CHAPTER

15

# Inheritance

*Animation 15.1: Inheritance*
*Source and Credit: Wikipedia*

For much of human history , people were unaware of the scientific details of how babies got the characteristics of their parents. People had always thought that there was some hereditary connection between parents and children, but the mechanisms were not understood. Many answers to the questions about how offspring get the characteristics from their parents came from Gregor Mendel's work. In this chapter, we will go through Mendel's work and other discoveries of inheritance.


*Animation 15.2: DNA*
*Source and Credit: Estrellamountain*

## 15.1 Introduction To Genetics

Genetics is the branch of biology in which we study inheritance. Inheritance means the transmission of characteristics from parents to offspring. These characteristics are called the **traits.** For example: in man height, colour of the eyes, intelligence etc. are all inheritable traits.

Parents pass characteristics to their young through gene transmission. Equal numbers of chromosomes from each parent are combined during fertilization. The chromosomes carry the units of inheritance called the genes.

## 15.2 Chromosomes And Genes

Genes consist of DNA. They contain specific instructions for protein synthesis. In order to know the nature and working of genes, we will have to study chromosomes in detail. The body cells have a constant number of paired **chromosomes.** The two chromosomes of a pair are known as homologous chromosomes. In human body cells, there are 23 pairs of homologous chromosomes for a total of 46 chromosomes. We may recall that during meiosis, the two members of each chromosome pair separate and each of them enters into one gamete.
Chromosome is made of chromatin material (simply as chromatin). **Chromatin** is a complex material, made of DNA and proteins (mainly histone proteins). DNA wraps around histone proteins and forms round structures, called **nucleosomes**. DNA is also present between nucleosomes. In this way, the nucleosomes and the DNA between them look like "beads on a string" (Fig. 15.1).

The fibres consisting of nucleosomes condense into compact forms and get the structure of chromosomes.

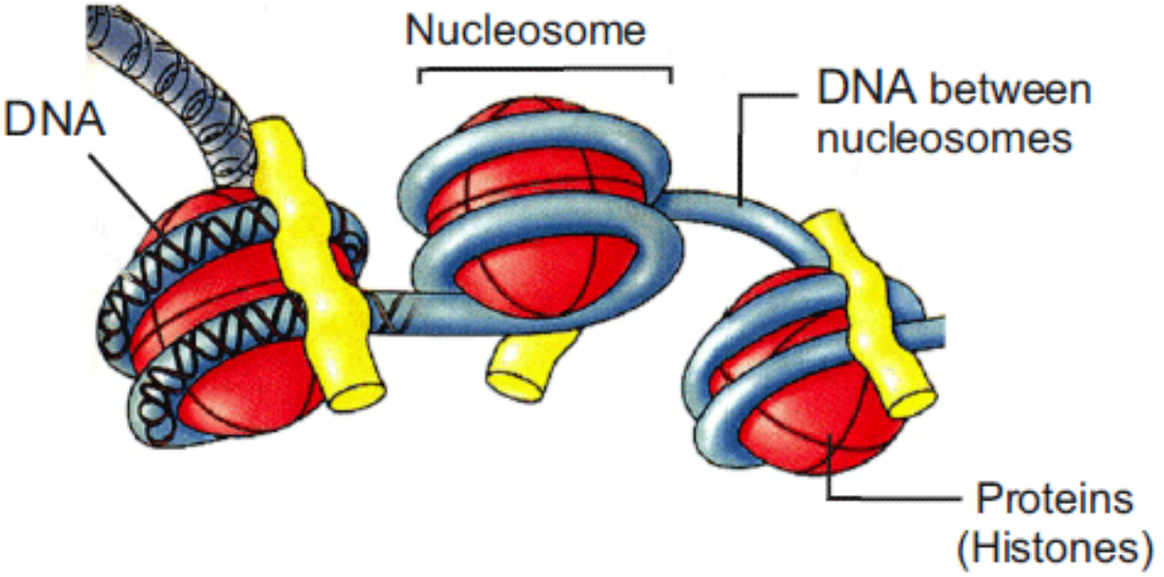



*Figure 15.1: Chemical composition of chromosome*

**Watson-Crick Model of DNA**

In 1953, **James Watson** and **Francis Crick** proposed the structure for DNA. According to the Watson-Crick model, a DNA molecule consists of two polynucleotide strands. These strands are coiled around each other in the form of a double helix. There is a phosphate-sugar backbone on the outside of double helix, and the nitrogenous bases are on the inside. In double helix, the nitrogenous bases of opposite nucleotides form pairs through hydrogen bonds. This pairing is very specific. The nitrogenous base adenine of one nucleotide forms pair with the thymine of opposing nucleotide, while cytosine forms pair with guanine. There are two hydrogen bonds between adenine and thymine while there are three hydrogen bonds between cytosine and guanine.

## DNA Replication

We have studied in Grade IX (cell cycle) that before a cell divides, its DNA is replicated (duplicated). It is done to make the copies of the chromatids of chromosomes. During replication, the DNA double helix is unwound and the two strands are separated, much like the two sides of a zipper. Each strand acts as a template to produce another strand. Its N- bases make pairs with the N-bases of new nucleotides. In this way, both template strands make new polynucleotide strands in front of them. Each template and its new strand together then form a new DNA double helix, identical to the original.

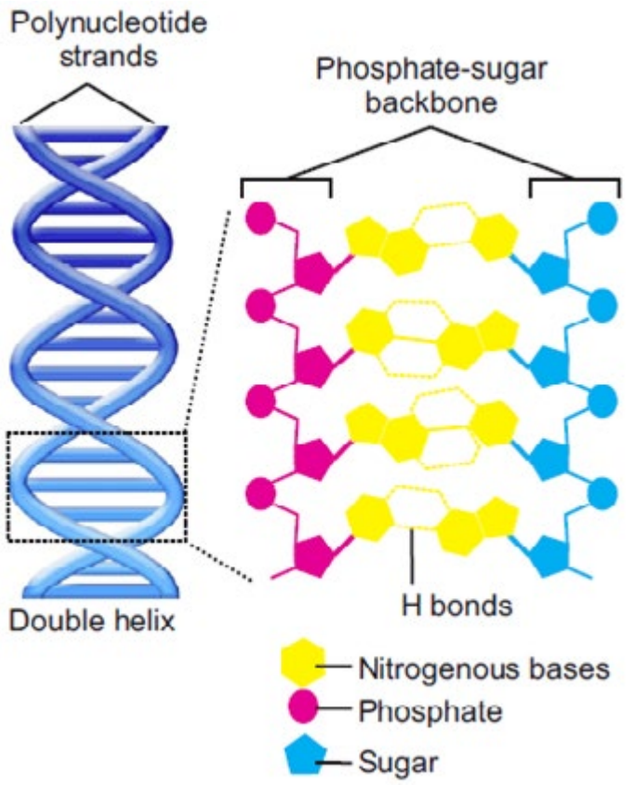



*Figure 15.2: The Watson and Crick model of DNA*

## How Does the DNA of Chromosome work?

DNA is the genetic material i.e. it contains the instructions to direct all the functions of cells. It performs its role by giving instructions for the synthesis of specific proteins. Some proteins perform structural roles while the others act as enzymes to control all biochemical reactions of cells. In this way, whatever a cell does, is actually controlled by its DNA. In other words, DNA makes the characteristic or trait of cell or organism. Let us see how DNA is responsible for this (Fig. 15.4).

