The Hardy-Weinberg Law of Genetic Equilibrium

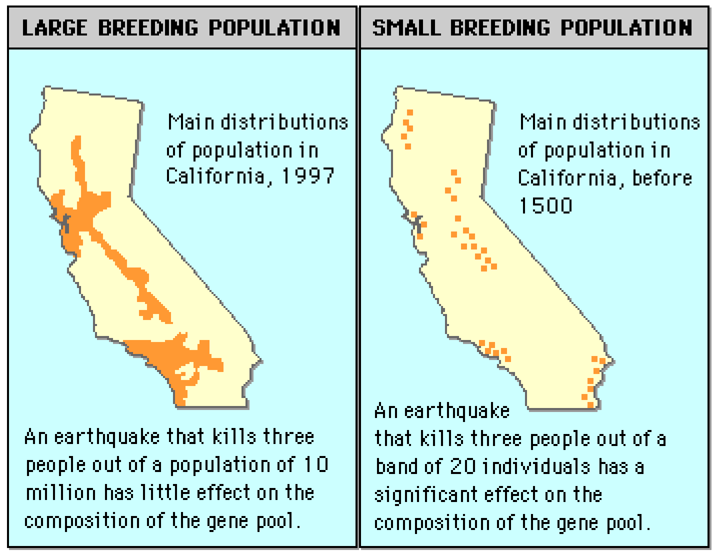
In 1908 G. Hardy and W. Weinberg independently proposed that the frequency of alleles and genotypes in a population will remain constant from generation to generation if the population is stable and in genetic equilibrium. Five conditions are required in order for a population to remain at Hardy-Weinberg equilibrium:

1. A large breeding population
2. Random mating
3. No change in allelic frequency due to mutation
4. No immigration or emigration
5. No natural selection

Let's look more closely to see how each factor functions to maintain genetic equilibrium and how the opposite condition can bring about a change in the gene pool.

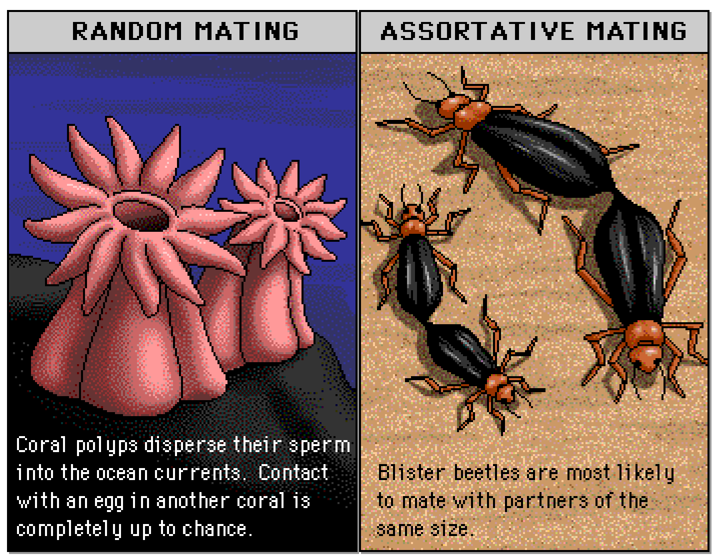
A Large Breeding Population

A large breeding population helps to ensure that chance alone does not disrupt genetic equilibrium. In a small population, only a few copies of a certain allele may exist. If for some chance reason the organisms with that allele do not reproduce successfully, the allelic frequency will change. This random, nonselective change is what happens in genetic drift or a bottleneck event.



