CHAPTER

1

CELLS AND CELL DIVISION

1.1 Introduction

In genetics, we view cells as vessels for the genetic material. Our main interest is in the chromosomes and their environment. This being said, we have found that the only way to truly understand the more molecular aspects of genetic regulation and development is to understand the cellular environment. Unfortunately, that sort of study will have to wait for more advanced classes.

1.2 Cells

Cells are incredibly complex structures, with dynamics we are nowhere close to understanding. We can distinguish between two types of cells, Prokaryotic and Eukaryotic cells. While there are certainly differences within each of these cell types, they will not concern us in our look at the genetic environment.

1.2.1 Prokaryotic Cells

Prokaryotic cells (such as given in Figure 1-1) are simple cells with their DNA arranged as a single circular chromosome. Within the cells are the various structures needed for the production of proteins in order to sustain life. In addition, some relatively small circular pieces of DNA, called plasmids, exist independently of the central chromosome. During cell division, the DNA replicates itself with one of the newly created DNA molecules ending in each of the daughter cells. Plasmids replicate independently of the cell and just end up in whatever daughter cell they end up in.

1.2.2 Eukaryotic Cells

While Eukaryotic cells (such as given in Figure 1-2) are more complex, they share many of the same elements as Prokaryotic cells,

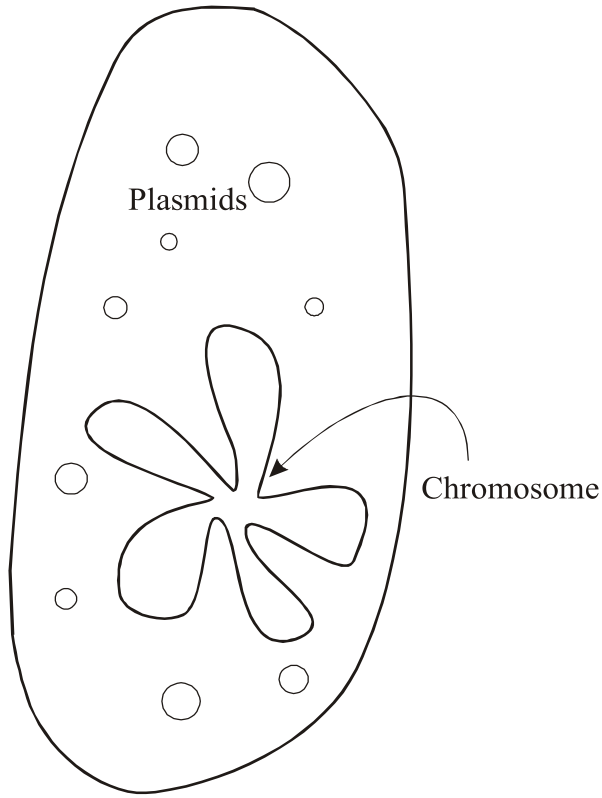

Figure 1-1 Stylized Prokaryotic Cell

particularly at the biochemical level. The cells are much larger, and contain some specialized structures. Some of the structures that are important to understanding genetic processes are given in the following sections.

Plasma Membrane

The plasma membrane is a membrane that encloses the cell. While it is tempting to think of these membrane as merely sacks, the cell interacts with the membrane in many different ways. In addition, it is important that the membrane is permeable to some things and not to others. Plants also have a cell wall that helps to give structure to the cells.

Nucleus

The cell's genetic material, the DNA, is located in the nucleus. It has a membrane that isolates the DNA from other cellular parts. The DNA is organized as long (up to several hundred million basepairs long) chromosomes. Inside the nucleus, the DNA is called chromatin.

