Lab 7. Mendelian Genetics

Prelab Assignment

Before coming to lab…,

1. Answer the *prelab questions* on pages 3 – 4 of the report sheet.
2. Read pages 1-2 of this lab and complete Report pages 5 – 6.

Goals of this Lab Exercise

- To understand the mechanisms of Mendelian Genetics
- To understand the process and application of the technique used by geneticists
- Be able to apply this knowledge to pedigree and karyotyping analysis

Introduction

In 1866 an Austrian monk, Gregor Mendel, presented the results of painstaking experiments on the inheritance patterns of garden peas. Those results were heard, but probably not understood, by Mendel's audience. Now, more than a century later, Mendel's work seems elementary to modern–day geneticists, but its importance cannot be overstated. The principles generated by Mendel's pioneering experimentation are the foundation for genetic counseling so important today to families with health disorders having a genetic basis. It's also the framework for the modern research that is making inroads in treating diseases previously believed to be incurable. In this era of genetic engineering the incorporation of foreign DNA into chromosomes of unrelated species—it easy to lose sight of the basics of the process that makes it all possible.

Depicting genetic make–up

Genes control the characteristics of an organism. Alleles are alternate forms of a gene. For example, there is an allele for blond hair, another for black hair, etc. Only two alleles, one from each parent, are inherited for any one trait. Geneticists depict an individual's genetic make–up in a variety of different ways depending on the particular set of alleles they are working with. This may be unfortunate for the casual observer or the novice, but there are some commonalties that help to diffuse potential obfuscations.

The most common system for identifying and relating genetic make–up is the use of capital and lower case letters. Let's look at long (dominant) vs. short (recessive) eyelashes in humans as an example. The capital letter "L" would express the dominant allele and the lower case letter "l" represents the recessive allele. Homozygous dominant individuals would be indicated by the notation LL and homozygous recessive individuals by the notation ll. The notation Ll would indicate heterozygous individuals, those that have one dominant allele and one recessive allele.

For the genetics of the ABO blood groups we use the capital letter "I" and then superscript the letter "i" with capital A's, or B's, or O's to represent the alleles presence (I^A, I^B, i). A similar type of notation occurs for other types of codominant genetic traits.

Name of Genotype	Genotype	Phenotype
Homozygous dominant	LL	Long Eyelashes
Heterozygous	Ll	Long Eyelashes
Homozygous recessive	ll	Short Eyelashes

Another type of notation is the use of the symbols + and -. The plus sign would indicate that the allele for the expression of a particular trait is present (usually the wild type or normal allele) and the minus sign would indicate that it is not present (or that some mutated form of the normal gene is present. Sometimes we use the phrase wild type and symbol "wild" as a superscript to indicate the presence of the dominant naturally occurring allele. Often times you will see other sequences of letters that indicate the presence or absence of certain alleles. These short sequences are acronyms for a description of what the allele causes to be seen in the phenotype.

In the case of simple dominance where a single dominant allele will mask the expression of a single recessive allele another nuance is added to the symbolic systems discussed. For example, a gene at a single locus controls ***tongue rolling***. Individuals that can roll their tongues can have a genetic constitution (genotype) of either **RR** or **Rr**. ***Non-tongue*** rollers have a genetic constitution of **rr**. *If you observe a person who can roll his tongue what is his/her genotype?* Without looking at the parents maybe for more than one generation back and/or one or more generations of progeny the answer is either **RR** or **Rr**. This is because you receive half of your genes from each parent. So, if one is uncertain, how do you express the genetic constitution of these individuals? The answer is **R?**. We know they can roll their tongue so we know that at least one of their alleles is the dominant R allele.

Procedure (work in teams of 2)

1. Pair up with a classmate. With your partner work through the following activities and answer the questions in the spaces provided—although you are working with a partner, you should *record your responses in your own words—doing otherwise is plagiarism and will result in no credit for the entire assignment*!