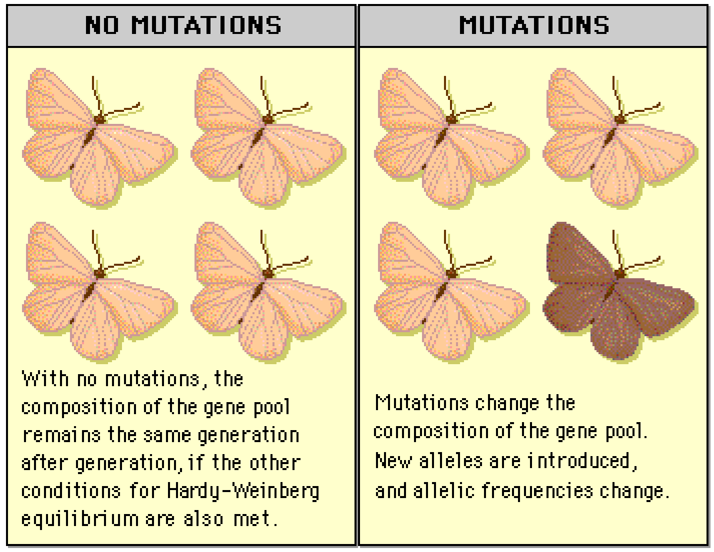
Random Mating

In a population at equlibrium, mating must be random. In assortative mating, individuals tend to choose mates similar to themselves; for example, large blister beetles tend to choose mates of large size and small blister beetles tend to choose small mates. Though this does not alter allelic frequencies, it results in fewer heterozygous individuals than you would expect in a population where mating is random.



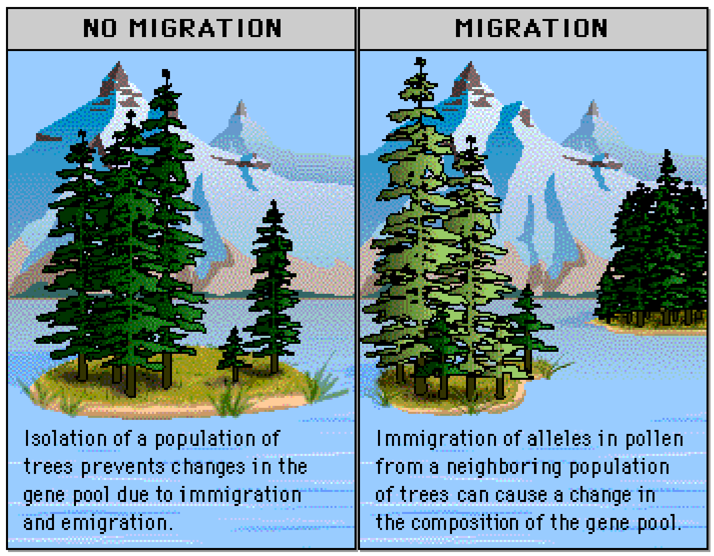
No Change in Allelic Frequency Due to Mutation

For a population to be at Hardy-Weinberg equilibrium, there can be no change in allelic frequency due to mutation. Any mutation in a particular gene would change the balance of alleles in the gene pool. Mutations may remain hidden in large populations for a number of generations, but may show more quickly in a small population.



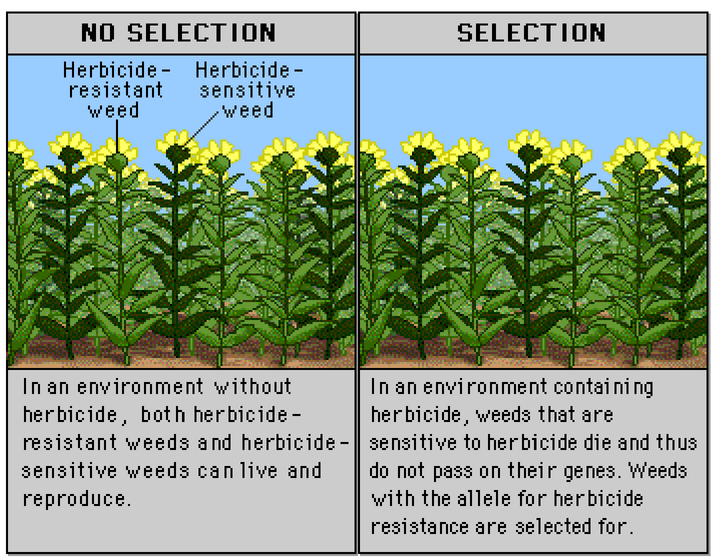
No Immigration or Emigration

For the allelic frequency to remain constant in a population at equilibrium, no new alleles can come into the population, and no alleles can be lost. Both immigration and emigration can alter allelic frequency.



