Mendelian Genetics

Booklet 5

Name: __________________________
Biology 3201 Unit 3 Genetics

Review of Chromosomes and Genes

| Genetics       |  
| ---------------|---|
| Heredity       |  
| Trait          |  
| Gene           |  
| Allele         |  

![Diagram of cell, chromosome, DNA, nucleus, gene, allele, loci, and homologous chromosomes.](image)
Examples of single-gene traits in humans

Write the info that applies to you in the table

<table>
<thead>
<tr>
<th>Phenotype (physical description)</th>
<th>Genotype (capital or lowercase letter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleft Chin</td>
<td>No Cleft</td>
</tr>
<tr>
<td>Widow’s Peak</td>
<td>No Widow’s Peak</td>
</tr>
<tr>
<td>Dimples</td>
<td>No Dimples</td>
</tr>
<tr>
<td>Brown/Black Hair</td>
<td>Blonde Hair</td>
</tr>
<tr>
<td>Freckles</td>
<td>No Freckles</td>
</tr>
<tr>
<td>Brown Eyes</td>
<td>Gray/Blue Eyes</td>
</tr>
<tr>
<td>Free Earlobe</td>
<td>Attached Earlobe</td>
</tr>
</tbody>
</table>

This is the early belief (before Mendel) that factors from the parents were blended in their offspring. This theory was not able to explain the appearance or disappearance of distinct traits (dominant or recessive) from one generation to another.

**Gregor Mendel and the Scientific Process**

Gregor Mendel used the scientific process to lay the foundation for the science of genetics. Mendel used garden peas. They were a good choice because they were easy to grow, matured quickly and showed distinct traits.

Mendel studied seven pairs of contrasting traits as follows:

<table>
<thead>
<tr>
<th>Trait</th>
<th>Dominant (capital letter)</th>
<th>Recessive (lowercase letter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed Shape</td>
<td>Round (R)</td>
<td>Wrinkled (r)</td>
</tr>
<tr>
<td>Seed Color</td>
<td>Yellow (G)</td>
<td>Green (g)</td>
</tr>
<tr>
<td>Seed Coat Color</td>
<td>Grayish brown</td>
<td>White</td>
</tr>
<tr>
<td>Pod Color</td>
<td>Green</td>
<td>Yellow</td>
</tr>
<tr>
<td>Pod Shape</td>
<td>Inflated</td>
<td>Wrinkled</td>
</tr>
<tr>
<td>Stem Length</td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td>Flower Position</td>
<td>Lateral</td>
<td>Terminal</td>
</tr>
<tr>
<td>Important Genetics Terms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P Generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1 Generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2 Generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant</td>
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</tr>
<tr>
<td>Recessive</td>
<td></td>
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<tr>
<td>Heterozygous</td>
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<tr>
<td>Homozygous</td>
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</tr>
<tr>
<td>Purebred</td>
<td></td>
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</tr>
<tr>
<td>Hybrid</td>
<td></td>
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<tr>
<td>Phenotype</td>
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<tr>
<td>Genotype</td>
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<tr>
<td>Punnett Square</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monohybrid Cross</td>
<td></td>
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<tr>
<td>Dihybrid Cross</td>
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<tr>
<td>Product Rule</td>
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</table>
Writing genetics:

<table>
<thead>
<tr>
<th>Pure Bred (homozygous)</th>
<th>Alleles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid (heterozygous)</td>
<td>Alleles</td>
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</table>

**Mendel’s First Cross (P₁ Cross)**
- Mendel crossed (P): Pure tall (TT) x pure dwarf (tt)
- The result (F₁): All offspring were tall (Tt)

• But these were not pure tall, because each parent had a different trait for stem height. Instead, these offspring are referred to as hybrids or hybrid tall.
  - If there is at least ONE dominant allele, they would have the **dominant trait** *(A capital letter is used to represent dominant. Ex: T)*
  - In order to show the recessive trait, you must have TWO recessive alleles. The dominant allele will mask or prevent the expression of the **recessive allele** *(A lowercase letter is used to represent recessive. Ex: t)*
**Mendel’s Second Cross (F1 Cross)**

- Mendel crossed: Hybrid tall (Tt) x Hybrid tall (Tt)
- The result (F2): Some of the offspring were tall and some were short (dwarf)
  - About ¾ were tall and ¼ were short (3:1 ratio). This showed that the factor that contained the shortness had not disappeared.

