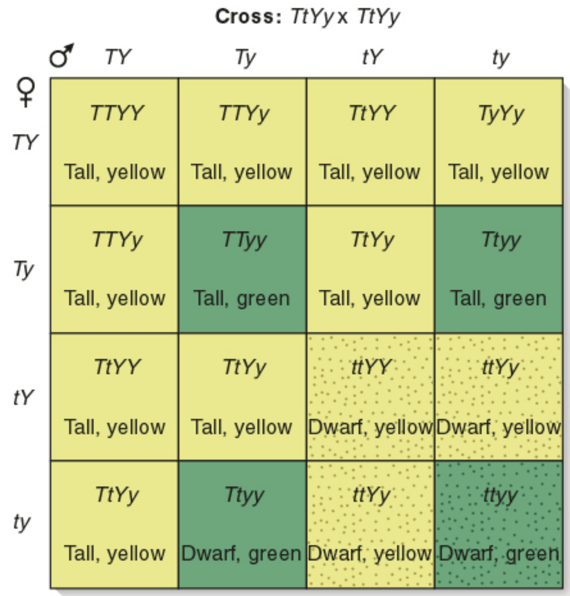
S1.A heterozygous pea plant that is tall with yellow seeds, *TtYy*, is allowed to self-fertilize. What is the probability that an offspring will be either tall with yellow seeds, tall with green seeds, or dwarf with yellow seeds?



Answer: This problem involves three mutually exclusive events, and so we use the sum rule to solve it. First, we must calculate the individual probabilities for the three phenotypes. The outcome of the cross can be determined using a Punnett square.

$$P_{\text{Tall with yellow seeds}} = 9/(9 + 3 + 3 + 1) = 9/16$$

$$P_{\text{Tall with green seeds}} = 3/(9 + 3 + 3 + 1) = 3/16$$

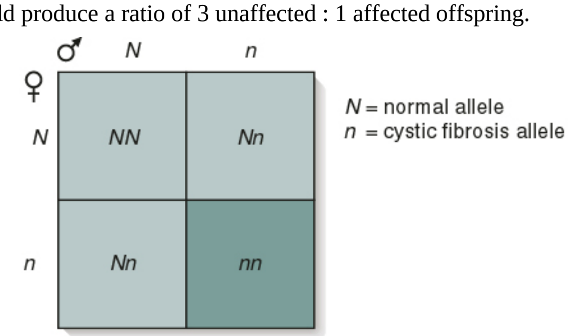
$$P_{\text{Dwarf with yellow seeds}} = 3/(9 + 3 + 3 + 1) = 3/16$$

Sum rule: 9/16 + 3/16 + 3/16 = 15/16 = 0.94 = 94%

We expect to get one of these three phenotypes 15/16, or 94%, of the time.

S2. As described in chapter 2, a human disease known as cystic fibrosis is inherited as a recessive trait. A normal couple’s first child has the disease. What is the probability that their next two children will not have the disease?

Answer: A phenotypically normal couple has already produced an affected child. To be affected, the child must be homozygous for the disease allele and, thus, has inherited one copy from each parent. Therefore, since the parents are unaffected with the disease, we know that both of them must be heterozygous carriers for the recessive disease-causing allele. With this information, we can calculate the probability that they will produce an unaffected offspring. Using a Punnett square, this couple should produce a ratio of 3 unaffected : 1 affected offspring.



The probability of a single unaffected offspring is

$$P_{\text{Unaffected}} = 3/(3 + 1) = 3/4$$

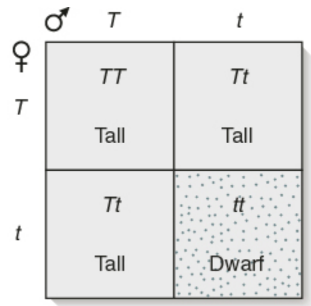
To obtain the probability of getting two unaffected offspring in a row (i.e., in a specified order), we must apply the product rule.

$$3/4 \times 3/4 = 9/16 = 0.56 = 56\%$$

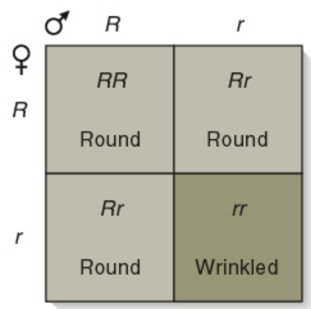
There is a 56% chance that their next two children will be unaffected.

