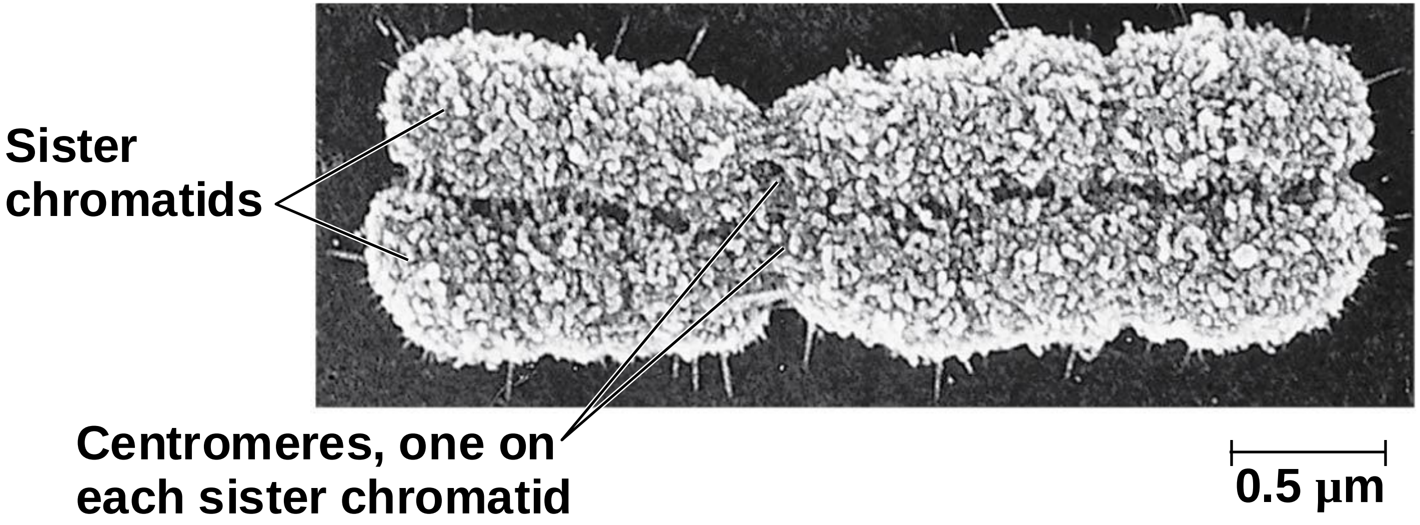
Distribution of Chromosomes During Eukaryotic Cell Division

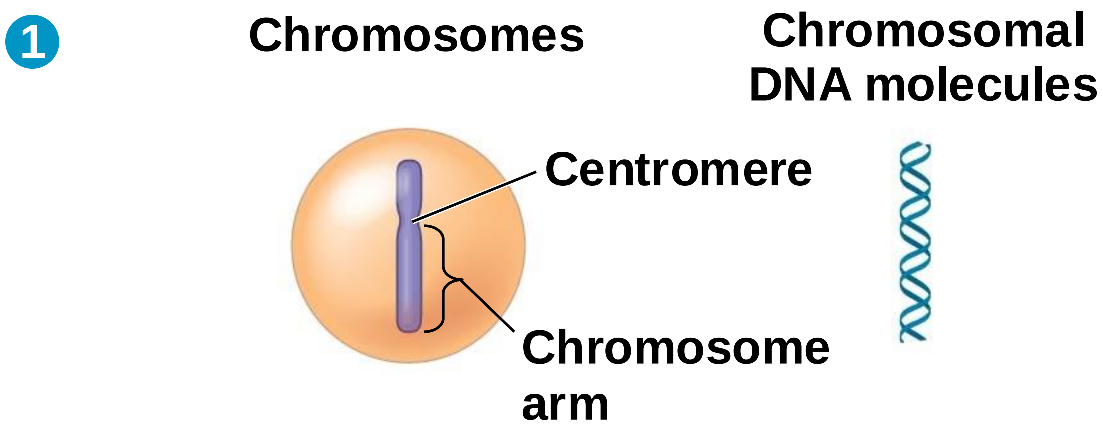
- In preparation for cell division, DNA is replicated and the chromosomes condense
- Each duplicated chromosome has two **sister chromatids** (joined copies of the original chromosome), attached along their lengths
- The **centromere** is the narrow "waist" of the duplicated chromosome, where the two chromatids are most closely attached

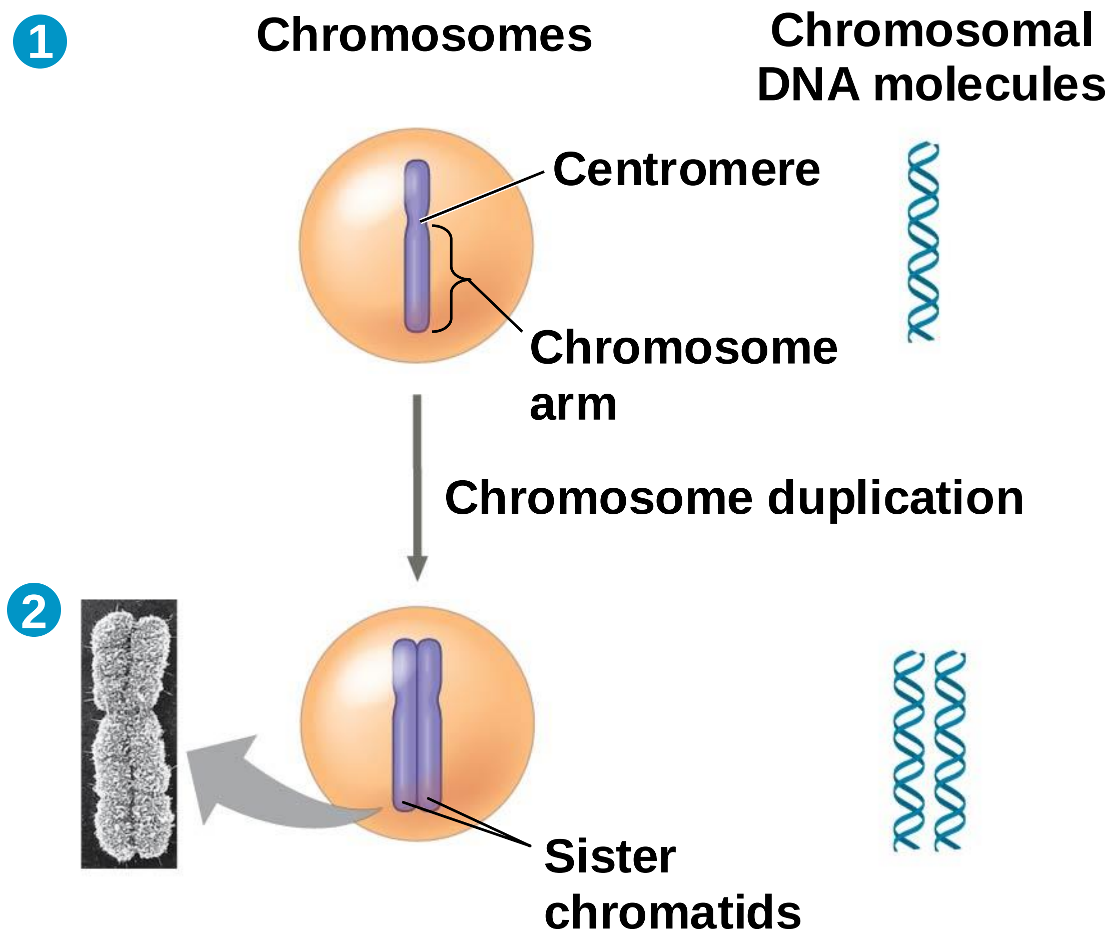


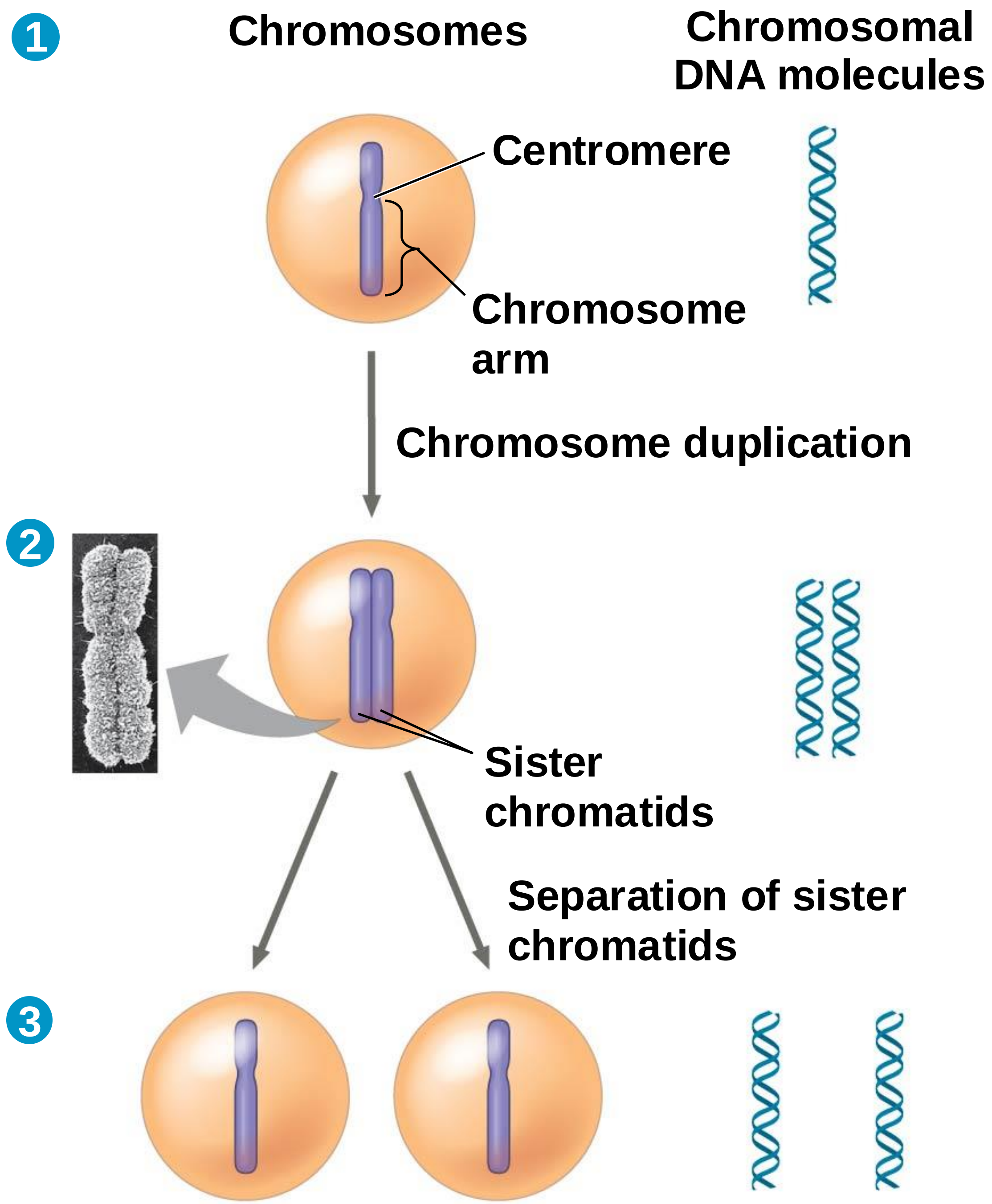
Distribution of Chromosomes During Eukaryotic Cell Division

- During cell division, the two sister chromatids of each duplicated chromosome separate and move into two nuclei




1
Chromosomes
Chromosomal
DNA molecules
Centromere
Chromosome
arm


1
Chromosomes
Chromosomal DNA molecules
Centromere
Chromosome arm
Chromosome duplication
2
Sister chromatids



1
Chromosomes
Chromosomal DNA molecules
Centromere
Chromosome arm
Chromosome duplication
2
Sister chromatids
Separation of sister chromatids
3

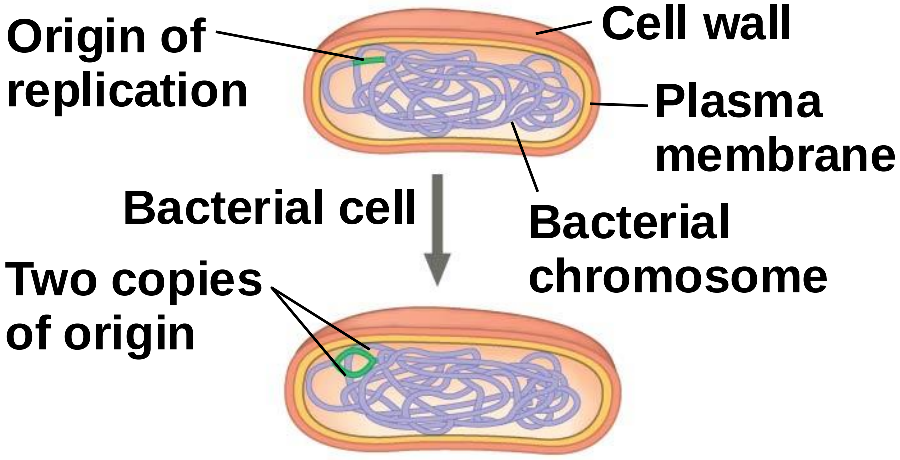
Chromosome Duplication

- Eukaryotic cell division consists of
  - **mitosis**, the division of the genetic material in the nucleus
  - **cytokinesis**, the division of the cytoplasm
- Gametes are produced by a variation of cell division called **meiosis**
- Meiosis yields non identical daughter cells that have half as many chromosomes as the parent cell

Binary Fission in Bacteria

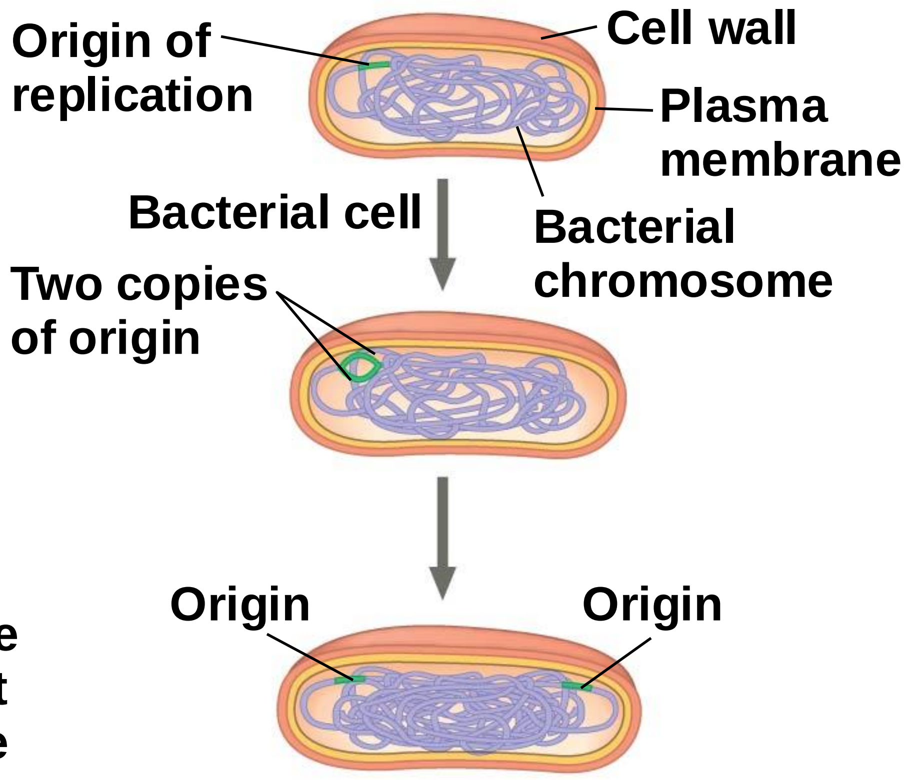
- Prokaryotes (bacteria and archaea) reproduce by a type of cell division called **binary fission**
- In binary fission, the chromosome replicates (beginning at the **origin of replication**), and the two daughter chromosomes actively move apart
- The plasma membrane pinches inward, dividing the cell into two