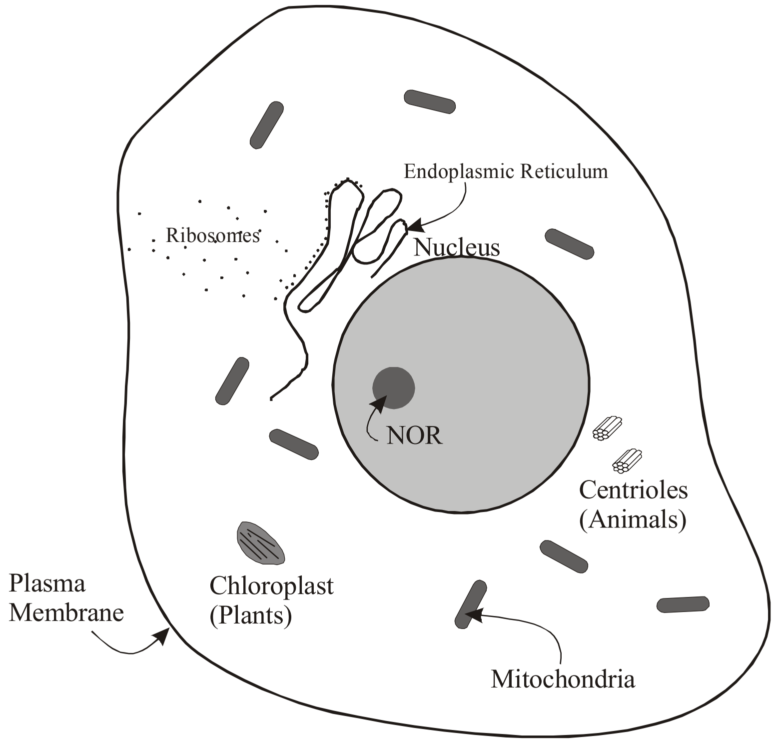

Figure 1-2 Stylized Eukaryotic Cell

As with the plasma membrane, the nucleus permeable to some things and not others. By and large, the cell determines what it wants to allow into the nucleus.

Nuclear Organizing Region (Nucleolus)

A darkly stained area in the nucleus is the location for some specialized processes, in particular, the production of Ribosomal RNA.

Centrioles

The centrioles are found in animal cells. They will become the spindle fibers during Mitosis and Meiosis. Plant cells also have spindle fibers, but they cannot be seen during Interphase. The spindle fibers are microtubules that attach to the centromeres during cell division. During Anaphase, these microtubules contract, causing the separation of Chromatids (during Mitosis and Second Division Meiosis) or Chromosomes (during First Division Meiosis).

Mitochondria

Found in plants and animals, mitochondria are used in the production of ATP (Adenosine Triphosphate), a major source of chemical energy in the cell. The Mitochondria contain their own DNA. Typically, cells have from 10-100 mitochondria, although some types of cells have thousands.

Chloroplasts

Found in plants, chloroplasts are used to convert light energy into chemical energy. The chloroplasts contain their own DNA. The chlorophyll in the chloroplasts give plant cells their green color.

Endoplasmic Reticulum

Several biological processes require a membrane to function. While the cell membrane for a Prokaryotic cell is adequate, the Eukaryotic cell requires more membrane. The Endoplasmic Reticulum meets that requirement. Often, the Endoplasmic Reticulum has Ribosomes associated with it, which can be seen through a microscope as Rough Endoplasmic Reticulum.

1.3 Mitosis

Since the chromosomes contain the genetic information for the organism, it is important to follow the chromosomes during cell division. The timing for the basic stages of Mitosis are shown in Figure 1-3.

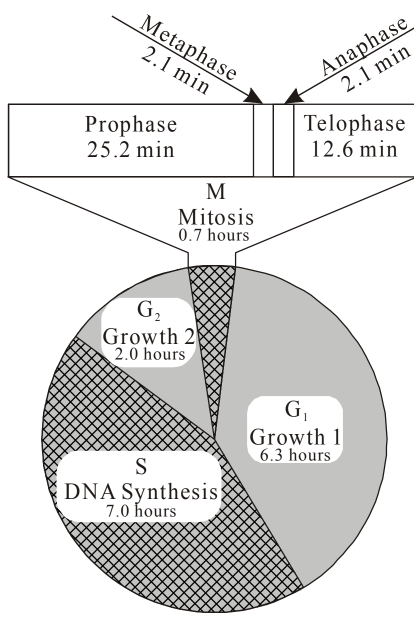

Figure 1-3 Cell Cycle for Eukaryotic Cell.