**Mendel’s Conclusions about his experiment:** *(Page 529 textbook)*

1. The inheritance of each trait is determined by "units" or "factors" that are passed on to descendents unchanged. We call these units genes today.

2. An individual inherits one such unit from each parent for each trait

3. A trait may not show up in an individual but can still be passed on to the next generation.

4. If the dominant factor is present, it will be expressed even if the recessive factor is also present. The recessive factor will be expressed if only recessive factors are present.
Mendel’s Explanations
• Purebred plants have two of the same allele.
  Example: Pure tall = TT or pure dwarf = tt
• Hybrid plants have two different alleles.
  Example: Hybrid tall = Tt
• Mendel concluded that heredity was not just a blending of traits and he developed the principle of dominance

Law of Dominance: When an organism is hybrid for a pair of contrasting traits, only the dominant trait can be seen in the hybrid. *Remember: A dominant trait is indicated by an upper case letter (Ex: T) whereas a recessive trait is indicated by a lower case letter (Ex: t)*

<table>
<thead>
<tr>
<th>Three possible Allele Combinations for plant height</th>
<th>Heterozygous or homozygous?</th>
<th>Dominant or recessive?</th>
</tr>
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<tbody>
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</tbody>
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Practice Questions:
1. In pea plants, yellow peas are dominant over green peas. Use a punnett square to predict the phenotypes and genotypes of the offspring from the cross between a heterozygous for yellow peas and a plant homozygous for green peas. (Use G for yellow and g for green in your cross).
Complete the following monohybrid crosses:

2. Pure Dominant (tall) with Pure Recessive (short)

\[
\begin{array}{c|c|c|c}
 & A & A & A \\
 & A & A & A \\
 & A & A & A \\
 & A & A & A \\
\end{array}
\]

Genotypic Ratio:

Phenotypic Ratio:

3. Recessive Male (wrinkled) and Heterozygous Female (round)

\[
\begin{array}{c|c|c|c}
 & A & a & A \\
 & a & A & A \\
 & A & a & A \\
 & a & A & A \\
\end{array}
\]

Genotypic Ratio:

Phenotypic Ratio:

4. Determine the phenotype and genotype ratios in a cross between a heterozygous black haired guinea pig and a white haired guinea pig. Note: Black hair is dominant to white in this example.
What is the Law of Segregation?

This law states that “factors” (genes) occur in pairs (alleles) and are separated from each other in gamete formation and recombined in fertilization.

One of these factors came from the mother and the other factor came from the father during zygote formation.

*Mendel’s Law of Segregation*
**Probability** – the chance, or likelihood, of a particular outcome.

*In genetics, we are often asked to determine the probability of an event occurring, such as “what is the probability of having a daughter?” Answer: ½ or 50% chance of having a girl*

**Product Rule** – the probability that two or more independent events will occur together is the product of their individual probabilities of occurring alone

- The law of probability forms the basis for solving genetics problems. A gamete with the \( T \) allele may combine with a gamete with either another \( T \) allele or \( t \) allele. This happens entirely by chance.

Sometimes you do not know if a parent is homozygous dominant \((TT)\) or heterozygous dominant \((Tt)\). When this is the case, you can perform a **test cross**.

**What is a Test Cross?**
- A test cross is used to determine an unknown genotype that may either be homozygous dominant or heterozygous for a trait.
- An individual of the unknown genotype is mated with an individual showing the contrasting recessive trait.

