Mendel's Laws: Human Inheritance of Single Gene Traits

A Brief Review of Mendel's Work with Garden Pea Plants

In garden pea plants, there are two character states for pea height, tall and short. Mendel began with pure lines of pea plants. In plants, **pure lines** are strains that consistently yield offspring with the same traits generation after generation. Mendel grew plants that were of pure line for tall and plants that were of pure line for short. He crossed a pure line tall parent plant with a pure line short parent plant (the **P generation**) to produce hybrids (the **F_1 generation** [first filial], in simple terms, the children of the parent plants). He then obtained a second hybrid generation (the **F_2 generation** [second filial], in simple terms, the grandchildren of the parent plants) by crossing the F_1 generation plants with each other. The following results were observed…

	Crossing	Results
1st cross	pure line tall X pure line short	100% tall hybrids (children of the pure line parent plants that were as tall as the parent plant)
2nd cross	hybrid tall F_1 X hybrid tall F_1	¾ tall to ¼ short plants (the grandchildren of the pure line parent plants)

Mendel made the following conclusions…

1. **Alleles** control an inherited characteristic & exist in individuals in pairs (You inherit one member of the pair from your father & one member of the pair from your mother). The two alleles of a pair are the same in **homozygous** individuals (e.g. the pure line short plants are homozygous for the character state of short. Their allele pair is short/short). The two alleles of the pair differ in **heterozygous** individuals (e.g. the hybrid F_1 generation inherited a tall allele from one parent and a short allele from the other parent. Thus their allele pair is tall/short). The **genotype** is the allele combination that produces a character state. The genotype of the hybrid F_1 generation is tall/short. The **phenotype** is the visible, physical trait. The phenotype of the hybrid F_1 generation is tall.

2. **LAW OF DOMINANCE**: Whenever the two alleles of a pair in a given individual differ, only one, the dominant one will be expressed. In the hybrid F_1 generation, the plants inherited one tall allele and one short allele. Yet, all of these plants appeared to be tall. Thus tall is the **dominant allele** (the allele that indicates the appearance of heterozygotes). One allele is said to be dominant over another if a heterozygous individual for that allele has the same appearance as an individual homozygous for it. The short allele is the **recessive allele** (an allele whose phenotype effects are masked in heterozygotes by the presence of a dominant allele).

3. **LAW OF SEGREGATION OF ALLELES**: When the gametes (egg & sperm) are formed by an individual, only one member of each allele pair is included in a gamete. Recall that gametes are **haploid**. When the hybrid F_1 generation plants produce gametes, each gamete will receive only one allele for plant height. So, an egg (or a sperm) will have an allele for tall or an allele for short, but not both. When the egg unites with the sperm during **fertilization**, the sperm will carry one allele for plant height, restoring the allele pair and the **diploid** condition.

4. **LAW OF INDEPENDENT ASSORTMENT**: All of the possible kinds of gametes that can be formed, will be formed in equal proportions. Alleles for different traits are inherited independently of each other if they are located on different homologous gene pairs.

If Mendel had a tall pea plant, how could he be certain that it was a pure line tall plant?

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Using Mendel's Laws to Solve Monohybrid (single trait) Problems

Steps to Solving Genetics Problems

1. READ the problem
2. Write down what you know
3. Assign letters for the alleles (traditionally, you should use the letter of the recessive allele)
    a. Use a capital letter for the dominant trait
    b. Use a lower case letter for the recessive trait
4. Determine the genotypes involved
5. Make gametes (sex cells – each gamete will carry only ONE allele for a trait, not both)
6. Solve using a Punnett Square
7. Reread the question & make sure that you have answered it

Single Trait Problems (Monohybrid Crosses)

Red pigeon is in front of the more commonly-colored brown pigeon.

Photo source: naturetales.blogspot.com

SAMPLE PROBLEM: The allele for red feather color in pigeons, B, is dominant to the allele for brown feathers, b. A red pigeon who had a red parent and a brown parent is mated with a brown pigeon.

a. What are the genotypes of the two pigeons being mated?
b. Identify the gametes produced by each of the pigeons being mated.
c. What proportion of the F_1 progeny would be expected to have brown feathers?

