# Law of independent assortment example

Home » Genetics In the 1860s, an Austrian monk named Gregor Mendel introduced a new theory of inheritance based on his experimental work with pea plants. Mendel believed that heredity is the result of discrete units of inheritance, and every single unit (or gene) was independent in its actions in an individual's genome. According to this Mendelian concept, the inheritance of a trait depended on the passing-on of these units. For any given trait, an individual inherits one gene from each parent so that the individual has a pairing of two genes. We now understand the alternate forms of these units as 'alleles'. If the two alleles that form the pair for a trait are identical, then the individual is said to be homozygous and if the two genes are different, then the individual is heterozygous for the trait. The breeding experiments of the monk in the mid-1800s laid the groundwork for the science of genetics. He studied peas plant for 7 years and published his results in 1866 which was ignored until 1900 when three separate botanists, who also were theorizing about heredity in plants, independently cited the work. In appreciation of his work he was considered as the "Father of Genetics". A new stream of genetics was established after his name as Mendelian genetics which involves the study of heredity of both qualitative (monogenic) and quantitative (polygenic) traits and the influence of environment on their expressions. Mendelian inheritance while is a type of biological inheritance that follows the laws originally proposed by Gregor Mendel in 1865 and 1866 and re-discovered in 1900. Mendel carried out breeding experiments in his monastery's garden to test inheritance patterns. He selectively cross-bred common pea plants (Pisum sativum) with selected traits over several generations.  After crossing two plants which differed in a single trait (tall stems vs. short stems, round peas vs. wrinkled peas, purple flowers vs. white flowers, etc), Mendel discovered that the next generation, the "F1" (first filial generation), was comprised entirely of individuals exhibiting only one of the traits.  However, when this generation was interbred, its offspring, the "F2" (second filial generation), showed a 3:1 ratio- three individuals had the same trait as one parent and one individual had the other parent's trait. Mendel's Laws Image Source: Encyclopædia Britannica. The Law of Segregation states that every individual organism contains two alleles for each trait, and that these alleles segregate (separate) during meiosis such that each gamete contains only one of the alleles. An offspring thus receives a pair of alleles for a trait by inheriting homologous chromosomes from the parent organisms: one allele for each trait from each parent. Hence, according to the law, two members of a gene pair segregate from each other during meiosis; each gamete has an equal probability of obtaining either member of the gene. Mendel's Law of Independent Assortment. Created with BioRender.com Mendel's second law. The law of independent assortment; unlinked or distantly linked segregating genes pairs behave independently. The Law of Independent Assortment states that alleles for separate traits are passed independently of one another. That is, the biological selection of an allele for one trait has nothing to do with the selection of an allele for any other trait. Mendel found support for this law in his dihybrid cross experiments. In his monohybrid crosses, an idealized 3:1 ratio between dominant and recessive phenotypes resulted. In dihybrid crosses, however, he found a 9:3:3:1 ratios. This shows that each of the two alleles is inherited independently from the other, with a 3:1 phenotypic ratio for each. The genotype of an individual is made up of the many alleles it possesses. An individual's physical appearance, or phenotype, is determined by its alleles as well as by its environment. The presence of an allele does not mean that the trait will be expressed in the individual that possesses it. If the two alleles of an inherited pair differ (the heterozygous condition), then one determines the organism's appearance and is called the dominant allele; the other has no noticeable effect on the organism's appearance and is called the recessive allele. Thus, the dominant allele will hide the phenotypic effects of the recessive allele. This is known as the Law of Dominance but it is not a transmission law: it concerns the expression of the genotype. The upper case letters are used to represent dominant alleles whereas the lowercase letters are used to represent recessive alleles. Verma, P. S., & Agrawal, V. K. (2006). Cell Biology, Genetics, Molecular Biology, Evolution & Ecology (1 ed.). S .Chand and company Ltd. Gardner, E. J., Simmons, M. J., & Snustad, D. P. (1991). Principles of genetics. New York: J. Wiley. ��notes.html About Author The Law of Independent Assortment states that different genes and their alleles are inherited independently within sexually reproducing organisms. During meiosis, chromosomes are separated into multiple gametes. Genes linked on a chromosome can rearrange themselves through the process of crossing-over. Therefore, each gene is inherited independently.   