INTRODUCTION TO MENDELIAN GENETIC TRAITS

I. Mendelian genetics traits are determined by a single gene locus with exactly two (2) alleles. One allele is DOMINANT and the other allele is recessive.

II. Dominant alleles are represented by capital letters while recessive alleles are represented by the corresponding small letter. Actual letter choices are a matter of personal preference but common practice uses the first letter of the dominant trait.

A. Brown hair is dominant to red hair.
   1. B = Brown hair
   2. b = red hair

III. Organisms can be described by their GENOTYPES or PHENOTYPES:

A. Genotypes - represent actual allelic composition
   1. heterozygous = alleles are different - eg. Bb, Aa
   2. homozygous dominant = alleles are both dominant - BB, AA
   3. homozygous recessive = alleles are both recessive - bb, aa

B. Phenotypes - represent the physical manifestation of the allelic composition
   1. DOMINANT phenotype vs. recessive phenotype
      a. BROWN HAIR vs. red hair
      b. TALL vs. short

   2. Homozygous dominant & Heterozygotes individuals express the DOMINANT phenotype.

   3. Homozygous recessive individuals express the recessive phenotype.

C. Organisms are diploid and have 2 alleles at each gene locus. Therefore, each trait is represented by two letters (BB, Bb, bb). This represents the organism's GENOTYPE for that trait.

D. Gametes are haploid and have one allele at each gene locus. Therefore, each trait is represented by one letter (B, b). This represents the gamete's GENOTYPE for that trait.

E. When determining the gametes that an organism can produce, take one allele (letter) from each gene locus (trait) for each gamete. It is not necessary to duplicate gamete genotypes.

   1. Single Gene Locus (Monohybrid crosses)
      a. BB - # of unique gametes: 1 = B
      b. Bb - # of unique gametes: 2 = B, b

   2. Two Gene Loci (Dihybrid Crosses)
      a. AaBB - # of unique gametes: 2 = AB, aB
      b. AaBb - # of unique gametes: 4 = AB, Ab, aB, ab
IV. The initial cross in a problem is called the PARENTAL GENERATION (P). The subsequent generations are called FILIAL GENERATIONS and indicated by subscripted numbers (F₁, F₂). The F₂ generation comes from crossing two F₁ offspring.

V. In any cross, each offspring will receive one allele (letter) from each parent. It is usually helpful to set-up a Punnent square to determine the genotypes of each offspring.

A. Bb x BB

1. gametes for Bb parent = B, b
2. gamete for BB parent = B
3. Note: Each gamete from each parent is placed in the first row or column. The genotype of each offspring is determined by combining one gamete from each parent

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<tr>
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<th>B</th>
<th>b</th>
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<tbody>
<tr>
<td>B</td>
<td>BB</td>
<td>Bb</td>
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VI. TEST CROSSES

A. Some of the problems that follow use test crosses. In a test cross, an individual expressing the dominant phenotype is crossed with an individual expressing the recessive phenotype. The recessive individual is the “tester”, since its genotype is known (a recessive phenotype can only be expressed in an individual with a homozygous recessive genotype).

B. By analyzing the offspring of such a cross, the genotype of the phenotypically DOMINANT individual can be determined with some certainty. The phenotypically DOMINANT individual may be homozygous dominant or heterozygous. In a cross with a recessive individual, each of these dominant phenotypes will yield characteristic offspring ratios. The Punnent squares are done below.

1. BB x bb

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</tbody>
</table>

All offspring are phenotypically dominant

Bb x bb

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<td>B</td>
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<tr>
<td>B</td>
<td>bb</td>
</tr>
</tbody>
</table>

Half the offspring are phenotypically dominant & the other half are phenotypically recessive.