STEPS TO THE SOLUTION:

1. Write down what you know

Grandparent Pigeons – Red X Brown
(Genotypes) __ __ __ __

Parent Pigeons - Red X Brown
(Genotypes) __ __ __ __

F_1 (first filial or offspring or babies) --

2. Assign letters for the alleles (traditionally, you should use the letter of the recessive allele)
    a. Use a capital letter for the dominant trait
    b. Use a lower case letter for the recessive trait

Since we know that red color is dominant to brown, we will use b for the alleles. Red is dominant, so it should be B. Brown is recessive, so it should be b.

3. Determine the genotypes involved

We know that the brown parent must be homozygous, or bb. Otherwise, it would appear red in color. The red parent is a little trickier. That parent could be either homozygous or heterozygous. Rereading the problem, we see that this parent was produced from the crossing of a red and a brown pigeon. In other words we are at the very least crossing B_ X bb to get the red parent. In order for the offspring of this cross to be red it must have one dominant allele that it will inherit from its red parent. We know that the brown pigeon must give all of its offspring the recessive allele. Thus, the red parent pigeon in this problem must have a heterozygous genotype for color, or Bb.

Now we can record the parent's genotypes.

Grandparent Pigeons –	Red	X Brown
(Genotypes)	B __	bb
Parent Pigeons -	Red	X Brown
(Genotypes)	Bb	bb

F_1 (first filial or offspring or babies) --

4. Make gametes (sex cells – each gamete will carry only ONE allele for a trait, not both)

The brown pigeon has a genotype of bb. Thus all of the gametes it will produce will have the b allele.

The red pigeon has a genotype of Bb. Thus it will produce gametes with B alleles and gametes b alleles in equal proportions.

Parent Pigeons	Red	X	Brown
(Parent Genotypes)	Bb		bb
Gametes Produced			

5. Solve using a Punnett Square

Gametes		

Genotypic ratio of the F_1 generation = 2 Bb : 2 bb. This can be simplified as 1 Bb : 1 bb because both numbers in the ratio are divisible by 2.

Phenotypic ratio of the F_1 generation = 2 red : 2 brown. Again, this can be simplified as 1 red : 1 brown.

6. Reread the question & make sure that you have answered it

   a. What are the genotypes of the two pigeons being mated?
   b. Identify the gametes produced by each of the pigeons being mated.
   c. What proportion of the F_1 progeny would be expected to have brown feathers?

a. The red parent's genotype is Bb. The brown parent's genotype is bb.
b. The red parent produces 2 types of gametes. Half carry the allele of red & half carry the allele for brown.
The brown parent produces only one type of gamete. All of it's gametes carry the allele for brown.
c. We would expect half of the offspring to have brown feathers.

SOME PRACTICE MONOHYBRID PROBLEMS

1. Several plants with purple flowers were crossed to plants with white flowers. The seeds from the cross produced plants on which only purple flowers appeared. These purple-flower plants were then crossed to each other & the seeds from the cross produced 346 purple flowered plants & 128 white flowered plants. Illustrate the crosses involved & determine the phenotypic & genotypic ratios of the last generation of plants.

2. In peas, long-stem (S) is dominant over short-stem (s). Give the expected phenotypic ratios for the following four crosses:

a. homozygous long X short
b. heterozygous long X short
c. heterozygous long X homozygous long
d. heterozygous long X heterozygous long

3. In humans, dimples (N) are dominant to nondimples (n). A couple who both have dimples, have a child without dimples. What must be the genotypes of the two parents? What is the probability that their next child will have dimples?

Sex-Linked Trait Problems

SAMPLE PROBLEM: In humans, red-green color blindness is a sex-linked trait. Normal color vision is due to allele B & color blindness is due to allele b. The heterozygous condition results in a carrier condition in females (they see red-green normally, but can pass the trait on to their offspring). What would be the phenotypic ratio of offspring produced by a color blind male and a carrier female?

For this problem,

$X^B X^b$ = carrier female

$X^b X^b$ = color blind female

X^b Y = color blind male

$X^B X^B$ = normal female

X^B Y = normal male

The color blind male in this case will have genotype X^b Y. He will produce 2 types of gametes: X^b & Y. The carrier female will have genotype $X^B X^b$. She will produce 2 types of gametes: X^B & X^b. We can use this information to complete a Punnett square.