2. Turn in the completed report sheets as directed by your instructor.

Report Sheet
Mendelian Genetics

Lab Section _____ **Group #** _____

Your Name _____

Lab Partners _____

_____

_____

Prelab Questions

Instructions

Refer to your textbook or other references and write *in your own words* in the spaces provided below the definition of each of the following 15 terms. For each term include ***at least one example*** *that demonstrates your understanding*:

1. Chromosome

2. Gene

3. Gene locus

4. Alleles

5. Dominant allele

6. Recessive allele

7. Genotype

8. Phenotype

9. Haploid

10. Diploid

11. Homozygous

12. Heterozygous

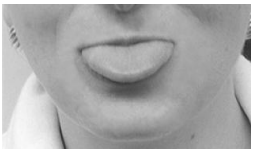
13. Homologous chromosomes

14. Autosomal chromosomes

15. Sex Chromosomes

Activity A: Tongue rolling

Tongue roller



Non-roller

1. What is the ***phenotype*** of an individual whose genotype is RR? (See *page 2* for the allele symbols!)

2. What is the ***phenotype*** of an individual whose genotype is Rr?

3. What is the ***phenotype*** of an individual whose genotype is rr?

4. What are your ***phenotype*** and genotype for tongue rolling?

The distribution of alleles during the formation of gametes was one of the principles described by Gregor Mendel. It is called the **Law of Segregation**. The two alleles of a gene segregate, or separate, from each other during meiosis so that each one ends up in a different gamete.

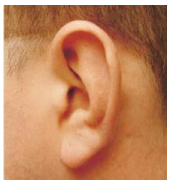
5. If a person's genotype is RR, what is the ***genotype*** of the resulting gametes?

6. If the person's genotype is rr, what is the ***genotype*** of the resulting ***gametes***?

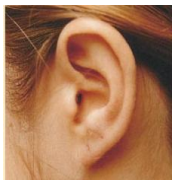
7. If the person's genotype is Rr, what are the *two* ***genotypes*** of the resulting ***gametes***?

8. If your phenotype was tongue roller, what would you have to find out in order to know your genotype for sure?

Activity B: Ear Lobes



Free Earlobes



Attached Earlobes

Free earlobes, **F** (i.e. unattached earlobes), is dominant to ***attached earlobes***, **f**. We can only guess at the biological significance of the kind of earlobe might make.

1. What is the ***phenotype*** of an individual whose genotype is **FF**?

2. What is the ***phenotype*** of an individual whose genotype is **Ff**?

3. What is the ***phenotype*** of an individual whose genotype is **ff**?

4. What is your ***phenotype*** and ***genotype*** with respect to earlobe attachment?

5. If a person's genotype is **FF**, what are the ***genotypes*** of the resulting ***gametes***?

6. If the person's genotype is ff, what are the ***genotypes*** of the resulting ***gametes***?

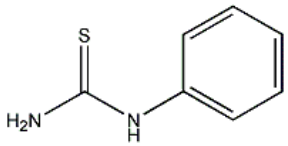
7. If the person's genotype is **Ff**, what are the ***genotypes*** of the resulting ***gametes***?

8. If your phenotype was unattached earlobe, what would you have to find out in order to know your genotype for sure?

9. Gene and the members of his immediate family have attached earlobes. His maternal grandfather has unattached earlobes. What is the ***genotype*** of his *maternal grandfather*?

10. His maternal grandmother is no longer living. What could have been the ***genotype*** of his *maternal grandmother*?

Activity C: Ability to taste PTC, predicting an outcome



phenylthiocarbamide

The ability to taste the chemical ***PTC*** (phenylthiocarbamide) is widely used for genetic, anthropological and evolutionary studies. The ability to taste PTC is an autosomal trait—i.e. on one of the 22 autosomal chromosomes and not on either of the sex chromosomes, X or Y. Tasting (**T**) is dominant to nontasting (**t**). The ability to taste PTC is present in about 70% of the overall human population, but varies significantly around the world: 98% for Native Americans, 97% in West Africa, 60% in western India.

Although PTC itself has not been found in nature, the ability to taste PTC is correlated strongly with the ability to taste other naturally occurring bitter substances, many of which are quite toxic—hence the ability to taste PTC and other bitter chemicals is was of great survival value to both humans and human ancestors. The correlation of PTC tasting with the tasting of other toxic bitter substances and the association of the inability to taste PTC with thyroid disease susceptibility combine to suggest that natural selection may have played an important factor in the evolution of this trait. As with many patterns of inheritance, the nature of the relationship between "tasting" and disease is not clear.

1. Can you taste PTC?

2. What is your **genotype**?

3. How do you know what your **genotype** is? *Explain*.

When the genotypes of the parents are known, we may determine the genotype(s) of the gametes the parents can make and in what proportion the gametes will occur. This information allows us to predict the genotypes and phenotypes of the offspring. The prediction is simply a matter of listing all the possible combinations of gametes. In this section your will be doing **monohybrid crosses**. Monohybrid crosses involve only *one trait*.