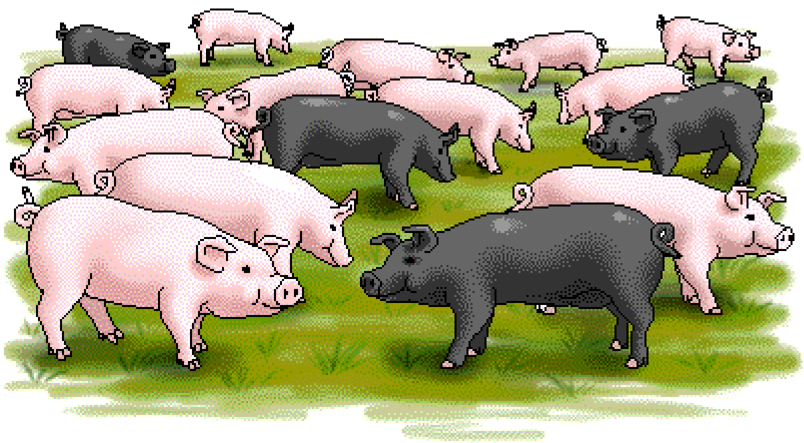
No Natural Selection

In a population at equilibrium, no alleles are selected over other alleles. If selection occurs, those alleles that are selected for will become more common. For example, if resistance to a particular herbicide allows weeds to live in an environment that has been sprayed with that herbicide, the allele for resistance may become more frequent in the population.



Estimating Allelic Frequency

If a trait is controlled by two alternate alleles, how can we calculate the frequency of each allele? For example, let us look at a sample population of pigs.



The allele for black coat is recessive to the allele for white coat. Can you count the number of recessive alleles in this population?

The Hardy-Weinberg Equation

To estimate the frequency of alleles in a population, we can use the Hardy-Weinberg equation. According to this equation:

p = the frequency of the dominant allele (represented here by *A*)
q = the frequency of the recessive allele (represented here by *a*)

For a population in genetic equilibrium:
$p + q = 1.0$ (The sum of the frequencies of both alleles is 100%.)

$(p + q)^2 = 1$

so
$p^2 + 2pq + q^2 = 1$

The three terms of this binomial expansion indicate the frequencies of the three genotypes:

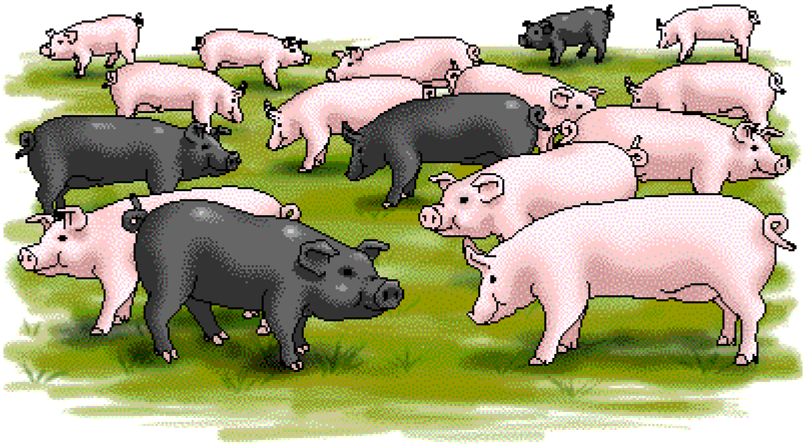
p^2 = frequency of *AA* (homozygous dominant)
$2pq$ = frequency of *Aa* (heterozygous)
q^2 = frequency of *aa* (homozygous recessive)

This page contains all the information you need to calculate allelic frequencies when there are two different alleles. You may want to print the page so you can refer back to it as you do the rest of this laboratory.

We start with some sample problems that will give you practice in using the Hardy-Weinberg equation.

Sample Problem 1

Let's return to our population of pigs. Remember that the allele for black coat is recessive. We can use the Hardy-Weinberg equation to determine the percent of the pig population that is heterozygous for white coat.



1. Calculate q2

Count the individuals that are homozygous recessive in the illustration above. Calculate the percent of the total population they represent. This is q2.

2. Find q.

Take the square root of q2 to obtain q, the frequency of the recessive allele.

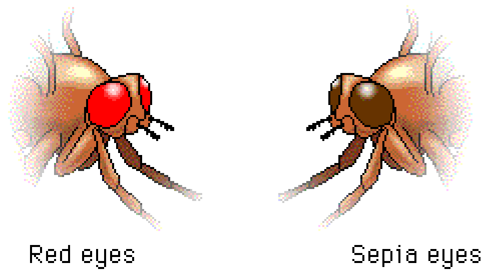
3. Find p.

The sum of the frequencies of both alleles = 100%, p + q = l. You know q, so what is p, the frequency of the dominant allele?

