Genes, Chromosomes, and Numbers

- Genes do not exist free in the nucleus of a cell; they are lined up on chromosomes.
- Typically, a chromosome can contain a thousand or more genes along its length.

Diploid and haploid cells

- In the body cells of animals and most plants, chromosomes occur in pairs.
- A cell with two of each kind of chromosome is called a diploid cell and is said to contain a diploid, or \(2n\), number of chromosomes.

Diploid and haploid cells

- This pairing supports Mendel’s conclusion that organisms have two factors—alleles—for each trait.
- Organisms produce gametes that contain one of each kind of chromosome.
- A cell containing one of each kind of chromosome is called a haploid cell and is said to contain a haploid, or \(n\), number of chromosomes.

This table shows the diploid and haploid number of chromosomes of some species.

<table>
<thead>
<tr>
<th>Organism</th>
<th>Body Cell (2n)</th>
<th>Gamete (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit fly</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Garden pea</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>Corn</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Tomato</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Leopard Frog</td>
<td>26</td>
<td>13</td>
</tr>
<tr>
<td>Apple</td>
<td>34</td>
<td>17</td>
</tr>
<tr>
<td>Human</td>
<td>46</td>
<td>23</td>
</tr>
<tr>
<td>Chimpanzee</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>Dog</td>
<td>78</td>
<td>39</td>
</tr>
<tr>
<td>Adder’s tongue fern</td>
<td>1260</td>
<td>630</td>
</tr>
</tbody>
</table>

This fact supports Mendel’s conclusion that parent organisms give one allele for each trait to each of their offspring.

Homologous chromosomes

- The two chromosomes of each pair in a diploid cell are called homologous chromosomes.
- Each pair of homologous chromosomes has genes for the same traits.
On homologous chromosomes, these genes are arranged in the same order, but because there are different possible alleles for the same gene, the two chromosomes in a homologous pair are not always identical to each other.

Homologous Chromosome 4
- Terminal
- Axial
- Inflated
- Constricted
- Tall
- Short

When cells divide by mitosis, the new cells have exactly the same number and kind of chromosomes as the original cells.

Imagine if mitosis were the only means of cell division.

Each pea plant parent, which has 14 chromosomes, would produce gametes that contained a complete set of 14 chromosomes.

The F₁ pea plants would have cell nuclei with 28 chromosomes, and the F₂ plants would have cell nuclei with 56 chromosomes.

Why meiosis?
There must be another form of cell division that allows offspring to have the same number of chromosomes as their parents.

This kind of cell division, which produces gametes containing half the number of chromosomes as a parent’s body cell, is called meiosis.

Meiosis consists of two separate divisions, known as meiosis I and meiosis II.

Meiosis I begins with one diploid (2n) cell.

By the end of meiosis II, there are four haploid (n) cells.

These haploid cells are called sex cells—gametes.

Male gametes are called sperm.

Female gametes are called eggs.

When a sperm fertilizes an egg, the resulting zygote once again has the diploid number of chromosomes.
This pattern of reproduction, involving the production and subsequent fusion of haploid sex cells, is called sexual reproduction.

Meiosis

- During meiosis, a spindle forms and the cytoplasm divides in the same ways they do during mitosis.
- However, what happens to the chromosomes in meiosis is very different.

The Phases of Meiosis

- During interphase, the cell replicates its chromosomes.
- After replication, each chromosome consists of two identical sister chromatids, held together by a centromere.

Interphase

- The chromosomes coil up and a spindle forms.
- As the chromosomes coil, homologous chromosomes line up with each other gene by gene along their length, to form a four-part structure called a tetrad.

Prophase I

- The chromatids in a tetrad pair tightly.
- In fact, they pair so tightly that non-sister chromatids from homologous chromosomes can actually break and exchange genetic material in a process known as crossing over.
**Prophase I**
- Crossing over can occur at any location on a chromosome, and it can occur at several locations at the same time.

**It is estimated that during prophase I of meiosis in humans, there is an average of two to three crossovers for each pair of homologous chromosomes.**

**Metaphase I**
- During metaphase I, the centromere of each chromosome becomes attached to a spindle fiber.
- The spindle fibers pull the tetrads into the middle, or equator, of the spindle.

