Meiosis

Lecture 20

Objectives

- Describe briefly meiosis I and meiosis II
- Describe the changes in the amount of DNA per cell starting from S phase until the end of meiosis II
- Be able to define, describe, and understand
- compare mitosis and meiosis using the following criteria: the Number of divisions, synapses of homologous chromosomes, daughter cell number & genetic composition, and roles in the body
  - locus
  - allele
  - haploid genome
  - diploid genome
  - homozygous diploid
  - heterozygous diploid
  - haploid cells
  - gametogenesis
  - fertilization

Haploid & Diploid

- Many multicellular eukaryotic species are sexually reproducing
  - They have parents: a "mom" & "dad" / male & female
  - Sexual reproduction provides genetic variation that helps give species a survival advantage
- They inherit a set of chromosomes from two parents
- The two sets of chromosomes in the cell makes cells diploid
- Sexual reproduction requires a process (meiosis) that produces gametes that have the haploid state in the individual of one sex to combine with gametes with individual of the other sex
- When gametes join (the fertilization process), if they did reduce ploidy by half, then DNA content of cell would be unmanageable

Meiosis I

The "reduction division"

because this takes cells from diploid (2n) to haploid (n) state

- Prophase I

  Genetic recombination occurs in prophase: "mixing" of parental genes on paired chromatids by homologous recombination

- Metaphase I
  - The homologous pairs line up on the equator of the spindle
  - in mitosis all chromosomes line on the equator; pairing of homologues does not occur
- Anaphase I
  - The homologous pairs migrate to spindle poles and become daughter cells
  - There is no sister chromatid separation at centromeres
- Telophase I / cell division

  The DNA content is 2C and the cells are now haploid (n)

Meiosis II

- There is NO S phase (DNA replication) between Meiosis I and II

  DNA content remains at 2C
- Prophase II

  Almost imperceptible since chromosomes really do not have to de-condense as if in interphase
- Metaphase II

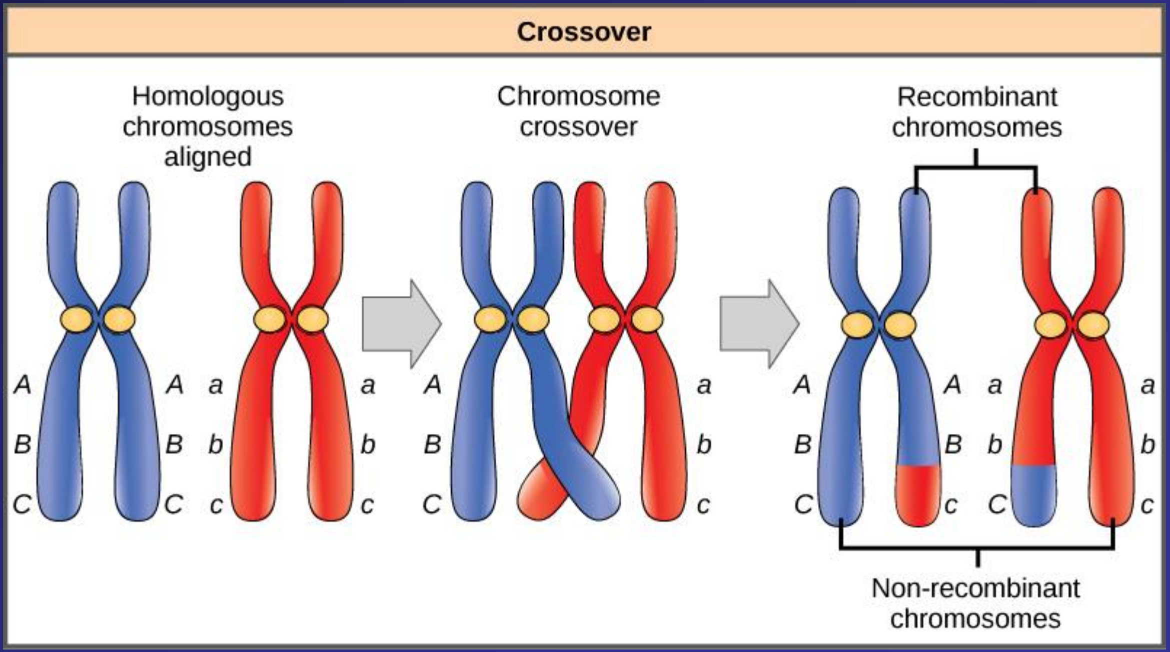
  All chromosomes, as in mitosis metaphase, are aligned on the spindle equator
- Anaphase II