Gametes	X^B	X^b
X^b		
Y		

What will be the phenotypic ratio of this couple's children?

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Use an Ishihara chart to check if you have some difficulty seeing color.

A PRACTICE SEX-LINKED TRAIT PROBLEM

Calico Cat

Photo source: http://www.hanne-mugaas.com/

Tortoise Shell Cat

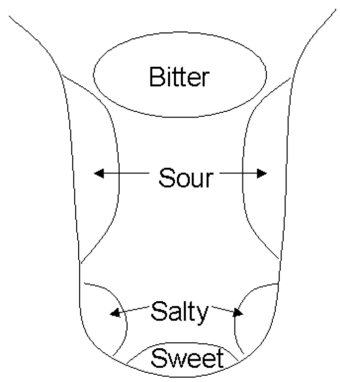
Photo source: http://www.catsarewonderful.com/

1. In cats, orange color is due to allele B' & black color is due to allele B. The heterozygous condition (B'B) results in a color known as calico (calico is a coat pattern that is mottled in tones of black, orange, and white) in females. These alleles are known to be sex-linked. What coat color types would be expected from a cross between a black male & a calico female?

Human Inheritance of Single Gene Traits

Determine your own phenotype for each of the following traits. For some of the more easily observed traits you may be able to recall the phenotypes of your parents. If it is possible, determine your own genotype by comparing phenotypes of your parents and your own phenotype. If you have the dominant phenotype, give both possibilities for your genotype where it cannot be determined definitely. Record your phenotypes in Table 4 and on the chalkboard so that the data of the entire class may be tabulated. Record in your table the class results.

Tasting: Does broccoli taste bitter? Is eating hot peppers intensely painful? Scientific evidence suggests a genetic basis for food preferences – and it's all on the tip of the tongue. We will explore your ability to taste 3 chemicals.



1. **PTC** (phenylthiourea), is an organic compound that **either tastes very bitter or is virtually tasteless**, depending on your genetic makeup. **About 70% of people can taste PTC**. Food choice is related to a person's ability to taste PTC. One study found that non-smokers and those that don't often drink coffee or tea are more likely to be able to taste PTC. The ability to taste PTC (P) is dominant to the inability (p) to taste this chemical.
2. **Thiourea** is another organic molecule that **either tastes very bitter or is virtually tasteless**. A study at Yale University found that people could be classified into three groups, "**supertasters**" who could not abide the taste test paper at all, **medium tasters** who did not like it but tolerated it, and **nontasters** who could not taste anything. **Supertasters will not consume any bitter foods**, like dark-green leafy vegetables, coffee or chocolate, and **represent perhaps 10 to 15%** of the population. Nontasters have higher rates of thyroid disease - and of course thiourea compounds are antithyroid agents. The ability to taste thiourea is dominant to the inability to taste it.
    a. Super tasters are homozygous dominant (TT).
    b. Medium tasters are heterozygous (Tt).
    c. Nontasters are recessive (tt)
3. **Sodium benzoate** is a type of salt that may occur naturally in some foods but is more likely to be added as a preservative to foods. It is used in small amounts only (usually in acidic foods like sodas and fruit juices) because too much makes the food taste very bitter. Sodium benzoate tastes differently to different people. Some may perceive a **salty taste** while others may claim the sodium benzoate tastes **sour, bitter or sweet**. Others may not taste the sodium benzoate at all. Approximately **75% of people can taste it**. The ability to taste Sodium benzoate (S) is dominant to the inability (s) to taste this chemical.