By convention, the **parental generation** is called the **P generation**. The first generation of offspring is called $\mathbf{F_1}$. F stands for filial, which refers to a son or daughter, so $\mathbf{F_1}$ is the first filial generation. If members of the F_1 generation are crossed, their offspring are called the $\mathbf{F_2}$ generation and so on.

Predict the results of the following cross using **T** and **t** to denote tasting and nontasting alleles, respectively

P generation: TT x TT

4. What ***genotype(s)*** will be found in the ***F_1 generation***? *Explain your reasoning*.

5. What ***phenotype(s)*** will be found in the ***F_1 generation***? *Explain your reasoning.*

Predict the results of the following cross**:** **P generation: TT x tt**

6. What ***genotype(s)*** will be found in the ***F_1 generation***? *Explain your reasoning.*

7. What ***phenotype(s)*** will be found in the ***F_1 generation***? *Explain your reasoning.*

The previous examples were fairly simple since the parents were only able to produce one type of gamete. However, the complexity escalates rapidly when parents can produce more than one type of gamete. To deal with the presence of more than one type of gamete we employ the Punnett Square to determine all possible combinations of gametes produced during fertilization.

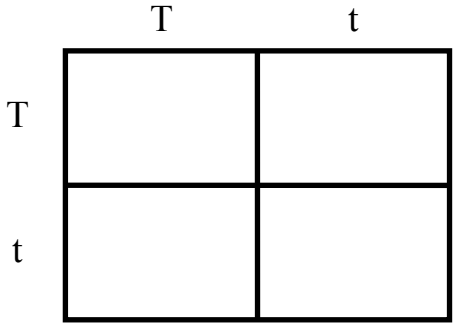
Consider the cross between the F_1 progeny above, Tt, to produce the F_2 generation.

The F_1 Cross: Tt x Tt

8. What are the ***genotypes*** of the *gametes* of the *1st parent*? *Explain your reasoning*.

9. What are the ***genotypes*** of the *gametes* of the *2nd parent*?

The Punnett square would look like this.



10. Fill in the Punnett square and use the completed Punnett square to answer the questions that follow.

11. What are the possible ***genotypes*** in the ***F_2 generation***?

12. What are the ***phenotypes*** of each genotype in the F_2 generation?

13. What is the ***genotypic ratio*** of the F_2?

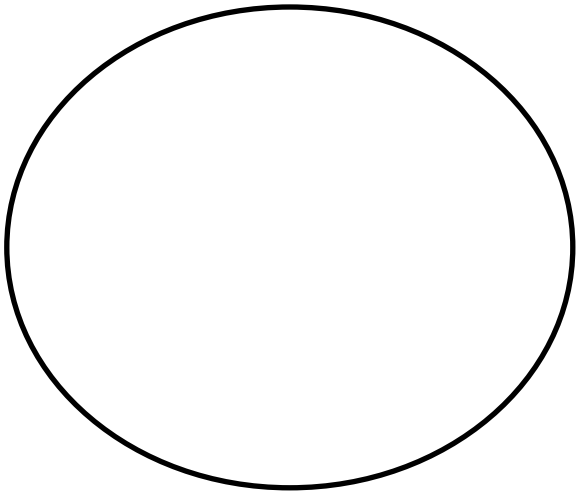
14. What is the **phenotypic ratio** of the F_2?

15. Suppose Jack Johnson cannot taste PTC, but both his mother and his father can taste PTC. Do a Punnett square to calculate the ***expected phenotypic ratio*** among Jack's siblings.

Activity D: The chromosomal basis of independent assortment

Genes that are located on the same chromosome are **linked** with each other, that is, they will be inherited together and will not segregate (separate) during meiosis. If genes are located on separate, nonhomologous chromosomes, they are not linked (unlinked). **Unlinked genes separate independently during meiosis** (gamete formation). For example, consider the alleles **T** and **t** and a second pair of alleles, **F** and **f**. If the **T-gene** (i.e. the gene for PTC tasting) and the **F-gene** (i.e. the gene for free earlobes) are *not* linked (i.e. they are on different chromosomes, their alleles can be found in any combination in the gametes. For example, the T-allele can be in the same gamete as either the F-allele *or* the f-allele. Moreover, the t-allele can be in the same gamete as either the F-allele *or* the f-allele. This is Mendel's **Law of independent assortment**. The word assortment in this case refers to the distribution, or sorting, of alleles into gametes.