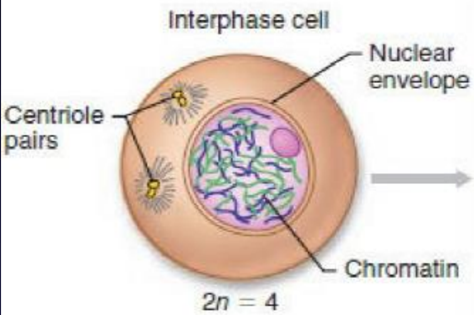
  Sister chromatids separate at centromeres just as in mitosis anaphase
- Telophase I / cell division

  The DNA content is 1C and the cells are still haploid (n)

Homologous Recombination

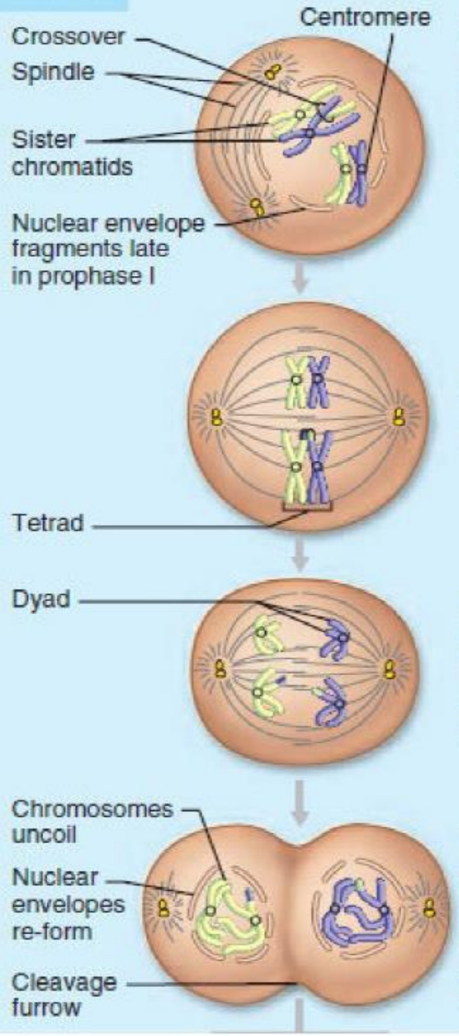
- Homologous chromosomes (from each parent) line up as spindle forms
- In process called synapsis, arms of chromatids from each pair exchange DNA strands
- This creates genetic variation for the species





Interphase events
As in mitosis, meiosis is preceded by DNA replication and other preparations for cell division.