1:1 phenotype ratio

NOTE: Problems 4, 6, 7, & 8 in Section 1 and Problems 5-8 in Section 2 involve Test Cross Data
Section I: Monohybrid Crosses

1. In tomatoes, red fruits are dominant over yellow fruits.
   
   A. What letter would you choose to represent the red and yellow alleles.
   
   RED ALLELE = _______     YELLOW ALLELE = _______

2. Using your answers from #1, determine the genotypes of these organisms (remember, 2 letters for each trait).
   
   A. homozygous red fruited plant = ______
   B. heterozygous plant = _______
   C. yellow fruited plant = ______
   D. What is the phenotype (appearance) of plant B? ________________
   E. Why is it unnecessary to call plant C homozygous yellow fruited?

_________________________________________________________________

3. For each of the answers in #2, list all the unique gametes that could be produced.
   
   A. _____________________
   B. _____________________
   C. _____________________

USE THE INFORMATION IN #1 - #3 ABOVE TO SOLVE THIS PROBLEM:

1. If you cross a homozygous red-fruited plant with a yellow-fruited plant, what is the appearance (phenotypes) and genotypes of the F₁ generation?

2. What will be the phenotypes and genotypes of the F₂ generation.

NOTE: Monohybrid crosses involving 2 Heterozygotes always produce the same PHENOTYPE and GENOTYPE RATIOS
• PHENOTYPE RATIO
  • 3 dominant :1 recessive
• GENOTYPE RATIO
  • 1 homozygous dominant: 2 heterozygotes: 1 homozygous recessive
MORE MONOHYBRID PROBLEMS:

3. In squash, white color is dominant over yellow. Pollen (male gametes) from a heterozygous white fruited plant is placed on the pistil (female organ) of a yellow fruited plant. Determine the genotypes of the parents and the genotypes and phenotypes of the $F_1$ generation.

4. A hornless bull is bred to three cows, A, B, and C. Cow A is horned and produces Calf D, which is also horned. Cow B is hornless and produces Calf E, which is horned. Cow C is horned and produces Calf F which is hornless. Note: Hornless is dominant to horned.

- Determine the genotypes of all seven animals.

Bull:_______

Cow A:______  Calf D:______

Cow B:______  Calf E:______

Cow C:______  Calf F:______

5. The gene for brown hair is dominant over that for blond hair. If two heterozygotes married, what proportions of these two traits would you expect in their children?
6. In humans the gene for farsightedness is inherited as a dominant (therefore normal vision is recessive). What fraction of children will have normal vision if a normal man marries a woman who is farsighted and had a normal father?

7. Two short-haired female guinea pigs are mated to a short-haired male guinea pig. Several litters are produced. The first female produces 25 short-haired offspring and no long-haired ones. The second female produces 15 short-hairs and 5 long-hairs. Based on this information, what deductions can be made concerning hair-length inheritance? List the genotypes of all the parents and offspring.

8. In horses, trotter is dominant over pacer. A trotter is mated to a pacer. Over the course of several matings, 5 pacers are produced along with 4 trotters. What were the genotypes of each original parents?

9. Silky feathers in fowl is recessive to normal feathers. If 96 birds were raised from a cross between two heterozygotes, how many would you expect to be normal? Silky?
Section 2: DiHybrid Crosses

Dihybrid crosses examine two unlinked (on different chromosomes) gene loci. The following problem uses many of the skills you learned in the section on monohybrid crosses.

In peas, a single gene codes for stem length and another single gene codes for seed shape. Each gene has two alleles, one dominant and one recessive. For stem length, tall plants are dominant over short plants. For seed shape, smooth peas are dominant over wrinkled peas.

A. Choose letters to represent each gene and its alleles.

   Seed shape: Smooth:_____ wrinkled:_____  
   Stem length: Tall:______ short:______

B. In the Table on the next page is a list of all the possible phenotypes for this pair of traits. Determine the genotypes for these plants, in some cases there will be multiple possible genotypes. When we worked with one gene locus, each individual genotype was represented by 2 letters since individual organisms are diploid. Now we are working with two gene loci, so each individual genotype will be represented by 4 letters, 2 letters for each gene locus. Fill in the first part of the Table on the next page with all the possible genotypes for each phenotype listed. The first genotype is given.

