Illustrate duplicate dominant epistasis by filling in all blanks below. Circle all gametes. A epistatic to B, b. B epistatic to A, a. A_B_, aaB_, A_bb = triangular seed; aabb = ovoid seed.

<table>
<thead>
<tr>
<th>P</th>
<th>Phenotypes</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Genotypes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AABB</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Gametes</td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Phenotypes</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Genotypes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gametes</td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>Genotypes</td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>Phenotypes</td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>Phenotypic ratio</td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>Genotypic ratio</td>
<td></td>
</tr>
</tbody>
</table>

USE THE INFORMATION ABOVE TO MAKE A TESTCROSS BELOW

<table>
<thead>
<tr>
<th>F1 Parent</th>
<th>Testcross Parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenotypes</td>
<td>x</td>
</tr>
<tr>
<td>Genotypes</td>
<td></td>
</tr>
<tr>
<td>Gametes</td>
<td>x</td>
</tr>
</tbody>
</table>

Testcross Progeny

<table>
<thead>
<tr>
<th>Phenotypes</th>
<th>Genotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

Testcross Phenotypic Ratio
Testcross Genotypic Ratio

<table>
<thead>
<tr>
<th>P</th>
<th>Phenotypes</th>
<th>triangular</th>
<th>x</th>
<th>ovoid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Genotypes</td>
<td>AABB</td>
<td>x</td>
<td>aabb</td>
</tr>
<tr>
<td></td>
<td>Gametes</td>
<td>1/1 AB</td>
<td>x</td>
<td>1/1 ab</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>F1</th>
<th>Phenotypes</th>
<th>triangular</th>
<th>x</th>
<th>triangular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Genotypes</td>
<td>AaBb</td>
<td>x</td>
<td>AaBb</td>
</tr>
<tr>
<td></td>
<td>Gametes</td>
<td>1/4 AB 1/4 Ab 1/4 aB 1/4 ab</td>
<td>x</td>
<td>1/4 AB 1/4 Ab 1/4 aB 1/4 ab</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>F2</th>
<th>Genotypes</th>
<th>Working space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phenotypes</td>
<td>Working space</td>
</tr>
</tbody>
</table>

F2 Phenotypic ratio 15:1
F2 Genotypic ratio 4:2:2:2:2:1:1:1:1
USE THE INFORMATION ABOVE TO MAKE A TESTCROSS BELOW

<table>
<thead>
<tr>
<th>F&lt;sub&gt;1&lt;/sub&gt; Parent</th>
<th>Testcross Parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenotypes</td>
<td>triangular</td>
</tr>
<tr>
<td>Genotypes</td>
<td>AaBb</td>
</tr>
<tr>
<td>Gametes</td>
<td>1/4 AB, 1/4 Ab, 1/4 aB, 1/4 ab</td>
</tr>
</tbody>
</table>

Testcross Progeny

<table>
<thead>
<tr>
<th>Phenotypes</th>
<th>Genotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>triangular, triangular</td>
<td>1/4 AaBb, 1/4 aaBb</td>
</tr>
<tr>
<td>triangular, ovoid</td>
<td>1/4 Aabb, 1/4 aabb</td>
</tr>
</tbody>
</table>

Testcross Phenotypic Ratio 3:1
Testcross Genotypic Ratio 1:1:1:1
Problem #1.a. on p. 73 in workbook-Epistasis

\[ \text{Aa Bb} \times \text{aa Bb} \]

\[ \begin{array}{c}
\text{Aa} \\
\text{aa}
\end{array} \]

\[ \begin{array}{c}
\frac{1}{2} \text{ Aa} \\
\frac{1}{2} \text{ aa}
\end{array} \]

\[ \begin{array}{c}
\text{Bb} \\
\text{Bb}
\end{array} \]

\[ \begin{array}{c}
\frac{1}{4} \text{ BB} \\
\frac{1}{4} \text{ BB}
\end{array} \]

\[ \begin{array}{c}
\frac{2}{4} \text{ Bb} \\
\frac{2}{4} \text{ Bb}
\end{array} \]

\[ \begin{array}{c}
\frac{1}{4} \text{ bb} \\
\frac{1}{4} \text{ bb}
\end{array} \]

\[ \begin{array}{c}
1/8 \text{ AaBB} - \text{maroon} \\
1/8 \text{ aaBB} - \text{white}
\end{array} \]

\[ \begin{array}{c}
2/8 \text{ AaBb} - \text{maroon} \\
2/8 \text{ aaBb} - \text{white}
\end{array} \]

\[ \begin{array}{c}
1/8 \text{ Aabb} - \text{white} \\
1/8 \text{ aabb} - \text{white}
\end{array} \]

\[ \frac{3}{8} \text{ maroon} \quad (3/8) \]

\[ \frac{5}{8} \text{ white} \quad (5/8) \]