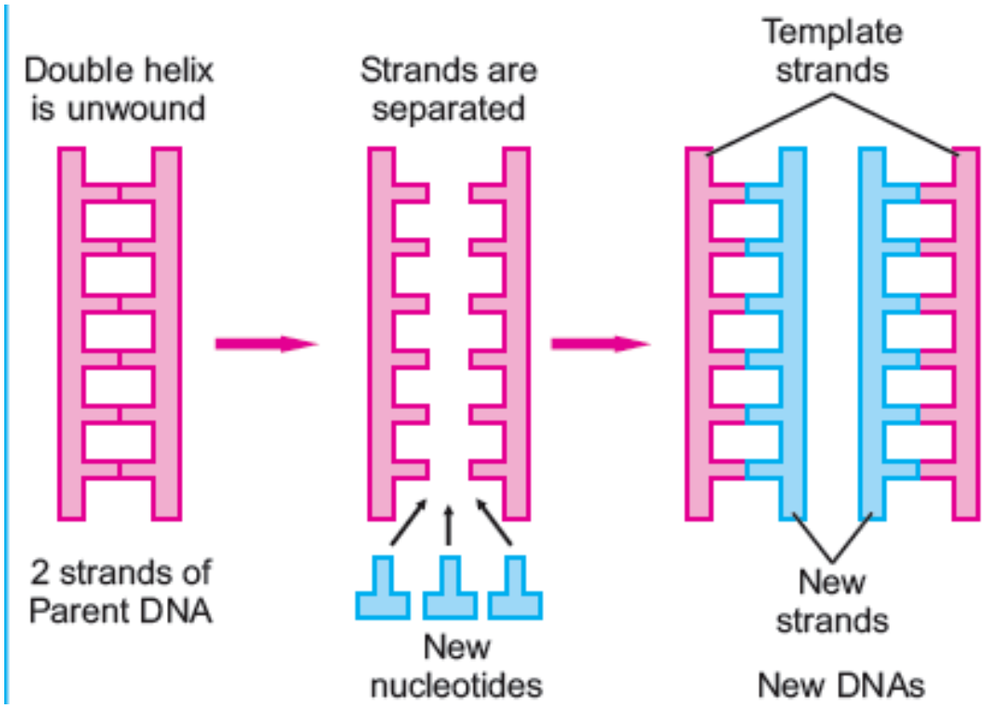



*Figure 15.3: How does DNA replicate?*

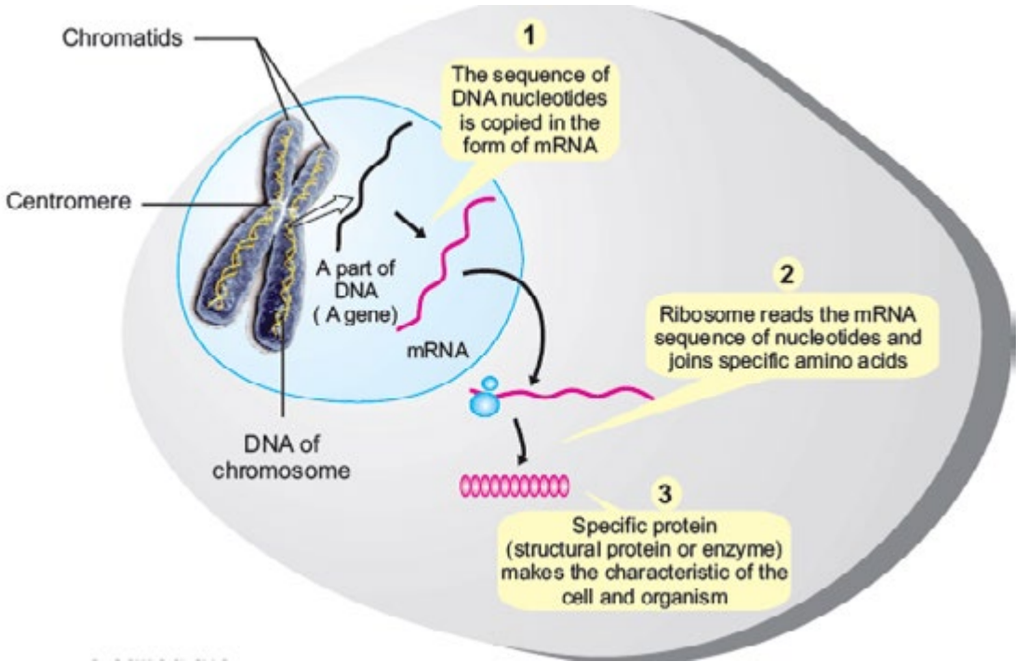
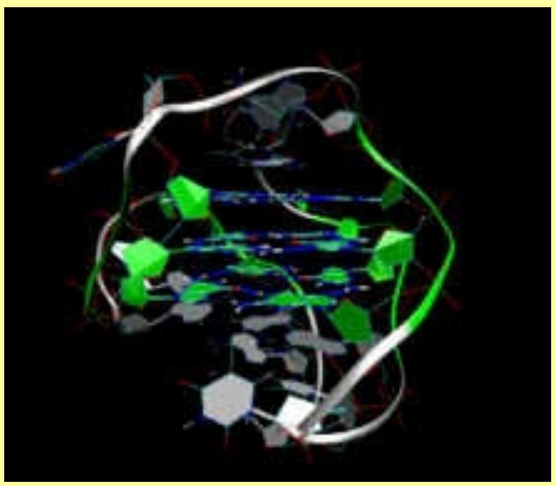
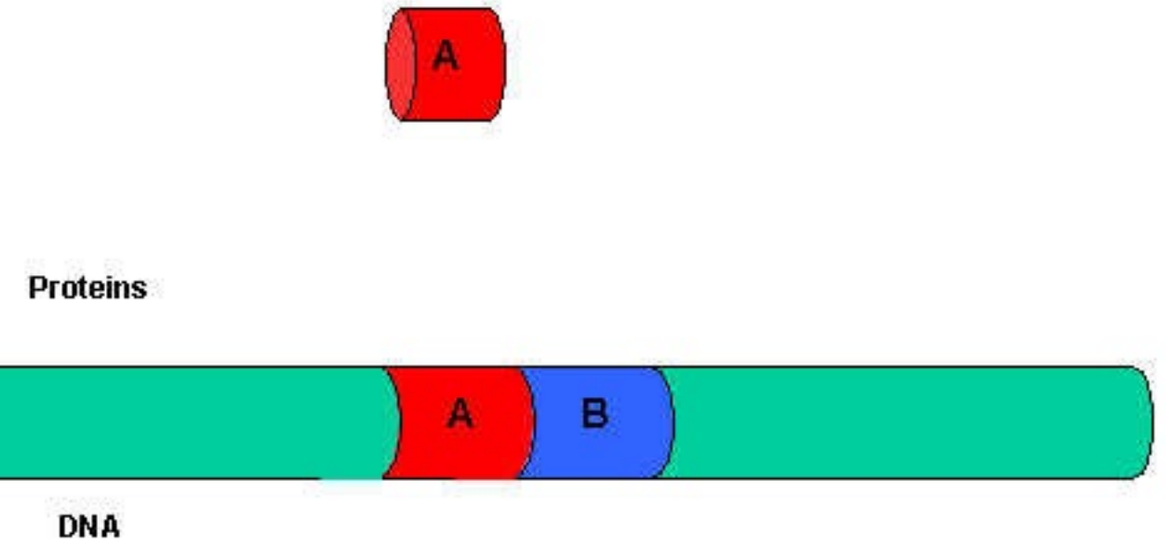



*Figure 15.4: Working of DNA (also called the Central Dogma)*

We studied that traits are made by specific proteins. Specific proteins have specific number and sequence of their amino acids. DNA controls this sequence of amino acids by the sequence of its nucleotides. During protein synthesis, the sequence of DNA nucleotides decides that what will be the sequence of amino acids. For this purpose, the specific sequence of DNA nucleotides is copied in the form of messenger RNA (mRNA) nucleotides. This process is called **transcription**. The mRNA carries the sequence of its nucleotides to ribosome. The ribosome reads this sequence and joins specific amino acids, according to it, to form protein. This step is known as **translation** (Fig. 15.4).The part of DNA (sequence of nucleotides) that contains the instructions for the synthesis of a particular protein is known as a gene. DNA of each chromosome contains thousands of genes. Like chromosomes, genes also occur in pairs, one on each homologous chromosome. The locations or positions of genes on chromosomes are known as loci (Singular: locus).



*Animation 15.3: DNA-Barcoding*
*Source and Credit: Dnal*




*Animation 15.4: DNA-Protein*
*Source and Credit: Employees.csbsju*


*Animation 15.5: Promoter and Terminator*
*Source and Credit: Biology.kenyon*

Each gene determines a particular trait in an organism. Each individual carries at least one pair of genes for each trait. For convenience, pairs of genes are represented by a letter or symbol. Both members of a gene pair may be the same in some individuals (a condition which we may represent as AA or aa or BB) and different in others (Aa or Bb). It means that a gene exists in more than one alternate forms. In the above example, 'A' and 'a' are the two alternate forms of a gene and 'B' and 'b' are the alternate forms of another gene. The alternate forms of a gene are called **alleles**. If an individual has Aa gene pair, 'A' and 'a' are the alleles of one another. In this individual, allele 'A' is located on one of the two homologous chromosomes and the allele 'a' is on the other chromosome as shown in Figure 15.5. When chromosomes separate during meiosis, alleles also separate and each gamete gets one of the two alleles. When gametes of both parents unite, the zygote (and the offspring also) receives one allele from each parent.