(Times are for Human Leukocytes)

This shows the phases for a cell that is actively dividing. If the cell is not dividing (quiescent), it is said to be in **G_0 Phase**.

The phases of Mitosis are

- **Interphase** DNA is replicated (sister chromatids are formed) during Interphase. This phase is further divided into three stages.
  - **G_1 Phase.** Growth 1 is where the cell is preparing to replicate its DNA. G_0 is the stage a cell is in when it is not actively dividing, nor preparing to divide.
  - **S Phase.** During S Phase, the DNA is replicated. The DNA is largely unavailable for transcription during this Phase, and the cell uses resources it has stockpiled during G_1.
  - **G_2 Phase.** During Growth 2, the cell cleans up from DNA replication, and prepares itself for the actual mitotic event.

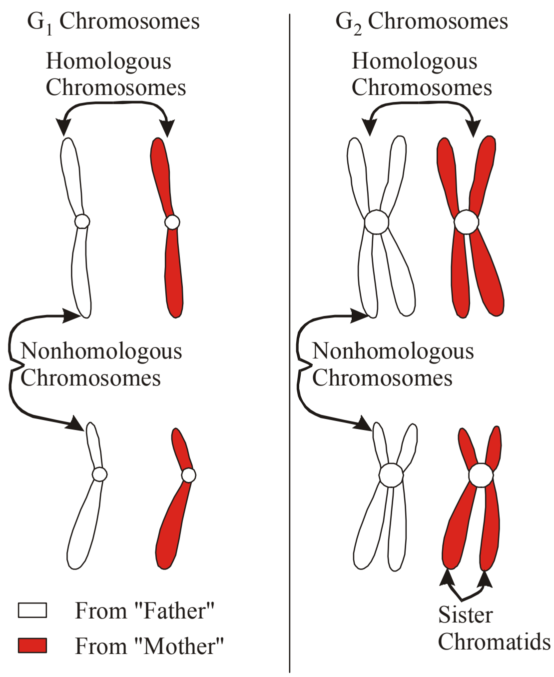

Figure 1-4 Chromosomes and Chromatids

Figure 1-4 shows the relationship of chromosomes to chromatids during Interphase. To ease the diagram, the chromosomes are shown as if they were condensed. In the actual cell, they would be diffuse through the nucleus.

- **Prophase** During Prophase, the chromatin condenses and associates with scaffold proteins. By the end of Prophase, the chromatids will be fully condensed, ready for cell division. At this stage, the chromosomes look like the diagram in Figure 1-4. Also during Prophase, the nuclear membrane dissolves, the centrioles move towards the poles (or, in the case of plants, the spindle fibers are created).

- **Metaphase** The centromeres line up along the midplate (the middle of the cell). The spindle fibers attach to the centromeres.
- **Anaphase** During Anaphase, the spindle fibers contract. This pulls the centromeres to opposite poles, separating the sister chromatids. This division is call *equational*, since both daughter cells have exactly the same DNA as each other (except for mutations).
- **Telophase** Telophase completes cell division. The new nuclear membranes form around the chromatin, the specialized structures (such as spindle fibers) are recycled, and the cytoplasm is divided. The chromosome relax into their active state.

The organelles do not have any mechanism to separate evenly. They end up in whatever daughter cell they happen to be in when the cells create new plasma membranes. This process is important to understanding the inheritance of mitochondrial and chloroplast traits (see Chapter 18).