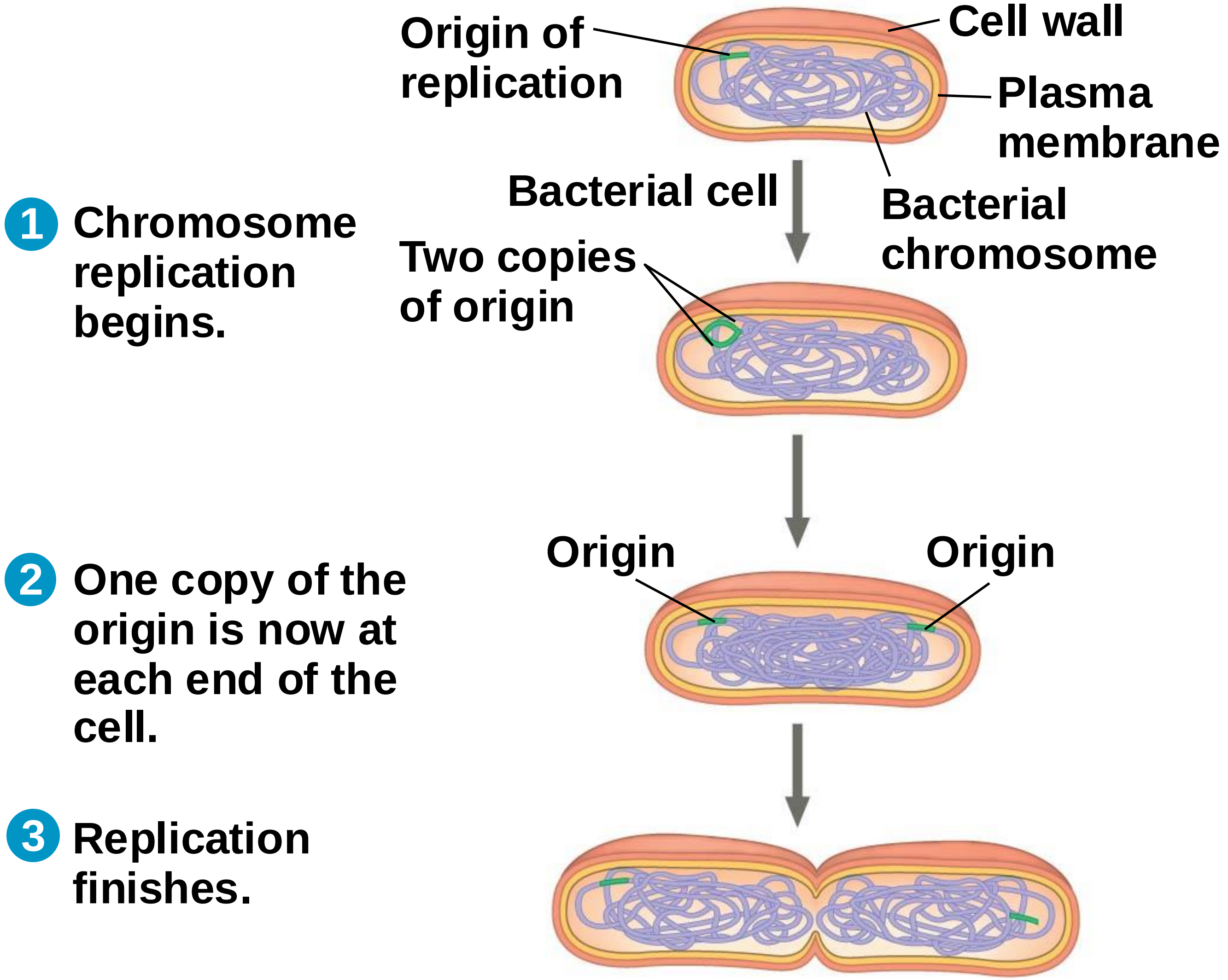
1 Chromosome replication begins.



1 Chromosome replication begins.

2 One copy of the origin is now at each end of the cell.



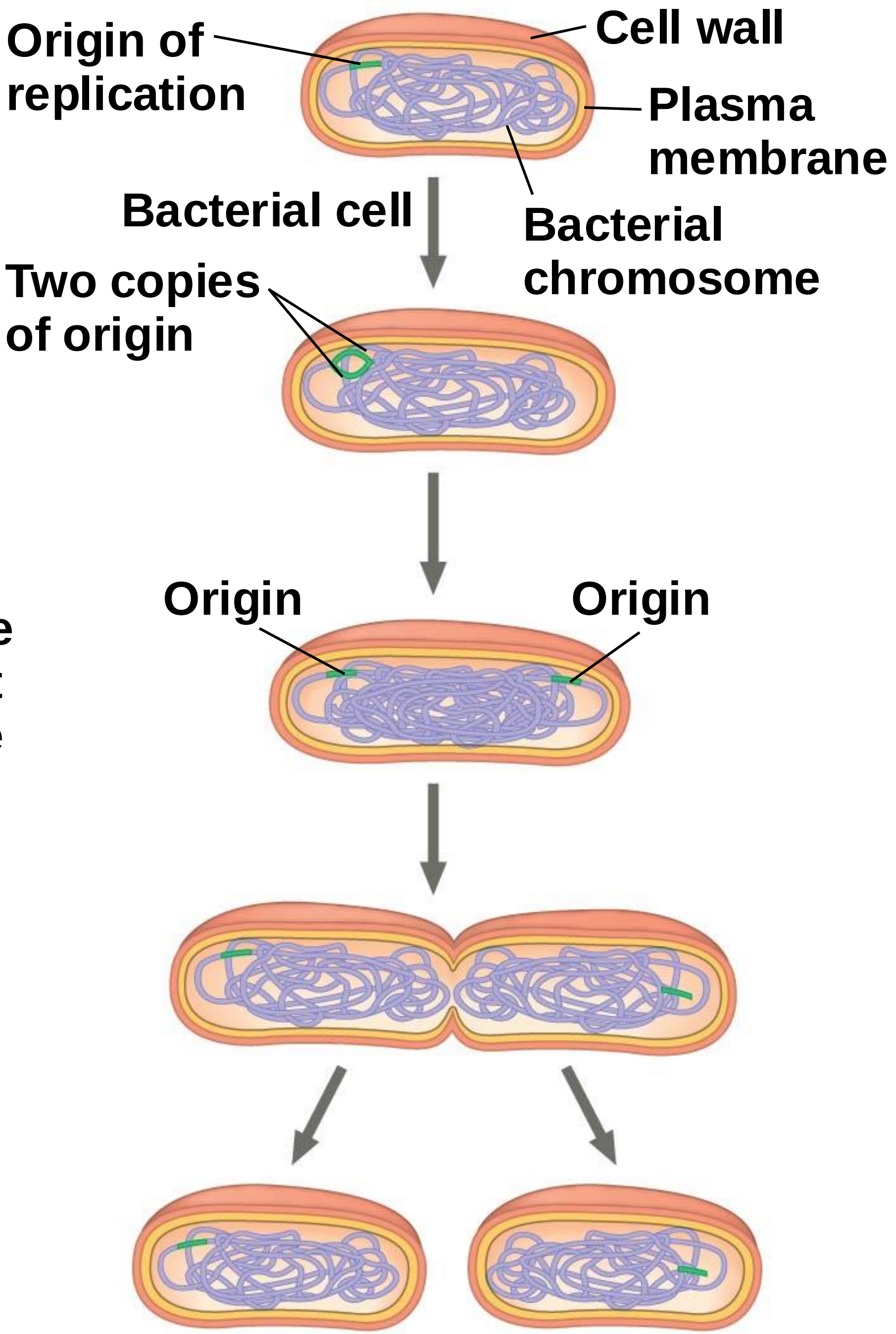

Origin of replication
Cell wall
Plasma membrane
Bacterial cell
Bacterial chromosome
1 Chromosome replication begins.
Two copies of origin
2 One copy of the origin is now at each end of the cell.
Origin
Origin
3 Replication finishes.

1 Chromosome replication begins.

2 One copy of the origin is now at each end of the cell.

3 Replication finishes.

4 Two daughter cells result.



The Evolution of Mitosis

- Because prokaryotes evolved before eukaryotes, mitosis probably evolved from binary fission

Sexual life cycle

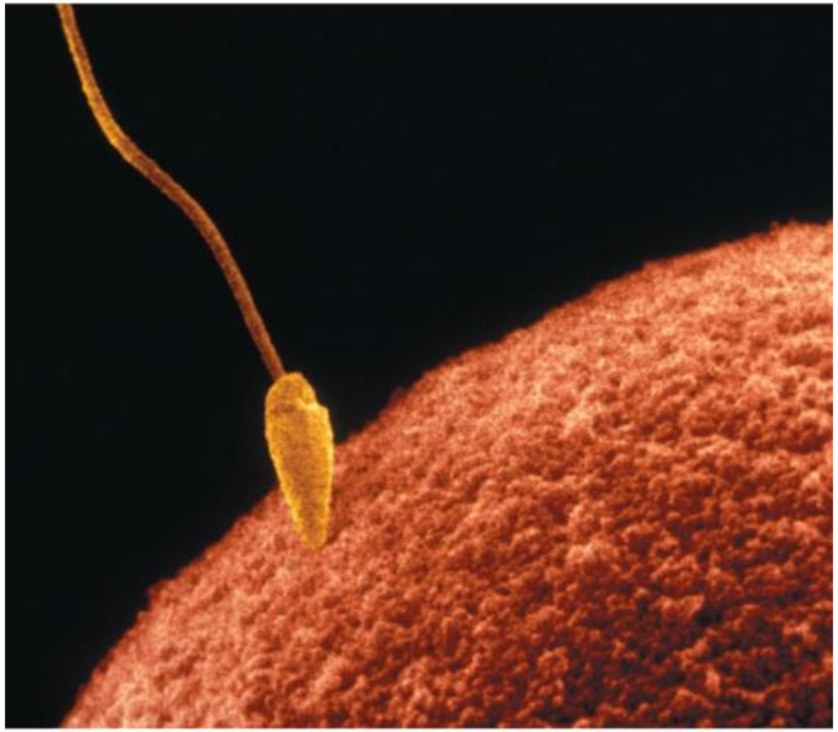
Variations on a Theme

- Offspring resemble their parents more than they do unrelated individuals

- **Heredity** is the transmission of traits from one generation to the next

- **Variation** is demonstrated by the differences in appearance that offspring show from parents and siblings

- **Genetics** is the scientific study of heredity and variation



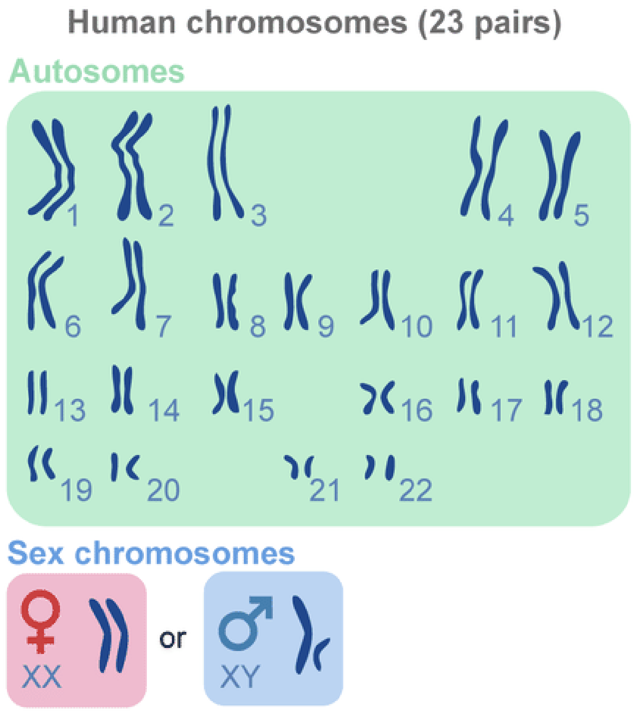
Offspring acquire genes from parents by inheriting chromosomes

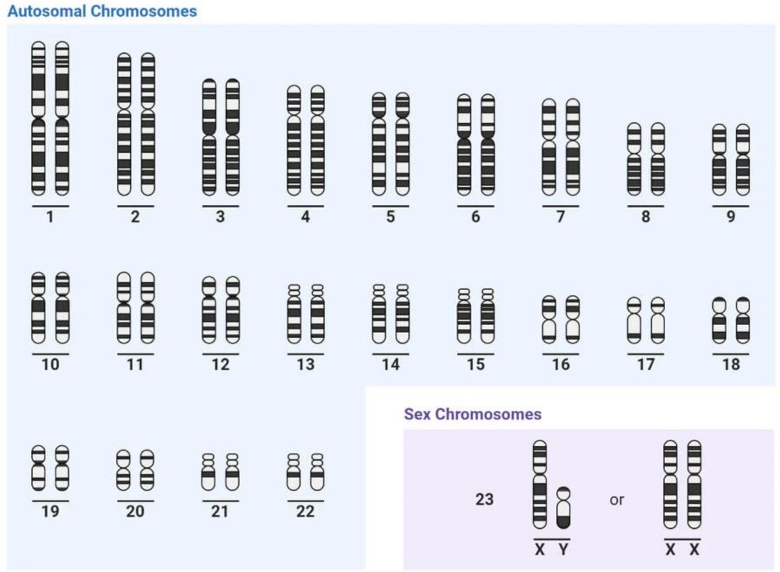
- In a literal sense, children do not inherit particular physical traits from their parents

- It is genes that are actually inherited

Inheritance of Genes

- **Genes** are the units of heredity and are made up of segments of DNA
- Genes are passed to the next generation via reproductive cells called **gametes** (sperm and eggs)
- Most DNA is packaged into chromosomes
- Humans have 46 chromosomes in the nuclei of their **somatic cells**, all cells of the body except gametes and their precursors



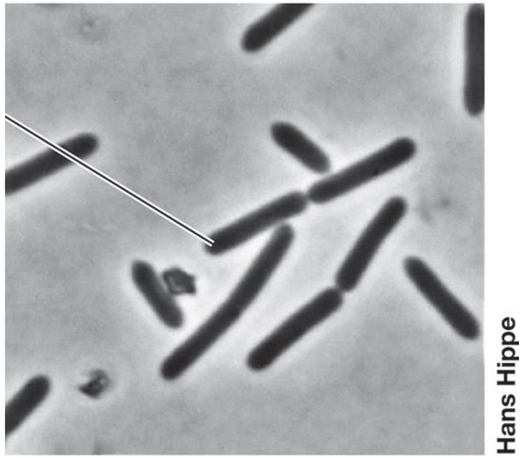


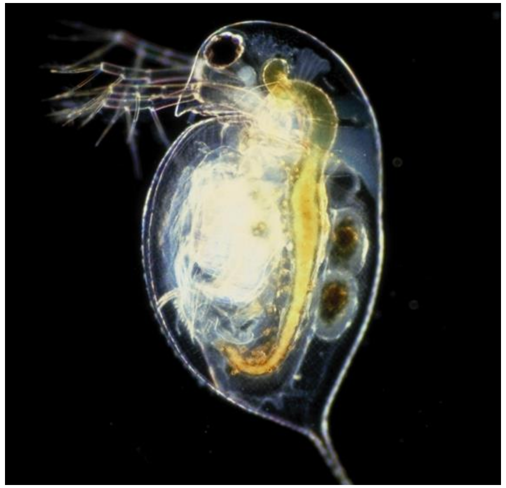
Comparison of Asexual and Sexual Reproduction

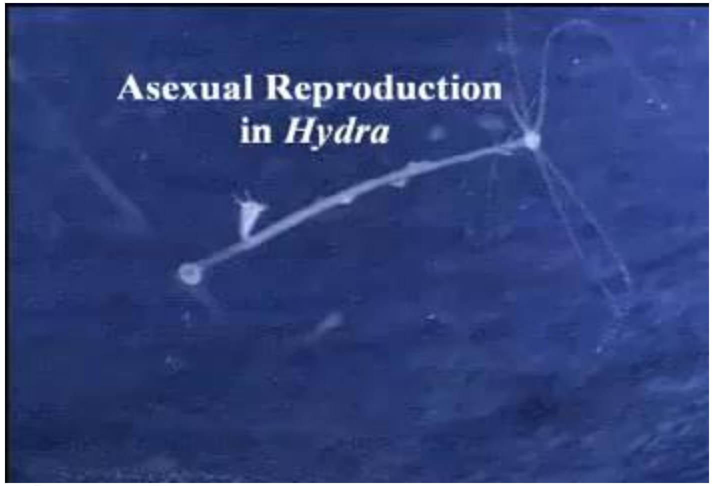
- In **asexual reproduction**, a single individual passes all of its genes to its offspring without the fusion of gametes

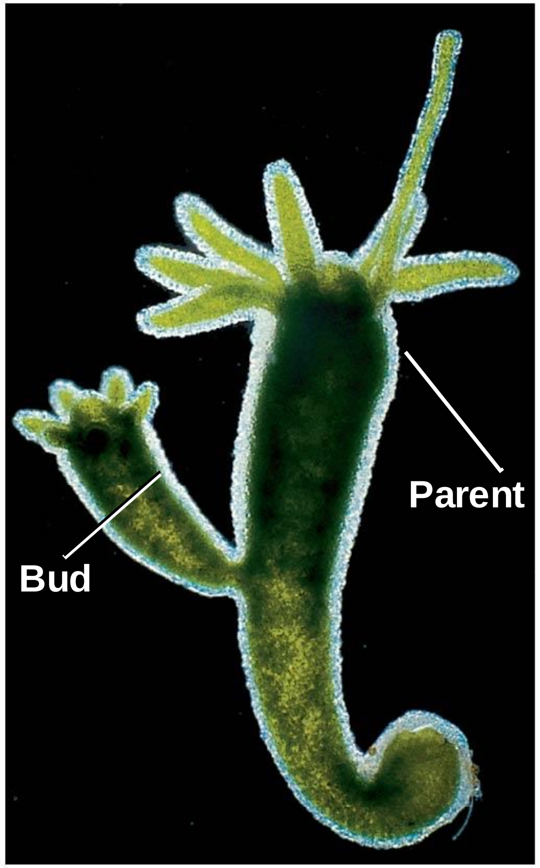
- A **clone** is a group of genetically identical individuals from the same parent