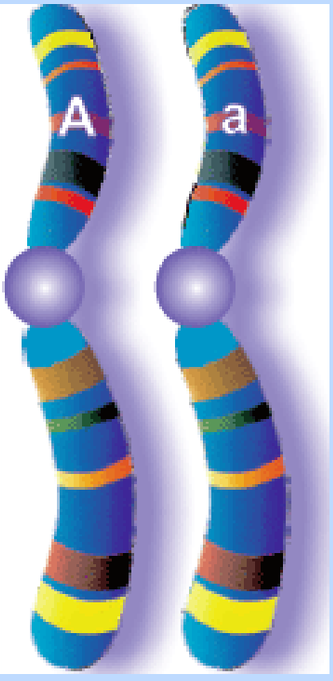
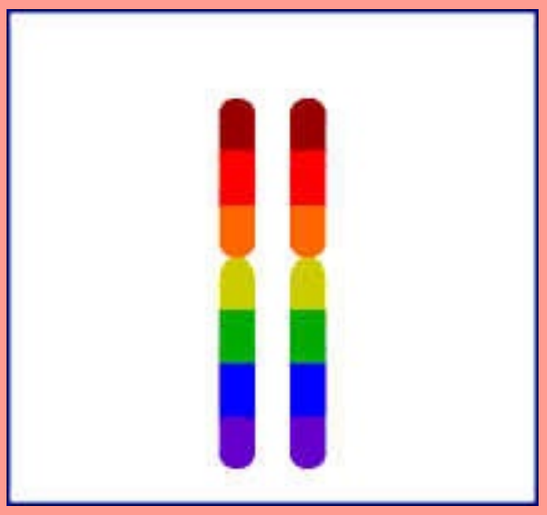



*Figure 15.5: Location of alleles on chromosomes*

## Genotype and its Types

The specific combination of genes in an individual is known as **genotype**. It is of two types i.e. homozygous and heterozygous. In order to understand the concept of genotype, let us consider an example trait i.e. **albinism** (a condition in which normal body pigments are absent). Like other traits, it is also controlled by one pair of genes. We can represent the two alleles of the pair as 'A' and 'a'. Three combinations i.e. genotypes are possible for these two alleles i.e. AA, Aa, and aa. These genotypes can be grouped into two types. The genotype in which the gene pair contains two identical alleles (AA or aa), is called **homozygous genotype**. The genotype in which the gene pair contains two different alleles (Aa), is called **heterozygous genotype.**



*Animation 15.6: Chromosomes*
*Source and Credit: Tokyo-med*

When in the heterozygous condition one allele masks or prevents the expression of the other, it is called the **dominant** allele. The allele which is not expressed is called **recessive.**

The dominant alleles are represented by capital letters and recessive alleles by lower case letters. Albinism is a recessive trait i.e. it is produced when both alleles are recessive. In humans, allele 'A' produces normal body pigments while allele 'a' does not produce pigments. If genotype is AA or Aa, the individual will produce pigments. On the other hand, if genotype is aa, no pigments will be produced and the individual will be albino. In this example, you see that the allele 'A' dominates over 'a', because in Aa indiviual pigments are produced and the effect of 'a' is suppressed by 'A'. The expression of this genotype in the form of trait (in our example, being albino or having normal pigmentation) is known as the **phenotype.**

A dominant allele only suppresses the expression of recessive allele. It does not affect its nature.

## 15.3 Mendel's Laws Of Inheritance

**Gregor Mendel** was a monk (priest) in Austria. He developed the fundamental principles of genetics. Mendel proposed that there are "special factors" in organisms, which control the expression of traits and their transmission to next generations. These factors were eventually termed genes.

*Mendel used 28,000 pea plants in his experiments. Source & Credit: Wikipedia*

Mendel selected pea plant (*Pisum sativum*) to carry out a large number of experiments. In his writings, he gave reasons for this selection. He argued that an organism for genetic experiments should have the following features:

- There should be a number of different traits that can be studied (Fig. 15.6).
- The organism should have contrasting traits e.g. for the trait of height there should be only two very different phenotypes i.e. tallness and dwarfness.
- The organism (if it is a plant) should be self-fertilizing but cross fertilization should also be possible.
- The organism should have a short but fast life cycle.

All these features are present in pea plant. Normally, the flowers of pea plant allow self-pollination. Cross pollination can also be done by transferring the pollen grains from the flower on one plant to the flower on another plant. Each trait studied in pea plant had two distinct forms. Mendel succeeded in his work not only because he selected the right organisms for his experiments but also because he analyzed the results by using the principles of statistics (ratios).

### 15.3.1 Mendel's Law of Segregation

Mendel studied the inheritance of seed shape first. For this purpose, he crossed (reproduced) two plants having one contrasting trait i.e. seed shape. A cross in which only one trait is studied at a time, is called as a **monohybrid cross.** Mendel crossed a true-breeding round-seeded plant with a true-breeding wrinkled-seeded plant.

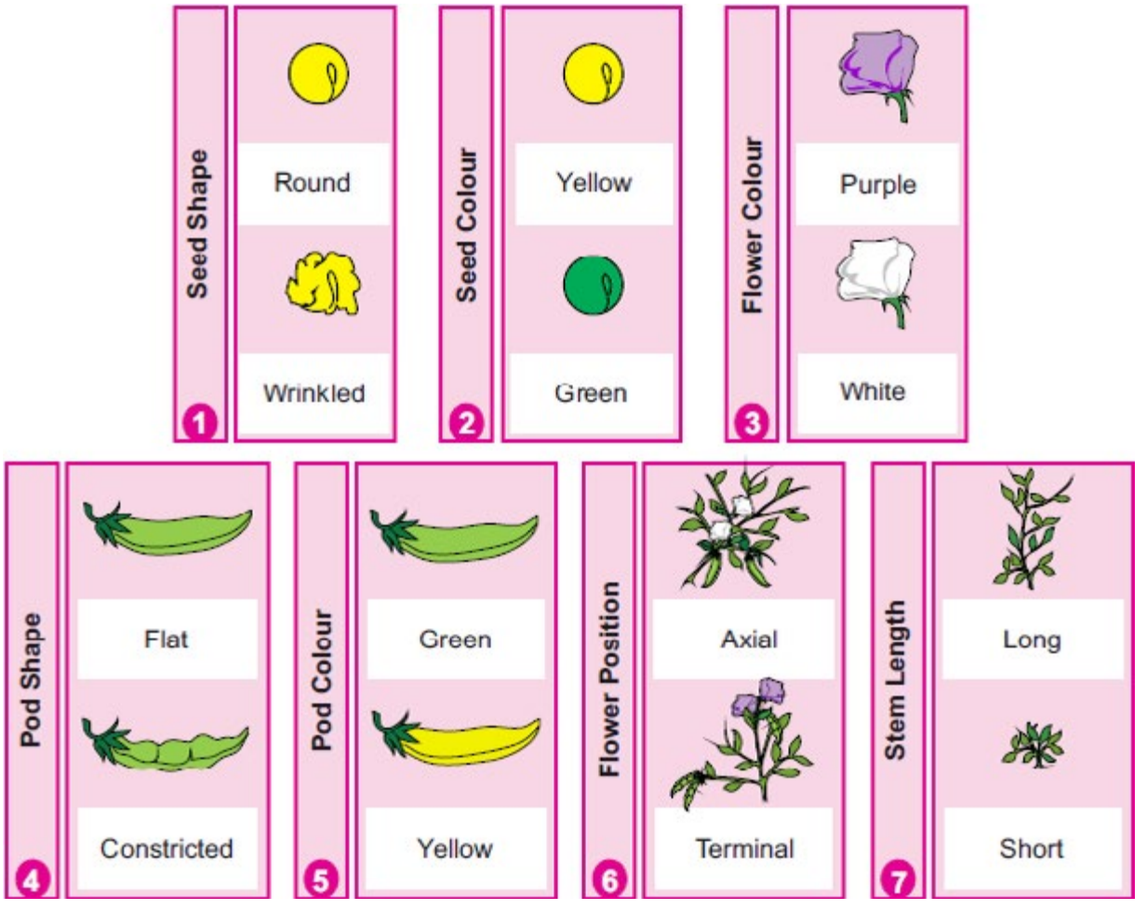
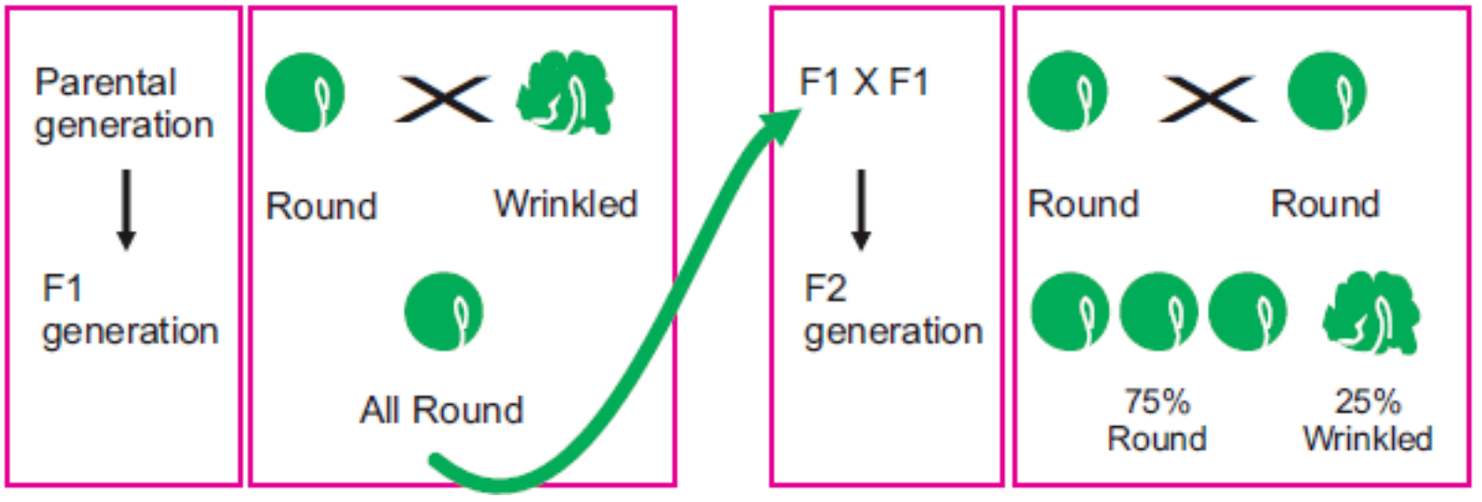
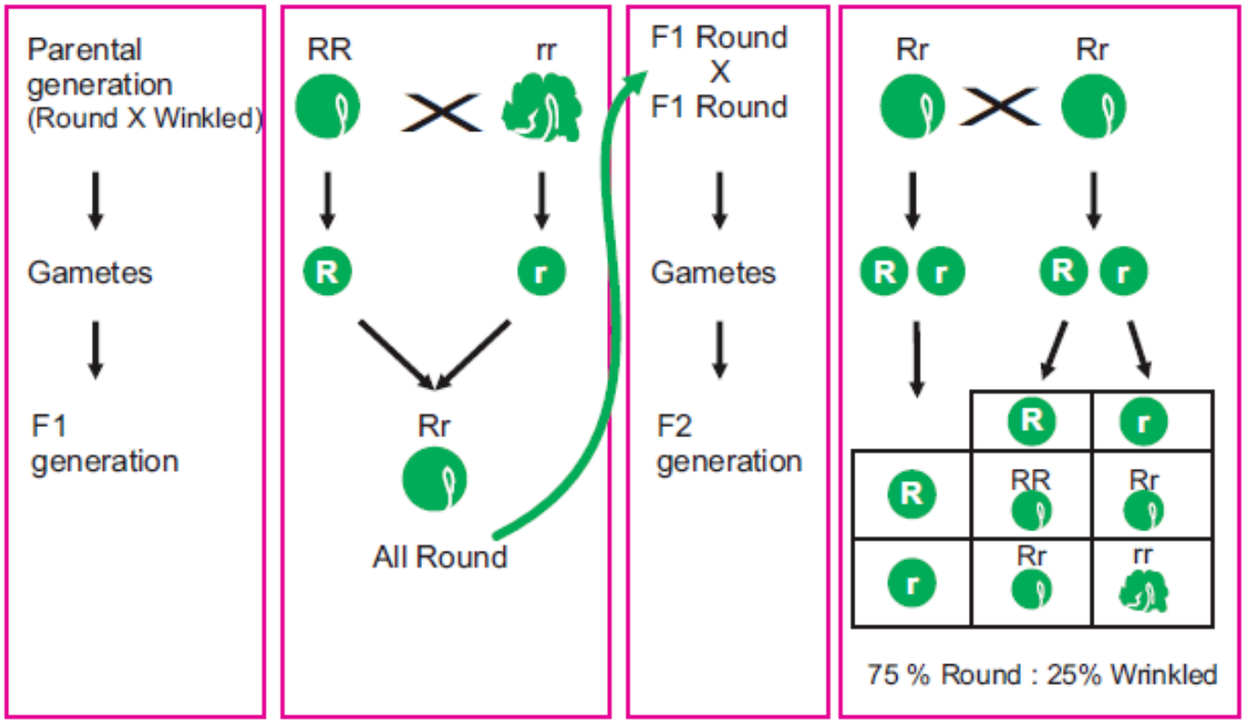