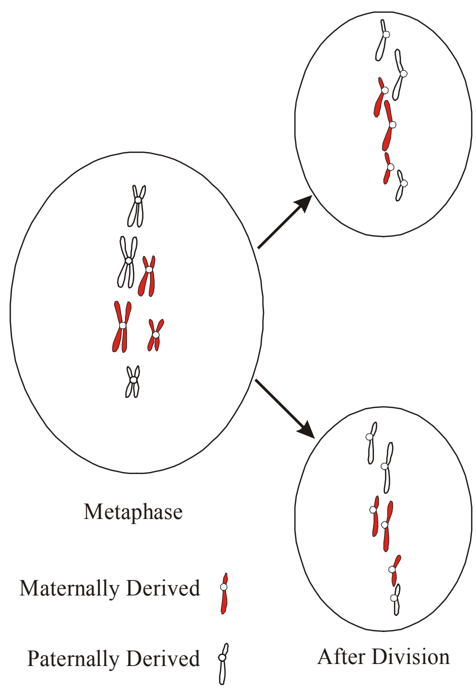

Figure 1-5 Mitotic Division

Figure 1-5 gives an indication of how the chromatids divide during Mitosis. During Metaphase, the centromeres line up along the midplate in a more orderly manner than is indicated in the Figure. After division, each daughter cell has an equal number of chromosomes. Notice that the number of chromosomes stays the same, but the number of chromatids is divided in half. This makes sense if you consider the informational content of the cell. Chromosomes represent information — we do not increase the amount of information during DNA replication, in the same way we do not increase information when we photocopy a journal article. After cell division, the cells must each have the complete set of genetic information.

Table 1-1 Chromosome & Chromatids during Mitosis

Mitotic Stage	Chromosomes	Chromatids*
Growth 1 (G_1)	2n	2n
Synthesis	2n	2n → 4n
Growth 2 (G_2)	2n	4n
Prophase	2n	4n
Metaphase	2n	4n
Anaphase	2n	4n
Telophase	2n	2n (after completion)

* Chromatin during Interphase is not normally referred to as chromatids. The notation is used here to demonstrate the continuity of DNA copies.

Table 1-1 shows the number of chromosomes and chromatids in each cell during this process. It is not normal to refer to *chromatin* during Interphase as chromatids, but we have retained that notation to help in understanding the process.

1.4 Meiosis

Meiosis can be viewed as essentially two Mitotic divisions back-to-back, without an additional S-phase between the two divisions. Figure 1-6 shows the division of chromosomes and chromatids during meiosis.

The phases of Meiosis are

- **S Phase** The DNA is replicated, forming sister chromatids. This Phase is exactly the same as for Mitosis.
- **Prophase I** During Prophase I, the chromatin must condense in preparation for separation. In addition, the cell allows for recombination during this time (actually, the cell actively recombines – it is under genetic control).
  - **Leptonema.** Condensation of chromatin.
  - **Zygonema.** Pairing of homologous chromosomes. This is accomplished with the help of the *synaptonemal complex*.

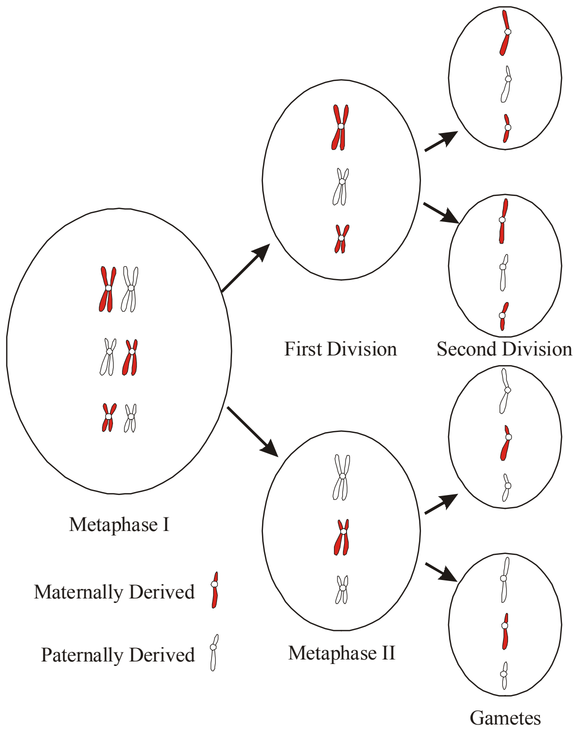

Figure 1-6   Normal Meiotic Division

Through unknown mechanisms, the synaptonemal complex pulls together homologous regions of the DNA. While not identical, homologous regions have a very high similarity.