- In **sexual reproduction**, two parents give rise to offspring that have unique combinations of genes inherited from the two parents

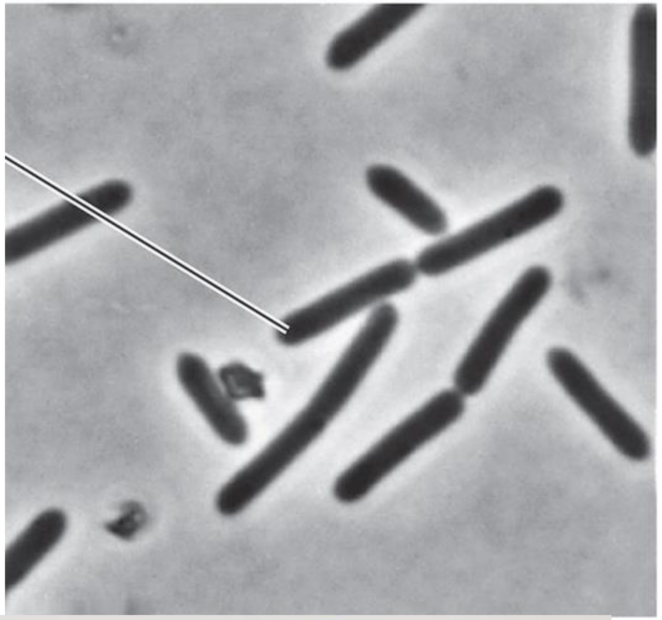








Hydra



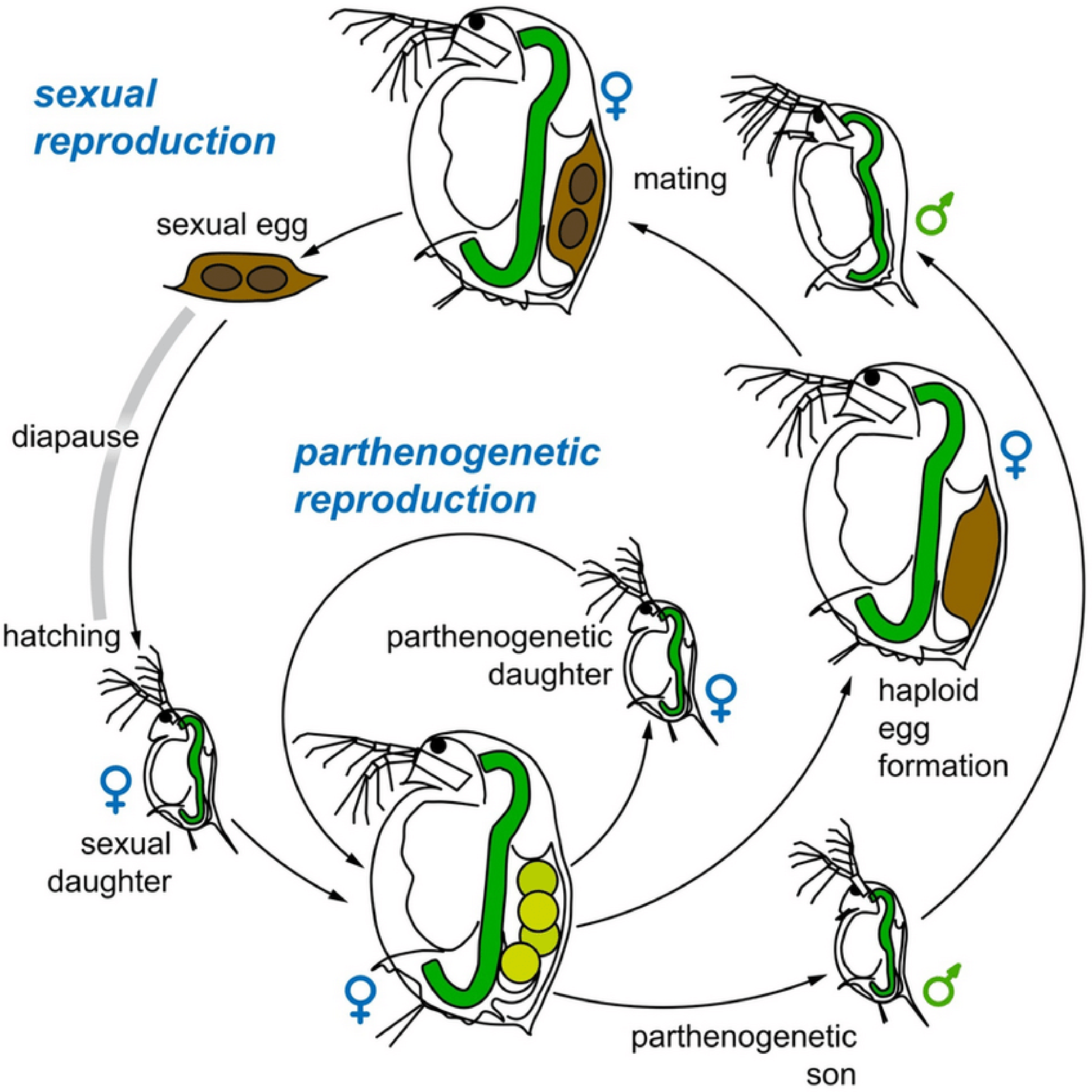
Hans Hippe

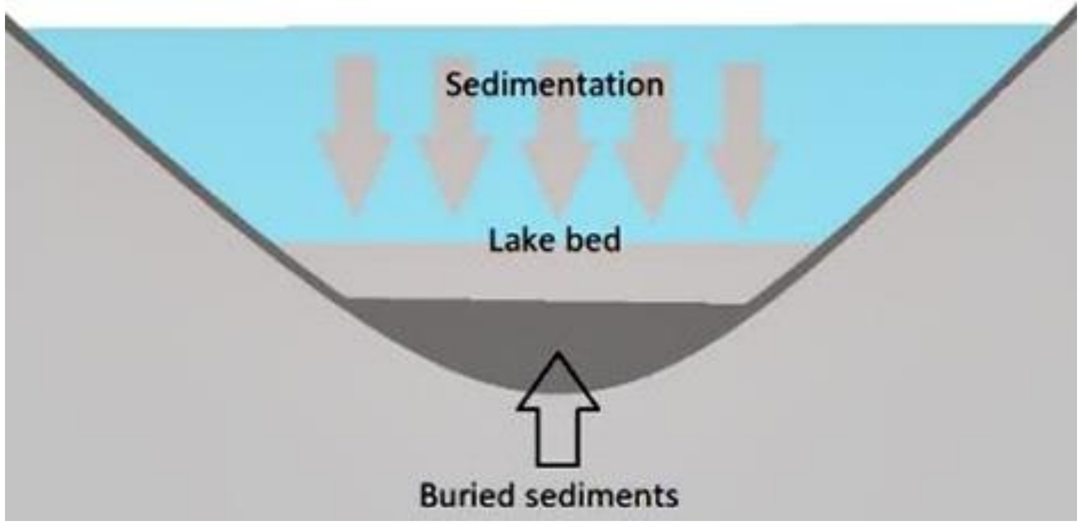
vegetative propagation

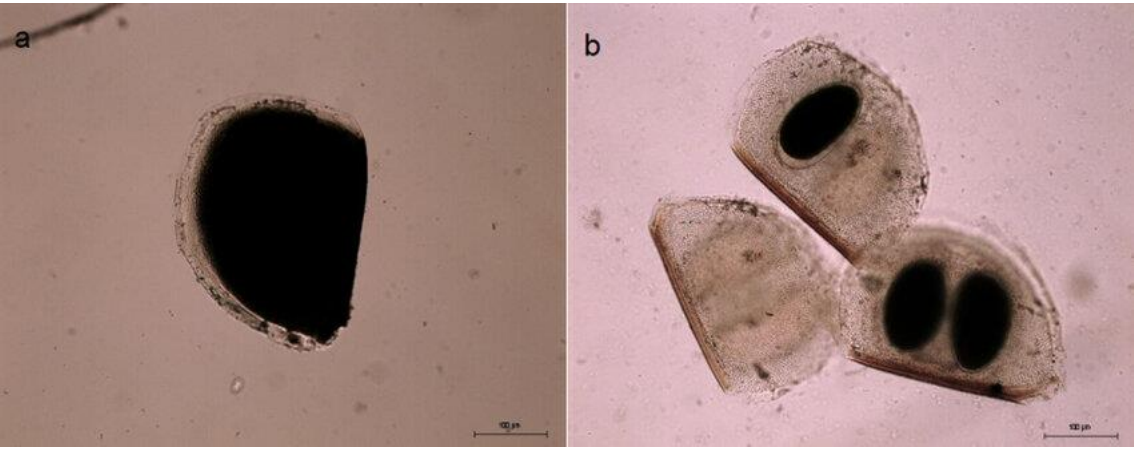
Daphnia: zooplankton that reproduces both sexual and asexual cycles

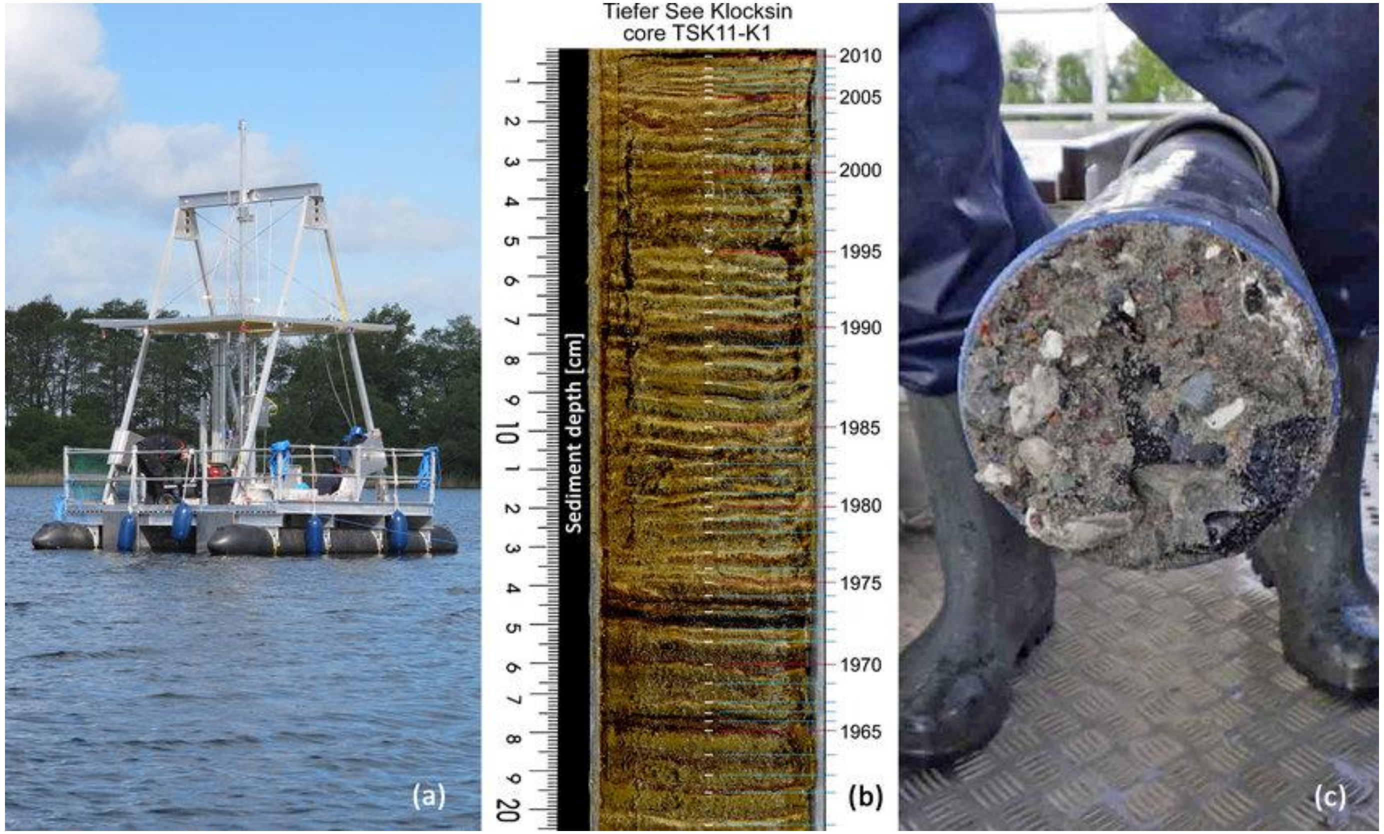

a
b
c
d
e
f


1 mm


sexual
reproduction
sexual egg
mating
diapause
parthenogenetic
reproduction
hatching
parthenogenetic
daughter
haploid
egg
formation
sexual
daughter
parthenogenetic
son


Sedimentation
Lake bed
Buried sediments


a
b

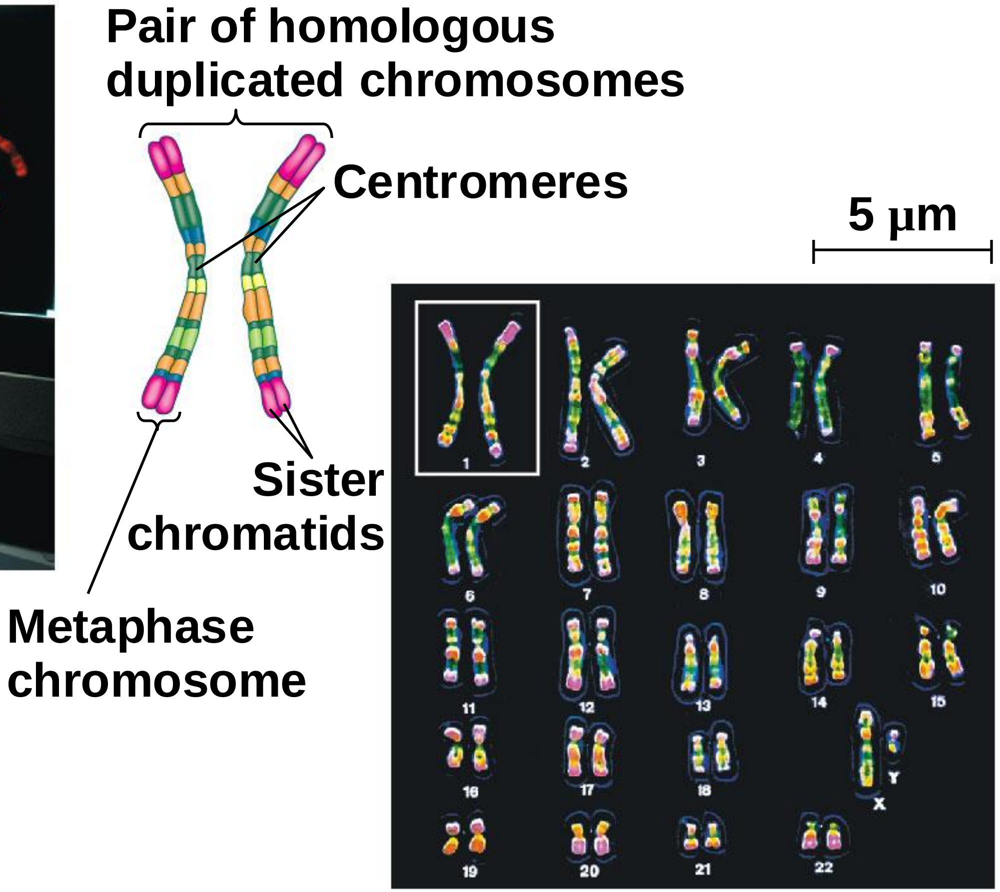

Tiefer See Klocksin
core TSK11-K1
Sediment depth [cm]
2010
2005
2000
1995
1990
1985
1980
1975
1970
1965
(a)
(b)
(c)

Sets of Chromosomes in Human Cells

- Human somatic cells have 23 pairs of chromosomes
- A **karyotype** is an ordered display of the pairs of chromosomes
- The two chromosomes in each pair are called **homologous chromosomes**, or **homologs**
- Chromosomes in a homologous pair are the same length and shape and carry the same genes