*Figure 15.6: Traits in Pea Plant studied by Mendel*

All resulting seeds of the next generation were round. Mendel declared the trait "round seeds" as dominant, while "wrinkled seeds" as recessive. The following year, Mendel planted these seeds and allowed the new plants to self-fertilize. As a result, he got 7324 seeds: 5474 round and 1850 wrinkled (3 round : 1wrinkled). The parental generation is denoted as P1 generation. The offspring of P1 generation are F1 generation (first filial). The cross in F1 generation produces F2 generation (second filial).



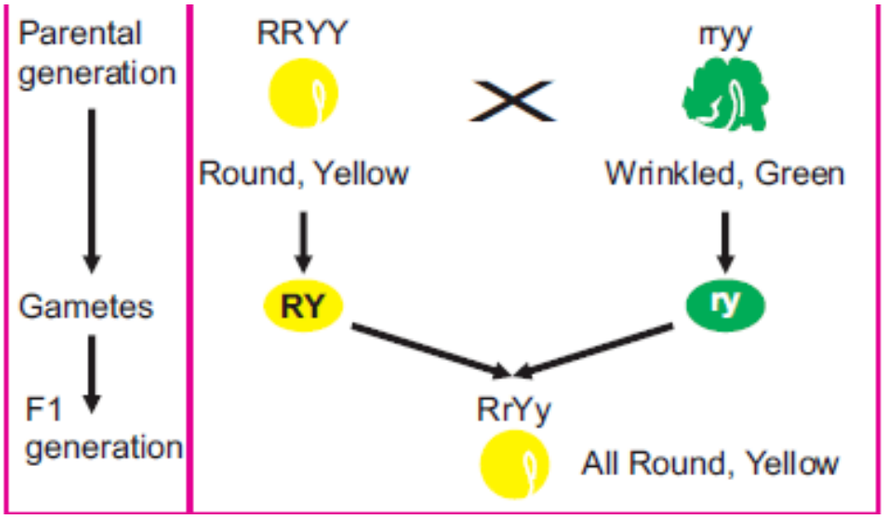
Similarly, when "true-breeding" tall plants were crossed with "true-breeding" short plants, all offspring of F1 were tall plants i.e. tallness was a dominant trait. When members of F1 generation were self-fertilized, Mendel got the ratio of tall to short plants in F2 as 3:1.



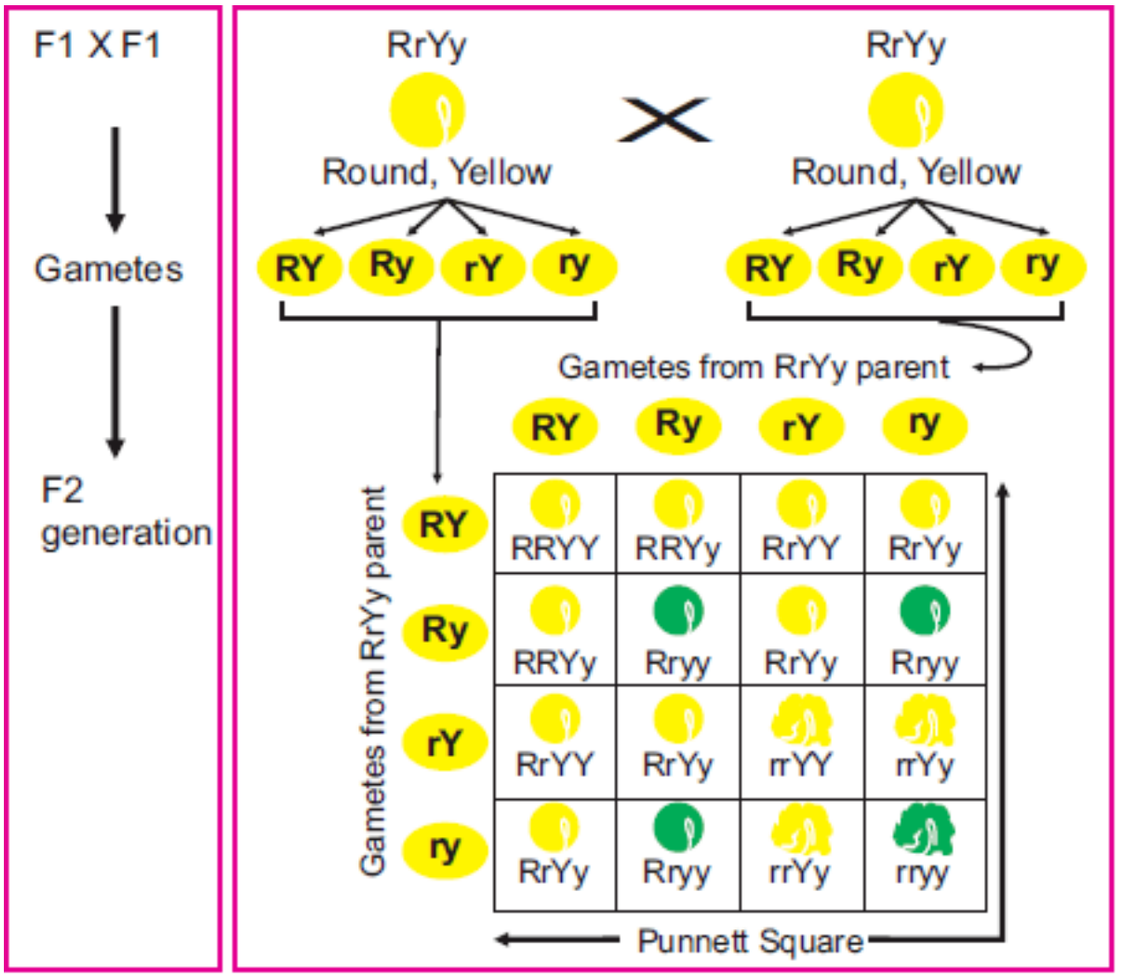

Mendel concluded that the traits under study were controlled by discrete (separable) factors or genes. In each organism, the genes are present in pairs. During gamete formation, the genes (alleles) of each pair segregate from each other and each gamete receives one gene from the pair. When the gametes of male and female parents unite, the resulting offspring agains gets the genes in pairs. These conclusions were called the **Law of Segregation.**

## 15.3.2 Mendel's Law of Independent Assortment

In the next crosses, Mendel studied two contrasting traits at a time. Such crosses are called **dihybrid crosses.** He performed experiments on two seed traits i.e. shape and colour. The trait of round seeds (controlled by allele R) was dominant over wrinkled (controlled by allele r) seeds. Similarly, yellow seed colour (controlled by Y) was dominant over green (controlled by y). Mendel crossed a truebreeding plant that had round yellow seeds (RRYY) with a truebreeding plant having wrinkled green seeds (rryy). All seeds in F1 generation were round yellow.