1. Assume the circle at the right represents a cell that at **metaphase I of meiosis**. Finish drawing the cell by adhering to the following conditions:
   - The cell is *heterozygous* for PTC tasting (alleles: T, t) and *heterozygous* earlobe attachment (alleles: F, f)
   - **There are *two pairs* of duplicated homologous chromosomes**—i.e. the cell is diploid, where 2n = 4.
   - The PTC tasting gene and the earlobe attachment genes are *not* linked—i.e. they assort independently from each other because they are on different chromosomes.
   - Label the alleles present on *all sister chromatids of all chromosomes.*



Cell at Metaphase I of Meiosis

2. What is the ***genotype*** of this cell?

3. The T gene is for tasting PTC and the F gene is for earlobe attachment. What is the ***phenotype*** of the individual represented by this cell?

4. Recall that when this cell undergoes meiosis, each gamete receives one member of each homologous pair. Moreover, how the homologous pairs line up during metaphase is due to chance. List the possible combinations of alleles that will be found in the gametes—list the *four* possible *genotypes of the gametes*.

5. In what proportion would you expect these gametes to occur—i.e. what would be the genotypic ratio for the gametes?

Activity E: Predicting the outcome of a dihybrid cross

The resulting phenotypic ratios in the F_2 generation of a **dihybrid cross** (2 traits) can be quite different than those observed from a monohybrid cross. But the process is essentially the same. First you list all possible gametes each parent and subsequent parents can produce. Second, you then assign the gamete possibilities to the Punnett square and fill it in. Finally you count the progeny and determine the number of progeny in each phenotypic category. **Remember, when determining the types of gametes possible, each gamete must have one member of each homologous pair of chromosomes**. Hence, if you are considering the PTC tasting gene (controls the ability to taste PTC) and the gene involved with earlobe attachment, each gamete must have one allele for the *tasting gene* (either T *or* t) and one allele for the earlobe attachment gene (either F *or* f).

1. What type of gametes will the following genotypes produce?

Genotype: **TTFF** → Gametes _____
Genotype: **TtFF** → Gametes _____
Genotype: **ttFf** → Gametes _____
Genotype: **TtFf** → Gametes _____

Cross a homozygous for *both* tasting and unattached earlobe parent with a homozygous nontasting attached earlobe parent:

P: (Homozygous for both Tasting and Free Earlobes) x (nontaster with attached earlobes)

2. What are the genotypes of these two parents?

Genotype of 1st parent: _____ Genotype of 2nd parent: _____

3. What are the genotypes of the gametes produced by each parent?

Genotype of 1st parent's gametes: _____ Genotype of 2nd parent's gametes: _____

4. How many different types of gametes can each parent produce?_____ How many squares will the Punnett square have that represents this cross?_____

5. Construct the Punnett square

6. What is (are) the possible genotype(s) of the F_1?

7. What is (are) the phenotype(s) of the F_1?

8. Let's now use the F_1's as parents to produce the F_2.

   a. How many *different* types of gametes can each parent produce?_____ *List the **genotype** of each* gamete.

   b. How many squares will the Punnett square have that represents this cross? _____

9. Construct the Punnett Square and use the completed Punnett square to answer the questions that follow on the next page.

10. List all possible genotypes of the F_2, their occurrence and their corresponding phenotypes

F_2 Genotype	No. offspring with Genotype	Phenotype

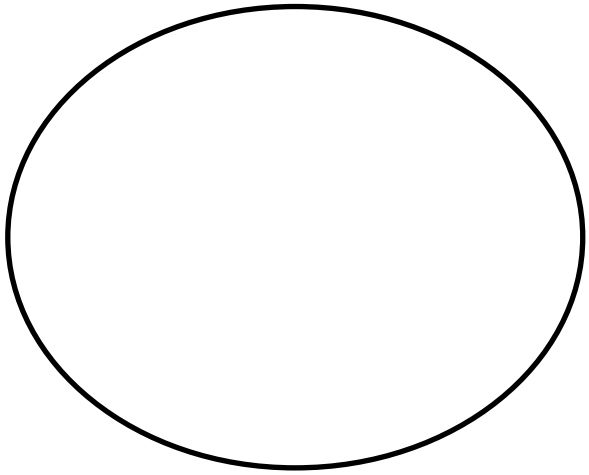
11. What is the expected phenotypic ratio of the F_2 progeny of a dihybrid cross?