Application

Technique



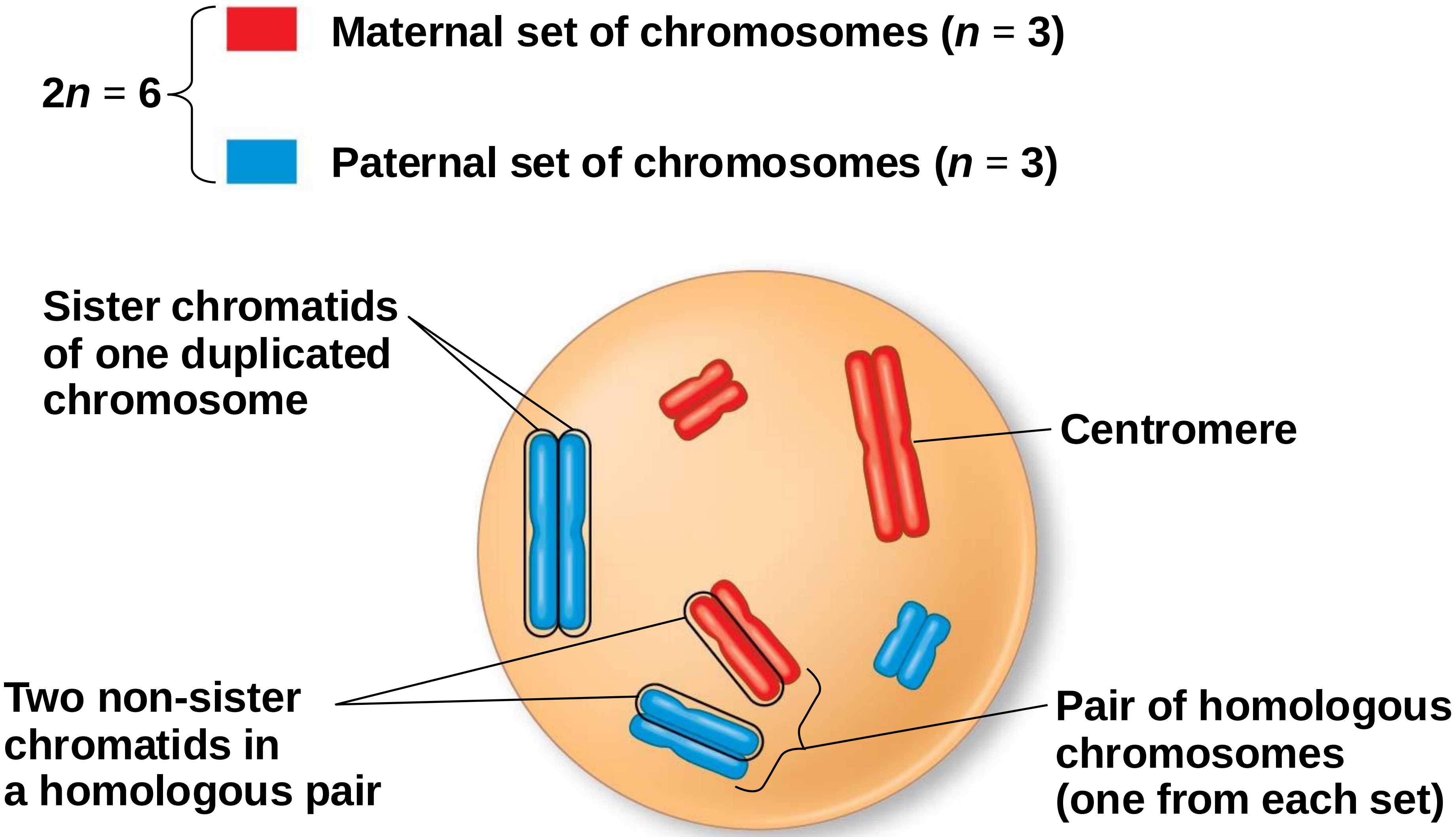
- The **sex chromosomes**, which determine the sex of the individual, are called X and Y
- Human females have a homologous pair of X chromosomes (XX)
- Human males have one X and one Y chromosome
- The remaining 22 pairs of chromosomes are called **autosomes**

- Each pair of homologous chromosomes includes one chromosome from each parent

- The 46 chromosomes in a human somatic cell are two sets of 23: one from the mother and one from the father

- A **diploid cell** ($2n$) has two sets of chromosomes

- For humans, the diploid number is 46 ($2n = 46$)


2n = 6
Maternal set of chromosomes (n = 3)
Paternal set of chromosomes (n = 3)
Sister chromatids of one duplicated chromosome
Centromere
Two non-sister chromatids in a homologous pair
Pair of homologous chromosomes (one from each set)

- A gamete (sperm or egg) contains a single set of chromosomes and is thus a **haploid cell** (*n*)
- For humans, the haploid number is 23 (n = 23)
- Each set of 23 consists of 22 autosomes and a single sex chromosome
- In an unfertilized egg (ovum), the sex chromosome is X
- In a sperm cell, the sex chromosome may be either X or Y

Behavior of Chromosome Sets in the Human Life Cycle

- **Fertilization** is the union of gametes (the sperm and the egg)

- The fertilized egg is called a **zygote** and has one set of chromosomes from each parent

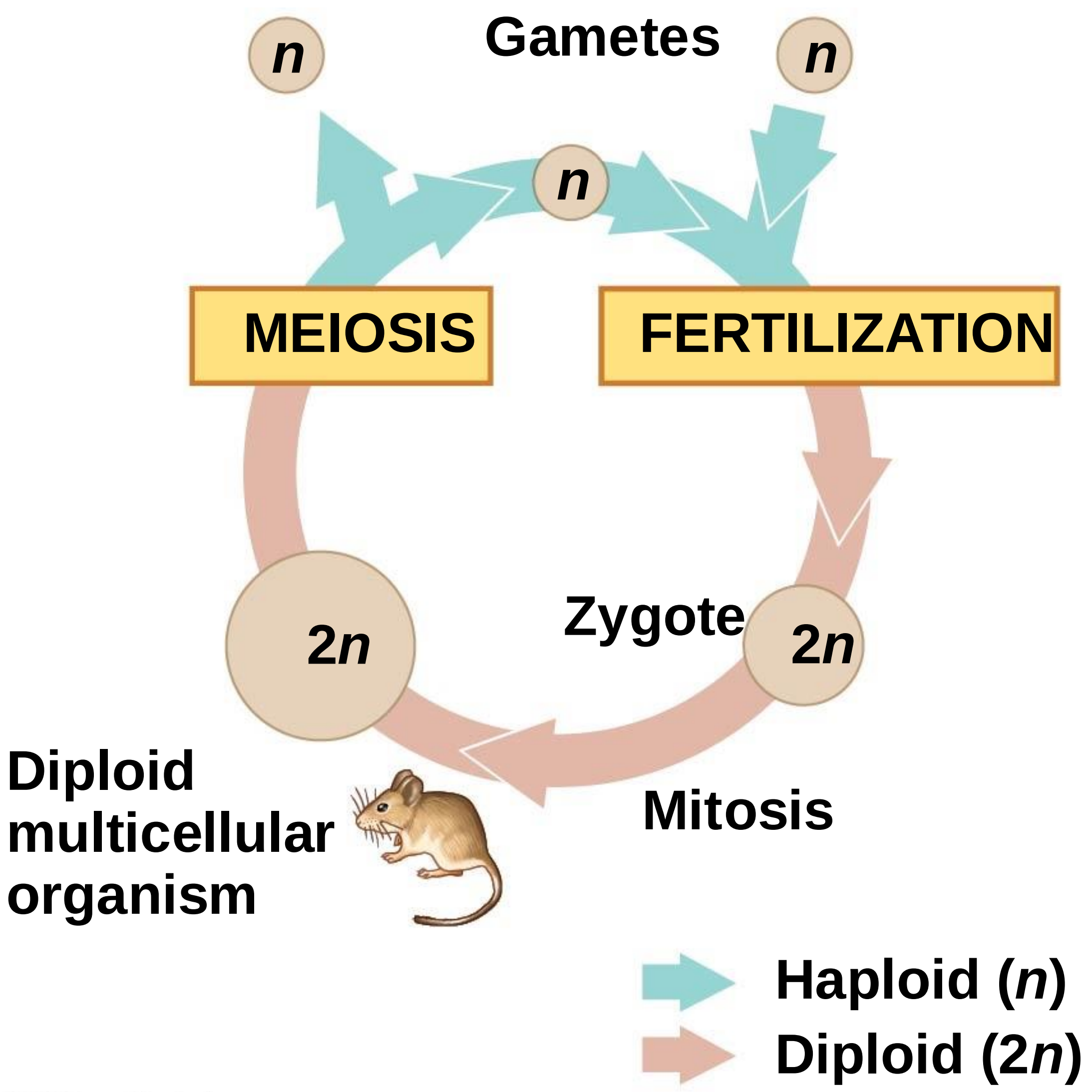
- The zygote produces somatic cells by mitosis and develops into an adult

The Variety of Sexual Life Cycles

- Meiosis and fertilization is common to all organisms that reproduce sexually

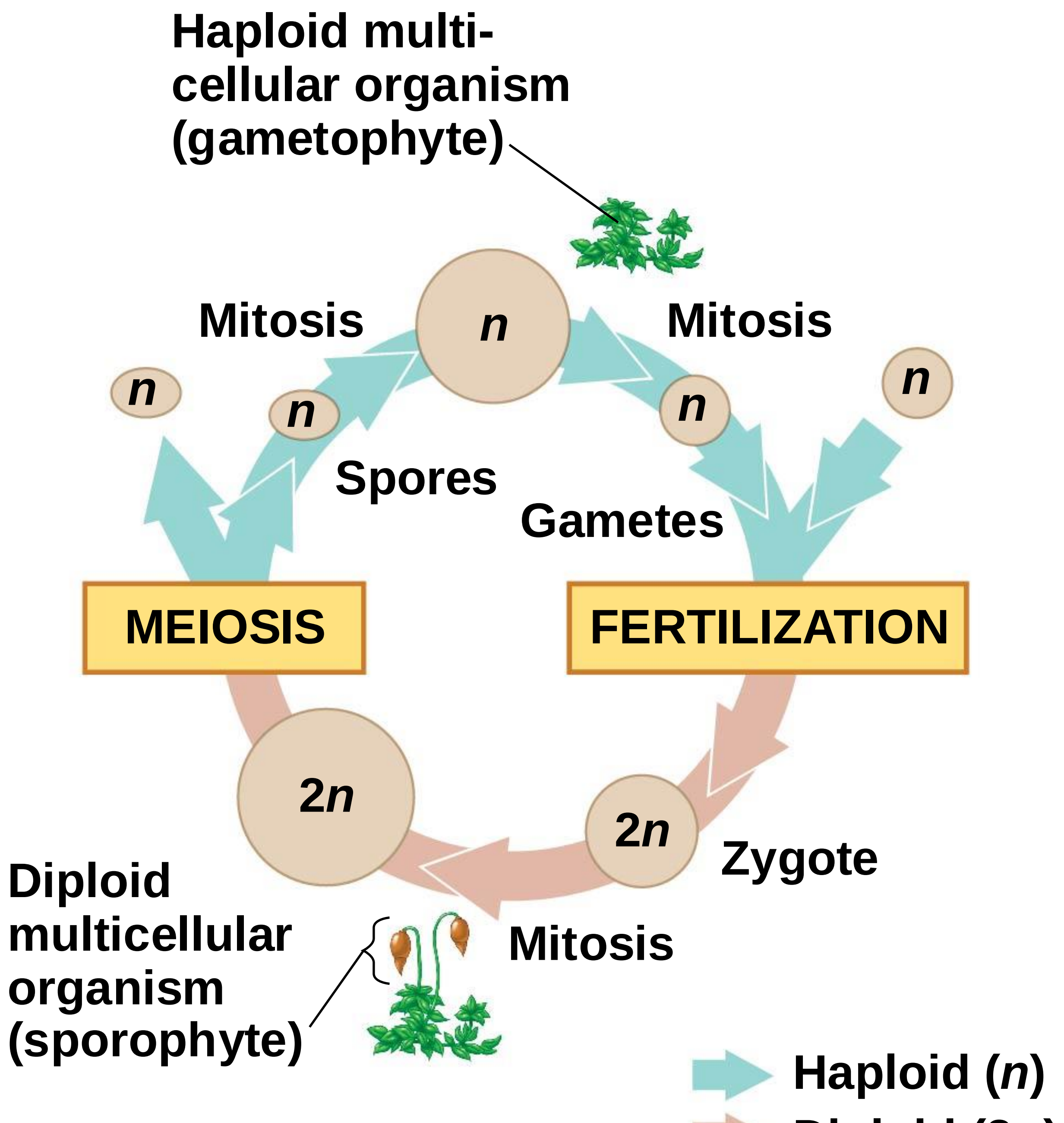
- The three main types of sexual life cycles differ in the timing of meiosis and fertilization

- Gametes are the only haploid cells in animals
- They are produced by meiosis and undergo no further cell division before fertilization
- Gametes fuse to form a diploid zygote that divides by mitosis to develop into a multicellular organism



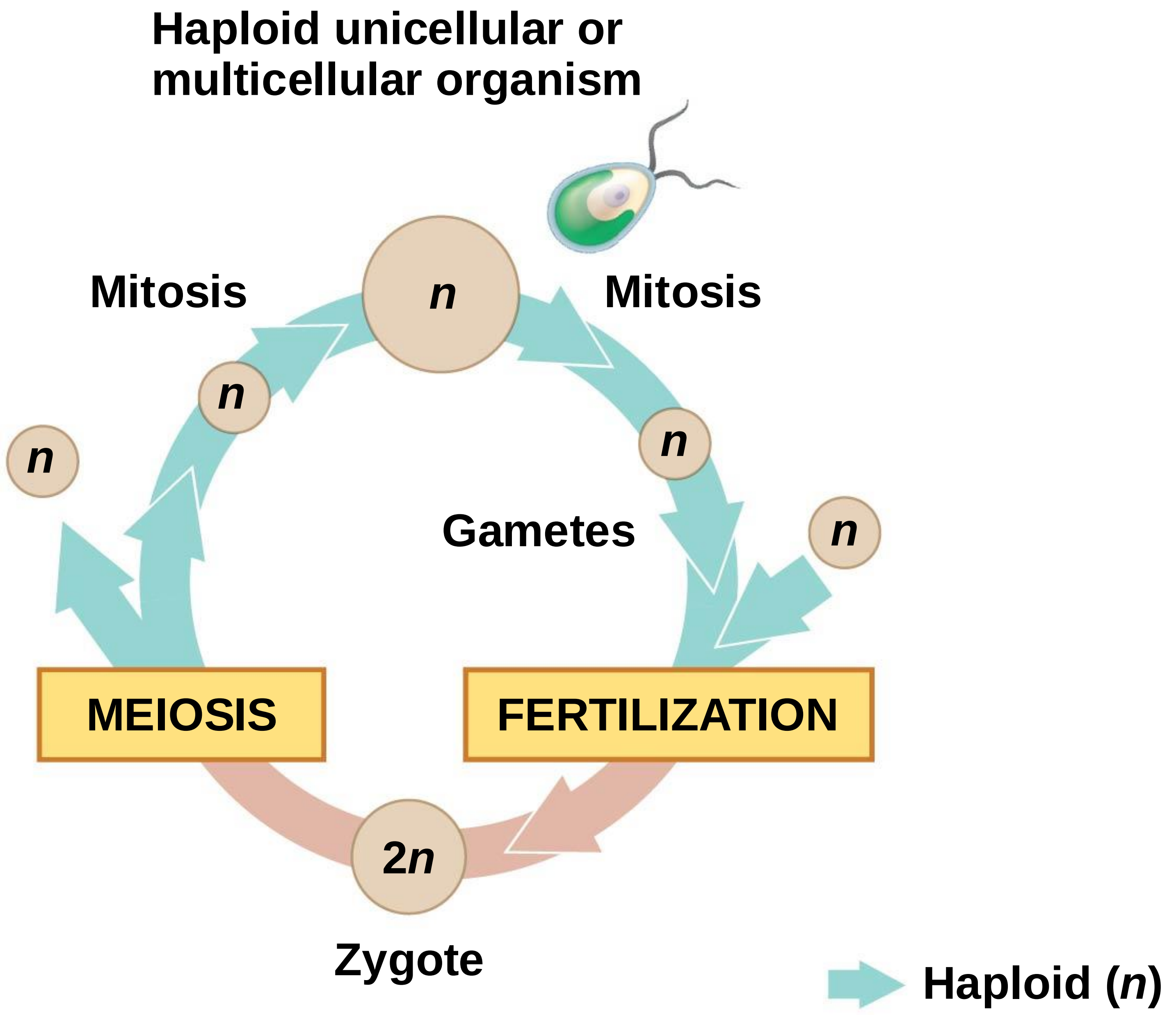
Animals

- Plants and some algae exhibit an **alternation of generations**
- This life cycle includes both a diploid and haploid multicellular stage
- The diploid organism, called the sporophyte, makes haploid spores by meiosis
- Each spore grows by mitosis into a haploid organism called a gametophyte
- A gametophyte makes haploid gametes by mitosis
- Fertilization of gametes results in a diploid sporophyte