This law describes the random inheritance of genes from maternal and paternal sources. According to the Law of Segregation, each chromosome is separated from its homolog, or counterpart, during meiosis. As such, the maternal and paternal chromosomes from your parents are "independently assorted", meaning that chromosomes from the same source do not have to end up in the same gamete. For instance, one gamete can end up with all maternal chromosomes, while another can have a mixture of both maternal and paternal chromosomes. This also means that the genes on these chromosomes are independently assorted. In effect, the Law of Independent Assortment creates a large amount of variety based on different combinations of genes which have not previously occurred. In one instance, genes cannot be assorted completely randomly. This occurs with linked genes, or genes which share the same chromosome. However, the process of crossing-over during meiosis ensures that even these genes get rearranged. During crossing-over, homologous parts of maternal and paternal chromosomes can be exchanged. This ensures that even linked genes get independently assorted. Independent assortment occurs during the process of meiosis. Meiosis is similar to mitosis, only the final product is gamete cells. Gamete cells have half the DNA of regular, diploid cells and are considered haploid. This is a necessary part of sexual reproduction which allows two gamete cells to then fuse together to create a diploid zygote, containing all the DNA necessary to create a new organism. To understand when independent assortment occurs, you must also understand the Law of Segregation. This law states that during meiosis, the two different copies of every gene are sorted into different gamete cells. The law of independent assortment, on the other hand, deals with the maternal and paternal sources of DNA being separated at random. To see these concepts in action, look at the image below: As you can see, the law of independent assortment takes place as maternal and paternal sources of DNA are randomly divided. Sometimes, the gamete inherits the maternal version of a gene, and sometimes it inherits the paternal version. Which version it gets is completely random, based on the order that these chromosomes lined up in during the first stage of meiosis. As a basic example, let us consider a hypothetical population of bunny rabbits that only have two visible traits: fur color (black or white), and eye color (green or red). The black fur allele (B) is dominant over the white (b), while the green eye allele (G) is dominant over red (g). In this hypothetical example, two hybrid rabbits are mixed. What this means is that both rabbits look black with green eyes, but are really they have a heterozygous genotype. Both rabbits have the genotype BbGg. In this population of 2 rabbits, all the individuals have the same mixture of characteristics. In other words, they are all black with green eyes. Before breeding, each rabbit will have to produce gametes. During this process, not only are the alleles separated (law of segregation), but each copy of each chromosome is randomly assigned to a different gamete. This means regardless of the parental phenotype (black with green eyes), the babies can inherit different combinations of these traits. For instance, one baby could receive the bbgg genotype, giving it white fur and red eyes. Alternatively, a baby rabbit could also receive the genotype Bbgg, giving it black fur and red eyes. This is the law of independent assortment. Gregor Mendel performed many experiments involving breeding pea plants. In doing so, he gleaned information about how "units of heredity" work, which would later on become known as genes after DNA was discovered and determined to be the material that encodes genetic information. Mendel developed the Law of Independent Assortment after breeding two different pea plants with two different characteristics; he bred plants with yellow, round peas with plants that had wrinkled, green peas. Since yellow and round were dominant over wrinkled and green, all the offspring had yellow, round peas. But, when this first generation was crossbred with each other in a dihybrid cross, there was a lot of variation in the second generation. Peas were no longer either just yellow and round or green and wrinkled; some were green and round, while some were yellow and wrinkled. Furthermore, the offspring showed their characteristics in a ratio of 9:3:3:1. Nine were round and yellow, three were round and green, three were wrinkled and yellow, and one was wrinkled and green. This ratio stayed the same even when hundreds of dihybrids were crossed. This occurred because each of the parent plants only gave their offspring one allele and because yellow and round were dominant traits and masked the green and/or wrinkled traits in certain individual plants. The diagram below depicts Mendel's dihybrid cross. Mendel's experiment showed that the alleles for round or wrinkled peas were inherited independently from the alleles for yellow or green peas since the plants were not just round and yellow or green and wrinkled. We now know that they exist on different chromosomes, which allows them to be mixed up during the process of meiosis. The Law of Independent Assortment explains the complex working of genes in inheritance. This law explains how traits are inherited and it was initially proposed by Gregor Mendel in the 19th century. In this article, we will look at the Law of Independent Assortment, giving an overview of its