12. A couple with the genotypes TtFf and TtFf have 16 children☺. Twelve of them can taste PTC and have unattached earlobes; the other 4 can't taste PTC, 2 of the 4 have attached earlobes and 2 of the 4 have unattached earlobes. Why doesn't this family match the expected ratio? (Hint: If the probability of having a male child is 50% why can one family have 7 daughters and no sons?)

Linked Genes

Now let's suppose the gene involved with PTC tasting and the gene responsible for earlobe attachment are *linked*—i.e. the genes are located on the *same* chromosome. Let's now cross two individuals that are both heterozygous for each trait: **TtFf x TtFf**
As before, the PTC tasting allele, **T**, is dominant to the nontasting allele, **t**, and free earlobes, **F**, is dominant to attached earlobes, **f**.

13. Assume the circle at the right represents a cell that at **metaphase I of meiosis**. Finish drawing the cell by adhering to the following *hypothetical conditions*:
    - The gene for PTC tasting and the gene for earlobe attachment are *linked*—i.e. found on the same chromosome.
    - The cell is *heterozygous* with respect to both of these genes with the dominant allele of each gene (i.e. T and F) located on the *same* chromosome.
    - Label the alleles present on *all* sister chromatids.



Cell at Metaphase I of Meiosis

14. a. How many *different* types of gametes can each parent produce?_____ (assume no cross-over) List the ***genotype*** of each.

    b. How many squares will the Punnett square have that represents this cross? _____

15. What would the expected phenotypic ratio of the cross **TtFf** x **TtFf** if the T gene and the F gene were linked (assume no crossover)? *Make a Punnett square to support your response*.

16. How does the ***phenotypic ratio*** of the cross above (TtFf x TtFf) involving gene linkage compare to the cross (TtFf x TtFf) when the genes assort independently as in the dihybrid cross (i.e. #12 in Activity E)?

Activity F. The ABO blood groups: an example of codominance

ABO blood groups are the most commonly known blood groups. Rh factor is another commonly known blood group. But in all fairness humans are much more complicated than that. There are currently over 300 different types of blood factors known to hematologists. ABO is an acronym for the three types of alleles an individual may potentially have. Of course a diploid individual can only have 2 alleles, one inherited from each parent during fertilization. The genotypes and phenotypes of different combinations of the three alleles are given below.

Allele Symbols: I^A = A allele; I^B = B allele; i = O allele

Phenotypes	Genotypes
A	I^AI^A, I^Ai
B	I^BI^B, I^Bi
AB	I^AI^B
O	ii

Notice that phenotypes A and B can have two possible genotypes. Notice also that blood types AB and O only have 1 possible type of genotypes. This situation is a pattern of inheritance referred to as codominance. The "A"allele (I^A) is dominant to the "O"allele (i). The "B"allele ($I^{B)}$, is dominant to the "O"allele (i). But the "A"allele (I^A), is ***codominant*** to the "B"allele (I^B), hence the phenotypic blood type AB.

The ***Rh blood factor's*** pattern of inheritance is the case of simple dominance that we have been assuming in this lab till now. The ***Rh blood factor*** is inherited as a single pair of alleles, R and r, with Rh-positive (**R**) dominant to Rh-negative (**r**). Blood type and Rh factor are inherited independently of each other (i.e. the genes obey Mendel's law of independent assortment) since the genes responsible for these traits are located on different chromosomes.

Answer the following questions.

1. A boy wonders if he is adopted. He compares his blood type to those of his parents.
   a. If the father is blood type AB and the mother is blood type O, what blood types would indicate that the child might have been adopted? _____ *Explain*.

   b. If the father is blood type A and the mother is blood type B would blood typing help the boy determine if he was adopted? *Explain*.

2. If you are Rh^+ can you know your genotype for sure? *Why*?

3. If you are Rh^+ and everybody in your family is Rh^+ (parents, siblings, offspring) what is your probable genotype? Why? Do you know your genotype with absolute certainty? Explain.

Activity G: Color Blindness—a sex-linked trait

Color blindness is a sex–linked recessive trait since the gene involved with color vision is located on the X chromosome, one of the two sex chromosomes. The possible genotypes and phenotypes are given below.