Plants and some algae

- In most fungi and some protists, the only diploid stage is the single-celled zygote; there is no multicellular diploid stage
- The zygote produces haploid cells by meiosis
- Each haploid cell grows by mitosis into a haploid multicellular organism
- The haploid adult produces gametes by mitosis



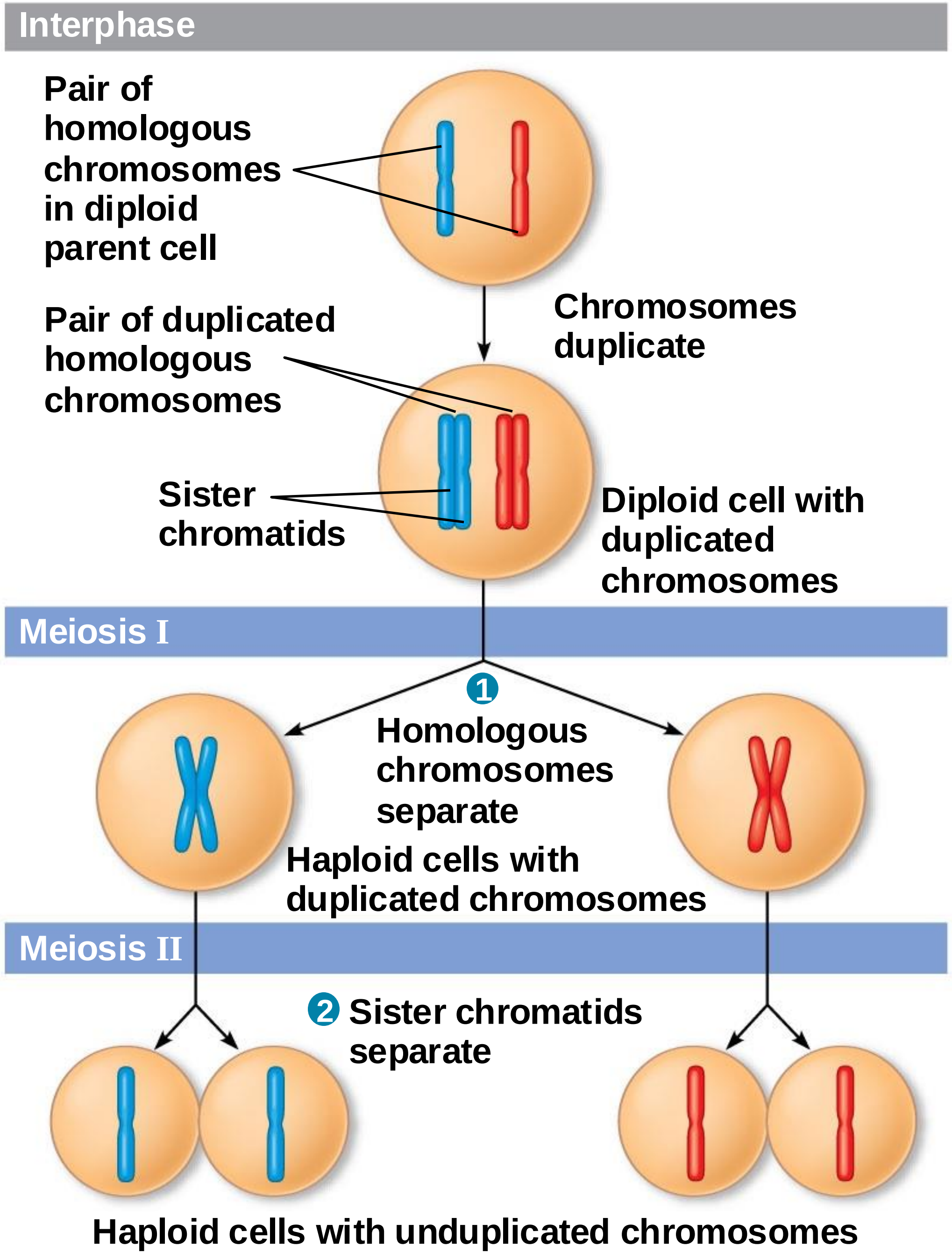
Most fungi and some protists

Meiosis reduces the number of chromosome sets from diploid to haploid

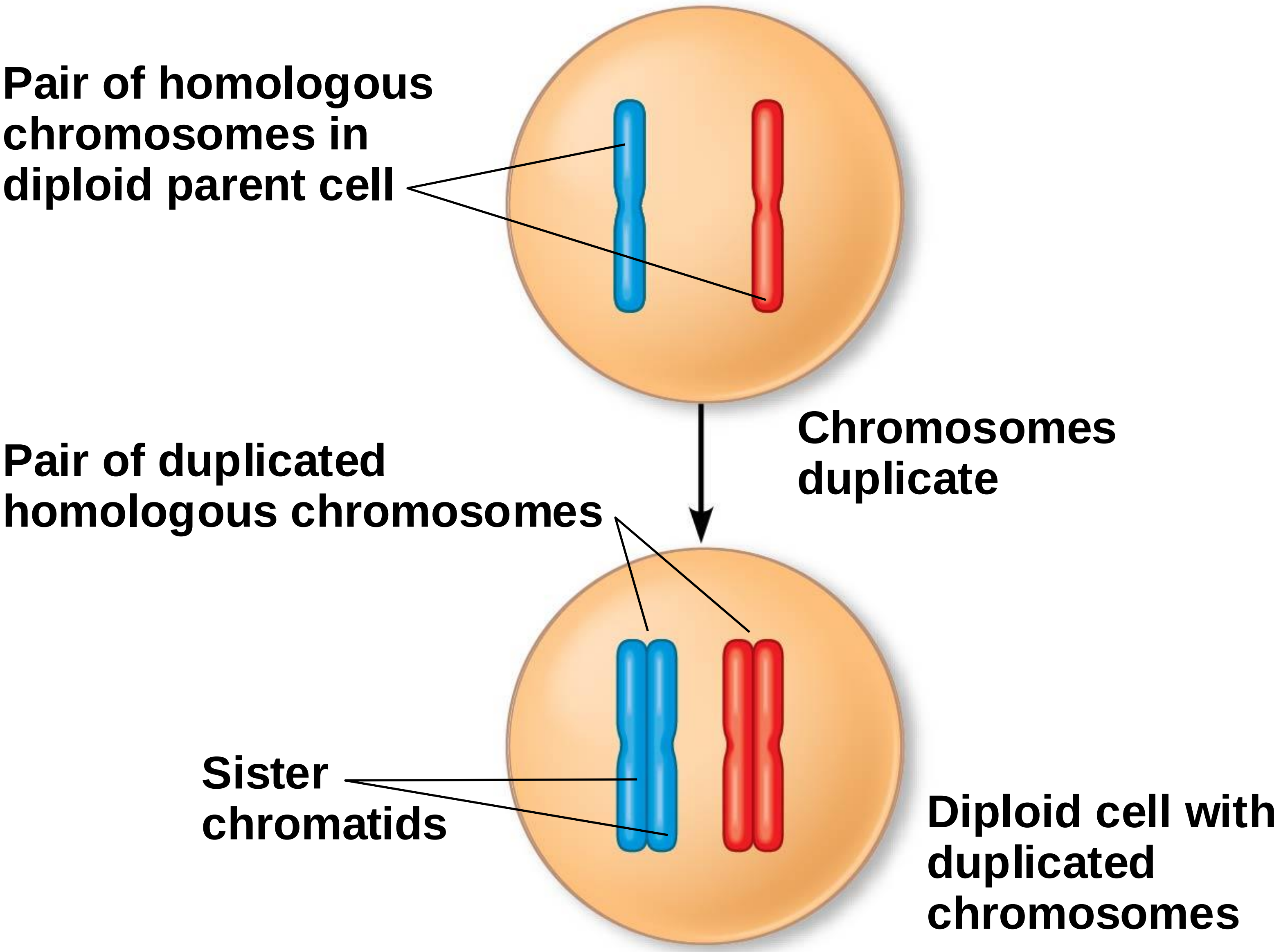
- Like mitosis, meiosis is preceded by the replication of chromosomes
- Meiosis takes place in two consecutive cell divisions, called **meiosis** I and **meiosis** II
- The two cell divisions result in **four** daughter cells, rather than the **two** daughter cells in mitosis
- Each daughter cell has only half as many chromosomes as the parent cell

The Stages of Meiosis

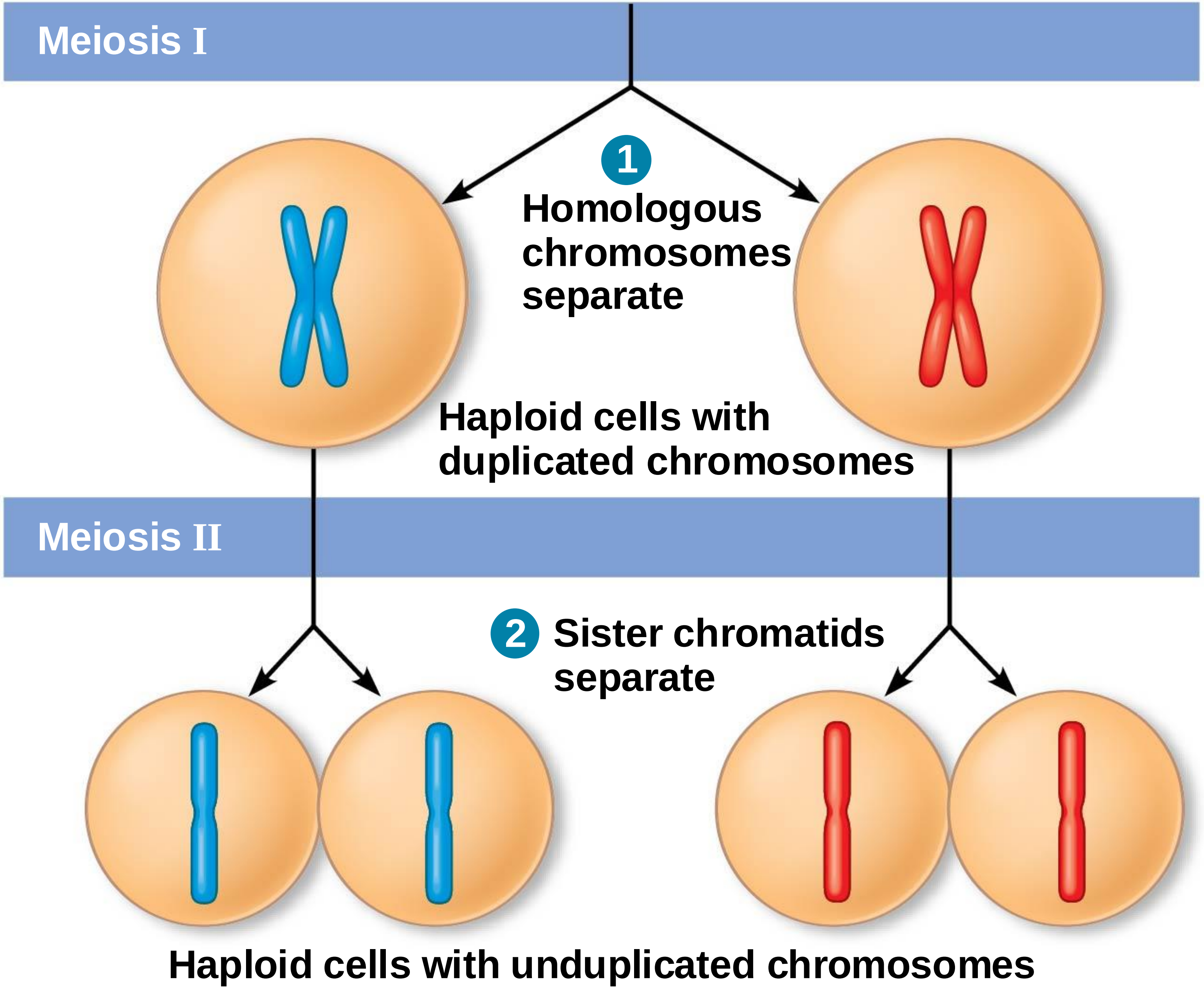
- Chromosomes duplicate before meiosis
- The resulting sister chromatids are closely associated along their lengths
- The chromatids are sorted into four haploid daughter cells



Interphase



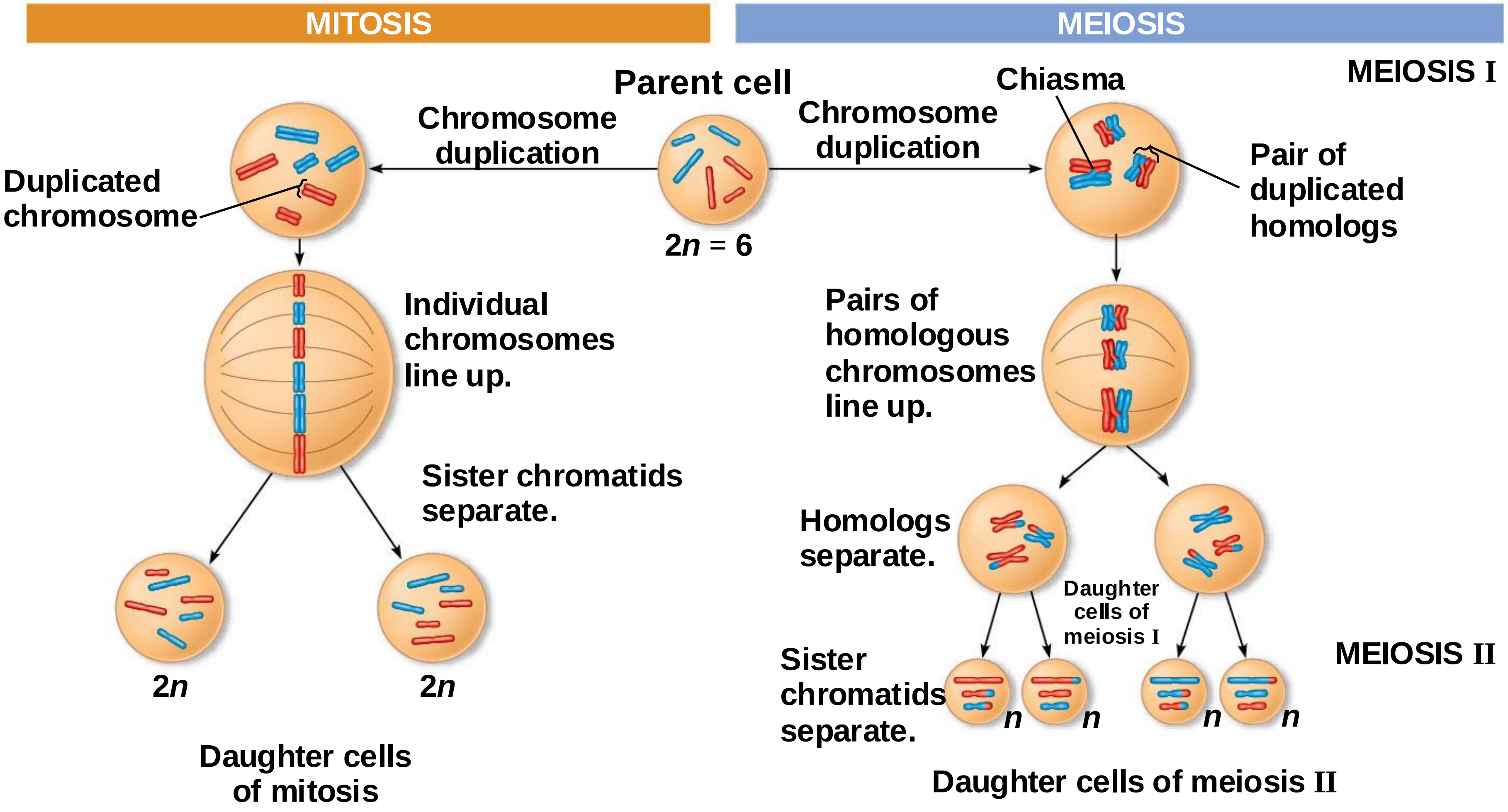
Pair of homologous chromosomes in diploid parent cell
Chromosomes duplicate
Pair of duplicated homologous chromosomes
Sister chromatids
Diploid cell with duplicated chromosomes


Meiosis I
1
Homologous chromosomes separate
Haploid cells with duplicated chromosomes
Meiosis II
2
Sister chromatids separate
Haploid cells with unduplicated chromosomes

A Comparison of Mitosis and Meiosis

- Mitosis conserves the number of chromosome sets, producing cells that are genetically identical to the parent cell