MEIOSIS I

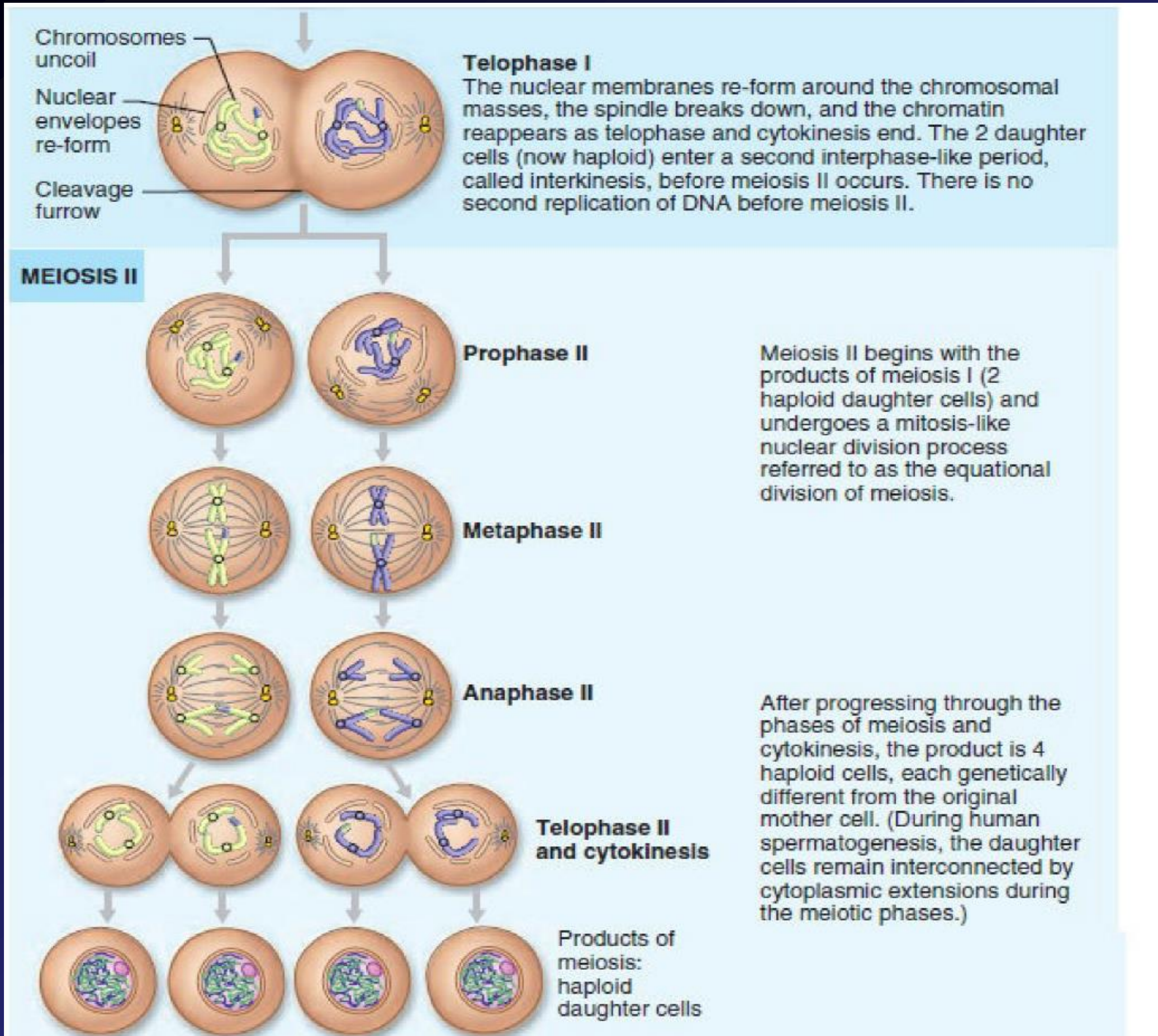


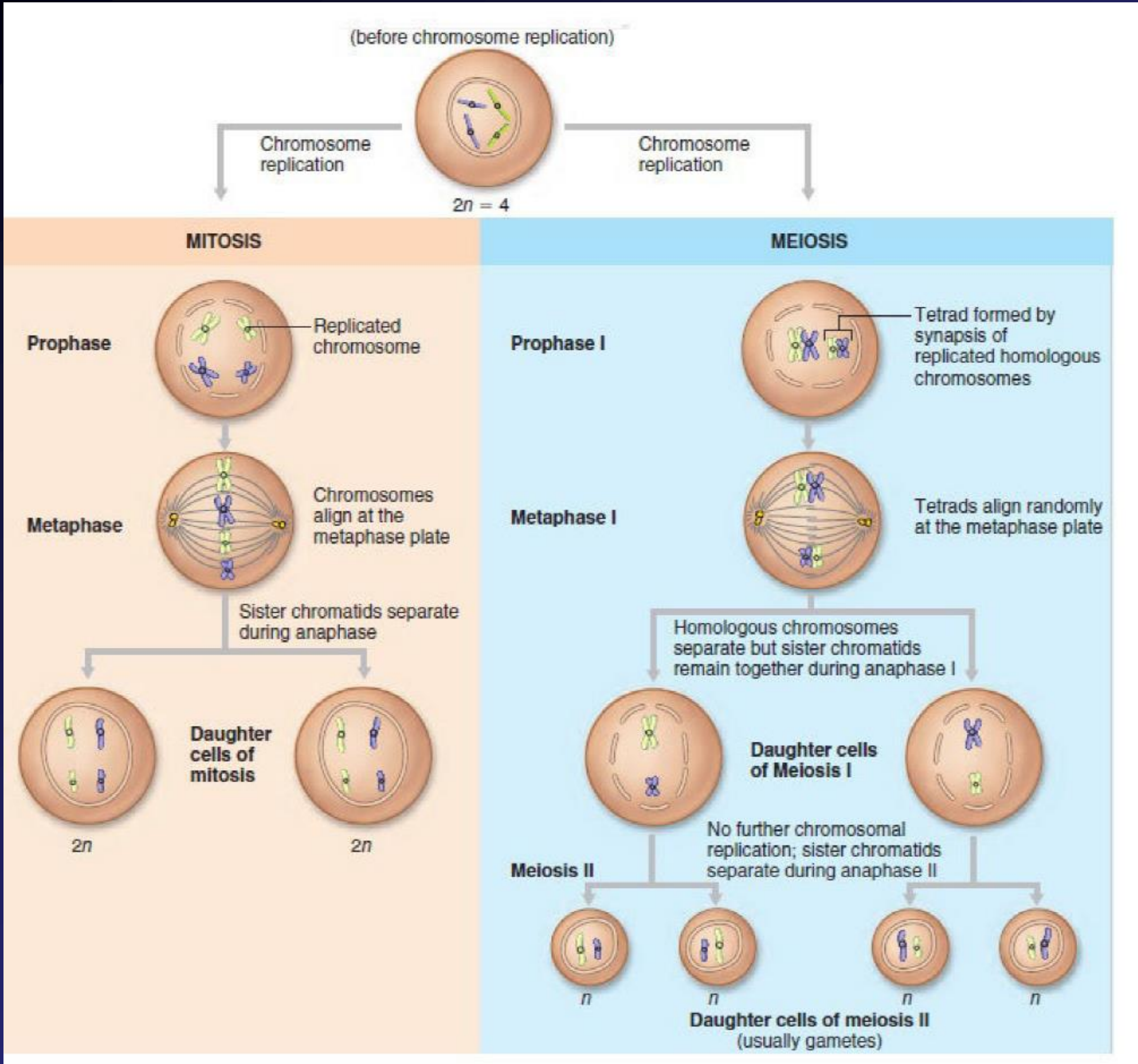
Prophase I
Prophase events occur, as in mitosis. Additionally, synapsis occurs: Homologous chromosomes come together along their length to form tetrads. During synapsis, the "arms" of homologous chromatids wrap around each other, forming several crossovers. The nonsister chromatids trade segments at points of crossover. Crossover is followed through the diagrams below.