- **Pachynema.** Full synapsis of the homologous chromosomes. Recombination (crossing over) occurs somewhere in the middle of Prophase I.
- **Diplonema.** Continued condensation of the chromatin. The formation of chiasmata, a structure seen in cells that appear to be left over from the recombination process.
- **Diakinesis.** Terminalization of the chiasmata. The centromeres on homologous chromosomes push apart.

- **Metaphase I**   The centromeres line up along the midplate. The spindle fibers attach to the centromeres.
- **Anaphase I (Reductional)**   The spindle fibers contract, separating the homologous centromeres. The first division is called the *Reductional Division,* since it is at this time that the chromosome count is reduced to one half. The division during Mitosis is always Equational, since the number of chromosomes does not change, although the number of chromatids is reduced to one half.

- **Telophase I** A resting stage between divisions. In some organisms, the telophase is extended, approximating the telophase during mitosis. In other organisms, the telophase is shortened, with the chromatin maintaining at least some condensation. The division of cytoplasm is not always equal.
- **Prophase II** The chromosomes recoil. This stage may be shortened if the chromatin did not completely relax during Telophase I.
- **Metaphase II** The centromeres line up along the midplate and the spindle fibers attach to them.
- **Anaphase II (Equational)** The spindle fibers contract, separating the centromeres for the sister chromatids. The second division is the *Equational Division*, since the number of chromosomes stays the same during the separation, while the number of chromatids is divided in half.
- **Telophase II** The cell division is complete. As with Telophase I, the division of the cytoplasm is not always equal.

Figure 1-6 shows a normal meiotic division. Notice that the first division separates homologous chromosomes, while the second division separates sister chromatids.

Table 1-2 Chromosome and Chromatids during Meiosis

Meiotic Stage	Chromosomes	Chromatids*
Growth 1 (G_1)	2n	2n
Synthesis	2n	2n → 4n
Growth 2 (G_2)	2n	4n
Prophase I	2n	4n
Metaphase I	2n	4n
Anaphase I	2n	4n
Prophase II	n	2n
Metaphase II	n	2n
Anaphase II	n	2n
Gametes	n	n

* Chromatin during Interphase is not normally referred to as chromatids. The notation is used here to demonstrate the continuity of DNA copies.

Table 1-2 shows the relationship of chromosomes and chromatids during the various stages of Meiosis.

1.4.1 Nondisjunction

Sometimes the separation of chromosomes and chromatids does not occur correctly. We term the even separation of chromatin as disjunction. When they do not separate evenly, this is termed nondisjunction. When a cell starts with the normal number of chromosomes and the first division does not divide correctly, we call it *First Division Primary Nondisjunction*, and is show in Figure 1-7. This same sort of mistake can occur during the second

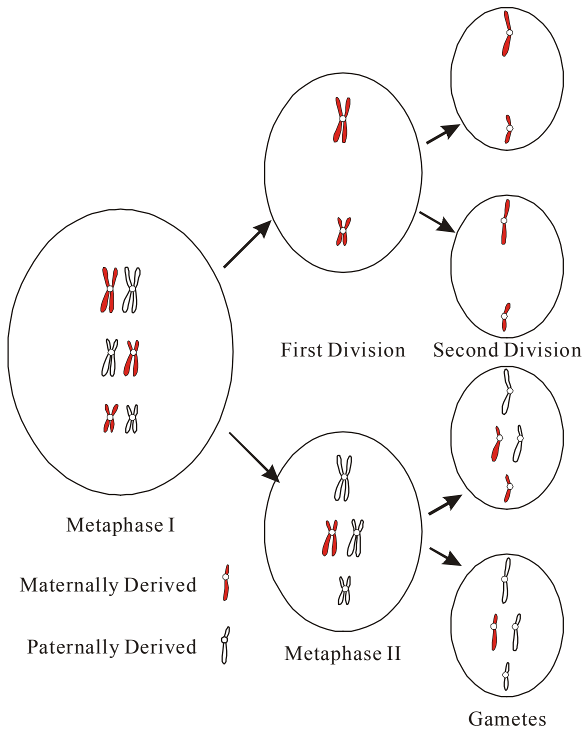

Figure 1-7 First Division Primary Nondisjunction

division, in which case it is called *Second Division Primary Nondisjunction*, and is shown in Figure 1-8.