- Meiosis reduces the number of chromosomes sets from two (diploid) to one (haploid), producing cells that differ genetically from each other and from the parent cell



Genetic variation produced in sexual life cycles contributes to evolution

- Mutations (changes in an organism's DNA) are the original source of genetic diversity
- Mutations create different versions of genes called alleles
- Reshuffling of alleles during sexual reproduction produces genetic variation

Origins of Genetic Variation Among Offspring

- The behavior of chromosomes during meiosis and fertilization is responsible for most of the variation that arises in each generation

- Three mechanisms contribute to genetic variation:
  - Independent assortment of chromosomes
  - Crossing over
  - Random fertilization

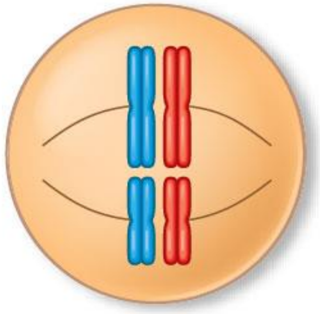
Independent Assortment of Chromosomes

- Homologous pairs of chromosomes orient randomly at metaphase I of meiosis

- In independent assortment, each pair of chromosomes sorts maternal and paternal homologs into daughter cells independently of the other pairs

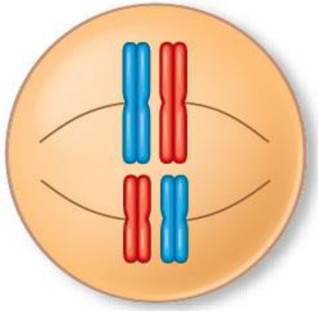
- The number of combinations possible when chromosomes assort independently into gametes is 2^n, where *n* is the haploid number
- For humans ($n = 23$), there are more than 8 million (2^{23}) possible combinations of chromosomes

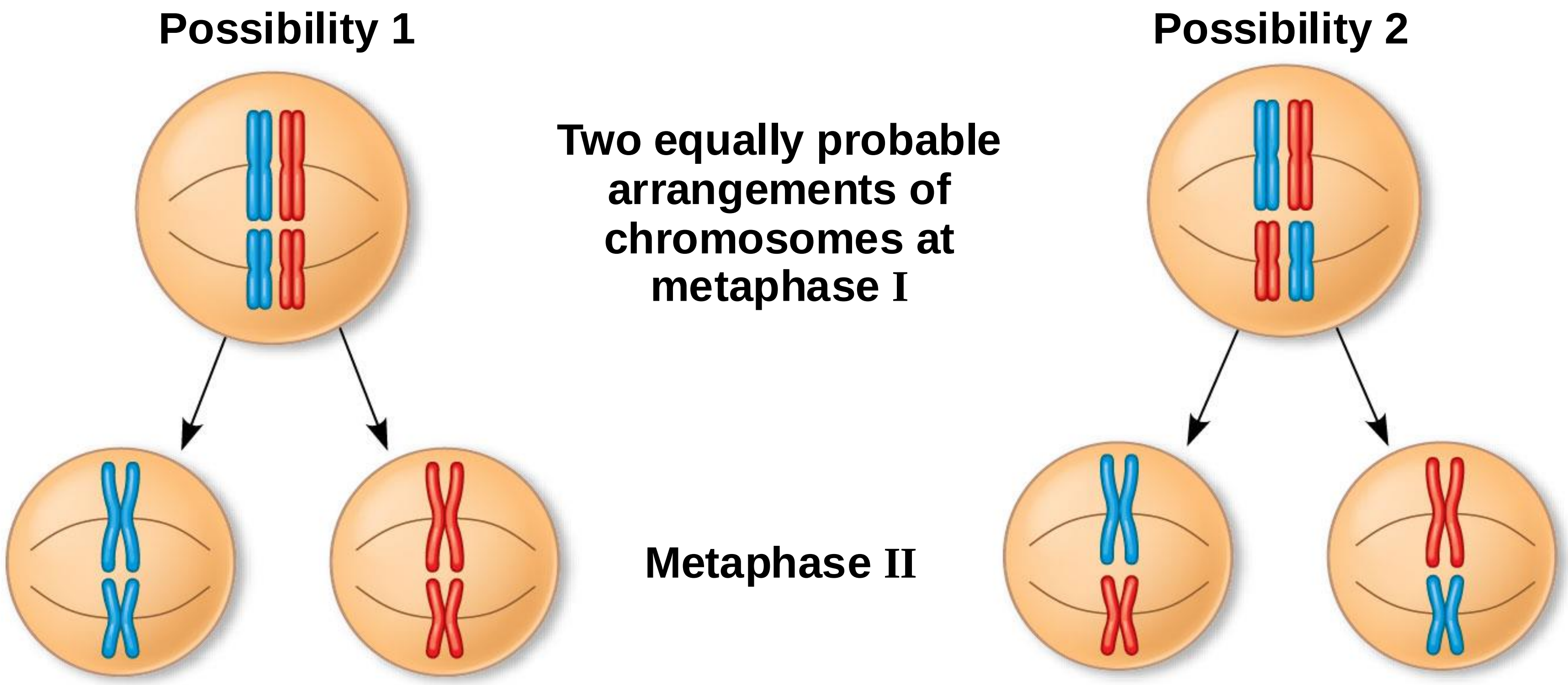
Possibility 1

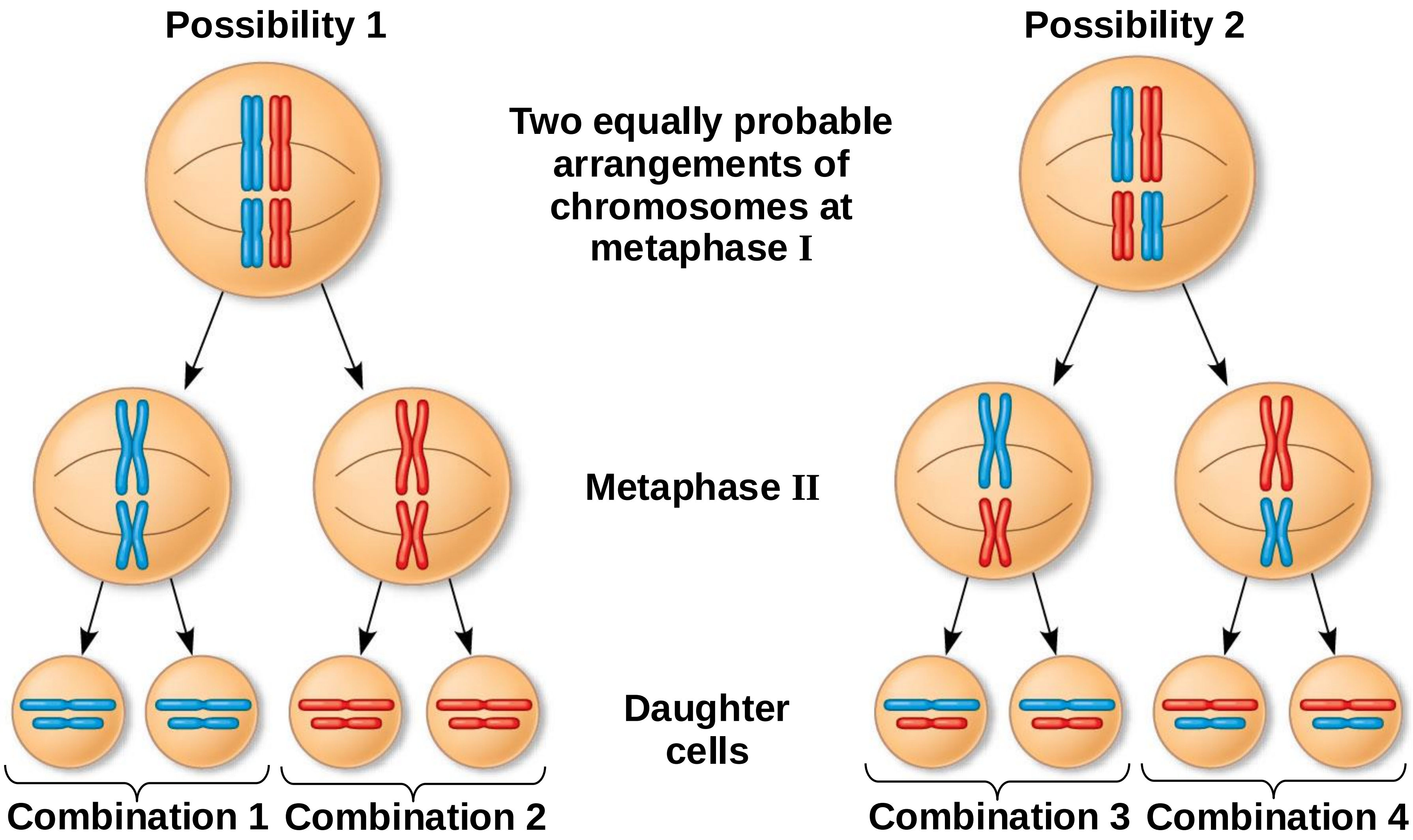


Two equally probable arrangements of chromosomes at metaphase I

Possibility 2




Possibility 1
Possibility 2
Two equally probable arrangements of chromosomes at metaphase I
Metaphase II

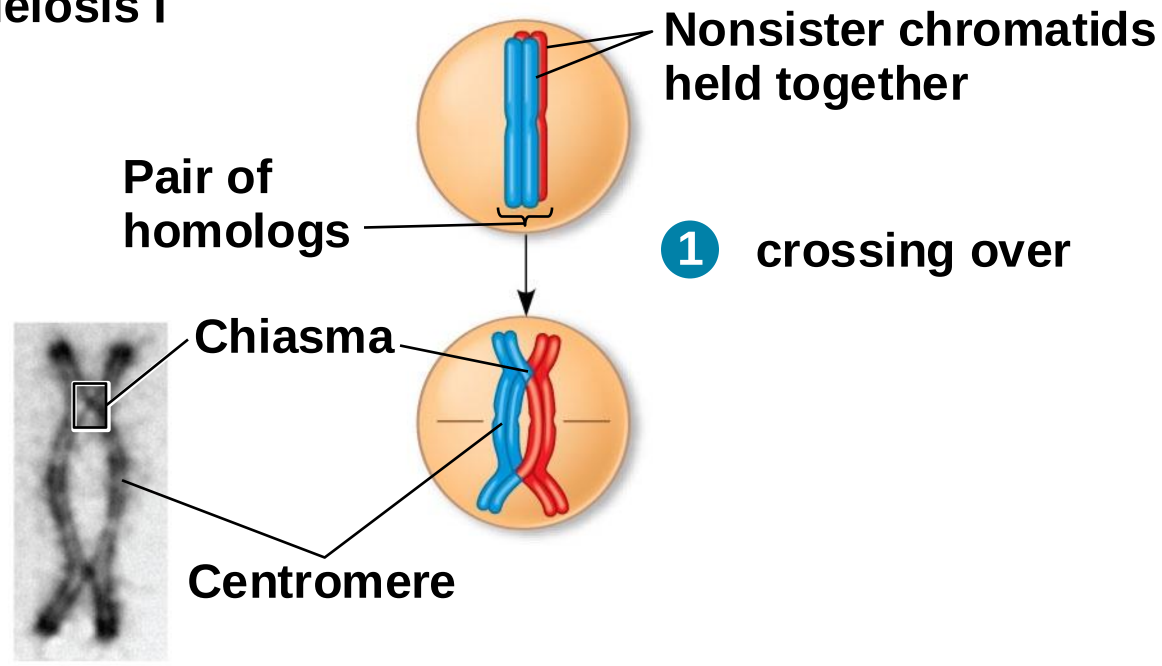


Possibility 1
Possibility 2
Two equally probable arrangements of chromosomes at metaphase I
Metaphase II
Daughter cells
Combination 1
Combination 2
Combination 3
Combination 4

Crossing Over

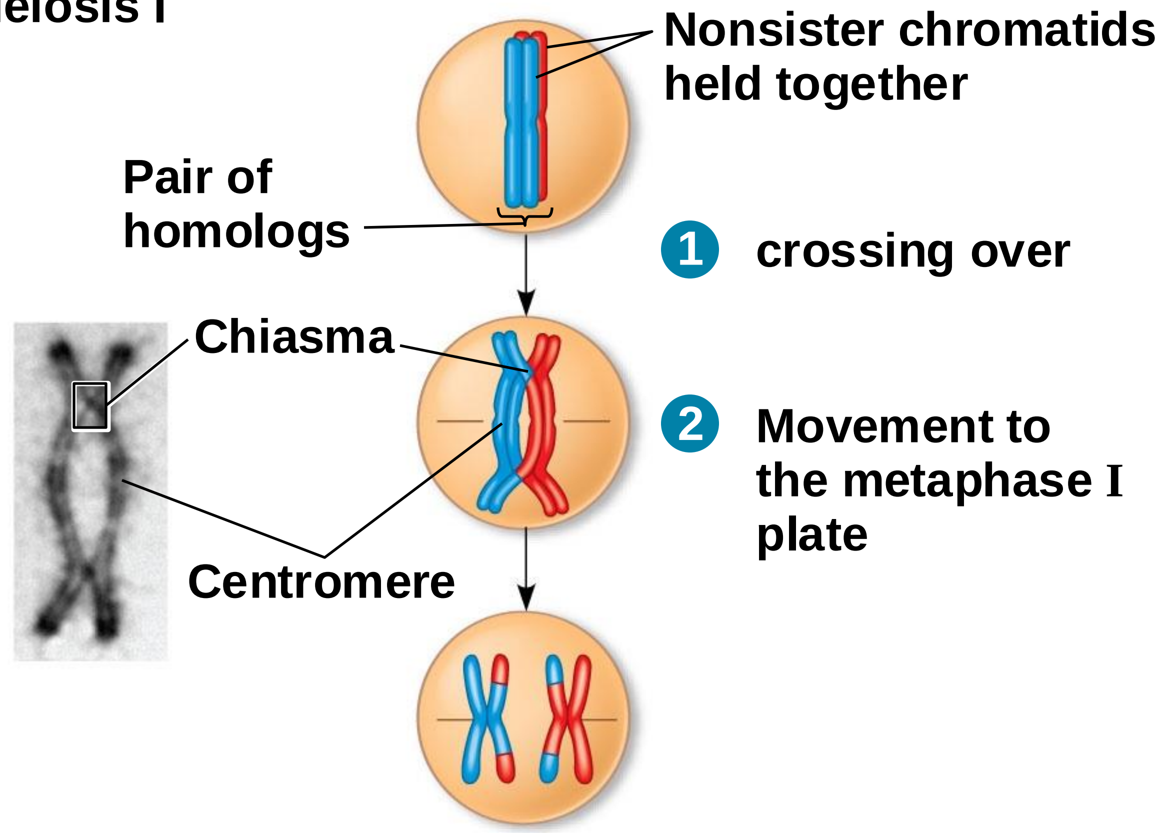
- Crossing over produces **recombinant chromosomes**, which combine DNA inherited from each parent
- Crossing over contributes to genetic variation by combining DNA from two parents into a single chromosome
- In humans, an average of one to three crossover events occurs per chromosome