3 : 5 or 5 : 3
m w w w m
STATEMENTS AND RULES ABOUT PROBABILITY

Probability - The ratio of the chances favoring an event to the total number of chances for and against the event.

Rules that Govern Probability

a) Addition Rule - The probability that one of two or more mutually exclusive events will occur is the sum of their separate probabilities.
   1) Mutually exclusive events cannot occur together.

b) Product Rule - The probability that two or more independent events will occur together is the product of their separate probabilities.
   1) Independent events can occur together.
The probability of anything may be expressed as a fraction \((1/4)\), decimal \((.25)\), or percent \((25\%)\).

The probability is the proportion of times anything **will** happen out of the total of times it **could** happen.

\[
\frac{\text{Particular outcome}}{\text{Possible outcome}}
\]

The probability of anything in a single case is equal to its **frequency** in a number of cases.

The probability of anything for which there is no alternative is \(1\) (100%).

Whenever \(P\) is less than 100\%, there must be one or more alternative probabilities of something different happening; e.g., \(P_1\) or \(P_2\) or \(P_3\) . . . , etc.
The sum of the probabilities of all possible alternatives equals 1 (100%).

The probability of anything not happening is 1 minus the probability that it will.

\[ P(\text{not } a) = 1 - P(a) \]

The probability of anything can never be greater than 1, but must be 1 or less.

Known probabilities are not affected by past outcomes, "luck", or "the law of averages".

Conditional probabilities may be altered by accumulating data.
1. Many problems in genetics concern not only the probability that a certain event will occur, but also the probability that a certain combination of events will occur.

2. By expanding the binomial \((a + b)^n\), we can obtain the chance of various combinations of two independent events happening together.

3. Let "a" represent the chance of one event and "b" the chance of the alternative event, and "n" the total number of events being considered.

4. \(a = \) chance for a girl being born = 1/2 \(b = \) chance for a boy being born = 1/2
Assume you want to know the chance of obtaining three girls and a boy. Total number of children is four, so: \(n = 4\)
\[(a + b)^4\]
\[a^4 + 4a^3b + 6a^2b^2 + 4ab^3 + b^4\]

5. The second term \(4a^3b\) is the one representing three girls and a boy; so by substituting for "a" and "b" we get: \(4 \times (1/2)^3 \times 1/2 = 4/16\)
6. Simple rules for expansion \((a + b)^n\)

a) The power of the binomial chosen \((n)\) is determined by the number of coins, people, etc. you are considering.

b) The number of terms in the expansion is \(n + 1\).

c) The exponent of "a" in any term after the first is one less than in the preceding term; the exponent of "b" is one more than in the preceding term. (The exponent of "a" in the first term is always "n" and there is no "b" in the first term.)

d) The coefficient of any term after the first is obtained by multiplying the coefficient of the preceding term by the exponent of "a" and dividing by the number of terms you have written. (The coefficient of the first term is always one.)

e) The coefficient may also be determined by referring to pascals pyramid.

f) The sum of the exponents always equals “n”.

78
7. Example: \[ \frac{1}{2} \cdot 3 \cdot 4 \]
\[(a + b)^3 = a^3 + 3a^2b + 3ab^2 + b^3\]

8. When the probability of only a certain combination in a given size group is required, factorials may be employed.

9. There are products of factors derived from functions by successfully increasing or decreasing by a constant, usually one.

