

EVOLUTION ALGEBRA

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Understanding Genetics

The study of genetics (the inheritance of traits in living organisms) is a basic concept in biology.

The same processes that provide the mechanism for organisms to pass genetic information to their offspring lead to the gradual change of species over time, which in turn produces biodiversity (the variety of life and the genetic differences among living organisms) and the evolution of new species.

An understanding of genetics is becoming increasingly important as genetics research and technology—and the controversies surrounding them—gain greater influence on social trends and individual lives.

To fully appreciate the benefits, risks, and ramifications of genetics research and to critically evaluate the related issues raised by ethicists, scientists, and other stakeholders, it is vital to understand the basics of genetics, a discipline that integrates biology, mathematics, sociology, medicine, and public health.

To understand genetics, the development of organisms, and the diversity of species, it is important to learn how **deoxyribonucleic acid (DNA)** functions as the information-bearing molecule of living organisms.

From the perspective of genetics, the DNA molecule has two major attributes.

The first is that it is able to replicate—that is, to make an exact copy of itself that can be passed to another cell, thereby conveying its precise genetic characteristics.

The second critical attribute is that it stores detailed instructions to manufacture specific proteins—molecules that are essential to every aspect of life.

Proteins are molecules that perform all the chemical reactions necessary for life and provide structure and shape to cells. Proteins can act as structural components by building the tissues of the body.

Many essential biological processes depend on the highly specific functions of proteins.

DNA is a blueprint or template for making proteins, and much of the behavior and physiology (life processes and functions) of a living organism depends on the repertoire of proteins its DNA molecules know how to manufacture.

Along the length of a DNA molecule there are regions that hold the instructions to manufacture specific proteins—a specific sequence of **amino acids** linked side by side. These regions are called protein-encoding genes and are an essential element of the modern understanding of genetics.

How does a gene make a protein? The process of protein synthesis is quite complex. The protein-synthesizing instructions present in DNA are interpreted and acted on by **ribonucleic acid (RNA)**.

Enzymes such as lactase, which helps in the digestion of lactose (milk sugar), and hormones such as insulin (a hormone that regulates carbohydrate metabolism by controlling blood sugar levels) are proteins that act to facilitate and direct chemical reactions. Defense proteins, which are able to combat invasion by bacteria or viruses, are embedded in the walls of cells and act as channels, determining which substances to let into the cell and which to block.

THE CELL IS THE BASIC UNIT OF LIFE

Ever since Matthias Jakob Schleiden (1804–1881) and Theodor Schwann (1810–1882) put forth their theories—Schleiden in 1838 and Schwann in 1839—that all plants and animals are composed of cells, there has been continuous refinement of cell theory.

Cells are the basic units and building blocks of nearly every organism. (One exception is viruses, which are simple organisms that are not composed of cells.)

Each cell of an organism contains the same genetic information, which is passed on faithfully when cells divide. Different types of cells arise because they use different parts of the information, as determined by the cell's history and the immediate environment.

Plants and animals, as well as other organisms such as fungi, are composed of eukaryotic cells, or **eukaryotes**, because they have nuclei and membrane-bound structures known as **organelles**, which sustain, support, and protect the cell.

The nuclei of eukaryotes contain the **chromosomes**, which are chains of genetic material coded in DNA. The threadlike chromosomes are contained in the nucleus of a typical animal cell.

Genes are segments of DNA that carry a basic unit of hereditary information in coded form. They contain instructions for making proteins.

The eukaryotic chromosome contains a linear array of genes. Human cells normally contain 23 pairs of chromosomes, or a total of 46 chromosomes,

Cells without nuclei, such as bacteria and blue-green algae, are called prokaryotic cells or **prokaryotes**.

The growth of an organism occurs as a result of cell division in a process known as **mitosis**.

Mitosis is a continuous process that occurs in several stages. It involves exact duplication of the cell's chromosomal material and a systematic method for evenly distributing this material.

Mitosis occurs in all eukaryotic cells, except the **gametes** (sperm and egg), and always produces genetically identical daughter cells with a complete set of chromosomes.

To prevent mitosis from occurring, the gametes undergo a process of reduction division known as **meiosis**, which reduces the number of chromosomes in the gametes by half, so that when fertilization occurs the normal number of chromosomes is restored.

For example, in humans the gametes produced by meiosis are **haploid**—they have just one copy of each of the 23 chromosomes.

Besides preventing the number of chromosomes from doubling with each successive generation, meiosis also provides genetic diversity in offspring.

The process of meiosis creates other opportunities to generate genetic diversity, namely, **crossing over**, and **independent assortment**.

In male animals gamete formation, known as spermatogenesis, begins at puberty and takes place in the testes. In female animals gamete formation, known as oogenesis, takes place in the ovaries.