occurrence, how it varies from linkage, its basic reasons, and Mendel's work that paved the way for our understanding of genetic inheritance. What is the Law of Independent Assortment?The Law of Independent Assortment is one of the important principles of genetics stated by Gregor Mendel in the 19th century based on his work with pea plants. It explains how different genes independently separate from one another when reproductive cells develop. It explains how traits are transmitted from parents to offspring and provides a basis for genetic variation and is also the fundamental of genetics and heredity. Also Read: Law of Inheritance When Does Independent Assortment Occur?Gametes are specialized cells used in sexual reproduction and their development depends on independent assortment. This crucial step occurs during meiosis, a kind of cell division that produces four separate haploid cells. During meiosis, homologous chromosomes having the genes for the same traits, align independently at the metaphase plate. Each gamete obtains a combination of genetic material from both parents which promotes genetic variability. Consider DNA as a set of instructions that shows characteristics such as the colour of the eyes or the shape of the nose. These genes are located on what are called chromosomes which are like chapters of a book. The Law of Independent Assortment is like a game in which these chapters shuffle separately during a special process called meiosis. This creates new combinations of traits which is similar to assembling many chapters to create one story. On the other hand, linkages are similar to sections of a book that are joined together on the same page. These chapters are closely connected and when these are shuffled they usually stay together. Thus, when a chapter ends and a new "book" begins, the related chapters resume together. To put it simply, independent assortment is the process of freely rearranging chapters to produce a unique story each time. In linkage, certain chapters always remain together. This distinction makes genetics interesting and complicates how traits are inherited from parents. Therefore, these processes shape everything. The Reason for Independent AssortmentIndependent assortment occurs during the development of gametes which are specialised cells that contain genetic material. It happens in the first phase of cell division, meiosis. Meiosis creates four unique daughter cells and each contains half of the genetic material of the parent cell for two rounds of division. Homologous chromosomes split into several cell types at the initial stage of meiosis. The Law of Independent Assortment starts at this moment because the distribution of one pair of chromosomes is independent of the distribution of other pairs. The wide variety of genetic linkages produced by this random distribution contributes to the diversity observed in offspring. Independent Assortment in Mendel's ExperimentsGregor Mendel, also known as the founder of modern genetics, provided the first explanation of the Law of Independent Assortment. Mendel conducted comprehensive investigations with pea plants in the 19th century and closely observed the inheritance patterns of many traits. In one of his major investigations, Mendel examined the simultaneous inheritance of seed form and colour. The two traits were controlled by different gene pairs on different chromosomes. Mendel crossed pea plants with different combinations of these traits and found that the inheritance of seed shape was different from the inheritance of seed colour. Law of Independent Assortment ExamplesTo help us better understand, let's look at several real-world examples that demonstrate the Law of Independent Assortment Dihybrid Cross Consider a dihybrid cross between two heterozygous pea plants having different flower colour (Rr) and plant height (Tt). The Law of Independent Assortment states that the genes related to plant height (T and t) and flower colour (R and r) separate independently. The gene combinations RT, Rt, rT and rt will be present in the gametes. As a result, the offspring can display different flower colours and plant height combinations which leads to a different population that meets independent assortment requirements. Fuit fly Eyes ColorIn fruit flies, the genes determining wing size (W) and eye colour (B) are located on different chromosomes. The Law of Independent Assortment states that the genes for wing size and eye colour will be sorted randomly into the gametes of heterozygous for both features (BbWw). The resulting progeny can show the genetic variability created by independent assortment by displaying a range of wing sizes and eye colours. ConclusionLaw of Independent Assortment rule which is in effect during meiosis ensures that different gene pairs will be distributed randomly into gametes, producing offspring with a diverse genetic make-up. Independent assortment is a way to reorganise and mix up genetic material as opposed to linkage which is the tendency for genes on the same chromosome to be inherited together. Mendel's research on pea plants established the basis for our understanding of this law by offering concrete evidence of its occurrence. Real-world examples such as fruit fly traits and dihybrid crosses in pea plants, highlight the part that independent assortment plays in creating genetic variation. Understanding the Law of Independent