**Anaphase I**
- Anaphase I begins as homologous chromosomes, each with its two chromatids, separate and move to opposite ends of the cell.
- This critical step ensures that each new cell will receive only one chromosome from each homologous pair.

**Telophase I**
- Events occur in the reverse order from the events of prophase I.
- The spindle is broken down, the chromosomes uncoil, and the cytoplasm divides to yield two new cells.
**Telophase I**
- Each cell has half the genetic information of the original cell because it has only one chromosome from each homologous pair.

**The phases of meiosis II**
- The second division in meiosis is simply a mitotic division of the products of meiosis I.
- Meiosis II consists of prophase II, metaphase II, anaphase II, and telophase II.

**The phases of meiosis II**
- During prophase II, a spindle forms in each of the two new cells and the spindle fibers attach to the chromosomes.

**The phases of meiosis II**
- Anaphase II begins as the centromere of each chromosome splits, allowing the sister chromatids to separate and move to opposite poles.

**The phases of meiosis II**
- Finally nuclei reform, the spindles break down, and the cytoplasm divides during telophase II.
• At the end of meiosis II, four haploid cells have been formed from one diploid cell.
• These haploid cells will become gametes, transmitting the genes they contain to offspring.

Meiosis Provides for Genetic Variation
• Cells that are formed by mitosis are identical to each other and to the parent cell.
• Crossing over during meiosis, however, provides a way to rearrange allele combinations.
• Thus, variability is increased.

Genetic recombination
• Reassortment of chromosomes and the genetic information they carry, either by crossing over or by independent segregation of homologous chromosomes, is called genetic recombination.
• It is a major source of variation among organisms.

Meiosis explains Mendel’s results
• The segregation of chromosomes in anaphase I of meiosis explains Mendel’s observation that each parent gives one allele for each trait at random to each offspring, regardless of whether the allele is expressed.
• The segregation of chromosomes at random during anaphase I also explains how factors, or genes, for different traits are inherited independently of each other.
The failure of homologous chromosomes to separate properly during meiosis is called **nondisjunction**.

Nondisjunction

Recall that during meiosis I, one chromosome from each homologous pair moves to each pole of the cell.

In nondisjunction, both chromosomes of a homologous pair move to the same pole of the cell.

Nondisjunction

The effects of nondisjunction are often seen after gametes fuse.

When a gamete with an extra chromosome is fertilized by a normal gamete, the zygote will have an extra chromosome.

This condition is called trisomy.

Nondisjunction

Although organisms with extra chromosomes often survive, organisms lacking one or more chromosomes usually do not.

When a gamete with a missing chromosome fuses with a normal gamete during fertilization, the resulting zygote lacks a chromosome.

This condition is called monosomy.

Nondisjunction

An example of monosomy that is not lethal is Turner syndrome, in which human females have only a single X chromosome instead of two.
Nondisjunction

- When a gamete with an extra set of chromosomes is fertilized by a normal haploid gamete, the offspring has three sets of chromosomes and is triploid.
- The fusion of two gametes, each with an extra set of chromosomes, produces offspring with four sets of chromosomes—a tetraploid.

Chromosome Mapping

- Genes that are farther apart on a chromosome are more likely to have crossing over occur between them than are genes that are closer together.

Geneticists determine that the frequencies of recombination among them are as follows: between A and B—50%; between A and D—10%; between B and C—5%; between C and D—35%.
- The recombination frequencies can be converted to map units: A-B = 50; A-D = 10; B-C = 5; C-D = 35.

These map units are not actual distances on the chromosome, but they give relative distances between genes. Geneticists line up the genes as shown.
**Chromosome Mapping**

- The genes can be arranged in the sequence that reflects the recombination data.
- This sequence is a chromosome map.

**Polyploidy**

- Organisms with more than the usual number of chromosome sets are called polyploids.
- Polyploidy is rare in animals and almost always causes death of the zygote.

**Gene Linkage and Maps**

- If genes are close together on the same chromosome, they usually are inherited together.
- These genes are said to be linked.

**Polyploidy**

- However, polyploidy frequently occurs in plants.
- Many polyploid plants are of great commercial value.

**Gene Linkage and Maps**

- Linked genes may become separated on different homologous chromosomes as a result of crossing over.
- When crossing over produces new gene combinations, geneticists can use the frequencies of these new gene combinations to make a chromosome map showing the relative locations of the genes.