When F1 seeds grew into plants, they were self-fertilized. This cross produced seeds with four phenotypes. There were 315 round yellow seeds, 108 round green seeds, 101 wrinkled yellow seeds and 32 wrinkled green seeds. The ratio of these phenotypes was 9:3:3:1.



The Punnett square is a diagram that is used to predict an outcome of a particular cross or breeding experiment. It is named after **R. C. Punnett** (an English mathematician). The gametes of both parents having all possible genetic set-ups are determined. A checker board is used to cross all the possible gametes of one parent with all the gametes of other parent. In this way, a biologist can find all the possible genotypes of offsprings.

Mendel explained that the two traits i.e. seed shape and seed colour are not tied with each other. The segregation of 'R' and 'r' alleles happens independently of the segregation of 'Y' and 'y' alleles. From his second experiment, Mendel concluded that different traits are inherited independently of one another. This principle is known as the **law of independent assortment.** It states as: "the alleles of a gene pair segregate (get separated and distributed to gametes) independently from the alleles of other gene pairs".

## 15.4 Co-Dominance And Incomplete Dominance

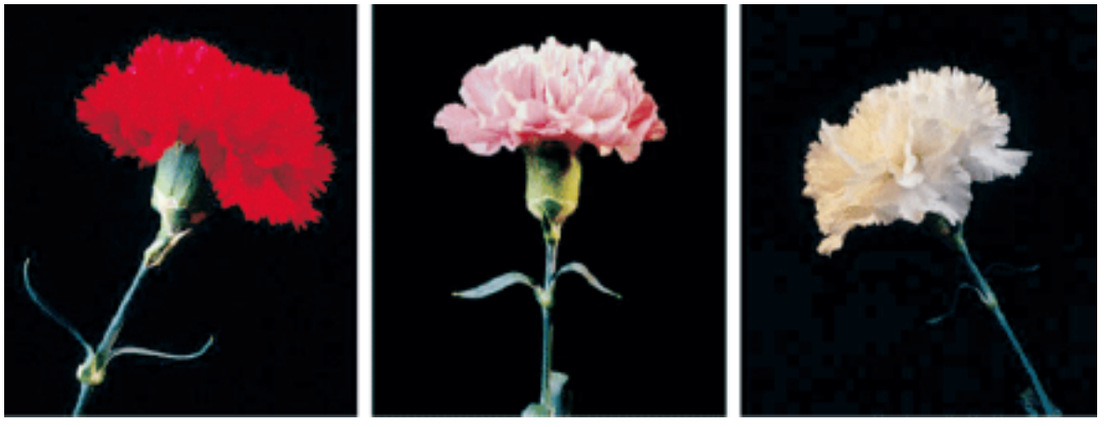
After the discovery of Mendel's work, scientists began experiments on the genetics of various organisms. These experiments proved that all the traits in organisms do not follow Mendel's laws. For example, it was found that there are many traits which are controlled by more than one pair of genes. Similarly for many traits, there are more than two alleles in a gene pair. Co-dominance and incomplete dominance are two examples of such deviations from Mendel's laws.

**Co-dominance** is the situation where two different alleles of a gene pair express themselves completely, instead of showing a dominant-recessive relationship. As a result, the heterozygous organism shows a phenotype that is different from both homozygous parents.

An example of co-dominance is the expression of human blood group AB. The ABO blood group system is controlled by the gene 'I'. This gene has three alleles i.e. $I^A$, $I^B$ and i. The allele $I^A$ produces antigen A in blood and the phenotype is blood group A. The allele $I^B$ produces antigen B in blood and the phenotype is blood group B. The allele i does not produce any antigen and the phenotype is blood group O. The alleles $I^A$ and $I^B$ are dominant over i. When there is a heterozygous genotype of $I^A$ $I^B$, each of the two alleles produces the respective antigen and neither of them dominates over the other.

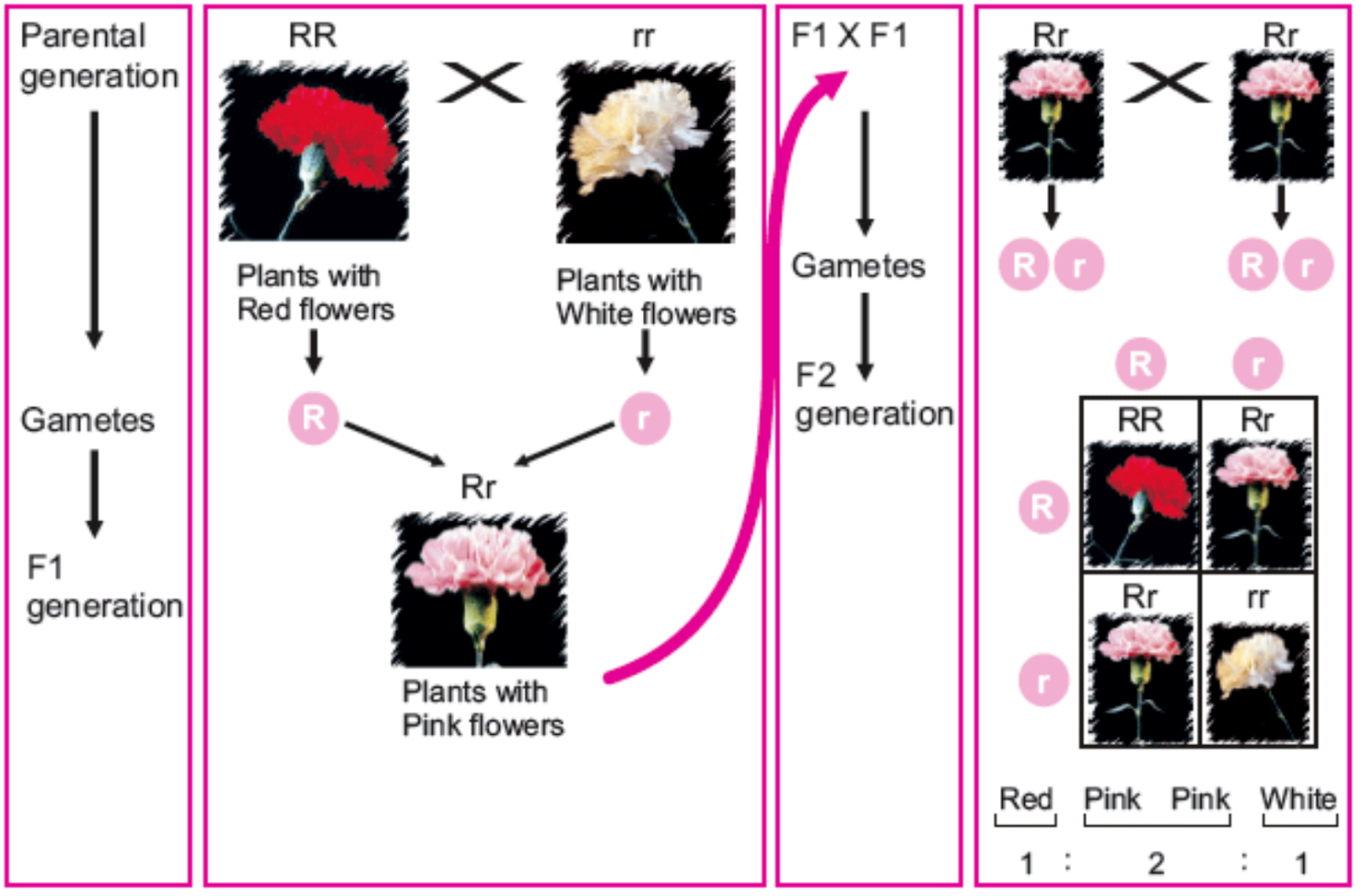
| Genotype | Antigen produced | Phenotype | Relationship Between Alleles |
|---|---|---|---|
| $I^AI^A$ or $I^Ai$ | Antigen A | Blood Group A | Allele $I^A$ is dominant over i |
| $I^BI^B$ or $I^Bi$ | Antigen B | Blood Group B | Allele $I^B$ is dominant over i |
| ii | No Antigen | Blood Group O | Allele i is recessive |
| $I^AI^B$ | Antigen A & Antigen B | Blood Group AB | Alleles $I^A$ and $I^B$ are co-dominant |

**In-complete dominance** is the situation where, in heterozygous genotypes, both the alleles express as a blend (mixture) and neither allele is dominant over the other. As a result of this blending, an intermediate phenotype is expressed. Following is the familiar example of incomplete dominance.