Females		Males	
Genotype	**Phenotype**	**Genotype**	**Phenotype**
X^BX^B	normal vision	X^BY	normal vision
X^BX^b	normal vision	X^bY	color blind
X^bX^b	color blind		

Look at the pictures provided by your instructor that test for colorblindness and then answer the following questions.

1. Are you color blind? _____

2. If you are (or were) color blind what is (would be) your genotype?_____

3. If you are a female and are *not* color blind, you can judge whether you are homozygous or heterozygous by knowing if any member of your family is color blind.

   If your father is color blind, what is your genotype? _____

   If your mother is color blind what is your genotype? _____

   If you know of no one in your family who is color blind, what is your probable genotype? _____

4. The only member of Josephine's family who is color blind is her brother.

   What is her brother's genotype? _____

   Her father's genotype? _____

   Her mother's genotype? _____

   What is Josephine's genotype if she later has a color–blind son? _____

Activity I: Pedigree and Karyotype Analysis

Through genetic counseling, it is sometimes possible to identify parents who are likely to produce children with genetic disorders. And then it is sometimes possible to test fetal cells to determine if the newborn does indeed have the disorder.

Pedigree charts can be constructed to show the inheritance of a genetic disorder within a family. Thereafter, it may be possible to determine whether any particular individual has an allele for that disorder. Then a Punnett square can be done to determine the chances of a couple producing an affected child. This process is called **analysis by pedigree charts**.

Some genetic disorders are discovered following amniocentesis, a procedure that allows a physician to withdraw a portion of the amniotic fluid and thereby fetal cells by means of a long needle. The fetal cells are cultured and then a karyotype of the chromosomes is prepared. A karyotype shows all the chromosomes of the individual arranged by homologous pairs (**analysis by karyotyping**). Homologous chromosomes have the same size and shape. Karyotypes can show genetic aberrations. For instance, in humans, if you have an extra chromosome 21 you will have Down syndrome.

Geneticists can now map human chromosomes, that is, they can find the exact loci for various genes. If the exact locus for a mutant gene causing a genetic disorder is known, geneticists can make copies of the gene and use these copies to test the chromosomes for the disorder. This is called **analysis by genetic markers** and involves the use of DNA probes (the copies of mutant genes) and restriction enzymes that cleave the DNA into manageable sizes for analysis.

Analysis by pedigree charts

There are three types of inheritance patterns you need to be aware of to complete this portion of the activity.

- Autosomal dominant
- Autosomal recessive
- Sex–linked recessive

A trait that is an autosomal dominant trait only needs one copy of the allele for the individual to be affected. A trait that is an autosomal recessive trait will require two copies of the recessive trait to be present in order for the individual to be affected. *Sex–linked recessive traits primarily affect men*. Women are not totally excluded, but the *likelihood of a woman being affected is low since she must inherit two copies of the X-linked recessive allele*, one from each of her parents. On the other hand, males must only inherit only one copy of an X-linked recessive allele.

Look at the following table to see the possible genotypes for each type of inheritance.

Genotypes and phenotypes for some common single gene inheritance patterns.