Double-jointed thumb. A dominant gene determines a condition of loose ligaments that allows one to throw the thumb out of joint. The homozygous recessive condition determines tight joints

	**Widow's peak**. The presence of a point in the middle of the hairline is called a widow's peak (the woman on the left) and is dominant to the straight hairline (the woman on the right).
	Hair shape. There is a lack of dominance in hair shape. Curly hair is one homozygous condition and straight hair is the alternate homozygous condition. Wavy hair results from the heterozygous genotype.
	Red hair. Nonred hair is dominant to its recessive allele.
	Dark hair. Brunette is dominant to blond hair.
	Freckles. Presence of freckles is dominant to absence of freckling
	**Cheek dimples**. The presence of dimples in the cheeks is a dominant trait.
	**Ear lobes**. In most people around the world, the ear lobe hangs free (diagram on the left) but in some individuals it is directly attached to the side of the head (diagram on the right). Attached ear lobe is recessive. Interestingly, in the United States, more people have attached ear lobes than free ear lobes.
	**Tongue rolling**. Ability to roll the tongue into a U-shape longitudinally (without the aid of lips) is dominant to the inability to curl the tongue.
	Mid-digital hair. Some people have hair on the second, or middle joint of the fingers, while others do not. The complete absence of mid-digital hairs on all fingers is recessive. There seems to be several dominant alleles which determine whether these hairs grow on all fingers or only one, two, three or four of the fingers. All are dominant to absence of hairs. These hairs may be very fine and a hand lens may be required to determine your phenotype for this trait.
	**Hitchhiker's thumb**. Hyperextensibility of the thumb (hitchhikers's thumb) is recessive to straight thumb. This can be determined by examining the position of your thumbs when they are in a relaxed position. When this condition is present, the usual position of the thumb is such that it is bent backward toward the wrist; there may be as much as a 45˚ angle between the two joints.
	Interlocking thumbs. When the hands are clasped, some people will place the right thumb on top while others will place the left thumb on top. This can be tested quite easily; usually the interlocking of the fingers will be the same each time a person does it. Placing the fingers in the alternate position feels "wrong." Evidence indicates that placing the left thumb over the right is dominant.

	**Bent little finger**. Hold your hands in front of your face with the palm toward you, pressing the little fingers together. If the two fingers are straight, they will be parallel to one another throughout their lengths; whereas, in the bent finger condition the terminal portions flare away from one another. The bent finger is dominant to the straight finger.
	**Cleft chin.** A cleft chin is, essentially, a dimple on the chin. It results from incomplete fusion of the left and right halves of the jaw during fetal development. The resulting bony peculiarity results in a cleft chin. Cleft chins is dominant to chins without a cleft.
	**Eyebrow position**. Some people have abundant hair between the eyebrows, so that they seem to converge to form one long eyebrow, known as a unibrow or monobrow. The condition is known as **synorphrys**. Connected eyebrows are dominant to unconnected.

Record your personal data and the collected classroom data for these traits on the next page. Then, use that information to answer the following questions.

For how many traits are you recessive? ____________________

On the basis of the tabulated results for the entire class, are there any recessive traits which are more common among the class members than the dominant condition? If so, name them.

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What difference would you expect in the tabulation if 1000 students were included in the table?

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Table 4. Tabulation of Human Traits

GENETIC TRAITS		YOUR RESULTS		CLASS TABULATION	
Phenotype	**Genotype**	**Phenotype**	**Genotype**	**# Dominants**	**# Recessives**
PTC taster Nontaster	PP or Pp pp				
Thiourea Supertaster Medium taster Nontaster	TT Tt tt				
Sodium Benzoate taster Non taster	SS or Ss ss				
Double-jointed thumb Tight joints	JJ or Jj jj				
Widow's Peak Straight hair line	WW or Ww ww				
Curly hair Wavy hair Straight hair	CC CC' C'C'				
Nonred hair Red hair	NN or Nn nn				
Dark hair Blond hair	MM or Mm mm				
Freckles No freckles	FF or Ff ff				
Cheek dimple No cheek dimple	DD or Dd dd				
Free earlobes Attached earlobes	EE or Ee ee				
Tongue rolling present Tongue rolling absent	RR or Rr rr				
Digital hair present Digital hair absent	MM or Mm mm				
Straight thumb Hitchhikers's thumb	HH or Hh hh				
Left thumb over right Right thumb over left	LL or Ll ll				
Bent little finger Straight little finger	BB or Bb bb				
Cleft chin present Absence	CC or Cc cc				
Unibrow Separate eyebrows	UU or Uu uu				