In Four 'O' Clock plants, the 3 flower colours are red, pink and white. There is no specific gene responsible for producing pink flowers.

In Four 'O' clock plant, the trait of flower colour is controlled by two alleles (let us say them R and r). The true breeding plants RR and rr have red and white flowers, respectively. When a homozygous red flowered plant (RR) is crossed with homozygous white flowered plant (rr), the heterozygous (Rr) plants of F1 generation produce pink flowers (pink is a blend of red and white colours). This result clearly indicates that neither of the red flower allele (R) and white flower allele (r) is dominant. However, when two heterozygous plants with pink flowers (Rr) are crossed, F2 generation shows phenotypes of red, pink and white flowers in the ratio 1:2:1.




## Initiating and Planning:

- Predict from pedigree charts the passage of traits from one generation to the other.
- Solve basic genetic problems involving monohybrid crosses, incomplete dominance and co-dominance, using the Punnet square.

? What is the dominance relationship between blood group alleles $I^A$ and $I^A$?

Co-dominance

## 15.5 Variations And Evolution

In the previous chapter, we studied that sexual reproduction produces variations in the next generation. No two individuals resulting from separate fertilizations are genetically identical. The main sources of variations in sexually reproducing populations are describes next.

- The genetic recombination produced through crossing over (recall from previous studies that crossing over occurs during meiosis) results in gametes with variations.
- Mutations (changes in DNA) are important source of variations. Mutations also happen during gametes formation through meiosis.
- During fertilization, one of the millions of sperms combines with a single egg. The chance involved in this combination also act as the source of variations.
- Gene flow i.e. movement of genes from one population to another is also an important source of variations.

**Practical:**

- Record the heights of class fellow's to predict which kind of variation is it.
- Present the data of class fellow's heights in graphical form.

### Discontinuous and Continuous Variations

The inheritable variations are of two types i.e. discontinuous and continuous variations. Discontinuous variations show distinct phenotypes. The phenotypes of such variations cannot be measured. The individuals of a population either have distinct phenotypes, which can be easily distinguished from each other. Blood groups are a good example of such variations. In a human population, an individual has one of the four distinct phenotypes (blood groups) and cannot have in between. Discontinuous variations are controlled by the alleles of a single gene pair. The environment has little effect on this type of variations. In continuous variations, the phenotypes show a complete range of measurements from one extreme to the other. Height, weight, feet size, intelligence etc. are example of continuous variations. In every human population, the individuals have a range of heights (from very small to tall). No population can show only two or three distinct heights. Continuous variations are controlled by many genes and are often affected by environmental factors.


*Animation15.8: Darwin-Evolution*
*Source and Credit: Zebu.uoregon9*

## 15.5.1 Variations lead to Evolution

Organic evolution (biological evolution) is the change in the characteristics of a population or species of organisms over the course of generations. The evolutionary changes are always inheritable. The changes in an individual are not considered as evolution, because evolution refers to populations and not to individuals. Organic evolution includes two major processes:

- Alteration in genetic characteristics (traits) of a type of organism over time; and
- Creation of new types of organisms from a single type.

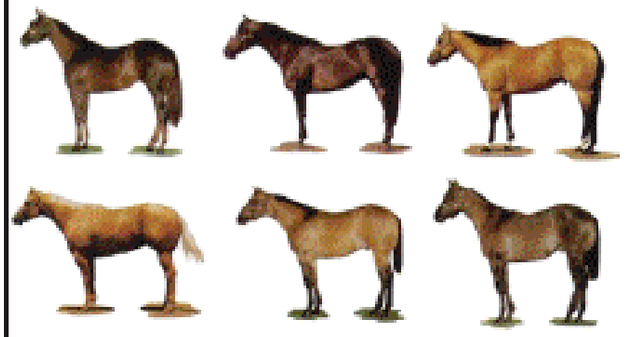
The study of evolution determines the ancestry and relationships among different kinds of organisms. The anti-evolution ideas support that all living things had been created in their current form only a few thousand years ago. It is known as the **"theory of special creation".** But the scientific work in eighteenth century led to the idea that living things might change as well.

Variations are also caused by different combinations of chromosomes in gametes and then in zygote. In the case of humans, the possible number of chromosomal combinations at fertilization is 70,368,744,177,664. In other words, a couple can produce more than 70 trillion genetically different children!

**Variations**
**Continuous or Discontinuous?**

Variations in human skin colour
Discontinuous ☐ Continuous ☐

Variations in human body weight
Discontinuous ☐ Continuous ☐



Variations in horse skin colour
Discontinuous ☐ Continuous ☐

Variations in rose flower colour
Discontinuous ☐ Continuous ☐

French biologist **C. de Buffon** (1707–1788) was the first to hint at evolution. His countryman **J. de Lamarck** (1744–1829) was the first to propose a mechanism of evolution. Lamarck's ideas were soon rejected due to the vagueness of the mechanisms he proposed.

**Charles Darwin** (1809–1882) proposed the mechanism of organic evolution in 1838. It was called as "The Theory of Natural Selection". Darwin proposed this theory after his 5-year voyage on the HMS (His Majesty's Ship) Beagle. He also published a book "On the Origin of Species by means of Natural Selection" in 1859. Darwin's theory of evolution was not widely accepted because of lack of sufficient evidence. Modern evolutionary theory began in the late 1920s and early 1930s. Some scientists proved that the theory of natural selection and Mendelian genetics are the same ideas just as Darwin had proposed.

**C. de Buffon**

**J. de Lamarck**

## Mechanism of Evolution - Natural Selection

Almost every population contains several variations for the characteristics of its members. In other words, there are morphological and physiological variations in all populations. Natural selection is the process by which the better genetic variations become more common in successive generations of a population.

The central concept of natural selection is the evolutionary fitness of an organism. Fitness means an organism's ability to survive and reproduce. Organisms produce more offspring than can survive and these offspring vary in fitness. These conditions produce struggle for survival among the organisms of population . The organisms with favourable variations are able to reproduce and pass these variations to their next generations.

On the other hand, the rate of the transmission of unfavourable to next generations is low. We can say that the favourable variations are “selected for” their transmission to next generations, while the unfavourable variations are “selected against” their transmission to next generations. In the example mentioned next, we can see a mouse population with variations in skin colour. Cat preys upon light and medium coloured mouse. In first generation, light coloured mouse is preyed upon by cat.