Meiosis I



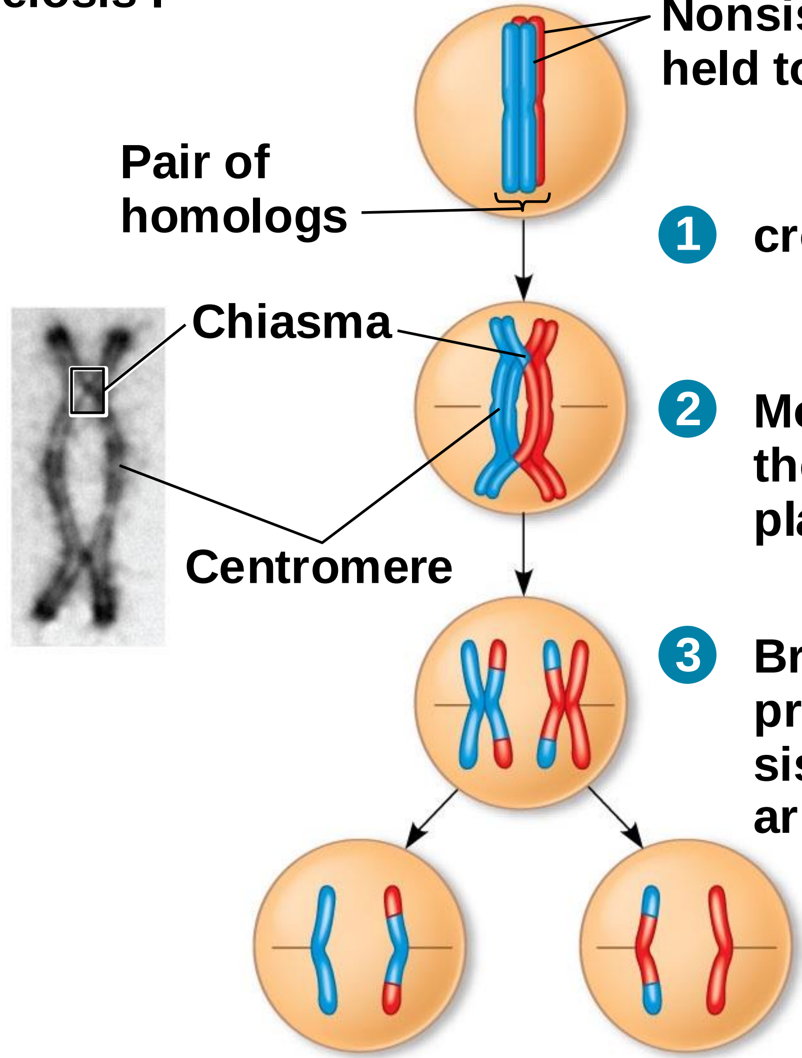
1 crossing over

Meiosis I

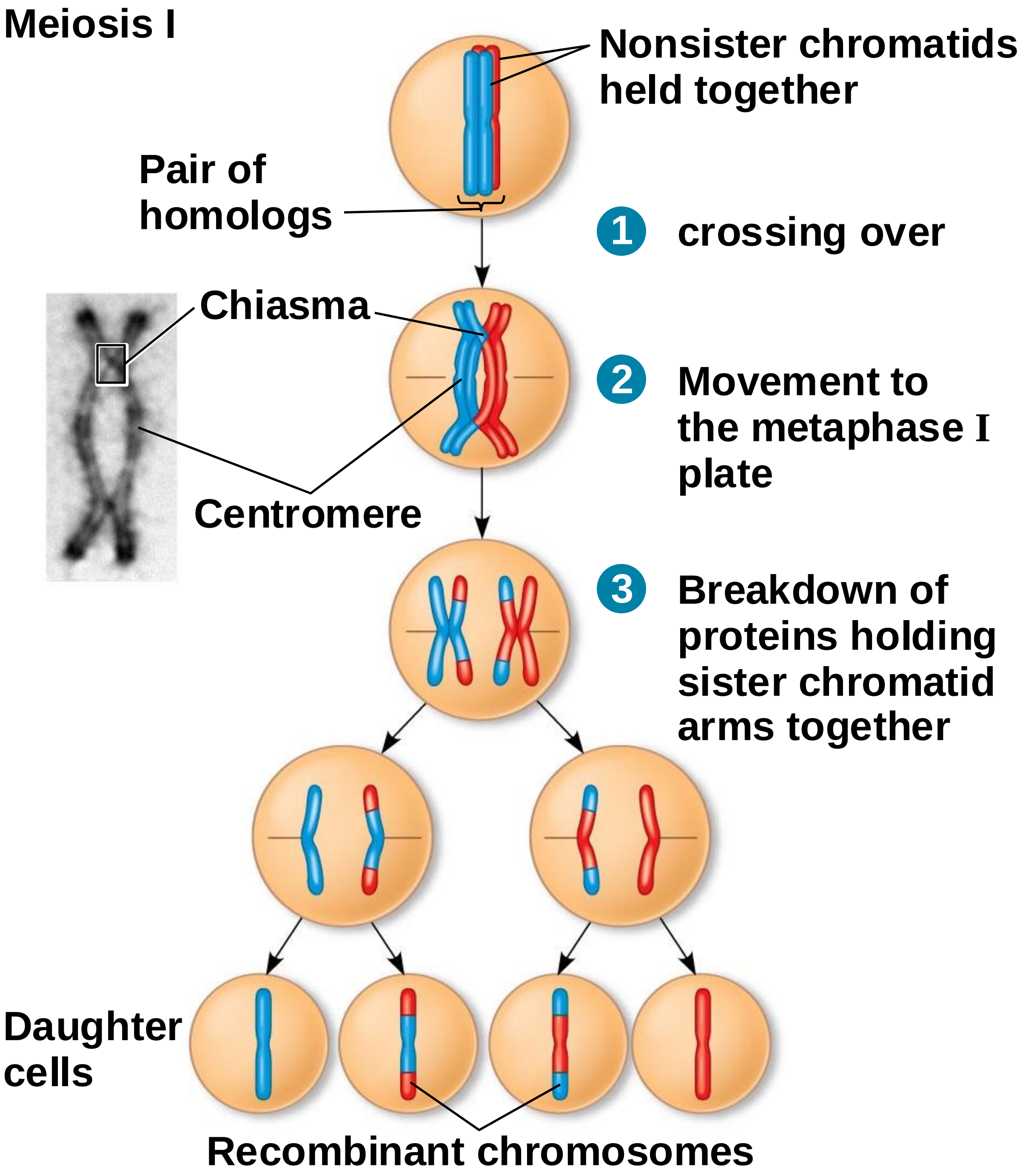


Nonsister chromatids held together
Pair of homologs
1 crossing over
Chiasma
2 Movement to the metaphase I plate
Centromere

Meiosis I



1. crossing over
2. Movement to the metaphase I plate
3. Breakdown of proteins holding sister chromatid arms together


Meiosis I
Nonsister chromatids held together
Pair of homologs
1 crossing over
Chiasma
2 Movement to the metaphase I plate
Centromere
3 Breakdown of proteins holding sister chromatid arms together
Daughter cells
Recombinant chromosomes

Random Fertilization

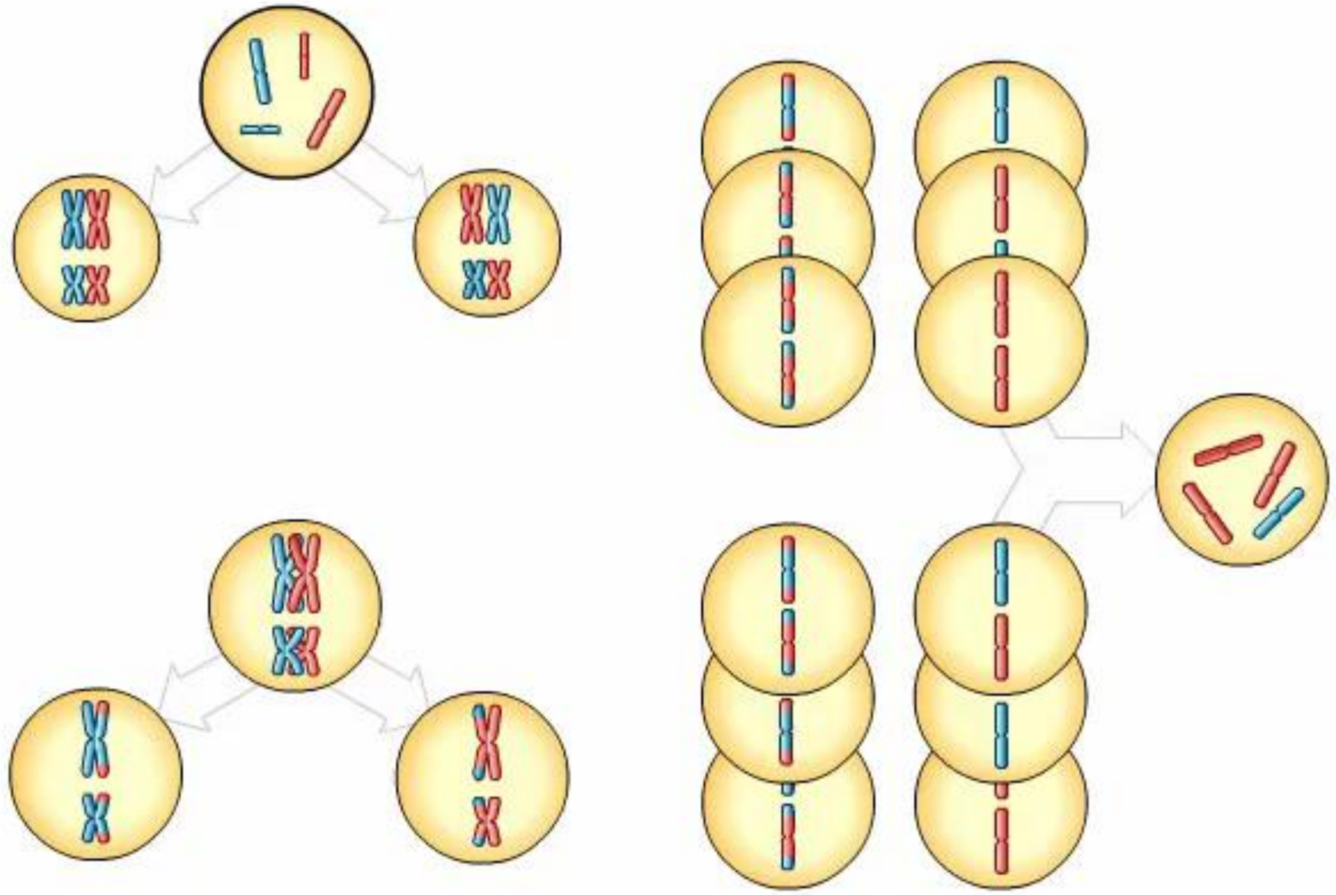
- Random fertilization adds to genetic variation because any sperm can fuse with any ovum (unfertilized egg)

- The fusion of two gametes (each with 8.4 million possible chromosome combinations from independent assortment) produces a zygote with any of about 70 trillion diploid combinations

- Crossing over adds even more variation

- Each zygote has a unique genetic identity

Genetic Variation



The Evolutionary Significance of Genetic Variation Within Populations

- Natural selection results in the accumulation of genetic variations favored by the environment
- Sexual reproduction contributes to the genetic variation in a population, which originates from mutations
- Animals that always reproduce asexually are quite rare
- Organisms like the bdelloid rotifer increase their genetic diversity through incorporation of foreign DNA from the environment

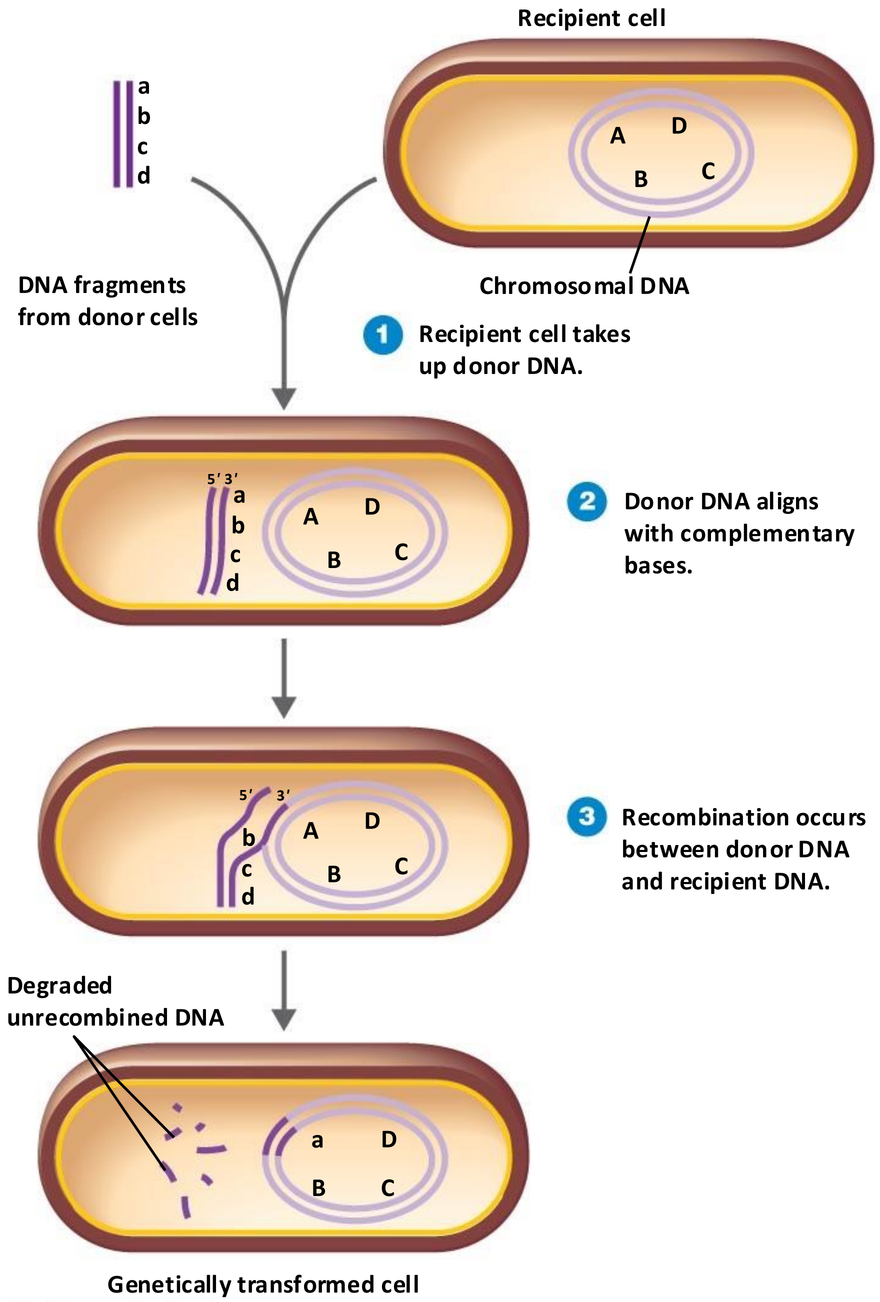
Genetic Transfer

- **Vertical gene transfer:** transfer of genes from an organism to its offspring

- **Horizontal gene transfer:** transfer of genes between cells of the same generation

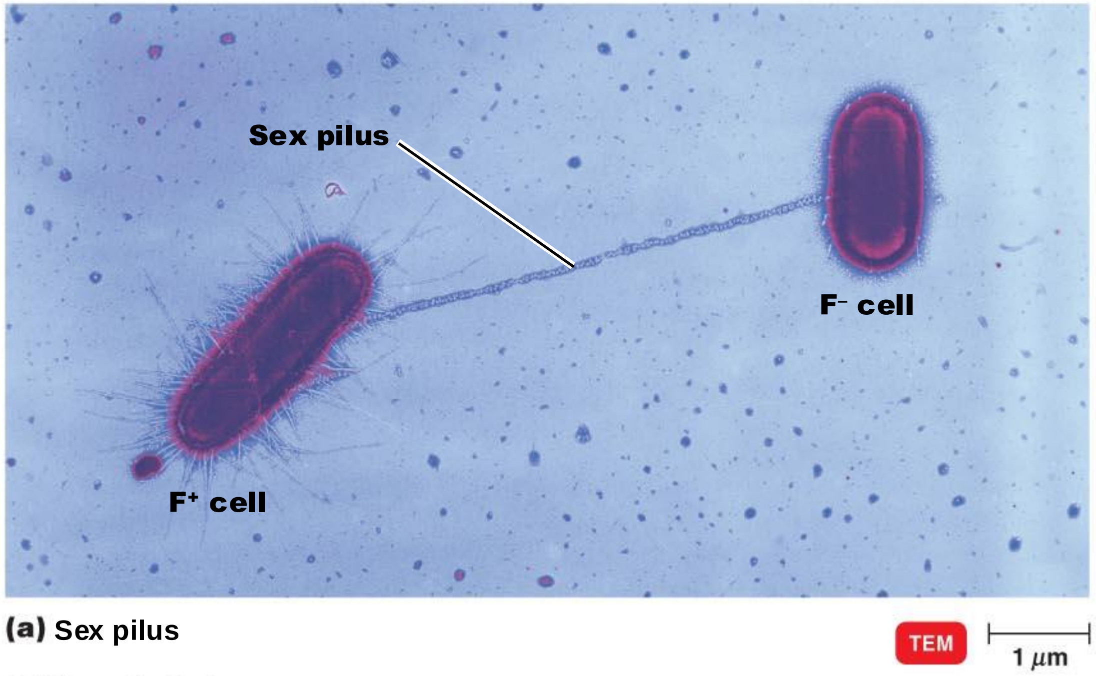
Transformation in Bacteria

- **Transformation:** genes transferred from one bacterium to another as "naked" DNA

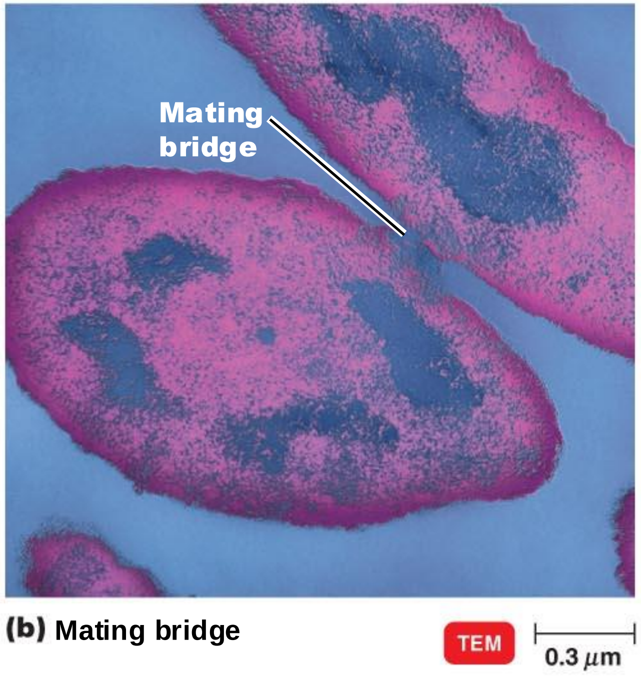


Conjugation in Bacteria

- **Conjugation:** plasmids transferred from one bacterium to another
- Requires cell-to-cell contact via sex pili



