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STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium >

Hardy-Weinberg Equilibrium

Subject & topics: Biology | Evolution | Theory **Stage & difficulty:** A Level P3

The Hardy-Weinberg principle states that, given certain conditions, genotype frequencies will remain constant at

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

where

- p^2 is the proportion of homozygotes for the allele for which the proportion is given by p
- $2pq$ is the proportion of heterozygotes in the population
- q^2 is the proportion of homozygotes for the allele for which the proportion is given by q

Note that $p + q = 1$.

Part A

Equal proportions

A gene has two alleles (**A**, **a**) in a population. The proportion of allele **A** in the population (given by p) is 0.5.

Find q, the proportion of allele **a** in this population.

Assuming the population is in Hardy-Weinberg equilibrium, what percentage of individuals will be homozygous for allele **A**?

Part B

Unequal proportions >

A gene has two alleles (**A**, **a**) in a population. The proportion of allele **A** in the population (given by p) is 0.8.

Find q, the proportion of allele **a** in this population.

Assuming the population is in Hardy-Weinberg equilibrium, what percentage of individuals will be homozygous for allele **a**?

Part C

How many heterozygotes? >

A gene has two alleles (**A**, **a**) in a population of $2\,000$ individuals.

65% of the copies of this gene in this population are allele **A**.

How many individuals would you expect to be heterozygous in this population?

Part D

Disequilibrium >

A gene has two alleles (**A**, **a**) in a population. The proportion of allele **A** in the population (given by p) is 0.5.

The genotype frequencies are as follows:

- **AA**: 45% of individuals
- **Aa**: 10% of individuals
- **aa**: 45% of individuals

Which of the following reasons may explain why this population is not in Hardy-Weinberg equilibrium for this gene? Select all that apply.

- [ ] The population is very small and so genotype frequencies are highly affected by genetic drift.
- [ ] Homozygotes prefer to mate with individuals of the opposite homozygote genotype.
- [ ] Recent emigration out of the population has occurred.
- [ ] Recent immigration into the population has occurred.
- [ ] Heterozygotes have a higher fitness than homozygotes.
- [ ] Heterozygotes have a lower fitness than homozygotes.
- [ ] Homozygotes prefer to mate with individuals of the same genotype.
- [ ] The population is very large and so genotype frequencies are highly affected by genetic drift.

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STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium >

Albino Rabbits

Subject & topics: Biology | Evolution | Theory **Stage & difficulty:** A Level P3

The Hardy-Weinberg principle, represented by the equations below, can be used to estimate the frequency of alleles in a population.

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

$$p + q = 1$$

Albino rabbits have white fur as these individuals are unable to produce the pigment melanin. The ability to produce melanin is controlled by a gene with a dominant allele (**B**), resulting in brown fur, and a recessive allele (**b**), resulting in an albino.

Of the 60 rabbits in a pet shop, 45 are brown.

A student decided to use the Hardy-Weinberg principle to estimate the frequencies of the alleles in this group of rabbits.

Part A

Hardy-Weinberg calculation

Using the Hardy-Weinberg equations, estimate the frequency of the **dominant** allele in this group.

Give your answer to 2 decimal places.

Part B

Hardy-Weinberg conditions >

Why was it not appropriate to use the Hardy-Weinberg principle to estimate the frequencies of alleles in this group of rabbits in the pet shop? Select all that apply.

- [ ] natural selection is likely to be occurring
- [ ] mating is **not** likely to be random
- [ ] mating is likely to be random
- [ ] rabbits will regularly be leaving the pet shop (and new rabbits will be brought in)
- [ ] the number of rabbits is very small
- [ ] albinism is a mutation

Adapted with permission from OCR A Level Biology A, June 2014, Control, Genomes and Environment, Question 6b

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Question deck:
STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium

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Budgie Genotypes

Subject & topics: Biology | Evolution | Theory **Stage & difficulty:** A Level P3

The Hardy-Weinberg principle, represented by the equations below, can be used to estimate the frequency of alleles and genotypes in a population.

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

$$p + q = 1$$

A breeder of birds keeps a population of 86 budgerigars in one enclosed area. Two distinct phenotypes are present, blue feathers and green feathers. Feather colour is controlled by one gene:

- **G** is the allele for green feathers
- **g** is the allele for blue feathers

Only 17 of the budgerigars have blue feathers.

Part A

Heterozygous individuals

Estimate the number of **heterozygous** individuals in the population.

Part B

Homozygous dominant individuals >

Estimate the number of **homozygous dominant** individuals in the population.

Part C

Hardy-Weinberg conditions >

The Hardy-Weinberg principle does not apply to all populations.

Which of the following are conditions in which the Hardy-Weinberg principle does **not** apply?

- [ ] the population size is extremely small
- [ ] the population size is extremely large
- [ ] mating is random
- [ ] mating is non-random
- [ ] one allele is more common than the other
- [ ] one allele has a selective advantage over the other
- [ ] individuals are migrating into the population
- [ ] individuals are migrating out of the population

Adapted with permission from CIE A Level Biology, June 2018, Paper 4, Question 2c

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Question deck:
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STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium >

Flour Beetle Eye Colour

Subject & topics: Biology | Evolution | Theory **Stage & difficulty:** A Level P3

In flour beetles one gene controlling eye colour is located on chromosome 5. Flour beetles have two copies of chromosome 5 in each cell. One allele causes black eyes and a second allele causes red eyes.

The allele for black eye (B) is dominant over the allele for red eye (b).

$\frac{3}{4}$ of the alleles present in a population of 1600 flour beetles were the dominant B allele.

Part A

Black eyes

What is the expected number of flour beetles with black eyes?