Metaphase I
The tetrads align randomly on the spindle equator in preparation for anaphase.

Anaphase I
Unlike anaphase of mitosis, the centromeres do not separate during anaphase I of meiosis, so the sister chromatids (dyads) remain firmly attached. However, the homologous chromosomes do separate from each other and the dyads move toward opposite poles of the cell.

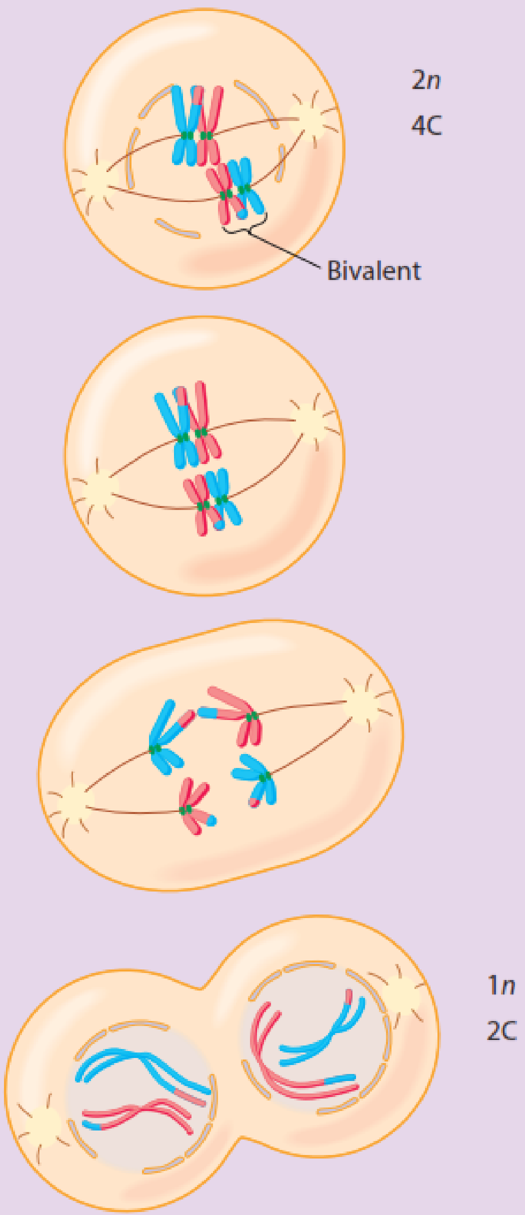
Telophase I
The nuclear membranes re-form around the chromosomal masses, the spindle breaks down, and the chromatin reappears as telophase and cytokinesis end. The 2 daughter cells (now haploid) enter a second interphase-like period, called interkinesis, before meiosis II occurs. There is no second replication of DNA before meiosis II.