S3. A pea plant is heterozygous for three genes (*Tt Rr Yy*), where *T* = tall, *t* = dwarf, *R* = round seeds, *r* = wrinkled seeds, *Y* = yellow seeds, and *y* = green seeds. If this plant is self-fertilized, what are the predicted phenotypes of the offspring and what fraction of the offspring will occur in each category?

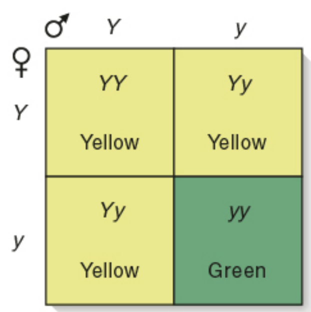
Answer: One could solve this problem by constructing a large Punnett square and filling in the boxes. However, in this case, there are eight possible male gametes and eight possible female gametes: *TRY, TRy, TrY, tRY, trY, Try, tRy,* and *try.* It would become rather tiresome to construct and fill in this Punnett square, which would contain 64 boxes. As an alternative, we can consider each gene separately and then algebraically combine them by multiplying together the expected phenotypic outcomes for each gene. In the cross *Tt Rr Yy* x *Tt Rr Yy,* the following Punnett squares can be made for each gene:



3 tall : 1 dwarf



3 round : 1 wrinkled



3 yellow : 1 green

Instead of constructing a large, 64-box Punnett square, there are two similar ways to determine the phenotypic outcome of this trihybrid cross. In the **multiplication method,** we can simply multiply these three combinations together:

(3 tall + 1 dwarf)(3 round + 1 wrinkled)(3 yellow + 1 green)

This multiplication operation can be done in a stepwise manner. First, multiply (3 tall + 1 dwarf) by (3 round + 1 wrinkled).

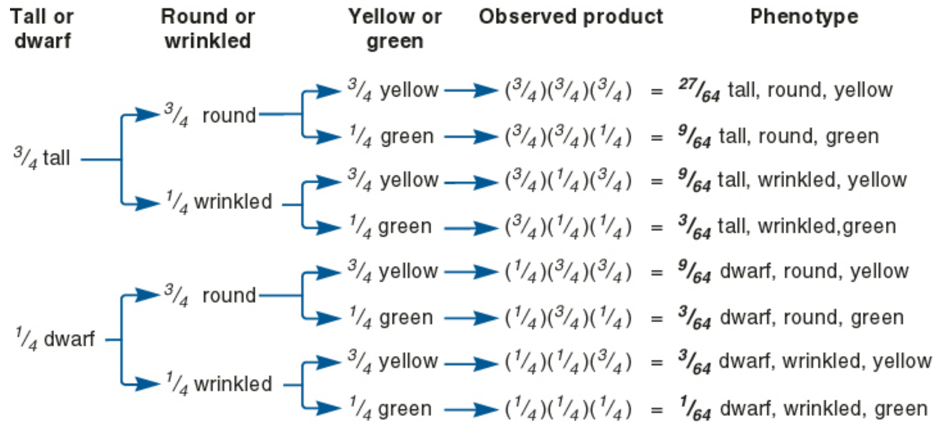
(3 tall + 1 dwarf)(3 round + 1 wrinkled) = 9 tall, round + 3 dwarf, round + 3 tall, wrinkled + 1 dwarf, wrinkled

Next, multiply this product by (3 yellow + 1 green).