10. Factorial 4 (4!) is the product of 4 x 3 x 2 x 1 or (4! = 4 x 3 x 2 x 1 = 24). Factorial 0 (0!) = 1 and 1! = 0!

11. The probability of a particular combination may be calculated from the following formula:
\[
P = \frac{n!}{x! (n - x)!} \cdot p^x q^{(n-x)}
\]
\[n = \text{total size of group}\]
\[x = \text{Number in one class (p)}\]
\[n - x = \text{Number in one class (q)}\]
Example:
6 babies born
Probability that 2 will be boys and 4 will be girls;
p = boys = 1/2; q = girls = 1/2
n = 6
x = number of boys = 2
n - x = number of girls = 4

\[ P = \frac{n!}{x!(n-x)!} \cdot p^x q^{(n-x)} \]

\[ P = \frac{6}{2!4!} \cdot \frac{(1/2)^2}{(1/2)^4} \]

\[ P = \frac{6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1}{2 \cdot 1} \cdot \frac{(1/4)}{(1/16)} \]

\[ P = 15 \cdot \frac{1}{4} \cdot \frac{1}{16} \]

\[ P = 15/64 = \text{Probability of 2 boys and 4 girls.} \]
13. Combinations: A combination is a group of objects in which the order is not important.
   Formula: \( nCr = \frac{N!}{(N-R)! \times R!} \)

   \( N = \) number of items  
   \( R = \) the number of objects to be combined in which the order is not important.

14. Permutations: An arrangement of objects in which the order is important:
   Formula: \( nPr = \frac{N!}{(N-R)!} \)

   \( N = \) number of items  
   \( R = \) the number of objects to be arranged in a specific order.
Heterozygous black lab with black skin $\times$ yellow lab with brown skin

$(AaBb \times aa \ bb)$

$\downarrow$

3 black labs with black skin, 1 yellow lab with brown skin

<table>
<thead>
<tr>
<th></th>
<th>AAB</th>
<th>Aabb</th>
<th>aAB</th>
<th>aabb</th>
</tr>
</thead>
<tbody>
<tr>
<td>ab</td>
<td>AaBb</td>
<td>Aabb</td>
<td>aaBb</td>
<td>aabb</td>
</tr>
<tr>
<td></td>
<td>Black hair</td>
<td>Brown hair</td>
<td>Yellow hair</td>
<td>Yellow hair</td>
</tr>
<tr>
<td></td>
<td>Black skin</td>
<td>Brown skin</td>
<td>Black skin</td>
<td>Brown skin</td>
</tr>
<tr>
<td></td>
<td>1/4</td>
<td>1/4</td>
<td>1/4</td>
<td>1/4</td>
</tr>
</tbody>
</table>

No order specified:

$$P = \frac{4!}{3!\ 1!} \left( \frac{1}{4} \right)^3 \left( \frac{1}{4} \right)^1 = \left( 4 \right) \left( \frac{1}{4} \right)^4 = \frac{4}{(4)^4} = \frac{4}{256}$$

Delivered in the sequence or order specified above:

$$P = \frac{4!}{3!\ 1!} \left( \frac{1}{4} \right)^3 \left( \frac{1}{4} \right)^1 = \left( \frac{1}{4} \right)^4 = \frac{1}{(4)^4} = \frac{1}{256}$$
FITTING RESULTS FROM CROSSES TO HYPOTHESIS

Chi-square

1. The geneticist must know how much the experimental data he has collected can deviate from his hypothesis and still be regarded as close to expectation.

2. Too much deviation would make the investigator question his hypothesis or discard it entirely.

3. Numerical data are his only means of evaluating "goodness of fit" of an experimental result as compared to expectations.

   a) Chi-square:

      1. The chi-square test is a valuable tool that aids the investigator in determining goodness of fit.
2. The test takes into account the size of the sample and the deviations from the expected ratio.

3. It can also be adapted to ratios with different numbers of classes.

4. The chi-square test is a mechanism by which deviations can be reduced to a single value based on the size of the sample.

5. Formula for $X^2$ for a sample consisting of 2 classes:

$$X^2 = \frac{(O_1 - e_1)^2 + (O_2 - e_2)^2 \ldots}{e_1 \quad e_2}$$

- $O_1$ is the observed number in the first class.
- $e_1$ is the expected number in the same class as $O_1$.
- $O_2$ is the observed number for the second class, etc.
- $e_2$ is the expected number in the same class as $O_2$. 
6. Simplified formula:
\[X^2 = \sum \left( \frac{d^2}{e} \right), \ d = O-e\]

7. For interpreting \(X^2\) values, the number of classes on which \(X^2\) is based must be considered.

8. It is, therefore, necessary to include the number of classes contributing to a given \(X^2\) in evaluating the "goodness of fit".