Chromosomes uncoil
Nuclear envelopes re-form
Cleavage furrow
Telophase I
The nuclear membranes re-form around the chromosomal masses, the spindle breaks down, and the chromatin reappears as telophase and cytokinesis end. The 2 daughter cells (now haploid) enter a second interphase-like period, called interkinesis, before meiosis II occurs. There is no second replication of DNA before meiosis II.
MEIOSIS II
Prophase II
Meiosis II begins with the products of meiosis I (2 haploid daughter cells) and undergoes a mitosis-like nuclear division process referred to as the equational division of meiosis.
Metaphase II
Anaphase II
After progressing through the phases of meiosis and cytokinesis, the product is 4 haploid cells, each genetically different from the original mother cell. (During human spermatogenesis, the daughter cells remain interconnected by cytoplasmic extensions during the meiotic phases.)
Telophase II and cytokinesis
Products of meiosis: haploid daughter cells



(before chromosome replication)
Chromosome replication
Chromosome replication
2n = 4
MITOSIS
MEIOSIS
Prophase
Replicated chromosome
Metaphase
Chromosomes align at the metaphase plate
Sister chromatids separate during anaphase
Daughter cells of mitosis
2n
2n
Prophase I
Tetrad formed by synapsis of replicated homologous chromosomes
Metaphase I
Tetrads align randomly at the metaphase plate
Homologous chromosomes separate but sister chromatids remain together during anaphase I
Daughter cells of Meiosis I
Meiosis II
No further chromosomal replication; sister chromatids separate during anaphase II
n
n
n
n
Daughter cells of meiosis II
(usually gametes)

MEIOSIS I



Prophase

Each condensing chromosome has two chromatids. In meiosis I, homologous chromosomes synapse, forming a bivalent. Crossing over occurs between nonsister chromatids, producing chiasmata. In mitosis, each chromosome acts independently.

Metaphase

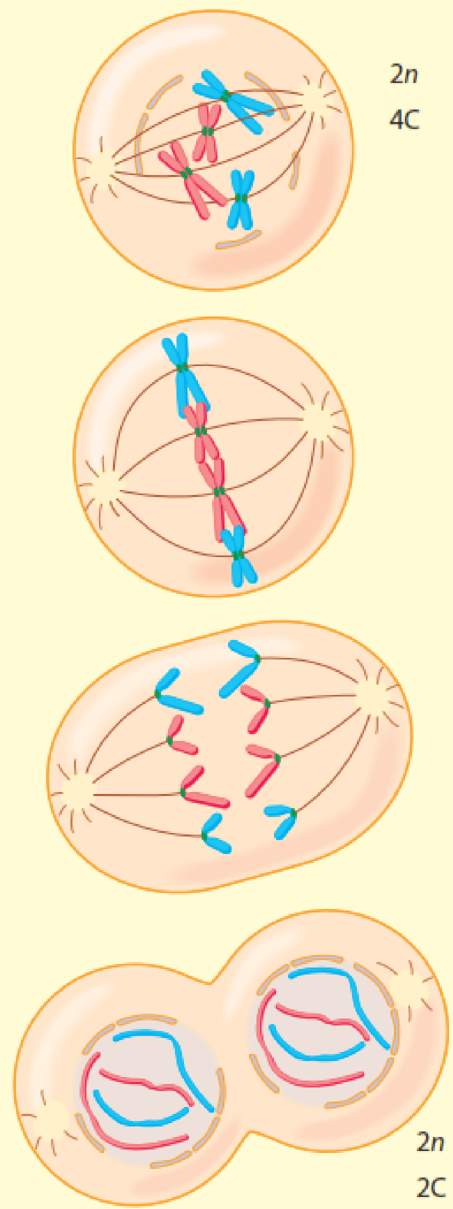
In meiosis I, the bivalents align at the metaphase plate. In mitosis, individual chromosomes align at the metaphase plate.

Anaphase

In meiosis I, chromosomes (not chromatids) separate. In mitosis, chromatids separate.