C. For each of the individuals in part B, list all the unique gametes that can be produced. Remember, each gamete will have 1 allele from each gene locus. When we worked with a single gene, each gamete genotype was represented by 1 letter. Now we are working with 2 gene loci, so each gamete genotype will be represented by 2 letters, one from each gene locus. Fill in the rest of the Table on the next page with all the possible gamete genotypes for each parent genotype listed. The first gamete genotype is given.

Table of Genotypes for Two Loci

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Possible Genotypes</th>
<th>Possible Unique Gamete Genotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMOOTH, TALL</td>
<td>SSTT</td>
<td>ST</td>
</tr>
<tr>
<td>Smooth, short</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wrinkled, TALL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wrinkled, short</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
USE THE TABLE OF INFORMATION ON THE PRECEDING PAGE TO SOLVE THE NEXT 2 PROBLEMS.

1. Determine the $F_1$ genotypes and phenotypes resulting from a cross of a homozygous Smooth and homozygous Tall plant with a wrinkled, short plant.

2. What are the $F_2$ genotypes and phenotypes (crossing two $F_1$ from problem #1)

MORE DIHYBRID PROBLEMS:

3. In fruit flies, the genes for wing length and body hair each have two alleles. Long wings and a hairless body are dominant to alleles for vestigial (functionally useless) wings and a hairy body.

   A. Calculate the genotypes and phenotypes of the offspring from the cross between a vestigial winged, hairy male and a homozygous dominant female.

   B. Calculate the genotypes and phenotypes of the $F_2$ offspring.

TAKE NOTE OF THE PHENOTYPE RATIO OF THE OFFSPRING FROM THE CROSS IN #3B.
THE 9:3:3:1 RATIO IS THE RATIO FROM CROSSING TWO DOUBLE HETEROZYGOTES.
4. In snerds, matted-hair is dominant to frizzled-hair and buck-toothed is dominant to snaggle-toothed.

   A. A frizzled-hair, snaggle-tooth snerd is mated to a pure breeding matted-hair, buck-toothed snerd. What is/are the genotypes and phenotypes of the F₁?

   B. Without doing any calculations, what will be the phenotype ratio of the F₂?

5. In rabbits, black fur and normal length fur are dominant to brown fur and short fur. The litter from a mating of a black, normal fur rabbit with a brown, short rabbit contains 6 black, shorts and 7 black, normals. What are the genotypes of the parents?

6. After eating asparagus, some individuals excrete the strongly odorous substance, methanethiol. The excretion of this substance is due to a recessive gene. After eating red beets, some individuals excrete the red pigment, betamin. This is due to a dominant gene. A man and a woman both excrete betamin but do not excrete methanethiol. Their son excretes methanethiol but does not excrete betamin. Give the genotypes of the man, woman, and their son. What genotype and phenotypes and in what proportions can be expected in subsequent progeny?
7. On the planet Zion, you have discovered two interesting plants. These plants exhibit several traits, two of which you decide to study genetically. The two traits are singing (production of a perfect "C" note upon touching) vs. non-singing and smelly (exude an odor of manure) vs. fragrant (exude an odor similar to earth roses). You manage to isolate a pure breeding singer, smelly and a pure breeding non-singer, fragrant. When you cross these two individuals all the progeny are non-singersmelly. Based in this information, what can you conclude about the nature of these two genes? What are the genotypes of your pure-breeding stock?
The following sections contain Non-Mendelian Inheritance Pattern Problems

Section 3: Incomplete Dominance

Some genes do not exhibit complete dominance (e.g., one dominant and one recessive allele). In these genes, the heterozygote is a blend of the two alleles. For example, in snapdragons, two alleles for flower color exist, one for red flowers (R) and another for white flowers (W). Flowers homozygous the red allele (RR) are red and those homozygous for the white allele (WW) are white. However, flowers heterozygous for the alleles (RW) are pink.

