Using Punnett Squares to Predict the Outcomes of Crosses

The possible gene combinations in the offspring that result from a genetic cross can be determined by drawing a diagram known as a Punnett square. A Punnet square shows the genes (represented by letters) in the parents' gametes along the top and left-hand side of a square and the possible gene combinations in the offspring, within the square.

A completed Punnett square gives the probable outcome of a given cross. However, actual results may vary from the probable results, especially if only a few organisms are considered.

ONE-FACTOR CROSSES

Crosses that involve one trait, such as seed coat color, are called one-factor crosses. For the one-factor crosses in this activity, we will use some of the traits Mendel observed in pea plants. The expressions of the dominant and recessive alleles for the genes controlling these traits are described in the following chart. The chart also assigns letters to represent the different alleles.

Trait	Dominant Allele	Recessive Allele
Pod shape	Smooth (*N*)	Constricted (*n*)
Pod color	Green (*G*)	Yellow (*g*)
Flower position	Axial (*A*)	Terminal (*a*)
Plant height	Tall (*T*)	Short (*t*)

In the example that follows, we will predict the results of a cross between a plant that is heterozygous for green pods and a plant that has yellow pods.

Sample Problem

A plant that is heterozygous for green pods is crossed with a plant that has yellow pods. What are the probable genotypic and phenotypic ratios in the offspring resulting from this cross?

Step 1 Choose a letter to represent the alleles in the cross.
In this case, the letters have already been selected—*G* for the dominant green allele and *g* for the recessive yellow allele.

Step 2 Write the genotypes of the parents.
Since the plant with the green pods is heterozygous for the trait, its genotype must be *Gg*. The problem does not state whether the plant with yellow pods is homozygous or heterozygous. But we know that yellow pods are a recessive character, and that recessive characters are expressed only in a homozygous recessive individual. Thus the genotype of this plant must be *gg*. The cross, therefore, is *Gg* X *gg*.

Step 3 Determine the possible gametes (reproductive cells) that the parents can produce.

The two alleles of any gene are segregated during the formation of gametes. Thus the green-pod parent (*Gg*) will produce two kinds of gametes—*G* and *g*. The yellow-pod parent (*gg*) will produce *g* gametes.

Step 4 Enter the possible gametes at the top and side of the Punnett square.

At this point, the Punnett square for this problem would look like this:

	G	*g*
g	Gg	gg
g	Gg	gg

Step 5 Complete the Punnett square by writing the alleles from the gametes in the appropriate boxes.

This step represents the process of fertilization, in which a male gamete from one parent combines with a female gamete from the other parent. To predict all possible offspring genotypes, each type of possible gamete from one parent is combined with each possible type of gamete from the other parent.

The completed Punnett square for this problem would look like this:

	G	*g*
g	*Gg*	*gg*
g	*Gg*	*gg*

As you can see, 1/2 of the offspring are genotype *Gg* and 1/2 are *gg*.

Step 6 Determine the phenotypes of the offspring.

Since green (*G*) is dominant over yellow (*g*), plants that have *G* in their genotypes have green pods. Only plants with genotype *gg* have yellow pods. In this example, 1/2 of the offspring have green pods and 1/2 have yellow pods.

Step 7 Using the results of Steps 5 and 6, answer the problem.

In this example, the genotypic ratio is 2 *Gg*:2 *gg*, or 1:1. The phenotypic ratio is 2 green:2 yellow, or 1:1.

Practice Problems

For each of the following problems, draw a Punnett square in the space provided and fill in the information on the indicated lines. Refer to the table on page 183 of your textbook for a description of pea traits.

N smooth n constricted

1. *Nn* × *NN*

	N	N
N	NN	NN
n	Nn	Nn

Genotypic ratio: hetero smooth : homo smooth

Phenotypic ratio: 100% smooth

Name ____________ Class ____________ Date ____________

A axial / a terminal

2. $Aa \times aa$

	A	a
a	Aa	aa
a	Aa	aa

Genotypic ratio: 1 : 1 hetero ax : homo term.

Phenotypic ratio: 1 : 1 ax term.