Assortment may teach us a lot about how traits are inherited and the subject of genetics that affects the living things around us. Also Read: The law of independent assortment is a fundamental concept in genetics proposed by Gregor Mendel, often recognised as the "Father of Genetics." It describes how different genes controlling distinct traits separate into gametes independently of one another. This principle, which is also Mendel's second law of inheritance, has been pivotal in our understanding of how offspring can exhibit new combinations of traits not always visible in their parents.In this article, we will explore what Mendel's second law of independent assortment is, how it differs from the law of segregation, relevant examples, a detailed law of independent assortment diagram, and more. IntroductionIn simple terms, Mendel's second law of independent assortment states that when two or more genes are inherited together, their alleles (alternative forms of a gene) segregate into gametes independently. Essentially, inheriting a particular allele for one trait does not influence which allele is inherited for another trait.Mendel arrived at this conclusion after performing dihybrid crosses with pea plants. He tracked the inheritance of two distinct traits simultaneously (e.g., seed shape and seed colour). The resulting progeny in these experiments exhibited combinations of traits that varied from their parents, proving that each pair of alleles assorted independently.The F1 generation of dihybrid crosses showed dominant traits for both characters.The F2 generation displayed a phenotypic ratio of 9:3:3:1.Traits of colour and shape were assorted into gametes independently, resulting in new trait combinations.Law of Independent Assortment Vs Law of SegregationThe law of independent assortment vs law of segregation comparison often helps clarify Mendel's findings:Law of Segregation (Mendel's First Law): Each parent carries two alleles for any given trait. These alleles segregate (separate) during gamete formation, ensuring that each gamete contains only one allele for each gene.Law of Independent Assortment (Mendel's Second Law): The segregation of alleles for one gene is independent of the segregation of alleles for another gene, provided the genes are not located too close on the same chromosome (i.e., they are usually on different chromosomes or far apart on the same chromosome).In short, the law of segregation focuses on how one pair of alleles separates during gamete formation, while the law of independent assortment highlights how different genes assort independently into gametes.How Does the Law of Independent Assortment Work?To understand the law of independent assortment, it's crucial to know the basics of meiosis—a specialised type of cell division that reduces the chromosome number by half, forming haploid gametes (sperm and egg cells).Formation of Haploid Cells: Each diploid organism carries two sets of chromosomes, one from each parent. During meiosis, these sets are halved, so each gamete receives only one copy of every chromosome.Random Orientation: When homologous chromosomes align at the cell's equator during meiosis I, they do so randomly. This random orientation ensures that chromosomes (and, therefore, the genes they carry) are assorted independently.Independent Segregation of Genes: For two genes on different chromosomes, the alleles separate into gametes independently of each other. This means each new gamete can have any combination of maternal or paternal alleles.Thus, if a parent's genotype is RrYy, there is a 50% chance that a gamete will receive either R or r and similarly a 50% chance of receiving Y or y. Combining these probabilities gives four possible allele combinations (RY, Ry, rY, ry), which explains how traits recombine in the offspring.Law of Independent Assortment Diagram Although we cannot show an image here, you can visualise a law of independent assortment diagram by imagining two pairs of chromosomes:Pair 1 with alleles R (dominant) and r (recessive).Pair 2 with alleles Y (dominant) and y (recessive).During meiosis, each pair segregates independently. Hence, you get four types of gametes: RY, Ry, rY, and ry. This visual representation typically highlights how each allele pair moves separately, reinforcing the principle that one trait's inheritance does not impact another's inheritance.Law of Independent Assortment ExampleOne classic law of independent assortment example is Mendel's dihybrid cross using pea plants for two traits—seed shape (round 'R' vs. wrinkled 'r') and seed colour (yellow 'Y' vs. green 'y'):Parental Generation (P): RRYY (round, yellow) × rryy (wrinkled, green).F1 Generation: All offspring are RrYy (round, yellow) because the dominant alleles mask the recessive ones.F2 Generation: When F1 plants self-pollinate, we observe four phenotypic classes in a 9:3:3:1 ratio:Round, Yellow (9)Round, Green (3)Wrinkled, Yellow (3)Wrinkled, Green (1)This 9:3:3:1 pattern demonstrates that the genes for shape and colour were passed on independently.Another law of independent assortment example includes considering two traits in rabbits: fur colour and eye colour. If we cross two rabbits that are hybrids for both traits, their offspring will display combinations of fur and eye colours in proportions that suggest independent sorting of each trait.Quick QuizTry this short quiz to test your understanding of the law of independent assortment:In a dihybrid cross of RrYy × RrYy, which of the following ratios represents the phenotypic distribution in the F2 generation?a) 3:1b) 9:3:3:1c) 1:1:1:1d) 2:1:1Which cell division process is crucial for the law of independent assortment?a) Mitosisb) Meiosisc) Binary Fissiond) BuddingIn the context of the law of independent assortment vs the law of segregation, which statement is true?a) Both laws refer to a single pair of alleles only.b) The law of segregation talks about how different gene pairs segregate.c) The law of independent assortment states that allele pairs for different traits segregate independently.d) Neither law applies to dihybrid crosses.