Part B

Expected ratio of genotypes >

What is the expected ratio of homozygous black eye beetles to heterozygous black eye beetles to red eye beetles? Express your answer as a ratio in its simplest form (e.g. 1 : 2 : 3)

Adapted with permission from NSAA 2022 Specimen Paper Section 2 Q30

Question deck:
STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium

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STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium >

Plant Heights & Hardy-Weinberg Equilibrium

Subject & topics: Biology | Evolution | Theory **Stage & difficulty:** A Level P3

In a particular species of plant, a gene that affects plant height has two codominant alleles (**T** and **t**).

- **TT** plants are tall.
- **Tt** plants are medium-height.
- **tt** plants are short.

A researcher counts the number of plants of each type in a population of 200 diploid plants. The results are shown in the table below.

Plant phenotype	Observed frequency
Tall	12
Medium-height	136
Short	52

The researcher wants to investigate whether the population is in Hardy-Weinberg equilibrium for this gene.

Part A

Allele proportions

State the **allele** proportions below, where

- p is the proportion of the **T** (tall) allele
- q is the proportion of the **t** (short) allele

Give your answers as exact decimals.

$p =$ ____

$q =$ ____

Part B

Expected frequencies >

Using your answers to the previous section, fill in the expected frequencies (assuming Hardy-Weinberg equilibrium) in the table below.

Plant phenotype	Observed frequency	Expected frequency
Tall	12	
Medium-height	136	
Short	52	

Part C

Conclusion >

We can see that the observed frequencies differ from the expected frequencies by a large amount. This suggests that this plant population is **not** in Hardy-Weinberg equilibrium for this gene.

Which of the following may explain why this population is not in Hardy-Weinberg equilibrium for this gene?

- [ ] Heterozygotes have a **higher** fitness than homozygotes.
- [ ] Heterozygotes have a **lower** fitness than homozygotes.
- [ ] The population is small and therefore allele/genotype frequencies are highly affected by genetic drift.
- [ ] Tall plants cannot successfully reproduce with short plants.

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Question deck:
STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium

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STEM SMART Biology Week 31 - Hardy-Weinberg Equilibrium >

ABO Blood Types & Hardy-Weinberg Equilibrium

Subject & topics: Biology | Evolution | Theory **Stage & difficulty:** A Level C3

An individual's blood type is determined by two genes: the ABO gene and the RhD gene.

The ABO gene has three main alleles: $\mathbf{I^A}$, $\mathbf{I^B}$, and **i** (alternatively named $\mathbf{I^O}$). $\mathbf{I^A}$ and $\mathbf{I^B}$ are codominant, and both are dominant to **i**.

A genomics study was carried out to measure the relative frequencies of different ABO genotypes in the UK. The genomes of $487\,236$ individuals were sequenced. The results are shown in the table below.

Blood type	Genotype	Frequency
A	$\mathbf{I^AI^A}$	$36\,326$
	$\mathbf{I^Ai}$	$175\,134$
B	$\mathbf{I^BI^B}$	$2\,787$
	$\mathbf{I^Bi}$	$44\,026$
AB	$\mathbf{I^AI^B}$	$17\,606$
O	**ii**	$211\,357$

Data from https://biobank.ctsu.ox.ac.uk/ukb/field.cgi?id=23165

Answer the questions below to determine whether, based on this sample, the UK population is in Hardy-Weinberg equilibrium for the ABO gene.

Part A

Three alleles

For a gene with two alleles, where the proportion of one allele is given by p and the proportion of the other allele is given by q, the expected genotype proportions in Hardy-Weinberg equilibrium are:

$$p^2 + 2pq + q^2$$

Fill in the expected genotype proportions in Hardy-Weinberg equilibrium for the ABO gene, where

- p is the proportion of the I^A allele
- q is the proportion of the I^B allele
- r is the proportion of the i allele

Blood type	Genotype	Expected genotype proportion
A	I^AI^A	
	I^Ai	
B	I^BI^B	
	I^Bi	
AB	I^AI^B	
O	ii	

Items:

p^2 p^3 q^2 q^3 r^2 r^3 $2pq$ $3pq$ $2pr$ $3pr$ $2qr$ $3qr$ $2pqr$ $3pqr$

Part B

Allele proportions ›

State the allele proportions below, where

- p is the proportion of the I^A allele
- q is the proportion of the I^B allele
- r is the proportion of the i allele

Give your answers to 4 sf.

$p =$ ____

$q =$ ____

$r =$ ____

Part C

Expected frequencies ›

Using your answers in the previous parts, calculated the expected frequency of each genotype in this dataset. You may use your rounded answers from part B. Give your answers to 3 sf.

Blood type	Genotype	Observed frequency	Expected frequency
A	I^AI^A	36 326	
	I^Ai	175 134	
B	I^BI^B	2 787	
	I^Bi	44 026	
AB	I^AI^B	17 606	
O	ii	211 357	

Part D

Conclusion >

We can see that the observed frequencies only differ from the expected frequencies by a few hundred individuals. Given the large size of our sample ($487\,236$), this is quite a small difference. This suggests that the UK population **is** in Hardy-Weinberg equilibrium for the ABO gene.

Based on this, which of the following conclusions are supported? Select all that apply.

- [ ] Individuals with the **ii** genotype have a higher fitness than individuals with any other genotype.
- [ ] There is **strong** selection acting on these alleles/genotypes.
- [ ] There is **no** selection acting on these alleles/genotypes.
- [ ] Individuals prefer to have children with individuals of a different blood type to themselves.
- [ ] Individuals do **not** show mating preferences based on blood type.

Created for isaacscience.org by Lewis Thomson. This question has been established using the UK Biobank Data Field 23165.