3. $Tt \times Tt$

T tall
t short

	T	t
T	TT	Tt
t	Tt	tt

Genotypic ratio: 1 homo tall : 2 hetero tall : 1 homo short

Phenotypic ratio: 3 : 1 tall short

4. Cross two plants that are heterozygous for green pods.

G green
g yellow

Gg x Gg

	G	g
G	GG	Gg
g	Gg	gg

Genotypic ratio: homo green 1 : hetero gr. 2 : homo yellow 1

Phenotypic ratio: 3 : 1 green yellow

5. Cross a plant that is heterozygous for axial flowers with a plant that has terminal flowers.

A axial
a term

Aa x aa

	A	a
a	Aa	aa
a	Aa	aa

Genotypic ratio: 1 hetero axial : 1 homo term

Phenotypic ratio: 1 : 1 axial term

6. Cross a homozygous tall plant with a short plant.

TT x tt

T tall
t short

	T	T
t	Tt	Tt
t	Tt	Tt

Genotypic ratio: 4 : 0 100% hetero tall

Phenotypic ratio: 100% tall 4 : 0

7. Cross a plant that is heterozygous for smooth pods with a plant that has constricted pods.

Nn x nn

	N	n
n	Nn	nn
n	Nn	nn

hetero smooth 1 : 1 homo constr

Genotypic ratio: Nn nn

Phenotypic ratio: 1 : 1 smooth : constr

8. When a tall plant is crossed with a short plant, some of the offspring are short. What are the genotypes of the parents and the offspring? What is the phenotypic ratio in the offspring?

T- tall
t- short

TT x tt

Tt	Tt
Tt	Tt

100% tall

Tt x tt

Tt	tt
Tt	tt

tall 1 : 1 short

Parent genotypes: tt, Tt

Offspring genotypes: Tt, tt

Phenotypic ratio: 1 : 1 tall short

9. Three-fourths (3/4) of the plants produced by a cross between two unknown pea plants have axial flowers and 1/4 have terminal flowers. What are the genotypes of the parent plants?

A-axial
a-terminal

offspring
75% : 25%
3 : 1
ax term

AA x aa

Aa	Aa
Aa	Aa

Aa x aa

Aa	aa
Aa	aa

Aa x Aa

AA	Aa
Aa	aa

Parent genotypes: Aa x Aa

10. What cross would result in 1/2 of the offspring having green pods and 1/2 of the offspring having yellow pods?

offspring 1 : 1 gr yel

G - green
g - yellow

GG x gg

Gg	Gg
Gg	Gg

Gg x gg

Gg	gg
Gg	gg

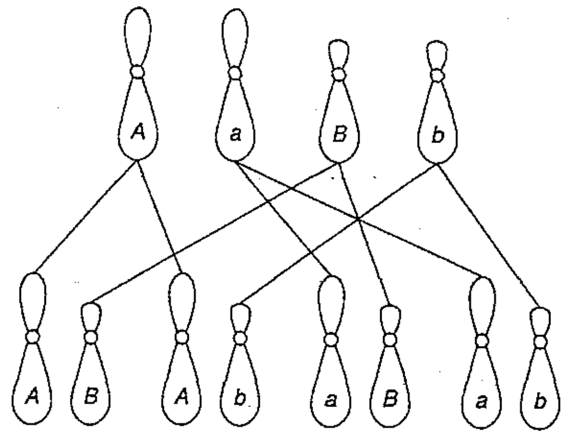
Cross: Gg x gg

TWO FACTOR CROSSES

Crosses that involve two traits, such as pod color and pod shape, are called two-factor crosses. Predicting the outcome of two-factor crosses requires basically the same procedure as that for crosses involving one trait. Keep in mind that in two-factor crosses the genes controlling the two different traits are located on nonhomologous chromosomes. During meiosis, nonhomologous chromosomes assort independently. This means that each of the chromosomes of any pair of homologous chromosomes has an equal probability of ending up

Name ______________________ Class ______________________ Date ______________

in a gamete with either chromosome from any other pair of homologous chromosomes. The genes that are located on nonhomologous chromosomes also assort independently, as you can see in the following diagram.



Because of independent assortment, a plant that is heterozygous for two traits (genotype *AaBb*) will produce equal numbers of four types of gametes—*AB*, *Ab*, *aB*, and *ab*.

In the example that follows, we will predict the results of a cross between two plants that are heterozygous for both pod color and pod shape.

Sample Problem

What are the genotypic and phenotypic ratios in the offspring resulting from a cross between two pea plants that are heterozygous for pod color and pod shape? What is the phenotype of the parents in this cross?

Step 1 Choose letters to represent the genes in the cross.
Let's use the letters we used in the one-factor crosses—*G* for green, *g* for yellow, *N* for smooth, and *n* for constricted.

Step 2 Write the genotypes of the parents.
Since the parents are heterozygous for both traits, their genotype must be *GgNn*. The cross can be written as *GgNn* × *GgNn*.

Step 3 Determine the possible gametes that the parents can produce.
Each parent produces four types of gametes—*GN*, *Gn*, *gN*, and *gn*.

Step 4 Enter the possible gametes at the top and side of the Punnett square.

	GN	*Gn*	*gN*	*gn*
GN	GGNN	GGNn	GgNN	GgNn
Gn	GGNn	GGnn	GgNn	Ggnn
gN	GgNN	GgNn	ggNN	ggNn
gn	GgNn	Ggnn	ggNn	ggnn

Step 5 Complete the Punnett square by writing the alleles from the gametes in the appropriate boxes.