**Example of a Test Cross:**
- A breeder wishes to know if a pea plant is \( TT \) or \( Tt \). He will cross the plant with a homozygous recessive plant \((tt)\).
**Practice Problems:**

1. Perform a test cross to determine the parental genotype of the pea plant flower color, with 50% of the offspring having white flowers and 50% of the offspring having purple flowers. *Purple flowers are dominant to white flowers.*

2. Perform a test cross to determine the parental genotype of the Alaskan malamutes. Note: we know that one parent is dd (dwarf size), but we are not sure if the other parent is Dd or DD? See page 534 - Figure 16.10

   **Test cross:**
   \[
   \begin{array}{c|c}
   \text{Dd} \times \text{dd} & \text{DD} \times \text{dd} \\
   \text{Genotypes:} & \text{Genotypes:} \\
   \text{Phenotypes:} & \text{Phenotypes:} \\
   \end{array}
   \]

3. Tall pea plants are governed by the allele T while short pea plants are governed by the allele t. Suppose a heterozygous tall pea plant was crossed with a short pea plant. What are the genotypes of the parents? Identify the genotypes and phenotypes of the offspring of the F\textsubscript{1} generation.
Complex Inheritance Patterns

- Mendel wanted to know if the inheritance of one characteristic influenced the inheritance of a different characteristic. (Ex: Does pea shape influence pea colour?).

- Mendel’s 2nd experiment looked at how multiple traits are inherited.

- He produced purebred pea plants which were: Round Yellow plants (RY) and Wrinkled Green plants (ry) and used a Dihybrid Cross to show his results.

What is a Dihybrid Cross?
- This is a chart to show the results of a cross between parents for two traits.

- Example: A yellow round seed male is crosses with a green wrinkled seed female.

  Yellow- Round seed Male (YYRR)
  Green – Wrinkled seed female (yyrr)

What are the results of Mendel’s 2nd experiment?
- A Dihybrid cross of the F1 generation produced nine different genotypes.

- These results represent a phenotypic ratio of 9:3:3:1

- This led Mendel to propose the Law of Independent Assortment
What is the Law of Independent Assortment?

• During Metaphase and Anaphase I of meiosis, the alleles for different traits **cross over** (tetrads). This mixes chromosomes from your father and mother.

• **Law of Independent Assortment** states that genes for different trait are separated and distributed to gametes independently from each other during crossing over. The inheritance of alleles for one trait does not affect the inheritance of alleles for another trait.

• This means that offspring may have new combinations of alleles that are not present in either parent, making them genetically unique.

**Practice Problems:**

1. A male and a female guinea pig are both **heterozygous** for fur colour and fur texture. Both dark fur (D) and rough fur (R) are dominant traits. (See page 540)
   
   A) What are the parent genotypes and phenotypes?

   B) Determine the phenotypic and genotypic ratios of the F₁ generation
2. In people, curly hair is dominant over straight hair and the ability to curl the tongue is dominant over not being able to curl the tongue. A man heterozygous for curly hair and who is homozygous for the ability to curl his tongue and a woman heterozygous for curly hair who cannot curl her tongue have children. What are the possible genotypic and phenotypic ratios of their offspring?
Practice Problems:

1. A father is heterozygous for black hair and heterozygous for tongue-rolling. The mother is light haired and cannot roll her tongue. What is the probability of having a child with light hair who can roll their tongue?

2. Tall tomato plants are produced by the action of a dominant allele T and dwarf plants by its recessive allele t. Hairy stems are produced by a dominant allele H and hairless stems by the recessive allele h. A heterozygous tall and heterozygous hairy plant is crossed with a dwarf hairless tomato plant. Determine the phenotypic ratio for this cross.
Review of Important Mendelian Laws

In your own words, explain and illustrate each of the following Mendelian Laws

1. Law of Dominance

2. Law of Segregation

3. Law of Independent Assortment
**Different Patterns of Inheritance**

Mendel found that inherited traits were either dominant or recessive. The dominant allele in an individual was always expressed, even if the recessive allele was present. However, some organisms show different patterns of inheritance.