THIS TYPE OF DOMINANCE IS TERMED INCOMPLETE DOMINANCE

BASED ON THIS INFORMATION, SOLVE THE FOLLOWING PROBLEMS.

1. Calculate the phenotype and genotype ratios for the F$_1$ in a cross between a red snapdragon and a white snapdragon.

2. Calculate the phenotype and genotype ratios of the F$_2$ from the above problem.
3. In cattle, the hornless vs. horned trait exhibit a complete dominance relationship with hornless dominant to horned. Coat color exhibits an incomplete dominance relationship where a cross between a Red animal and a White animal results in all Roan (a mix of red and white hairs) animals. Based on this information solve these two problems.

A. What will genotypes and phenotypes of the F₁ generation in a cross between a horned, white bull and a homozygous hornless, red cow.

B. Calculate the phenotypes and genotypes of the F₂ generation from the above cross.

Section 4: Sex-Linked Genes

Some genes are physically linked (on the same chromosome) as other genes. As a result the two traits do not segregate independently during meiosis. The classic example of this is sex-linked genes. Genes of this type are on the X-chromosome but are absent on the truncated (shortened) Y-chromosome. As a result, these genes appear more frequently in males than in females.

The notation for this type of gene is slightly different as chromosome location as well as allele must be denoted. It is common to use a single capital letter to indicate the chromosome (X or Y) with a superscript indicating the allele.

eg. colorblindness is sex-linked.

\[
\begin{align*}
B &= \text{normal vision} \\
\text{b} &= \text{color blind}
\end{align*}
\]

Male colorblind individual = X⁰Y

Female normal individual = X⁰X⁰ or X⁰X⁰

BASED ON THIS INFORMATION, SOLVE THESE PROBLEMS

1. If a color-blind woman marries a man with normal vision, what are the sexes and phenotypes of the offspring?
Section 4: Sex-Linked Genes (con’t)

2. Hemophilia is a hereditary disease characterized by poor clotting of the blood. As a result, hemophiliacs bleed excessively when injured. A certain kind of hemophilia is sex-linked and recessive. Sex-linked means that the allele for hemophilia is found on the X chromosome. Although recessive, the hemophilia allele ($X^h$) determines the phenotype of males as they have only one X chromosome. For females, who have 2 X chromosomes, $X^h$ with a normal allele $X^H$ on the second X chromosome would exhibit the normal phenotype.

A "normal" woman whose father was a hemophiliac marries a normal man. What genotypes and phenotypes are expected in the children and in what proportions?

Section 5: Multiple Alleles

Some genes have more than 2 alleles. The dominance and recessive relationships vary within different combinations of alleles (some allele pairs are Mendelian, some are not). For example, the ABO Blood group in Humans.

Background Information

Antigens are molecules, often proteins, which are recognized by the body's immune system. When an antigen is foreign to the body, for example, surface molecules on bacterial cells or viruses, certain lymphocytes (a type of white blood cell) are stimulated to produce specific serum proteins called antibodies. These antibodies can then chemically react with the antigen and help to neutralize it. This reaction is called an antigen-antibody reaction.

Cells of the immune system can also recognize the surface molecules on the body's own cells. The immune system does not mount an antigen-antibody response to cells identified as "self," except in certain autoimmune diseases. Among those surface molecules on the body's cells are those membrane-bound polysaccharides which determine the ABO blood groups of erythrocytes.
The ABO System

If one has blood type A, the antigen we call A is present on the surface of his/her erythrocytes. The person's immune system recognizes type A cells as self, but if the person receives a blood transfusion of cells with type B antigen, an antigen-antibody reaction occurs. Since the reaction causes the type B erythrocytes to stick together in large clumps, a process called agglutination, dangerous clogging of small blood vessels might occur, with other life-threatening effects to follow. A similar reaction would occur if erythrocytes with type A antigen were transfused into a person with blood type B.