The alleles from the gamete above the box and the alleles from the gamete to the side of the box are combined inside each of the boxes. Write the capital letter first for each pair of alleles. The letters inside each box represent the probable genotypes of the offspring resulting from the cross.

	GN	*Gn*	*gN*	*gn*
GN	*GGNN*	*GGNn*	*GgNN*	*GgNn*
Gn	*GGNn*	*GGnn*	*GgNn*	*Ggnn*
gN	*GgNN*	*GgNn*	*ggNN*	*ggNn*
gn	*GgNn*	*Ggnn*	*ggNn*	*ggnn*

Step 6 Determine the phenotypes of the offspring.

In this example, 9/16 have green smooth pods, 3/16 have yellow smooth pods, 3/16 have green constricted pods, and 1/16 have yellow constricted pods.

Step 7 Using the results of Steps 5 and 6, answer the problem.

Note that in this example, as in many of the genetics problems you will encounter, you are asked for more than just the ratios resulting from the cross. This is one reason why it is important to read genetics problems carefully. In this example, the genotypic ratio is 1/16:2/16:1/16:2/16:4/16:2/16:1/16:2/16:1/16 = 1:2:1:2:4:2:1:2:1. The phenotypic ratio is 9/16:3/16:3/16:1/16 = 9:3:3:1. The phenotype of the parent is green smooth pods.

Practice Problems

In mice, the ability to run normally is a dominant trait. Mice with this trait are called running mice (*R*). The recessive trait causes mice to run in circles only. Mice with this trait are called waltzing mice (*r*). Hair color is also inherited in mice. Black hair (*B*) is dominant over brown hair (*b*). For each of the following problems, draw a Punnett square in the space provided and fill in the information on the indicated lines.

1. Cross a heterozygous running, heterozygous black mouse with a homozygous running, homozygous black mouse.

Parental genotypes: RrBb x RRBB

Phenotypic ratio: 16 : 0 : 0 : 0
Run bl, Run bR, waltz bl, waltz bR

Rr x RR

	R	r
R	RR	Rr
R	RR	Rr

Bb x BB

	B	b
B	BB	Bb
B	BB	Bb

R - Running
r - waltzing
B - black
b - brown

Phenotype probabilities

Running black 4/4 x 4/4 = 16/16 = 1
Running brown 4/4 x 0/4 = 0/16
waltzing black 0/4 x 4/4 = 0/16
waltzing brown 0/4 x 0/4 = 0/16

Name ______________________ Class ______________________ Date ______________

2. Cross a homozygous running, homozygous black mouse with a heterozygous running, brown mouse.

RR x Rr BB x bb

	R	R
R	RR	RR
r	Rr	Rr

	B	B
b	Bb	Bb
b	Bb	Bb

Parental genotypes: RRBB x Rrbb

Phenotypic ratio: 16 : 0 : 0 : 0

running black 4/4 x 4/4 = 16/16 = 1
running brown 4/4 x 0/4 = 0/16
waltzing black 0/4 x 4/4 = 0/16
waltzing brown 0/4 x 0/4 = 0/16

3. Cross a waltzing brown mouse with a waltzing brown mouse.

rr x rr bb x bb

	r	r
r	rr	rr
r	rr	rr

	b	b
b	bb	bb
b	bb	bb

Parental genotypes: rrbb x rrbb

Phenotypic ratio: 0 : 0 : 0 : 16

run bl 0/4 x 0/4 = 0/16
run br 0/4 x 4/4 = 0/16
waltz bl 4/4 x 0/4 = 0/16
waltz br 4/4 x 4/4 = 16/16 = 1

4. Cross a homozygous running, heterozygous black mouse with a waltzing brown mouse.

RR x rr Bb x bb

	R	R
r	Rr	Rr
r	Rr	Rr

	B	b
b	Bb	bb
b	Bb	bb

Parental genotypes: RRBb x rrbb

Phenotypic ratio: 8 : 8 : 0 : 0

run bl 4/4 x 2/4 = 8/16 = 1/2
run br 4/4 x 2/4 = 8/16 = 1/2
waltz bl 0/4 x 2/4 = 0/16
waltz br 0/4 x 2/4 = 0/16

5. Cross a heterozygous running, brown mouse with a heterozygous running, homozygous black mouse.

Rr x Rr BB x bb

	R	r
R	RR	Rr
r	Rr	rr

	B	B
b	Bb	Bb
b	Bb	Bb

Parental genotypes: Rrbb x RrBB

Phenotypic ratio: 3 : 0 : 0 : 1

run bl 3/4 x 4/4 = 12/16 = 3/4
run br 3/4 x 0/4 = 0/16
waltz bl 1/4 x 4/4 = 4/16 = 1/4
waltz br 1/4 x 0/4 = 0/16