**What is Incomplete Dominance?**

- **Incomplete Dominance** - The blending of two allele
- There is no definitive dominant or recessive allele.
- Red and white flowers make **pink**

[https://www.youtube.com/watch?v=8bHua84azgI&safe=active](https://www.youtube.com/watch?v=8bHua84azgI&safe=active)

Example: White and Red snapdragons are homozygous; Pink snapdragons are heterozygous

Red snapdragon (RR)
White snapdragon (WW)
Pink snapdragon (RW)

**Practice Problem:**

In snapdragon flowers, red is incompletely dominant to white. What is the phenotypic ratio of the offspring in the F$_2$ generation in a cross between a red flower and a white flower?
What is Co-Dominance?

- When more than two alleles can code for a gene
- There is no definitive dominant or recessive allele.
- Ex: Red and white flowers make red and white spotted flowers

Practice Problem:
In some cattle the genes for brown hair (B) and for white hair (W) are co-dominant. Cattle with alleles for both brown and white hair have both brown and white hairs. This condition gives the cattle a reddish colour and is referred to as Roan (BW). For each of the following crosses, give the phenotypic and genotypic ratios of the offspring:

(a) A roan cow and a white bull

(b) A brown cow and a roan bull

(c) A roan cow and a roan bull
Review - Practice Problems

1. If brown fur (B) is dominant to white fur (b), which best describes the phenotype of an individual with the genotype, Bb?

   (A) heterozygous dominant
   (B) heterozygous recessive
   (C) homozygous dominant
   (D) homozygous recessive

2. Which states that the inheritance of alleles for one trait does not affect the inheritance of alleles from another trait?

   (A) disjunction
   (B) dominance
   (C) independent assortment
   (D) natural selection

3. Which best describes the frequency of genotypes of the F₂ generation produced from the parental cross, BB × bb?

   (A) ¼ BB, ½ Bb and ¼ bb
   (B) ½ BB, ¼ Bb and ¼ bb
   (C) ½ Bb and ½ BB
   (D) ½ Bb and ½ bb

4. Pink flowers of some species may be produced by crossing red flowers with white flowers. Which explains how this can happen?

   (A) codominance
   (B) incomplete dominance
   (C) multiple alleles
   (D) sex linkage
5. In some cats the gene for tail length shows incomplete dominance. Cats with long tails and cats with no tails are homozygous for their respective alleles. Cats with one long and one no tail allele have short tails. For each of the following construct a punnet square and give the phenotypic and genotypic ratios of the offspring:

<table>
<thead>
<tr>
<th>genotype</th>
<th>phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>long tail</td>
<td>long tail</td>
</tr>
<tr>
<td>no tail</td>
<td>no tail</td>
</tr>
<tr>
<td>short tail</td>
<td>short tail</td>
</tr>
</tbody>
</table>

a) long tail x no tail

Genotype: ____________________________  Phenotype: ____________________________

b) two short tails

Genotype: ____________________________  Phenotype: ____________________________

6. Birds can be blue, white, or white with blue-tipped feathers. For each of the following construct a punnet square and give the phenotypic and genotypic ratios of the offspring:

<table>
<thead>
<tr>
<th>genotype</th>
<th>phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>blue feathers</td>
<td>blue feathers</td>
</tr>
<tr>
<td>white feathers</td>
<td>white feathers</td>
</tr>
<tr>
<td>blue-tipped feathers</td>
<td>blue-tipped feathers</td>
</tr>
</tbody>
</table>

a) White x blue-tipped feathers

Genotype: ____________________________  Phenotype: ____________________________

b) Blue x blue-tipped

Genotype: ____________________________  Phenotype: ____________________________
What is Polygenic Inheritance (Multiple Gene Inheritance)?

- When many genes are responsible for a trait. This is an exception to Mendel’s Rule
- For example, humans are not just tall or short. Sometimes traits vary between two extremes, such as tall and short
- When two or more independent genes affect a characteristic, it is called polygenic or multiple-gene inheritance.
- Other examples are: eye color, skin color

What are Multiple Alleles?

A trait that is determined by more than two alleles (ex. Human blood types)
- Human blood types are determined by 3 alleles
- These alleles control the production of antigens on the surface of the blood cells
  - Allele \( I^A \) produces antigen A
  - Allele \( I^B \) produces antigen B
  - Allele \( i \) produces no antigen

ABO Genotypes/Phenotypes Compatibility
- **Type O blood** can donate blood to anyone (universal donor)
- **Type AB blood** can receive blood from anyone (universal recipient)

*Example:*
If a woman has blood type AB, and a man has blood type A, what possible blood types will their children have?