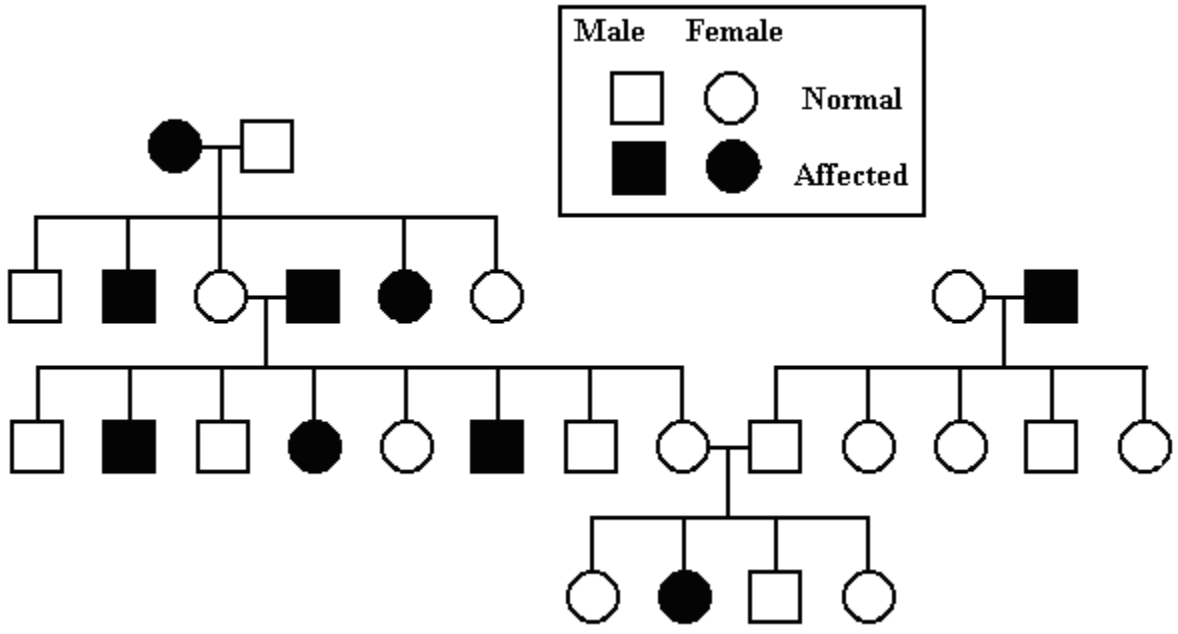
Inheritance Pattern	Genotype	Phenotype
Autosomal Dominant	AA	Affected
	Aa	Affected
	aa	Not affected
Autosomal Recessive	NN	Not affected
	Nn	Not affected
	nn	Affected
Sex–linked Recessive	X^NX^N	Normal female
	X^NX^n	Normal female
	X^nX^n	Affected female
	X^NY	Normal male
	X^nY	Affected male

Pedigree Analysis

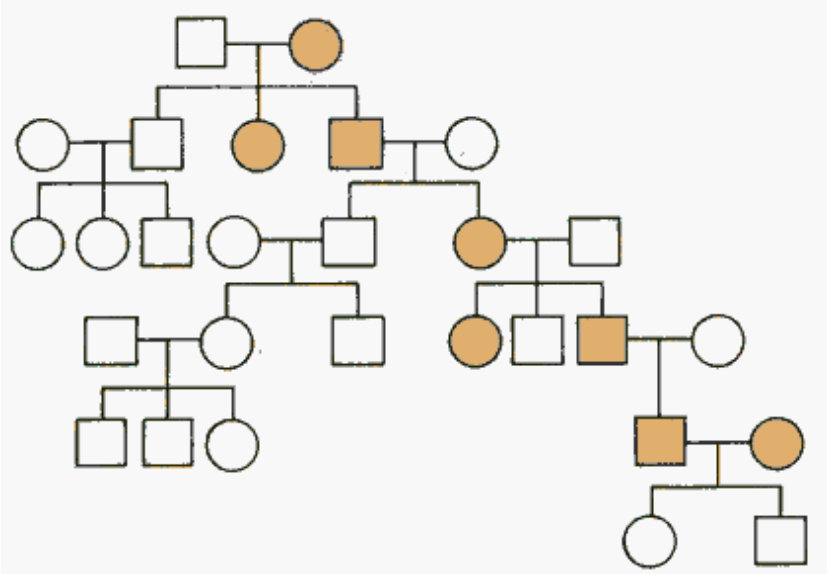
Instructions:

1. **Examine the following three pedigrees**.
2. Determine the *most probable* pattern of inheritance for each pedigree and record it in the space provided at the top of each pedigree.
3. Determine the genotype of each individual in each pedigree. Using the appropriate allele symbols in the table, above, record the genotype next to each person in pedigrees 1-3, below.

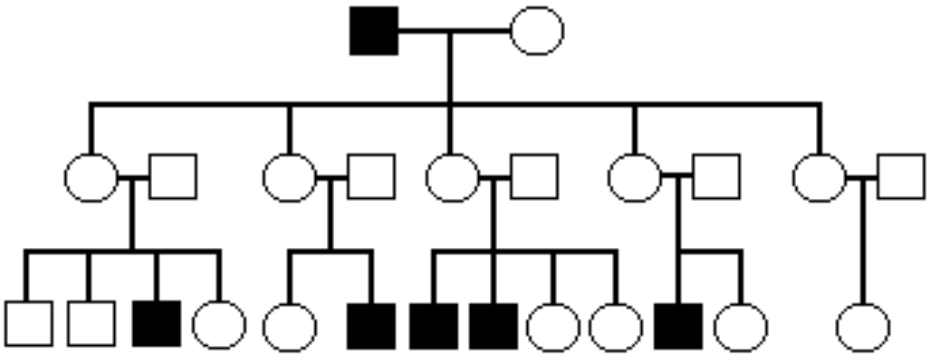
Pedigree #1 **Most probable pattern of inheritance:**_____