The reactions described above are immediate, due to the presence of circulating antibodies in the plasma (liquid) portion of the recipients' blood. Specifically, type A blood contains antibody-B and type B blood contains antibody-A. Type 0 blood, whose erythrocytes have neither A nor B antigens, has both antibody-A and antibody-B in the serum. Finally, the rare type AB blood, whose red cells have both A and B antigens, has no circulating antibody-A or antibody-B.

Antibody-A, and antibody-B are often described as "natural" antibodies, since they are present lifelong. These antibodies are an exception to the normal pattern of antibody production. Usually, specific antibodies are only produced after the body has been exposed to a foreign antigen, and the immune system has recognized the antigen as non-self. The reasons for these natural antibodies are not fully understood. Antibody-A, antibody-B and other antibodies are found in the serum, the cell-free portion of the blood after the clotting factors have been removed. Figure 2 summarizes the serum antibodies and the associated red blood cell types:

Figure 2. Characteristics of the ABO Blood Groups

<table>
<thead>
<tr>
<th>Blood Type</th>
<th>Erythrocyte Antigen</th>
<th>Serum Antibody</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>antibody-B</td>
<td>antibody-A</td>
</tr>
<tr>
<td>B</td>
<td>antibody-A</td>
<td>antibody-B</td>
</tr>
<tr>
<td>0</td>
<td>both</td>
<td>neither</td>
</tr>
<tr>
<td>AB</td>
<td>neither</td>
<td>both</td>
</tr>
</tbody>
</table>
Section 5: Multiple Alleles (con’t)

**The Inheritance of the ABO Blood Types**

Often, inheritance is more complicated than the simple dominant recessive pattern governing pea color in Mendel’s plants. Sometimes there are multiple alleles for a trait, rather than just two alleles. This occurs in the genetics of human ABO blood groups. In this example, we also find codominance between the $I^A$ and $I^B$ alleles, with both of them being expressed when present (therefore people with the genotype $I^A I^B$ have blood group AB). However, since $I^A$ and $I^B$ alleles are both dominant over the recessive $i$ allele, people can have the blood group 0 only if their genotype is $ii$. The four basic blood types (phenotypes) are associated with six genotypes as shown in Figure 3.

**Figure 3. Genotypes Associated with Blood Types**

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Genotype</th>
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<tbody>
<tr>
<td>A</td>
<td>$I^A I^A$ or $I^A i$</td>
</tr>
<tr>
<td>B</td>
<td>$I^B I^B$ or $I^B i$</td>
</tr>
<tr>
<td>O</td>
<td>$ii$</td>
</tr>
<tr>
<td>AB</td>
<td>$I^A I^B$</td>
</tr>
</tbody>
</table>

**BASED ON THIS INFORMATION SOLVE THESE PROBLEMS**

1. What are the possible genotypes and phenotypes of the children from a AB father and a O mother?

2. What are the possible genotypes and phenotypes of the children from a heterozygous A father and a heterozygous B mother?
Section 5: Multiple Alleles-The Inheritance of the ABO Blood Types (con't)

3. What blood types might occur among the children of a marriage between a person of blood type AB and a person of blood type O? Construct a Punnett Square for this problem that shows the gamete genotypes of each parent, then determine the offspring blood types.

What is the probability of the parents having a child with type A blood?

4. If you are blood type O and your father is also blood type O, what type or types must your mother be?

'Your' father's and 'your' blood type:

Possible genotypes of mother:

Could these same parents have a child with blood type AB? Explain

5. Can a person of blood type A who marries a person of blood type B have type O children?
The following sections contains problems on Meiotic Crossing-Over (Recombination) and Gene Linkage.