When cells start off with an abnormal number of chromosomes (see Figure 1-9), there must be a nondisjunction event. This is termed *Secondary Nondisjunction*, and occurs during the first division (when the chromosomes are separated.)

1.5 Chromosomes and Genetics

Figure 1-10 presents the relationship among chromosomes, genes, loci, and alleles.

- **Gene** The gene is the basic unit of heredity. It is a portion of the DNA that produces a product. Usually, we think of the product as a protein, but it can also be an RNA. We have come to also use this term to refer to a molecular marker (a known DNA sequence that usually doesn't produce a product, but can be visualized using various techniques).

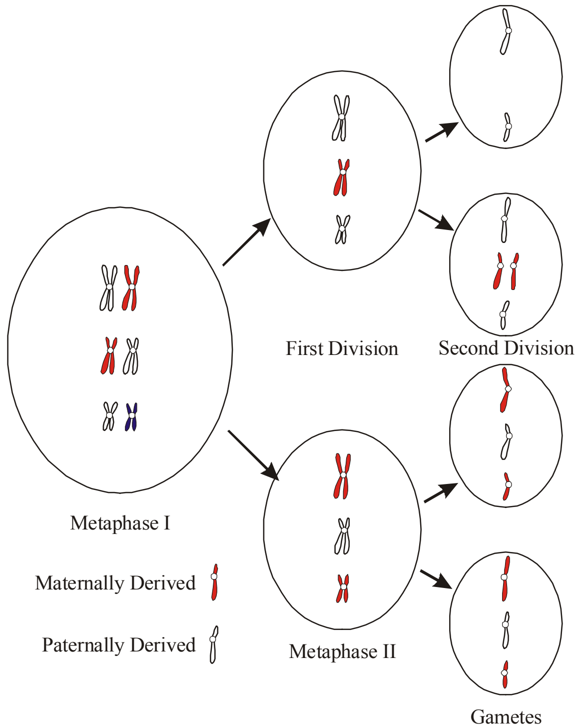

Figure 1-8 Second Division Primary Nondisjunction

The gene has some purpose, as a structural protein, or an enzyme that mediates some biochemical reaction.

- **Locus** Locus (plural is loci) refers to the physical location of the Gene. Often, we use locus and gene interchangeably. In general, geneticists use locus when they refer to the location of the gene.
- **Allele** An allele is a specific realization of that gene. Different alleles for the same locus are slightly different from each other in the protein they produce. The alternate forms of the gene may have different effects on the organism, or they may be functionally equivalent. Alleles at molecular marker genes simply have different sequences. We will look at molecular markers in Chapter 24.
- **Characteristic** A characteristic is an observable phenotype. It is the result of the genetics of the individual along with their environment. While we can look at the proteins produced (amino acid sequence or activity), we normally consider phenotype to be observable at the organismal level. The only time we will consider the protein sequence or activity to be a phenotype is when we use it as a molecular marker.