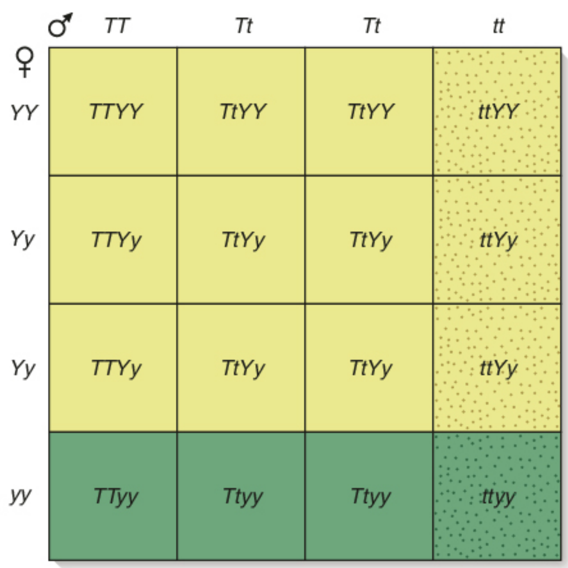
(9 tall, round + 3 dwarf, round + 3 tall, wrinkled + 1 dwarf, wrinkled)(3 yellow + 1 green) = 27 tall, round, yellow + 9 tall, round, green + 9 dwarf, round, yellow + 3 dwarf, round, green + 9 tall, wrinkled, yellow + 3 tall, wrinkled, green + 3 dwarf, wrinkled, yellow + 1 dwarf, wrinkled, green

Even though the multiplication steps are also somewhat tedious, this approach is much easier than making a Punnett square with 64 boxes, filling them in, deducing each phenotype, and then adding them up!

A second approach that is analogous to the multiplication method is the **forked-line method.** In this case, the genetic proportions are determined by multiplying together the probabilities of each phenotype.



S4. A cross was made between two heterozygous pea plants, *TtYy* x *TtYy*. The following Punnett square was constructed:



Phenotypic ratio:

9 tall, yellow seeds : 3 tall, green seeds : 3 dwarf, yellow seeds : 1 dwarf, green seed

What is wrong with this Punnett square?

Answer: The outside of the Punnett square is supposed to contain the possible types of gametes. A gamete should contain one copy of each type of gene. Instead, the outside of this Punnett square contains two copies of one gene and zero copies of the other gene. The outcome happens to be correct (i.e., it yields a 9:3:3:1 ratio), but this is only a coincidence. The outside of the Punnett square must contain one copy of each type of gene. In this example, the correct possible types of gametes are *TY*, *Ty*, *tY*, and *ty* for each parent.

S5. For an individual expressing a dominant trait, how can you tell if it is a heterozygote or a homozygote?

Answer: One way is to conduct a cross with an individual that expresses the recessive version of the same trait. If the individual is heterozygous, half of the offspring will show the recessive trait, whereas if the individual is homozygous, none of the offspring will express the recessive trait.

Dd × *dd*	or	*DD* × *dd*
1 *Dd* (dominant trait) 1 *dd* (recessive trait)		All *Dd* (dominant trait)

Another way to determine heterozygosity involves a more careful examination of the individual at the cellular or molecular level. At the cellular level, the heterozygote may not look exactly like the homozygote. This phenomenon is described in chapter 4. Also, gene cloning methods described in chapter 18 can be used to distinguish between heterozygotes and homozygotes.

S6. In dogs, black fur color is dominant to white. Two heterozygous black dogs are mated. What would be the probability of the following combinations of offspring?

A. A litter of six pups, four with black fur and two with white fur.

B. A litter of six pups, the firstborn with white fur, and among the remaining five pups, two with white fur and three with black fur.

C. A first litter of six pups, four with black fur and two with white fur, and then a second litter of seven pups, five with black fur and two with white fur.

D. A first litter of five pups, four with black fur and one with white fur, and then a second litter of seven pups in which the firstborn is homozygous, the second born is black, and the remaining five pups are three black and two white.

Answer:

A. This is an unordered combination of events, so we use the binomial expansion equation where: $n = 6$, $x = 4$, $p = 0.75$ (probability of black), and $q = 0.25$ (probability of white).

The answer is 0.297, or 29.7%, of the time.

B. We use the product rule because there is a specific order. The first pup is white and then the remaining five are born later. We also need to use the binomial expansion equation to determine the probability of the remaining five pups.