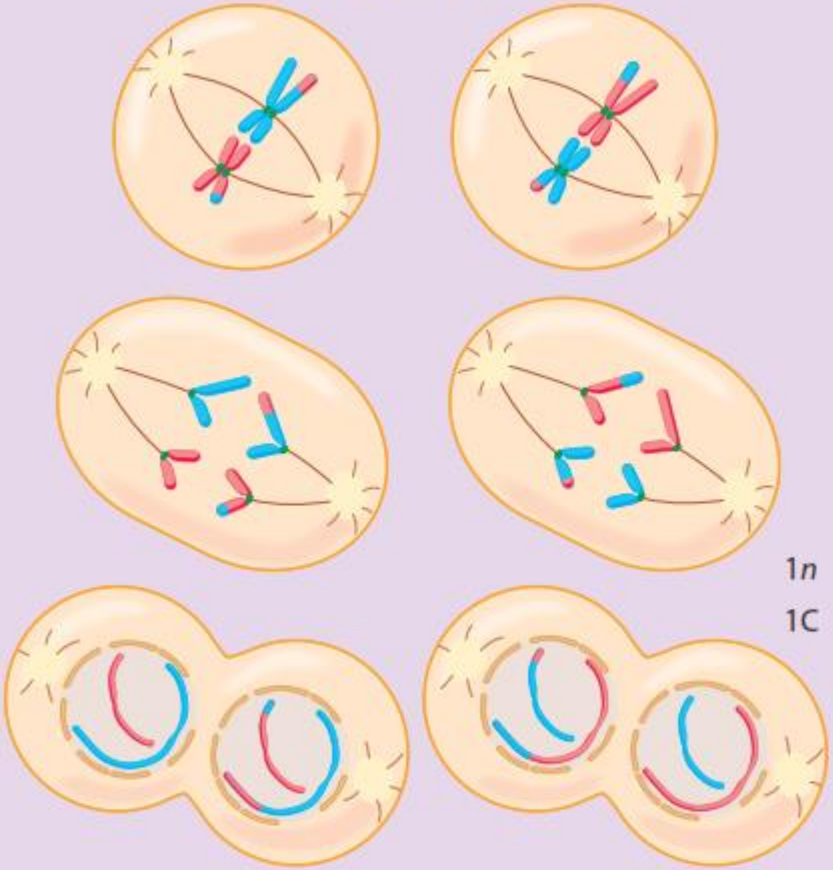
Telophase and Cytokinesis

MITOSIS



Result of mitosis: two cells, each with the same number of chromosomes as the original cell.

MEIOSIS II



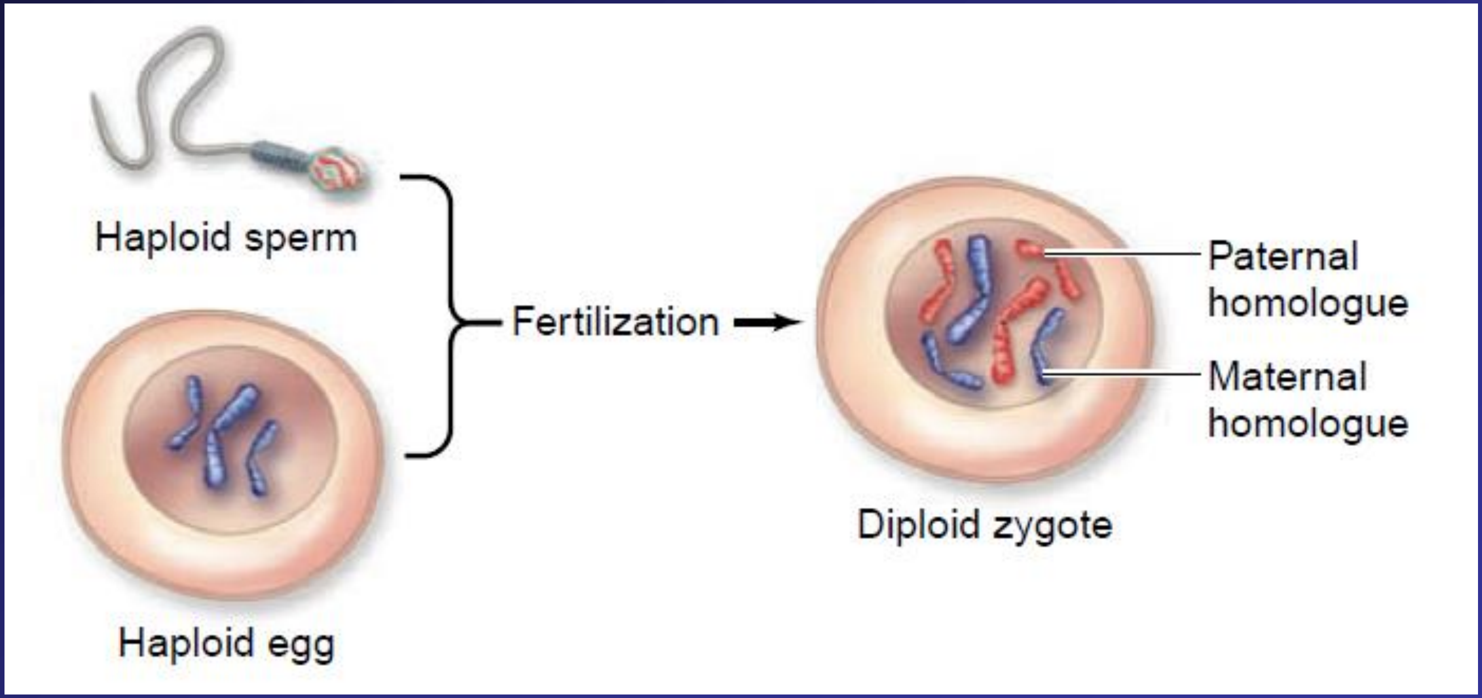
In meiosis II, sister chromatids separate.