Like gamete formation, fertilization is a process, as opposed to a single event. It begins when the sperm and egg first come into contact and fuse together and culminates with the intermingling of two sets of haploid genes to reconstitute a **diploid** cell with the potential to become a new organism.

The resulting cell—the first cell of an entirely new organism—is called a **zygote**.

GENETIC INHERITANCE

For inheritance of simple genetic traits, the two inherited copies of a gene determine the **phenotype** (the observable characteristic) for that trait.

When genes for a particular trait exist in two or more different forms that may differ among individuals and populations, they are called **alleles**. For example, brown and blue eye colors are different alleles for eye color.

For every gene, the offspring receives two alleles, one from each parent. The combination of inherited alleles is the **genotype** of the organism, and its expression (the observable characteristic) is its phenotype.

For many traits the phenotype is a result of an interaction between the genotype and the environment. Some of the most readily apparent traits in humans, such as height, weight, and skin color, result from interactions between genetic and environmental factors.

For a specific trait some alleles may be **dominant** whereas others are **recessive**. The phenotype of a dominant allele is always expressed, whereas the phenotype of a recessive allele is expressed only when both alleles are recessive.

Recessive genes continue to pass from generation to generation, but they are only expressed in individuals who do not inherit a copy of the dominant gene for the specific trait.

Conventionally, geneticists use uppercase letters to represent dominant alleles and lowercase letters to stand for recessive alleles.

An organism with a pair of identical alleles for a trait is described as a **homozygote**, or homozygous for that particular trait.

When organisms are homozygous for a dominant trait, all uppercase letters symbolize the trait, whereas those that are homozygous for a recessive trait are represented by all lowercase letters.

A **heterozygote** is an organism with different alleles for a trait, one donated from each parent, and when one is dominant and the other is recessive the trait is shown using a combination of uppercase and lowercase letters.

Even though the combination of alleles is a random event, it is possible to predict the probability that an offspring will have the same or a different phenotype from its parents when the genotypes with respect to the specific trait of both parents and the phenotype associated with each possible combination of alleles are known.

The formula used to determine genetic possibilities was developed by the British geneticist Reginald Crundall Punnett (1875–1967).

The **Punnett square** is a grid configuration that depicts genotype and phenotype. In Punnett squares the genotypes of parents are represented with four letters. There are two alleles for each trait.

Genotypes of haploid gametes are represented with two letters. Gametes will contain one allele for each trait in every possible combination, and all possible fertilizations are calculated.

Punnett squares are used to compute the cross of a single gene or two genes and their alleles, but they become extremely complicated when used to predict the offspring of more than two alleles.

To construct a Punnett square, the alleles in the gametes of one parent are placed along the top, and the alleles in the gametes of the other parent are placed along the left side of the grid.

The number of characteristics considered determines the size of the Punnett square. A monohybrid cross looks at one trait and has a two-by-two structure, with four possible genotypes resulting from the cross. A dihybrid cross looks at two traits and has a four-by-four structure, providing sixteen possible genotypes.

Mitochondrial Inheritance—will be discussed later

DETERMINING GENDER

From the moment of fertilization, the new organism has been assigned a gender, and its growth will proceed to develop either as a male or a female organism.

The determination of gender occurs in all complex organisms, but the processes vary, even among animals.

In humans 22 of the 23 pairs of chromosomes are as likely to be found in males as in females. These 22 chromosomes are known as the **autosomes**, and the 23rd pair is the **sex chromosome**.

The sex chromosomes of females are identical and are called X chromosomes. In males the pair consists of an X chromosome and a smaller Y chromosome.

Chromosome Theory of Sex Determination

The genetic influence on gender is called the chromosome theory of sex determination, which states that:

- ▶ Gender is determined by the sex chromosome.
- ▶ In females the sex chromosomes are identical—both are X chromosomes. Because females have an XX genotype, all egg cells contain an X chromosome.
- ▶ In males the sex chromosomes are not identical; one is X and one is Y. Because males have an XY genotype, half of all sperm cells contain an X chromosome and half contain a Y chromosome.
- ▶ After fertilization, the egg may receive either an X or a Y chromosome from the sperm. Because all egg cells contain an X chromosome, the determination of gender is wholly dependent on the chromosomal composition of the sperm.
- ▶ Sperm carrying the Y chromosome are known as androsperm; those containing the X chromosome are called gynospem.
- ▶ If the sperm carries the Y chromosome, the offspring will be male (XY); if it carries an X chromosome, the offspring will be female (XX).

The two sex chromosomes also differ in terms of the genes they contain, which relate to many traits other than gender. The Y chromosome is quite small and carries few genes other than the one that determines male gender.

The X chromosome is larger and holds many genes that are as necessary for males as they are for females. The genes on the X chromosome are called X-linked, and characteristics or conditions arising from these genes are called X-linked traits or conditions.

Algebras in Genetics