9. The effect of the number of classes is included in the mathematical concept as degrees of freedom.

10. The number of the degrees of freedom is one less than the number of classes.
11. When $X^2$ and the degrees of freedom have been determined, the chi-square table may be consulted for the probability (P) value.

12. A hypothesis is never proved or disproved solely by a P value but it can indicate that it is unlikely to be true.

13. Results of an experiment are evaluated by the investigator as acceptable or unacceptable with respect to the hypothesis.

14. The 5 percent point (0.05) on the table is usually chosen as an arbitrary standard for determining the goodness of fit.
15. Probability at this point is one in twenty that a true hypothesis will be rejected.

16. The P value represents the probability that a deviation as great as or greater than that obtained from the experiment will occur by chance alone.

17. If the P value is small, it is concluded that the deviations are not due entirely to chance, and the hypothesis is rejected. The null hypothesis (Ho) is rejected, so choose the alternative (H₁) hypothesis.

18. If the P is greater than the predetermined level, the hypothesis is accepted. The null hypothesis (Ho) is accepted.
# PROBABILITY IN MENDELIAN INHERITANCE

## Table of Chi-Square (X²)*

<table>
<thead>
<tr>
<th>Degrees of freedom</th>
<th>P = .99</th>
<th>.95</th>
<th>.80</th>
<th>.50</th>
<th>.20</th>
<th>.05</th>
<th>.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.000157</td>
<td>.00393</td>
<td>.0642</td>
<td>.455</td>
<td>1.642</td>
<td>3.841</td>
<td>6.635</td>
</tr>
<tr>
<td>2</td>
<td>.020</td>
<td>.103</td>
<td>.446</td>
<td>1.386</td>
<td>3.219</td>
<td>5.991</td>
<td>9.210</td>
</tr>
<tr>
<td>3</td>
<td>.115</td>
<td>.352</td>
<td>1.005</td>
<td>2.366</td>
<td>4.642</td>
<td>7.815</td>
<td>11.345</td>
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</tbody>
</table>
### CHI-SQUARE EXAMPLE PROBLEM #2

F<sub>2</sub> progeny

<table>
<thead>
<tr>
<th>Classes</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>100</td>
</tr>
<tr>
<td>Pink</td>
<td>200</td>
</tr>
<tr>
<td>White</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>400</td>
</tr>
</tbody>
</table>

1. Observed ratio = 1:2:1

\[
\frac{100}{100} = 1; \quad \frac{200}{100} = 2; \quad \frac{100}{100} = 1
\]

2. Hypothesis - 1:2:1

3. Proportion expected in each class

\[1 + 2 + 1 = 4; \quad \text{Prop. } e_1 = 1/4; \quad \text{Prop. } e_2 = 2/4; \quad \text{Prop. } e_3 = 1/4\]
4. Number expected in each class
\[ e_1 = \frac{1}{4} \times 400 = 100; \quad e_2 = \frac{2}{4} \times 400 = 200; \quad e_3 = \frac{1}{4} \times 400 = 100; \]
\[ \sum e_i = 400 \]

5. Observed number in each class
\[ O_1 = 100; \quad O_2 = 200; \quad O_3 = 100; \quad \sum O_i = 400 \]
Note: \( \sum e_i (400) = \sum O_i (400) \)

6. Calculating chi-square
\[ X^2 = \frac{(100 - 100)^2}{100} + \frac{(200 - 200)^2}{200} + \frac{(100 - 100)^2}{100} = (0)^2 + (0)^2 + (0)^2 = 0 \]
Note: \( \sum d = 0 \)
7. $\text{df} = 3 - 1 = 2$

8. Chi-square value in chi-square table at 0.05 probability level for 2 df is 5.991.

9. The hypothesis is accepted.
## ADDITIONAL CHI-SQUARE PROBLEMS

1. Testcross Progeny

<table>
<thead>
<tr>
<th>Class</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>1950</td>
</tr>
<tr>
<td>Red</td>
<td>2106</td>
</tr>
</tbody>
</table>

2. $F_2$ Phenotypes

<table>
<thead>
<tr>
<th>Class</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>290</td>
</tr>
<tr>
<td>Brown</td>
<td>110</td>
</tr>
</tbody>
</table>

3. $F_2$ Phenotypes

<table>
<thead>
<tr>
<th>Class</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth</td>
<td>2060</td>
</tr>
<tr>
<td>Wrinkled</td>
<td>685</td>
</tr>
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</table>