Mother genotype \( I^A I^B \)  
Father’s potential genotypes \( I^A i \) or \( I^a i \)
1. Blood types are controlled by three alleles: A, B and O. Blood types A and B are codominant and O is recessive to both A and B. Write the allele for each blood type:

Blood type A: ______ or ______
Blood type AB: ______ (universal recipient)
Blood type B: ______ or ______
Blood type O: ______ (universal donor)

a) A woman heterozygous for blood type B decides to have a baby with a man that is heterozygous for blood type A. State the possible phenotypic ratios of the offspring.

b) A man with blood type O decides to have a baby with a woman with type AB blood. State the possible phenotypes of the offspring.

c) A woman sues a man for child support. She has blood type A, her child has blood type O, and the man has blood type B. Could the man be the father of the child? Explain.
Practice Problems:

1. A Dihybrid cross is made of pea plants. Purple flowers (P) are dominant and white flowers are recessive. Tall plants (T) are dominant and short plants recessive. Both parents are heterozygous for both traits. Prepare a Punnett square to determine the phenotype ratios of the offspring. What Mendelian law does this ratio demonstrate?

3. Explain how a person can be a carrier for a particular disease and yet not have the disease. Is this true for all people who are carriers?
Remember: Mendel formulated came up with the Law of Segregation and the Law of Independent Assortment

What happened next?
Theodor Boveri and Walter Sutton started to study chromosomes

What observations did Boveri and Sutton make?
1. Chromosomes occur in pairs
2. The pairs segregate during the anaphase I stage of meiosis
3. Chromosomes line up independently of one another (metaphase)

What is the Chromosome theory of inheritance?
1. Mendel’s ‘factors’ (genes) are carried on chromosomes
2. It is the segregation and independent assortment of chromosomes during meiosis that accounts for the patterns of inheritance

Video: Punnett Squares and Sex-Linked Traits
https://www.youtube.com/watch?v=h2xufrHWG3E&safe=active
**What is sex-linked inheritance?**

The transmission of genes located on one of the sex chromosomes, either X or Y

- A gene that is located on the X chromosome only is called X-linked.
- A gene that is located on the Y chromosome only is called Y-linked.

Most of the known sex-linked traits are X-linked.

**Sex-Linked Traits in Fruit Flies**

- Thomas Morgan (1910) studied eye color in fruit flies (Scientific name *drosophila*)
- He discovered that eye color is an X-linked trait.
- He also discovered that white eyes are a recessive trait and red eyes are dominant.

**Writing sex linked traits**

**Example:**
A female fruit fly homozygous for red eyes mates with a male fruit fly with white eyes. Determine the genotypic ratios and phenotypic ratios of their offspring.
How is color blindness inherited?

- Red Green color blindness is a sex-linked condition.
- The gene loci are on the non-homologous region of the X-chromosomes.
- Red Green color blindness is more common in males than in females.

WHY?

Writing alleles for color blindness

Example:
Calculate the phenotypic ratio of a cross between a female carrier for red green color blindness and a normal vision male.
**How is haemophilia inherited?**

- Haemophilia is a recessive, sex-linked genetic disorder.
- Persons suffering from haemophilia are unable to produce clotting factor.
- The haemophiliac allele \((X^h)\) is recessive to the normal allele \((X^H)\).
- The gene is located on the non-homologous region of the x-chromosome.
- Haemophilia is more common in men than women.

**WHY?**

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*Since (until recently) the prognosis for survival was poor and haemophiliac males did not survive to pass on the allele to their daughters (it’s on the X-chromosome). Therefore, female haemophilia was rare.*

**Writing alleles for Haemophilia**

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*Example:*
Determine the genotypic and phenotypic ratios for a cross between a mother who is heterozygous for haemophilia \((X^H X^h)\) and normal father \((X^H Y)\).*