(Answers: 1. b, 2. b, 3. c)Feel free to explore our other resources on Law of SegregationMendel's Laws of Inheritance  After the law of segregation that explains the inheritance of a single characteristic related to one gene, Mendel questioned how characteristics related to two or more different genes get inherited. He found that inherited genes assort independently of one another, which Mendel put forward as the law of independent assortment. The law states that alleles of two or more different genes separate independently from the other into gametes that reproduce sexually. Thus, the allele received from one gene does not influence the allele received from the other.     In 1865 while studying pea plants involving dihybrid crosses, Mendel found that the traits in the offspring did not always match the traits in the parental organisms. He crossed two pure-breeding pea plants in his experiment: one with yellow, round seeds (YYRR) and one with green, wrinkled seeds (yyrr). By the law of segregation, the gametes made by the round, yellow plant are all RY, and the gametes made by the wrinkled, green plant all are ry. Thus, all the F1 offspring are RrYy that are phenotypically identical, producing yellow and round seeds. In the F2 generation, Mendel self-pollinated all F1 plants. He found four categories of pea seeds: yellow and round, yellow and wrinkled, green and round, and green and wrinkled. They were found to be phenotypically in the ratio of 9:3:3:1. Law of Independent Assortment This ratio confirms Mendel's law of independent assortment as the result of 9:3:3:1 is expected to produce four types of gametes with equal frequency: YR, Yr, yR, and yr. The result is explained when each gamete randomly receives a Y/y allele or R/r allele in separate processes, making four equally probable combinations. Thus, the chance of forming gametes with the gene R/r or Y/y is 50:50.  The result showing the 16 equally likely genotypic combinations are represented in a 4 × 4 Punnett square, where the gametes are arranged along the top and left. The 9:3:3:1 phenotypic ratio can be divided into two separate 3:1 ratios, showing a dominant and a recessive pattern of a monohybrid cross. Considering only seed color, we expect three-quarters of the F2 offspring to be yellow and one-quarter to be green. Similarly, considering only seed texture, we expect three-quarters of the F2 offspring to be round and one-quarter to be wrinkled. Thus, the sorting of alleles for color and texture are separate events. Thus, the proportion of round and yellow F2 offspring is expected to be $(3/4) \times (3/4) = 9/16$. In contrast, the proportion of wrinkled and green offspring is $(1/4) \times (1/4) = 1/16$. Similarly, the proportion of round/green and wrinkled/yellow offspring is expected as $(3/4) \times (1/4) = 3/16$. This result is identical to that obtained in the 4 × 4 Punnett square. The independent assortment forms the basis of meiosis I during gamete formation when homologous pairs line up in random orientations at the middle of the cell as they prepare to separate. At the end of cell division, we can get gametes with a combination of genes from both parents. For genes on different chromosomes, such as in pea plants, the genes for seed color are on chromosome 1, while the genes for seed shape are on chromosome 7, and they assort independently. Also, genes far apart on the same chromosome assort independently due to crossing over in meiosis I. Independent assortment is also critical in recombination, where pieces of genes from the parent's mix and match, ensuring that genes assort independently from one another. Sometimes, when genes are very close to each other in a chromosome, they do not assort independently. The alleles on the same chromosome are more likely to be inherited as a unit. Such genes are said to be linked and do not exhibit independent assortment. In such cases, the genes for the color and shape of the seed are always inherited as a pair. Yellow and round alleles and green and wrinkled alleles always stayed together. Rather than giving a separate color allele and a shape allele, the F1 hybrid gives one same unit for each gamete: a YR allele pair or a yr allele pair. One can use a Punnet square to predict the result of self-fertilization of the F1 offspring in such a case. Suppose the color and shape genes were inherited as a unit or are entirely linked. In that case, a dihybrid cross will form two types of offspring, yellow/round and green/wrinkled, in a 3:1 ratio, which is different from the 9:3:3:1 obtained from Mendel's experiment. This result of 3:1 further proves independent assortment during sexual reproduction. Article was last reviewed on Wednesday, April 26, 2023