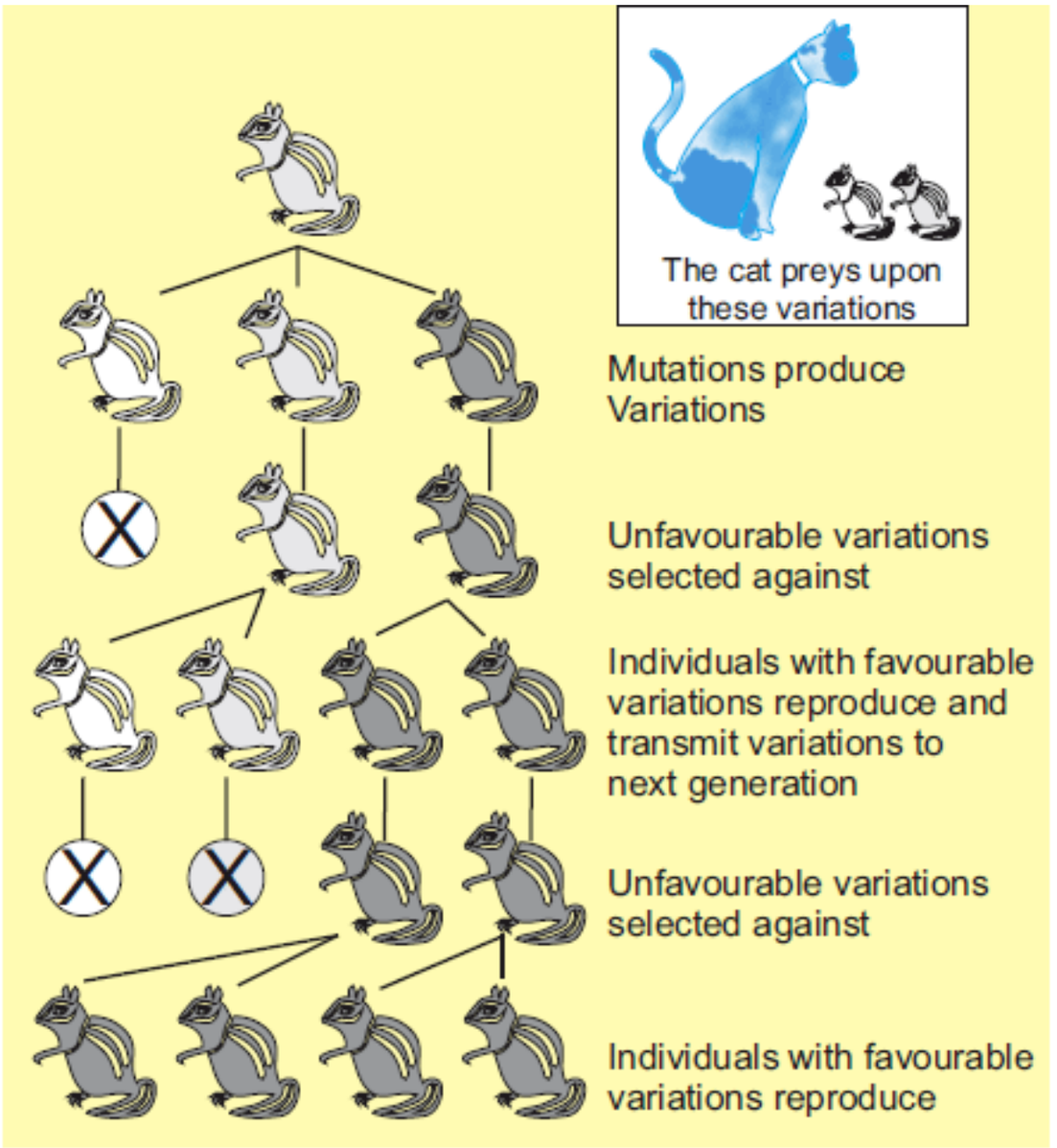



*Figure 15.7: The concept of natural selection*

Different populations face different environments and they have to adapt to different conditions.

Only medium and dark coloured mouse can make their next generations. In next generation, population again contains light, medium and dark coloured mouse. Cat preys upon the light and medium coloured mouse. Now only the dark coloured mouse make new generation. If this happens in many generations, we will see only the dark coloured (favourable variation) mouse in the population (Fig. 15.7).

As a result of natural selection, the allele that gives more fitness of characteristics (favourable variations) than other alleles becomes more common within population. So, the individuals with favourable variations become a major part of population while the individuals with harmful or unfavourable variations become rarer.

In England, the moths had two variations i.e. dark and white coloured moths (Fig.15.8). The moths used to rest on the light coloured tree trunks (on which white lichens had grown). In the 19th century when industries were established in England, the lichens on tree trunks died (due to polluted air) and the naked tree trunks turned dark. Now the white moth variation became harmful because a white moth resting on a dark tree trunk was easily visible to the predatory birds. The natural selection selected dark moths to reproduce. In this way dark coloured moth became more common and at last the white moths disappeared from population. In this case, the dark colour variation in moth may be considered an adaptation to environment.

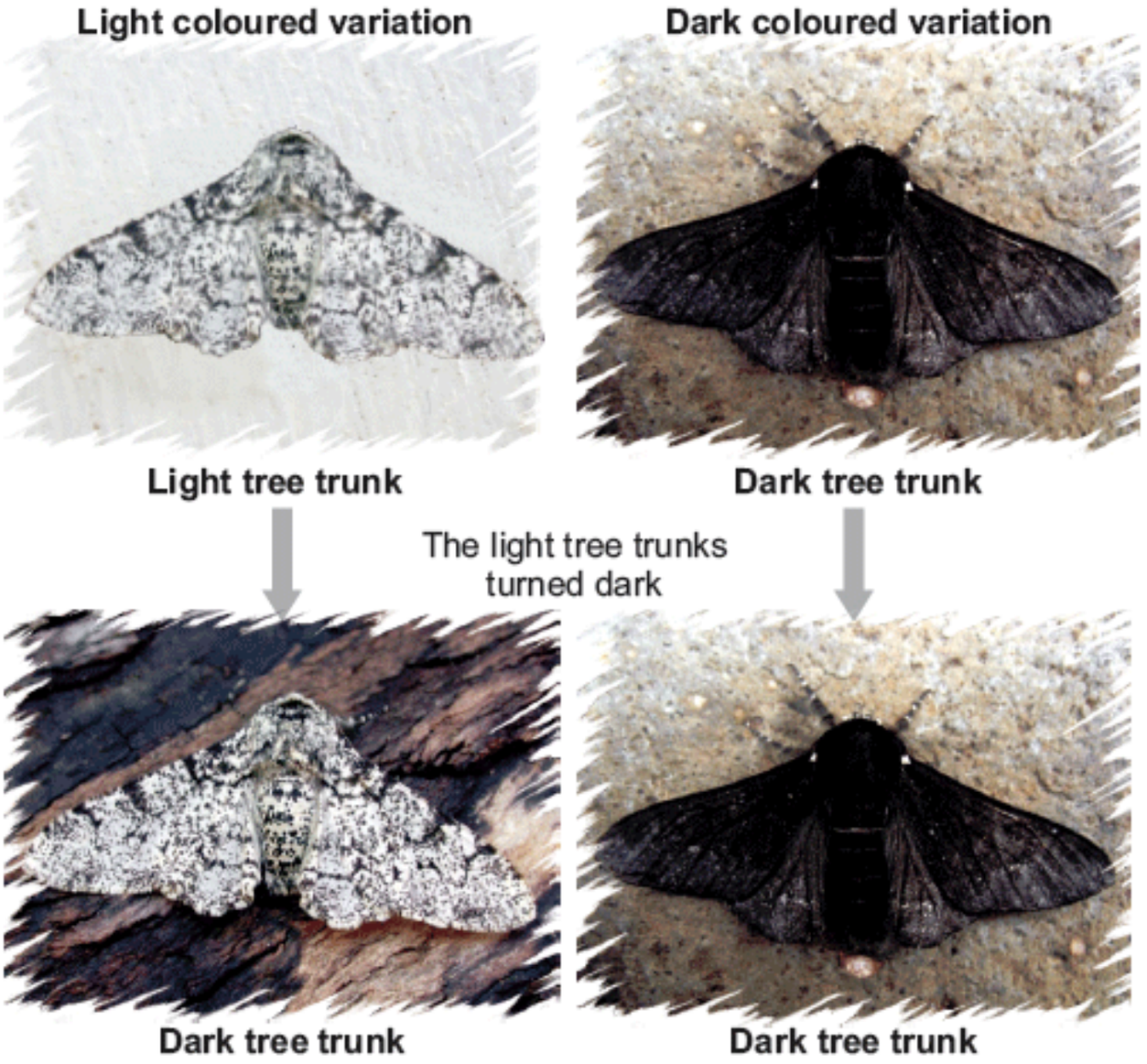



*Figure 15.8: White and dark coloured moths*

## Initiating and Planning:

Write down the procedure of an experiment in which you can cross true-breeding tall and short plants to get tall plants and can test the natural selection of these variants.

### 15.5.2 Artificial Selection

The term “artificial selection” was expressed by the Persian scientist Abu Rayhan Biruni in the 11th century. Charles Darwin also used this term in his work on natural selection. He noted that many domesticated animals and plants had special properties that were developed by:

- Intentional breeding among individuals with desirable characteristics; and
- Discouraging the breeding of individuals with less desirable characteristics

Artificial selection (or selective breeding) means intentional breeding between individuals for certain traits, or combination of traits. Selective breeding has revolutionized agricultural and livestock production throughout the world. Animals or plants having desirable characteristics are selected for breeding. In this way, many new generations with desirable characteristics are produced. In artificial selection, the bred animals are known as **breeds,** while bred plants are known as **varieties** or **cultivars.** Numerous breeds of sheep, goat, cow, hen etc. have been produced by artificial selection to increase the production of wool, meat, milk, eggs etc.