Pedigree #2 **Most probable pattern of inheritance:**_____



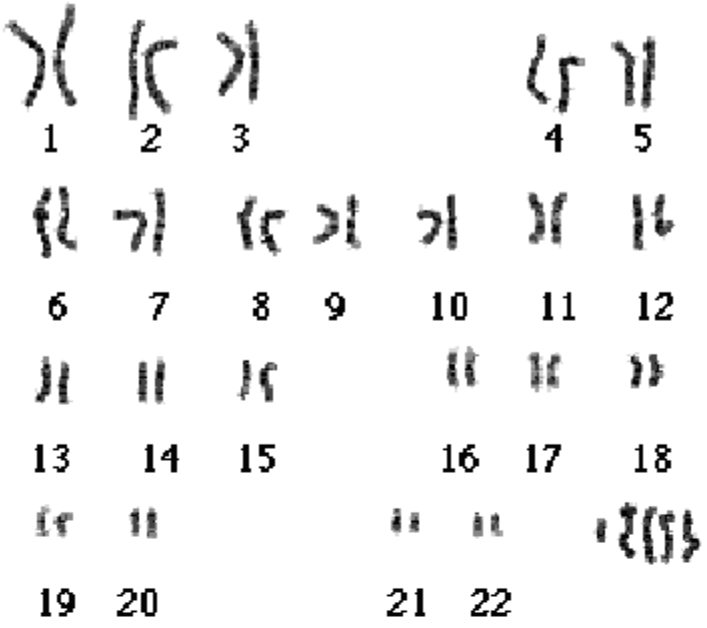
Pedigree #3 **Most probable pattern of inheritance:**_____



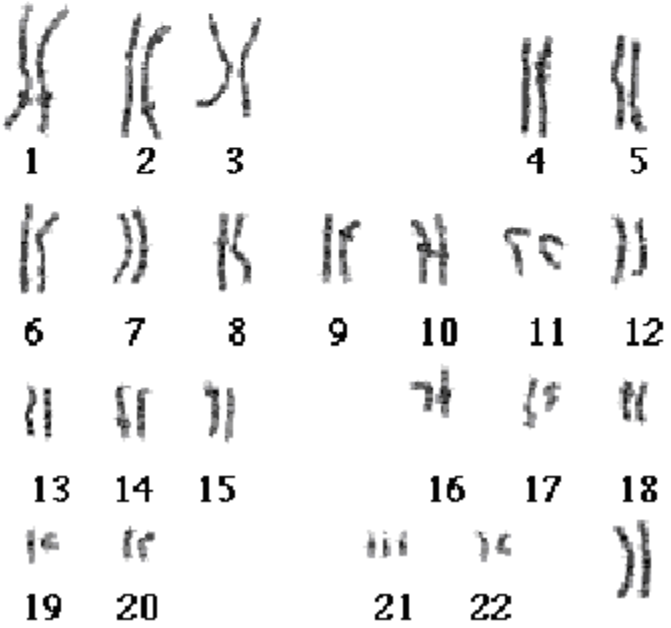
Karyotype Analysis

1. Examine carefully the two human karyotypes on the next page. Identify each karyotype with respect to the five syndromes that follow. Note that in most cases the syndrome is due to nondisjunction of homologous chromosomes during anaphase I during egg formation and is associated with the age of the woman.
    a. ***Down's syndrome***: Trisomy 21 (an extra copy of chromosome #21)
    b. ***Edwards's syndrome***: Trisomy 18 (an extra copy of chromosome #18)
    c. ***Patau syndrome***: Trisomy 13 (an extra copy of chromosome #13)
    d. ***Klinefelter's syndrome***: a male with *2 or more* X chromosomes (e.g. XXY)
    e. ***Turner's syndrome***: A female lacking an X chromosome (X instead of XX)
2. When determining the gender of each individual consider the relative sizes of sex chromosomes: the X chromosome is much larger than the Y chromosome. Presence or absence of a Y chromosome determines gender: Presence of a Y chromosome = male, absence of a Y chromosome = female.

Karyotype 1



Karyotype 2



	Gender of Individual	Genetic Syndrome
Karyotype 1		
Karyotype 2		