4. Find 2pq.

The frequency of the heterozygotes is represented by 2pq. This gives you the percent of the population that is heterozygous for white coat:

Sample Problem 2



In a certain population of 1000 fruit flies, 640 have red eyes while the remainder have sepia eyes. The sepia eye trait is recessive to red eyes. How many individuals would you expect to be homozygous for red eye color? Hint: The first step is always to calculate q2! Start by determining the number of fruit flies that are homozygous recessive. If you need help doing the calculation, look back at the Hardy-Weinberg equation.

In a certain population of 1000 fruit flies, 640 have red eyes while the remainder have sepia eyes. The sepia eye trait is recessive to red eyes. How many individuals would you expect to be homozygous for red eye color?

Your Answer:
.36

Answer:
You should expect 160 to be homozygous dominant.
Calculations:
q^2 for this population is 360/1000 = 0.36
$q = \sqrt{0.36} = 0.6$
$p = 1 - q = 1 - 0.6 = 0.4$
The homozygous dominant frequency = $p^2 = (0.4)(0.4) = 0.16$.
Therefore, you can expect 16% of 1000, or 160 individuals, to be homozygous dominant.

Sample Problem 3

The Hardy-Weinberg equation is useful for predicting the percent of a human population that may be heterozygous carriers of recessive alleles for certain genetic diseases. Phenylketonuria (PKU) is a human metabolic disorder that results in mental retardation if it is untreated in infancy. In the United States, one out of approximately 10,000 babies is born with the disorder. Approximately what percent of the population are heterozygous carriers of the recessive PKU allele? If you need help, look back at the Hardy-Weinberg equation.

Allelic Frequency vs. Genotypic Frequency

Allelic Frequency

If you are told that the frequency of a recessive allele in a population is 10%, you are directly given q, since by definition q is the frequency of the recessive allele. This comprises all the copies of the recessive allele that are present in heterozygotes as well as all the copies of the allele in individuals that show the recessive phenotype. What is q for this population?

Answer:
Approximately 2% of the U.S. population carries the PKU allele.
Calculation:
$q^2 = 1/10{,}000 = 0.0001$
$q = \sqrt{0.0001} = 0.01$
$p = 1 - q = 1 - 0.01 = 0.99$
The carriers are heterozygous. Therefore, $2pq = 2\,(0.99)\,(0.01) = 0.0198 = 1.98\%$

Allelic Frequency vs. Genotypic Frequency (continued)
Genotypic Frequency

Genotypic frequency is the frequency of a genotype - homozygous recessive, homozygous dominant, or heterozygous - in a population. If you don't know the frequency of the recessive allele, you can calculate it if you know the frequency of individuals with the recessive phenotype (their genotype must be homozygous recessive).

Sample Problem
If you observe a population and find that 16% show the recessive trait, you know the frequency of the aa genotype. This means you know q2. What is q for this population?

Answer:
$q = 0.1$

Quiz

1. If the frequency of two alleles in a gene pool is 90% A and 10% a, what is the frequency of individuals in the population with the genotype Aa?
a. 0.81
b. 0.09
c. 0.18
d. 0.01
e. 0.198

2. If a population experiences no migration, is very large, has no mutations, has random mating, and there is no selection, which of the following would you predict?
a. The population will evolve, but much more slowly than normal.
b. The makeup of the population's gene pool will remain virtually the same as long as these conditions hold.
c. The composition of the population's gene pool will change slowly in a predictable manner.
d. Dominant alleles in the population's gene pool will slowly increase in frequency while recessive alleles will decrease.
e. The population probably has an equal frequency of A and a alleles.

3. Which of the following is NOT a condition that must be met for Hardy-Weinberg equilibrium?
a. Large population size
b. No mutations
c. No immigration or emigration
d. Dominant alleles more frequent than recessive alleles
e. No natural selection

4. In a population that is in Hardy-Weinberg equilibrium, the frequency of the homozygous recessive genotype is 0.09. What is the frequency of individuals that are homozygous for the dominant allele?
a. 0.7
b. 0.21
c. 0.42
d. 0.49
e. 0.91

5. In humans, Rh-positive individuals have the Rh antigen on their red blood cells, while Rh-negative individuals do not. If the Rh-positive phenotype is produced by a dominant gene (A), and the Rh-negative phenotype is due to its recessive allele (a), what is the frequency of the Rh-positive allele if 84% of a population is Rh-positive?
a. 0.04
b. 0.16
c. 0.48
d. 0.60
e. 0.84