Result of meiosis: four haploid cells, each with half as many chromosomes as the original cell. Each haploid cell contains a random mixture of maternal and paternal chromosomes.

Gametogenesis

- The production of gametes includes the process of meiosis
- Because meiosis starts with a single cell in the diploid state with newly replicated DNA (went through S phase), its first division produces two haploid cells that undergo a mitotic-like division in meiosis II to produce four haploid cells
- With the four cells made, they undergo differentiation to complete gametogenesis
  - each cell in a human female *can* become an ovum
  - each cell in a human male becomes a spermatozoon
- Gametes ARE haploid cells

- Note that the spermatozoon has red-colored chromosomes and the ovum has the blue-colored chromosomes
- These haploid cells (gametes) will join in fertilization to form the diploid cell



Quick Molecular Mendel

- In the previous slide on homologous recombination as shown by chromosomal crossover, the places marked with letters represent the loci of genes
- Genes are involved with traits, but genes are molecularly represented as sequences on DNA in chromosomes. A locus is the molecular place where a gene resides on the chromosome
- The DNA sequences of genes can have variation: e.g. the gene for eye color can have different DNA sequences, one which produces blue eye color and another producing brown eye color
- Variation in a gene is called an allele: molecular geneticists see variation as difference one or more bases of a DNA sequence coding the gene

Homozygous & Heterozygous

- The gene for eye color has two alleles: *B* for brown and *b* for blue
- Because of the diploid state, two alleles are possible for a gene
- So with eye color, we can have the following possible pairs of alleles or genotypes: *BB*, *Bb*, and *bb*
- When the alleles in genotypes are identical, such as *BB* and *bb*, these are called homozygous (diploid)
- When the alleles in genotypes are different, such as *Bb*, these are called heterozygous (diploid)

Genotypes

- The genotype of a single gene of an organism are the symbolic representations of the two alleles it has
- Suppose a gene has two alleles, W and X: it can form WW, WX, and XX for the diploid set
- If it has three possible alleles, W, X, and Z, then it can form 6 possible genotypes WW, WX, XX, WZ, XZ, and ZZ for the diploid set