(probability of a white pup)(binomial expansion for the remaining five pups)

The probability of the white pup is 0.25. In the binomial expansion equation, $n = 5$, $x = 2$, $p = 0.25$, and $q = 0.75$.

The answer is 0.066, or 6.6%, of the time.

C. The order of the two litters is specified, so we need to use the product rule. We multiply the probability of the first litter times the probability of the second litter. We need to use the binomial expansion equation for each litter.

(binomial expansion of the first litter)(binomial expansion of the second litter)

For the first litter, $n = 6$, $x = 4$, $p = 0.75$, $q = 0.25$. For the second litter, $n = 7$, $x = 5$, $p = 0.75$, $q = 0.25$.

The answer is 0.092, or 9.2%, of the time.

D. The order of the litters is specified, so we need to use the product rule to multiply the probability of the first litter times the probability of the second litter. We use the binomial expansion equation to determine the probability of the first litter. The probability of the second litter is a little more complicated. The firstborn is homozygous. There are two mutually exclusive ways to be homozygous, *BB* and *bb.* We use the sum rule to determine the probability of the first pup, which equals 0.25 + 0.25 = 0.5. The probability of the second pup is 0.75, and we use the binomial expansion equation to determine the probability of the remaining pups.

(binomial expansion of first litter)([0.5][0.75][binomial expansion of second litter])

For the first litter, $n = 5$, $x = 4$, $p = 0.75$, $q = 0.25$. For the last five pups in the second litter, $n = 5$, $x = 3$, $p = 0.75$, $q = 0.25$.

The answer is 0.039, or 3.9%, of the time.

S7. In chapter 2 the binomial expansion equation was used in situations where there are only two possible phenotypic outcomes. When there are more than two possible outcomes, it is necessary to use a **multinomial expansion equation** to solve a problem involving an unordered number of events. A general expression for this equation is:

$$P = \frac{n!}{a!b!c!\ldots} p^a q^b r^c \ldots$$

where P = the probability that the unordered number of events will occur.

n = total number of events
$a + b + c + \ldots = n$
$p + q + r + \ldots = 1$

(p is the likelihood of a, q is the likelihood of b, r is the likelihood of c, and so on)

The multinomial expansion equation can be useful in many genetic problems where there are more than two possible combinations of offspring. For example, this formula can be used to solve problems associated with an unordered sequence of events in a dihybrid experiment. This approach is illustrated next.

A cross is made between two heterozygous tall plants with axial flowers (*TtAa*), where tall is dominant to dwarf and axial is dominant to terminal flowers. What is the probability that a group of five offspring will be composed of two tall plants with axial flowers, one tall plant with terminal flowers, one dwarf plant with axial flowers, and one dwarf plant with terminal flowers?

Answer:

Step 1. *Calculate the individual probabilities of each phenotype.* This can be accomplished using a Punnett square.

The phenotypic ratios are 9 tall with axial flowers, 3 tall with terminal flowers, 3 dwarf with axial flowers, and 1 dwarf with terminal flowers.

The probability of a tall plant with axial flowers is
9/(9 + 3 + 3 + 1) = 9/16.

The probability of a tall plant with terminal flowers is
3/(9 + 3 + 3 + 1) = 3/16.

The probability of a dwarf plant with axial flowers is
3/(9 + 3 + 3 + 1) = 3/16.

The probability of a dwarf plant with terminal flowers is
1/(9 + 3 + 3 + 1) = 1/16.

$p = 9/16$

$q = 3/16$

$r = 3/16$

$s = 1/16$

Step 2. *Determine the number of each type of event versus the total number of events.*

$n = 5$

$a = 2$

$b = 1$

$c = 1$

$d = 1$

Step 3. *Substitute the values in the multinomial expansion equation.*

$$P = \frac{n!}{a!b!c!d!} p^a q^b r^c s^d$$

$$P = \frac{5!}{2!1!1!1!} (9/16)^2 (3/16)^1 (3/16)^1 (1/16)^1$$

$$P = 0.04 = 4\%$$

This means that 4% of the time we would expect to obtain five offspring with the phenotypes described in the question.