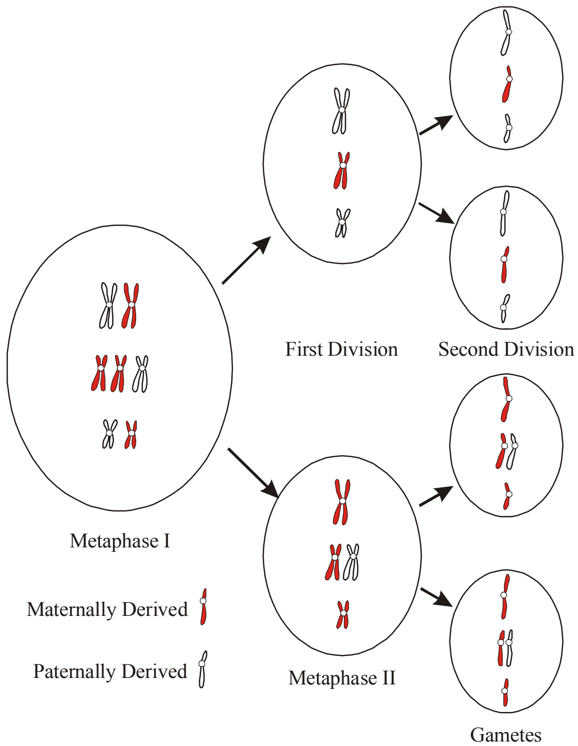

Figure 1-9 Secondary Nondisjunction

The chromosomes are the way the species organize their genomes. Closely relates species have similar (but rarely the same) chromosomal arrangements. The exact number of chromosomes is the result of evolutionary pressures and chance, and show marked variation among larger phylogenetic groups.

Table 1-3 shows the haploid chromosome number for some organisms.

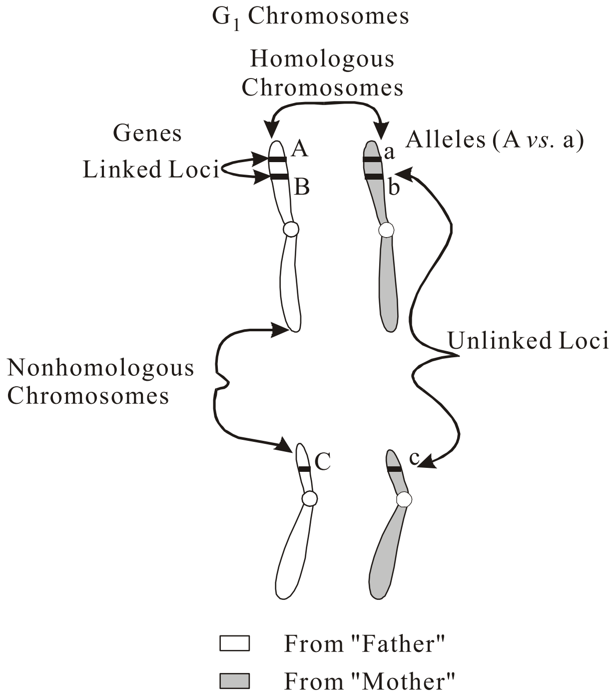

Figure 1-10 Genes, Loci, Alleles, and Linkage

Table 1-3 Haploid Chromosome Number for Some Organisms

Common Name	Genus-species	Haploid Size (n)
Broad bean	*Vicia faba*	6
Butterfly	*Lysandra nivenscens*	191
Cat	*Felis domesticus*	19
Cattle	*Bos taurus*	30
Chicken	*Gallus domesticus*	39
Corn	*Zea mays*	10
Cotton	*Gossypium hirsutum*	26
Dog	*Canis familiaris*	39
Evening primrose	*Oenothera biennis*	7
Fruit fly	*Drosophila melanogaster*	4
Garden onion	*Allium cepa*	8
Garden pea	*Pisum sativum*	7
Grasshopper	*Melanoplus differentialis*	12
Green Algae	*Chlamydomonas reinhardi*	16
Horse	*Equus caballus*	32
House fly	*Musca domestica*	6
House mouse	*Mus musculus*	20
Human	*Homo sapiens*	23
Indian fern	*Ophioglossum reticalatum*	630

Table 1-3 Haploid Chromosome Number for Some Organisms

Common Name	Genus-species	Haploid Size (n)
Mold	*Aspergillus nidulans*	8
Mosquito	*Culex pipiens*	3
Pink bread mold	*Neurospora crassa*	7
Rhesus monkey	*Macaca mulatta*	21
Slime mold	*Dicyostelium discoidium*	7
Snapdragon	*Antirrhinum majus*	8
Tobacco	*Nicotiana tabacum*	24
Tomato	*Lycopersicon esculentum*	12
Wheat	*Triticum aestivum*	21
Yeast	*Saccharomyces cerevisiae*	9