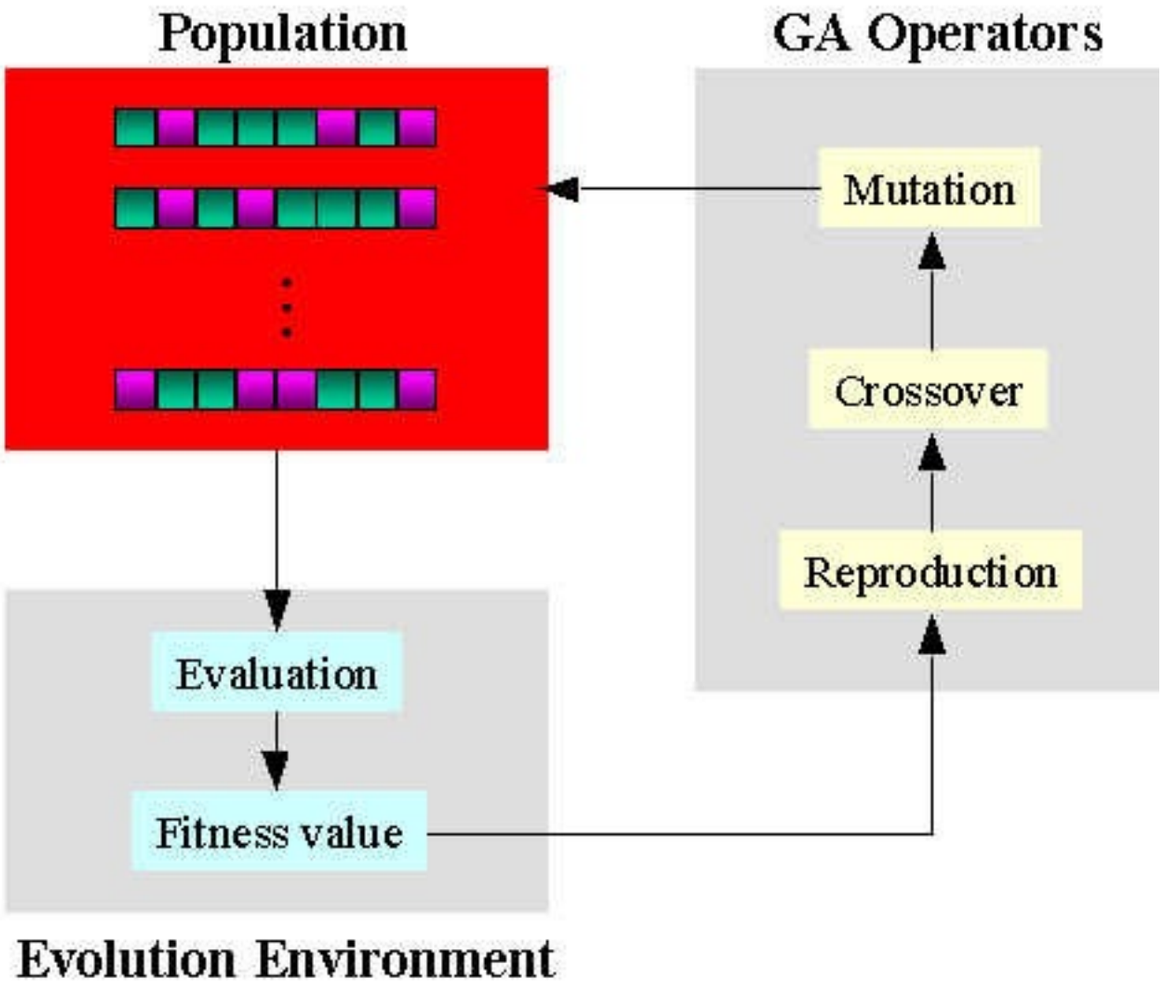
Similarly many plant varieties (cultivars) have been produced for better quantity and quality of cereals, fruits and vegetables.

*Figure 15.9: Breeds of hen, produced through artificial selection*

In artificial selection, humans favour specific variations for selection while in natural selection the environment selects or rejects variations.

**Initiating and Planning:**

- Analyze a case study of variation and selection e.g. in peppered moth.
- Analyze how artificial selection can lead to the development of crop plants with higher yields.




Genetic Algorithm Evolution Flow

*Animation 15.9: Evolution*
*Source and Credit: Ewh.ieee*

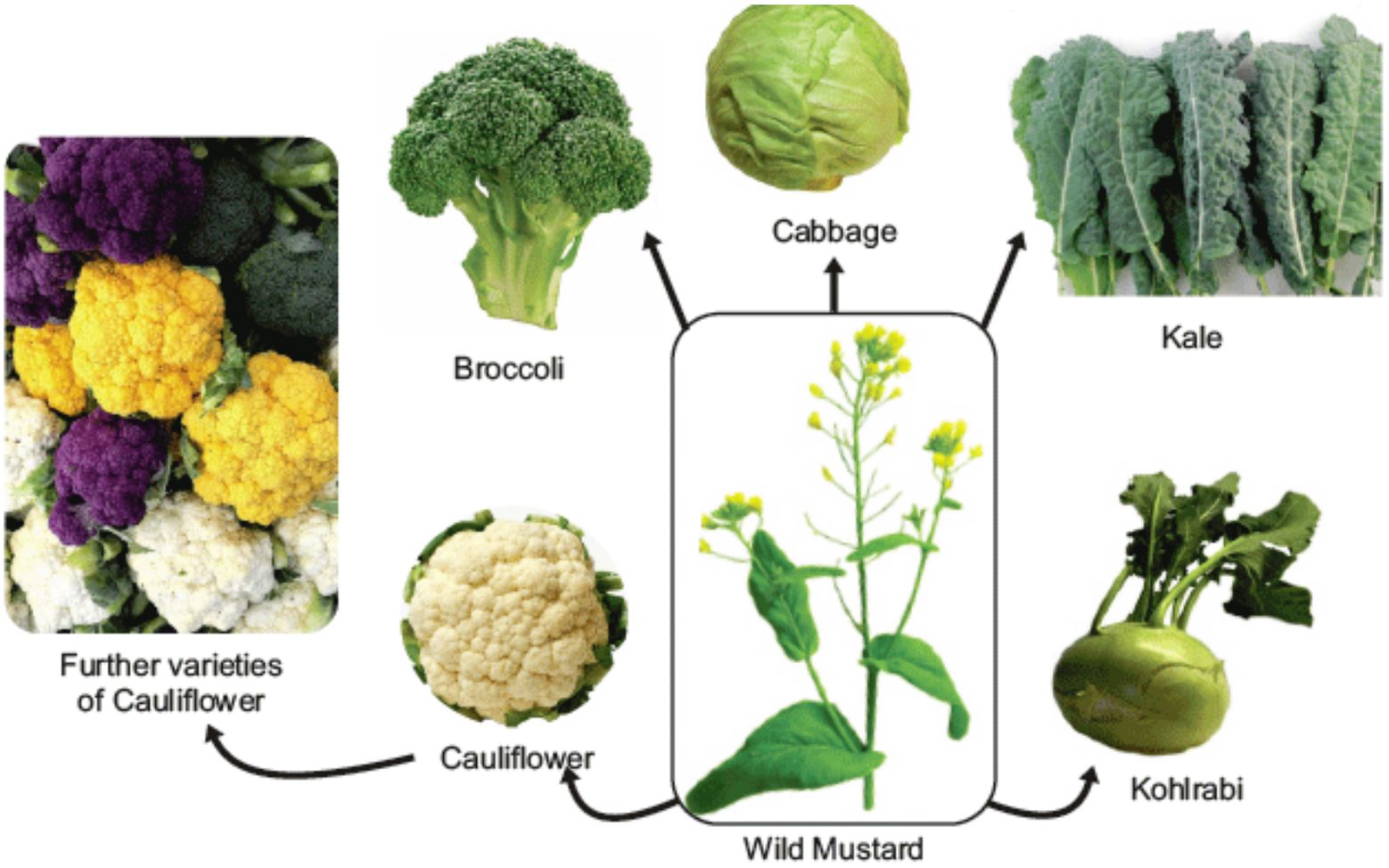



*Figure 15.10: Plant varieties produced through artificial selection in wild mustard*

## UNDERSTANDING THE CONCEPT

1. Describe the structure of chromatin.
2. Describe Mendel's law of segregation.
3. Explain how Mendel proved the law of independent assortment.
4. How would you prove that variations lead to evolution?
5. Explain the phenomenon of incomplete dominance with the help of example.
6. What do you mean by co-dominance. Give an example.

## SHORT QUESTIONS

1. Define genotype and phenotype.
2. What do you mean by dominant and recessive alleles?
3. What are the homozygous and heterozygous genotypes?
4. Differentiate between natural and artificial selection.

## ACTIVITIES

1. Draw the chromosomes of a plant cell after observing in prepared slides unlabelled charts.
2. Record the heights of class fellows to predict which kind of variation is it.
3. Present the data of class fellows' heights in graphical form.

| THE TERMS TO KNOW | | |
|---|---|---|
| Allele | Genotype | Mutation |
| Artificial selection | Heterozygous | Natural selection |
| Breeds | Histone | Nucleosome |
| Chromatin | Homologous chromosomes | Organic evolution |
| Co-dominance | Homozygous | Phenotype |
| Cultivar | Incomplete dominance | Recessive trait |
| Dihybrid cross | Inheritance | Trait |
| Dominant | Locus | True-breeding |
| Gene | Monohybrid cross | Variations |

## SCIENCE, TECHNOLOGY AND SOCIETY

1. Describe various possibilities if humans could be able to control the functioning of genes.
2. Prepare a report using newspaper clippings on the recent advances and future possibilities in genetics.
3. Rationalize life as a product of the diversity brought about by chromosomes, genes and DNA.
4. Outline the scientific findings and some of the technological advances that led to the modern concept of gene.
5. Analyse the concept of gene to produce various proteins of the body.
6. Describe the importance of scientific investigation and mathematical know how in genetics.
7. Explain how genetics can predict the progeny of two individuals which are crossed.
8. What is the role of environment on the selection of better variations?

### ON-LINE LEARNING

1. en.wikipedia.org/wiki/Punnett_square
2. www.uic.edu/classes/bios/bios101/genes1
3. www.human-nature.com/darwin/
4. en.mimi.hu › Biology