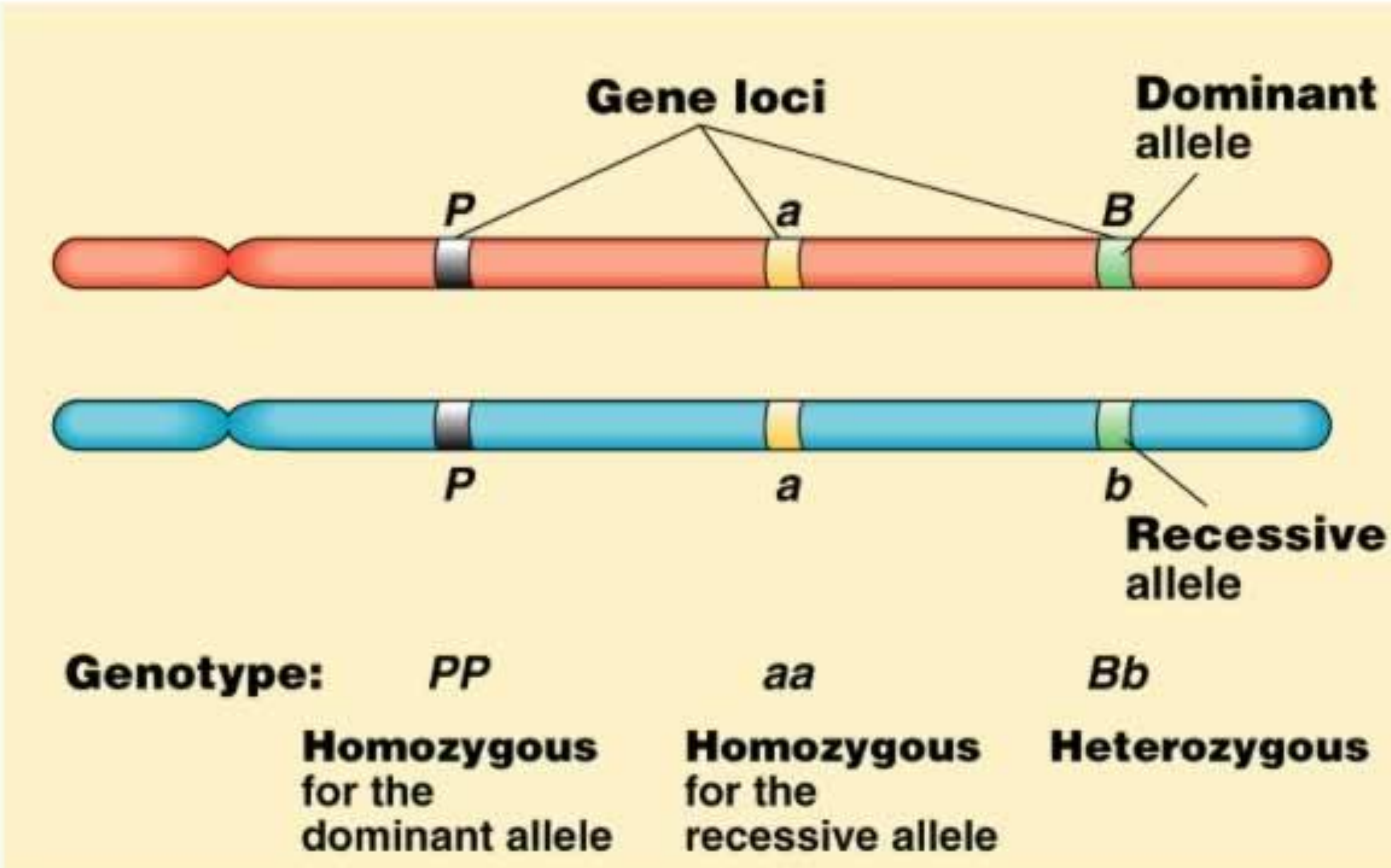
$G = \frac{a(a+1)}{2}$ G = #genotypes possible, a = # alleles

Dominant, Recessive & Phenotype

- In Mendelian genetics, some alleles for MANY but NOT ALL genes show dominance
- In eye color, those with the brown allele (*B*) show brown eyes even though their other allele in the diploid genome is blue (*b*): the *B* allele is dominant over the *b* allele
- Individuals with *BB* and *Bb* genotype show brown eyes; those with *bb* genotype show blue eyes
- The brown eye color is dominant and the blue eye color is recessive
- The phenotype is how the genotype expresses itself:
  - *BB* & *Bb* genotypes → brown eye color phenotype
  - *bb* genotype → blue eye color phenotype

Mendel → Molecule

- Keep in mind that Mendel knew nothing of the molecular details of how genes (traits) were organized as DNA sequences on chromosomes
- We can now understand dominant & recessive phenotypes and alleles as changes in the qualitative (presence or absence) and quantitative (low or high) expression of proteins coded by DNA
- As many as 16 different genes (not merely alleles) are involved in determining the coloration of the iris, although there are two main genes with one regulating the other that provide what we see as generally brown eyes and variations on blue eye color



Gene loci
Dominant allele
P
a
B
P
a
b
Recessive allele
Genotype:
PP
aa
Bb
Homozygous for the dominant allele
Homozygous for the recessive allele
Heterozygous

Comparing Mitosis & Meiosis

	Meiosis I	Meiosis II	Mitosis
S phase	DNA: 4C diploid (2n) cells	no S phase	DNA: 4C diploid (2n) cells
prophase: homologous recombination	synapsis + crossing over	as in mitosis	doesn't happen
metaphase: equatorial alignment	homologous pairs (bivalents)	as in mitosis	all chromosomes
anaphase: separation	one chromosome of the homologous pairs	as in mitosis	sister chromatids
daughter cells	DNA: 2C haploid (n) cells	DNA: C haploid (n) cells	DNA: 2C diploid (2n) cells

Reading (Sources)

- Becker's WotC: pp 602-611
- Raven: pp 207-217