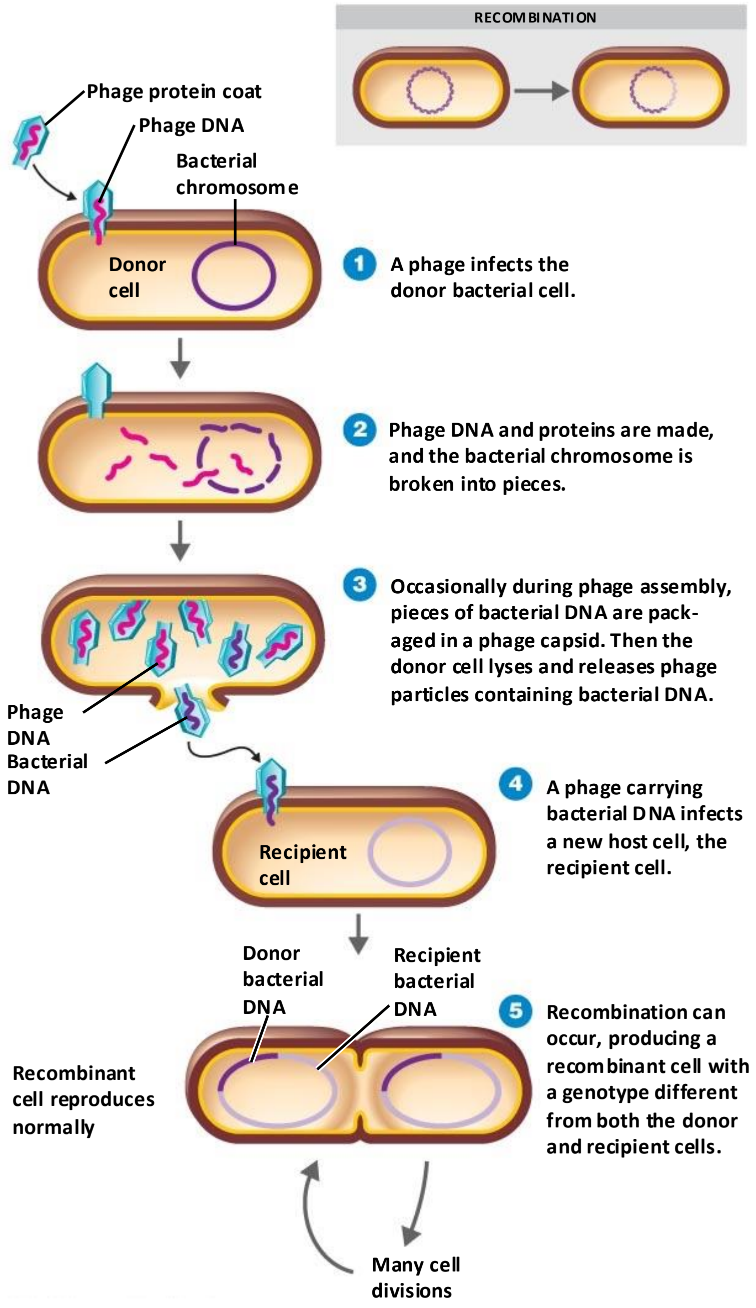
(a) Sex pilus



(b) Mating bridge

Transduction in Bacteria

- DNA is transferred from a donor cell to a recipient via a **bacteriophage**
- **Generalized transduction:** Random bacterial DNA is packaged inside a phage and transferred to a recipient cell
- **Specialized transduction:** Specific bacterial genes are packaged inside a phage and transferred to a recipient cell

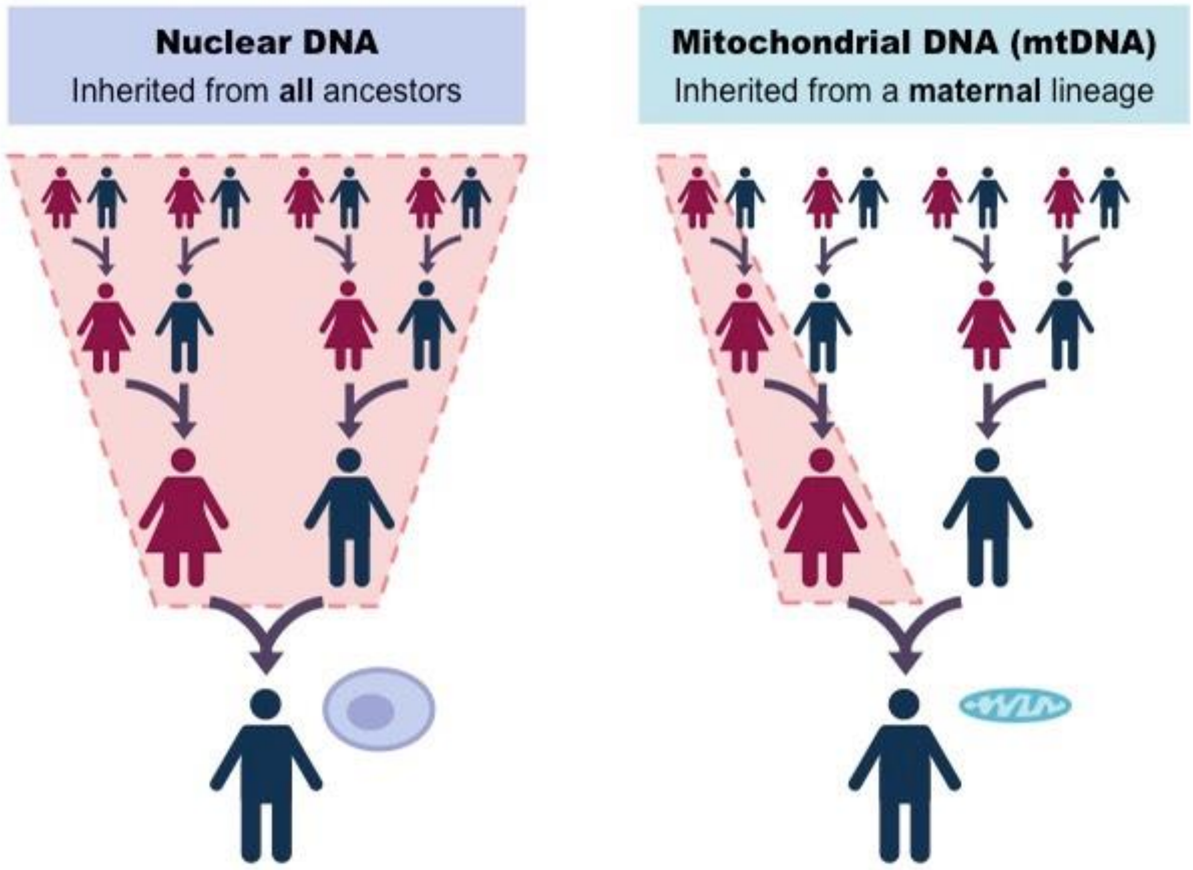


Mitochondria

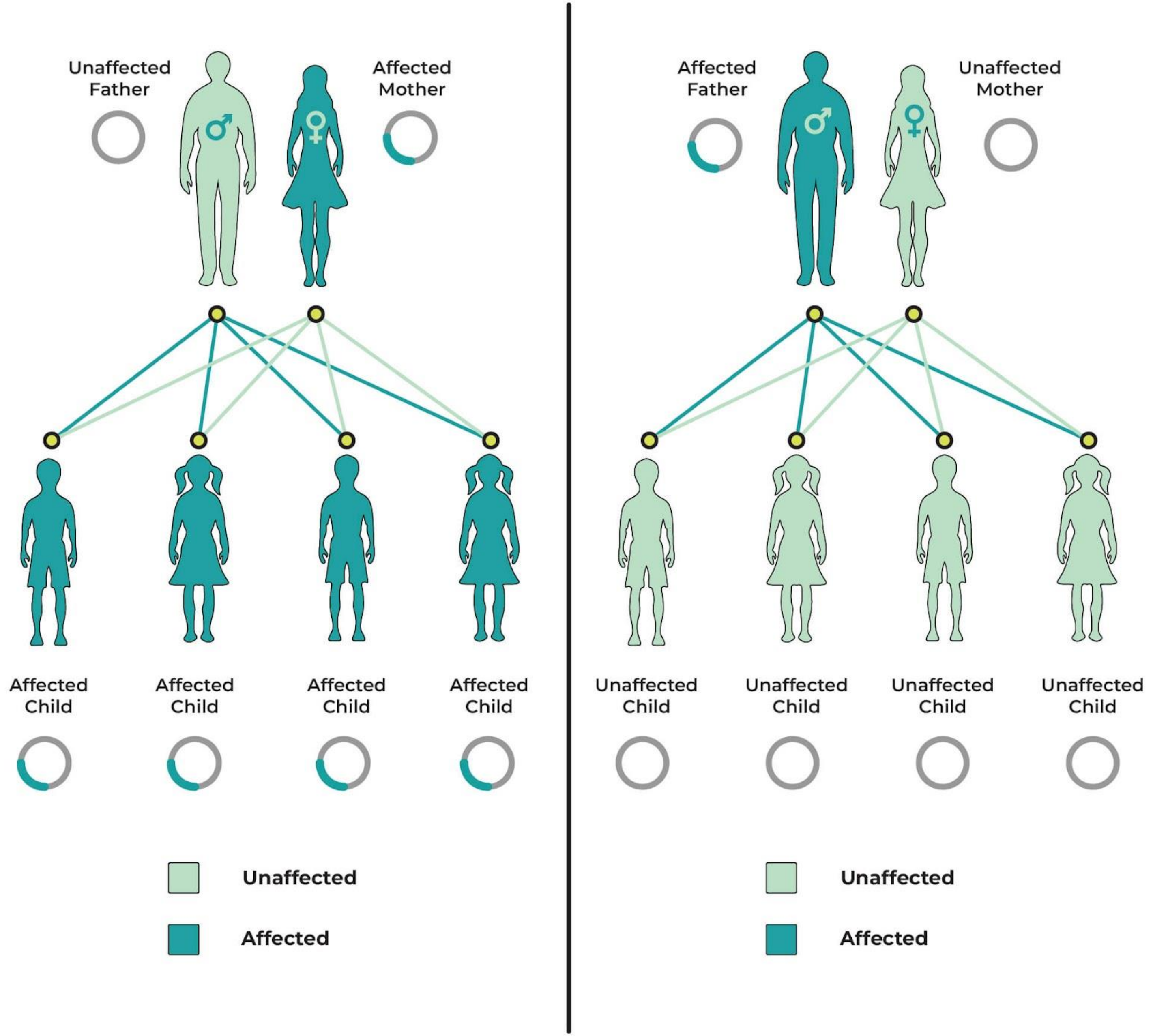
- Mutation rate 10–20 times higher than that of the nuclear genome
  - less effective DNA repair system
  - respiratory chain generates reactive oxygen species (ROS) and exposes the mitochondrial genome to oxidative damage

Mitochondria

- In humans, mitochondrial DNA represents about 1% of total DNA
- Mitochondrial DNA is only of maternal origin

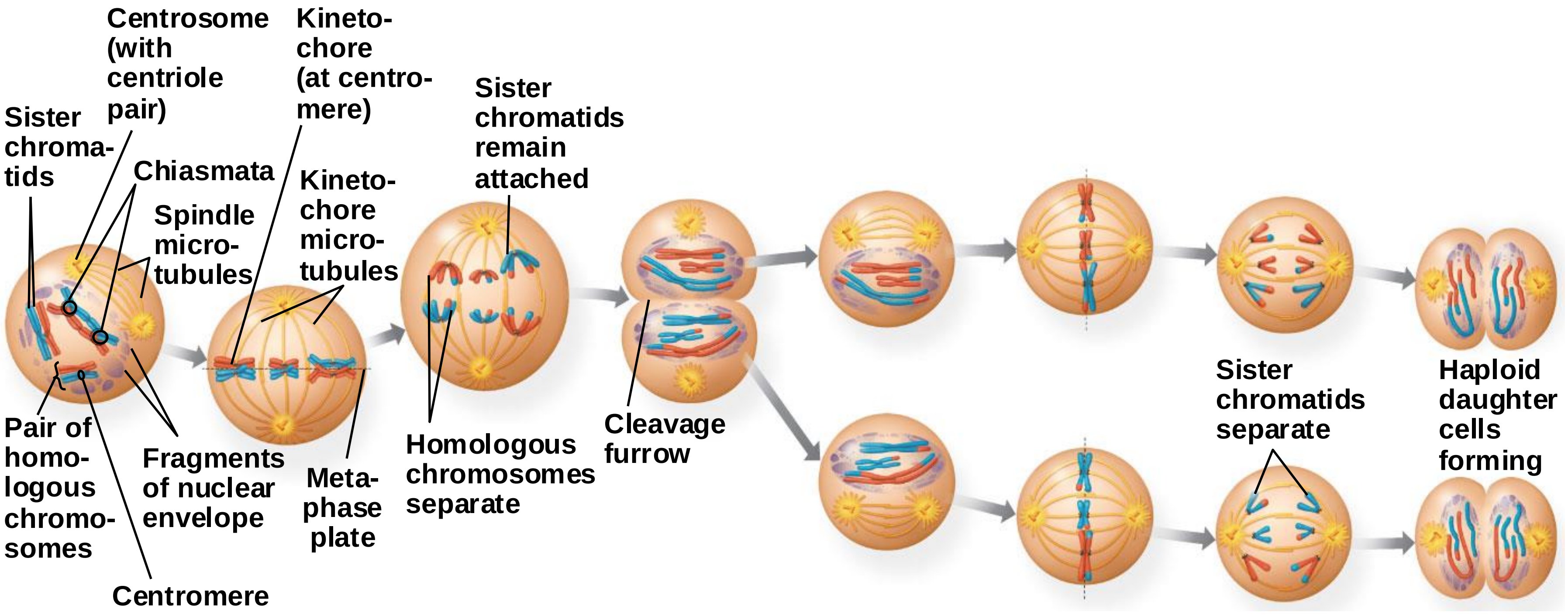


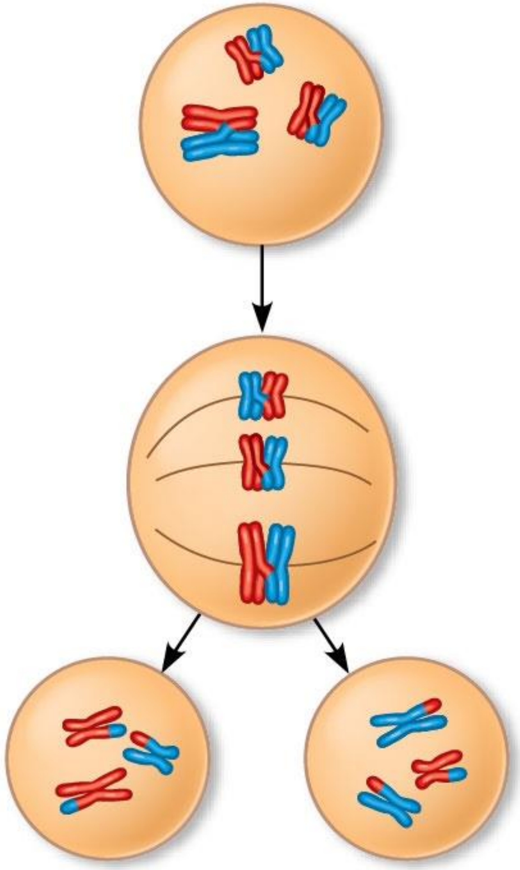
Mitochondrial Diseases



Extra slides

MEIOSIS I: Separates homologous chromosomes				MEIOSIS II: Separates sister chromatids			
Prophase I	Metaphase I	Anaphase I	Telophase I and Cytokinesis	Prophase II	Metaphase II	Anaphase II	Telophase II and Cytokinesis





Prophase I: Each pair of homologous chromosomes undergoes synapsis and crossing over between nonsister chromatids with the subsequent appearance of chiasmata.

Metaphase I: Chromosomes line up as homologous pairs on the metaphase plate.

Anaphase I: Homologs separate from each other; sister chromatids remain joined at the centromere.

SUMMARY		
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 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