Section 6: Calculating % Recombination of Linked Genes.

Genes on the same chromosome are referred to as Linked Genes. During Meiosis, instead of sorting independently (as stated in Mendel's 2nd law), they do not separate during meiosis. The only time that linked genes sort independently is when a crossing-over event occurs between the linked genes. The physical distance between linked genes is the main contributing factor to the chances that a crossing-over event will occur between any two linked genes. Recall that with 2 unlinked genes, a test cross will produce a ratio of 1:1:1:1. If the observed ratio deviates significantly from the expected ratio then the genes may be linked.

1. In a certain flower, Flower Color and Pollen Grain Shape are determined as follows:
   a. Flower color locus - Mendelian trait: (R) RED Flowers and (r) white flowers
   b. Pollen Grain Shape locus - Mendelian trait: (E) ELONGATED pollen grains and (e) rounded pollen grains
   c. Assuming that these 2 loci are unlinked, determine the ratio and number of parental and recombinant phenotypes if the following cross produced 1000 offspring:

      EeRr x eerr (ELONGATED/RED x rounded/white)

   d. Now assume the loci are linked and produced the following 1000 offspring.

      380 ELONGATED/RED
      370 rounded/white
      125 rounded/RED
      125 ELONGATED/white

   ▷ What percentage of the offspring are parental? _____ recombinant? _______

   ▷ The % recombinant offspring is referred to as the recombination frequency.
   So the recombination frequency for these 2 loci is 25%
Section 6: Calculating % Recombination of Linked Genes (con't)

2. In blast-ended skrewts, expelling green blasts is dominant to red blasts and possessing a stinger is dominant to not possessing a stinger (stingerless).

**Blast Color Locus**
- GREEN (G) - Dominant
- red (g) - recessive

**Stinger Locus**
- HAVE STINGER (S) - Dominant
- stingerless (s) - recessive

A double heterozygous, GREEN-BLASTING male WITH A STINGER mates with a red-blasting, stingerless female producing the following offspring

740 GREEN-BLASTING, HAVE STINGER
640 red-blasting, stingerless
300 GREEN-BLASTING, stingerless
320 red-blasting, HAVE STINGER

Answer these questions:

a. How many of each offspring phenotype would be expected if the Blast Color locus IS NOT LINKED to the Stinger Locus?

c. Calculate the % recombination rate for the Blast Color and Stinger loci.
Section 7: Mapping Genes using Recombination Frequencies.

Recombination Frequencies can be used to map linked genes. So-called "Gene Mapping" determines the "relative distances" between linked genes. The frequency of crossing-over between linked genes (loci) can be used to develop a "map" of the relative location of the loci on the chromosome.

The relative distance between 2 loci is equal to the percent (%) recombination between the 2 loci when crossing a double-Heterozygous individual with an individual that is double-recessive.

For example, if 2 genes demonstrate a recombination frequency of 25% then the relative distance between those genes is 25 map units (m.u.). A map unit is measure in "centimorgans" (cM), a designation created by Alfred Henry Sturtevant in recognition of his genetist mentor Thomas Hunt Morgan.

Example: Map the following linked Gene Loci – P, T, W, G based on the following recombination data

- P-W = 5%
- P-T = 11%
- P-G = 33%
- W-T = 16%
- W-G = 38%
- T-G = 22%

STEPS
1. Begin by drawing a line to represent chromosome
2. Place the 2 genes with largest recombination frequency (W & G) at either end of the line.
3. Place each successive gene on the map based on frequency. Begin with those genes that have recombination frequencies with either W and G (P).
Section 7: Mapping Genes using Recombination Frequencies (con’t)

Problem: Map these Loci: A,F,Q,Z given the following recombination data.

- A-Z = 12%
- Q-F = 37%
- Q-Z = 22%
- A-Q = 10%

After you have mapped these loci, determine what recombination frequencies would be helpful in validating your map.