Mendel & Nonmendelian Problems Name:

Like any language, the language of genetics consists of symbols and rules for using these symbols. The capitalized letter of the dominant form becomes its symbol (Ex. R stands for round seeds). For the recessive form of the same trait (the recessive allele); the symbol remains the same but not capitalized (Ex. r stands for wrinkled seeds). Two versions (i.e. alleles) of one gene require two versions of one symbol. Note: frequency has nothing to do with dominance. Sometimes the dominant form is more frequent (brunettes in Korea) and sometimes the recessive form is more frequent (blondes in Finland). Complete the following chart using these rules of symbols.

Dominant: tall stems, coloured seed coats, green pods, yellow seeds, purple flowers, round seeds, axial flowers
Recessive: short stems, white seed coats, yellow pods, green seeds, white flowers, wrinkled seeds, terminal flowers

	height	coats	pods	seed	color	shape	flower
Dominant:							
Recessive:							

1. Using the symbols from the above chart, write the allele symbols that would be present in the following homozygotes. Next, indicate whether they are going to express the dominant or recessive trait.

tall stemmed plants _____ _____
terminal flowers _____ _____
white seed coats _____ _____
yellow seeds _____ _____
yellow pods _____ _____

2. Write the symbols for the following heterozygotes

yellow seeded peas _____ round seeds _____
colored seed coats _____ axial flowers _____
green podded peas _____ tall stemmed plants _____

3. The following letters represent pairs of alleles. Indicate whether each pair is a heterozygote or homozygote. Then indicate whether each pair would display a dominant or recessive phenotype.
Cc _____ TT _____

yy _____ Gg _____

4. What percent of the alleles does each parent contribute to their offspring? _____

5. What are the phenotypes for the following dihybrids:

TtCc _____ AaRr _____

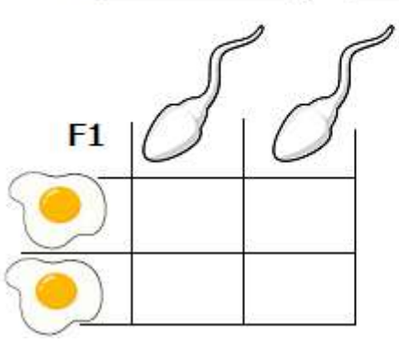
GgYy _____ TtAa _____

Single Trait Crosses (Monohybrid)

6. Tall pea plants are dominant over short pea plants. Pollen from a homozygous tall parent is applied to another homozygous tall parent.

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀



F1 Genotype Ratio:

F1 Phenotype Ratio:

Memory trick for our class:

Male Gametes = Sperm swim to the top
Female Gametes = "Eggs on the side" (sunny side up)

It really doesn't matter, but let's do it the same way in class.

Write the alleles on the gametes shown.

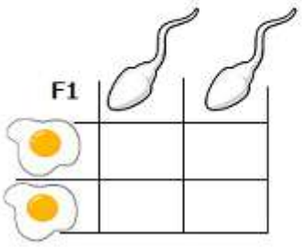
(So, what is meant by a pure breeding line?)

Tom Mueller RHS

7. If two heterozygous yellow seeded plants are crossed:

Symbols: ___ = _____
___ = _____

Cross: P _____ ♂ X _____ ♀



F1 Genotype Ratio:

F1 Phenotype Ratio:

8. If two white flowered plants are crossed, then

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

9. If pollen from a hybrid Green Podded is crossed with a Yellow-podded Plant,

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

10 If pollen from a purebred Axial-flowered plant is crossed with a Terminal-flowered plant

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

In a certain species of rat, black color dominates over white.

11. Cross two hybrid black rats

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

12. Cross a heterozygous male black rat with a white rat

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

13. If black fur is dominant to white fur in rabbits, what would be the genotypic and phenotypic ratios resulting from the following crosses?

a. homozygous black males and white females?

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

b. two heterozygotes?

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

c. a black male and a white female never have white offspring, ever!

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

d. a black male and a and a white female sometimes have white offspring

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

14 The last two examples (c & d) are called “test crosses”! Explain what that means in your own words:

_____

Exceptions to Mendel's Laws: Incomplete Dominance

Mendel had good fortune to study pea plants and not Snapdragons. With Mendelian dominance, alleles can sometimes be dominant when only one copy of an enzyme is present in the cytoplasm. Consider the possible scenario where the presence of Dad's enzyme masks the absence of Mom's enzyme: that means Dad's allele is dominant. Sometimes, gene dosage is important. In the case of Snapdragons, the red phenotype only occurs when both Dad's and Mom's alleles both are simultaneously expressed. When only one functional allele is expressed, a pink phenotype results. Two non-functional alleles become white. Incomplete dominance looks like "blending".

When describing symbols, you must define all possible genotypes:
For example, with Japanese four o'clock plants, you must write: **RR = red; Rr = pink; rr = white**

In Japanese four o'clock plants, the flowers may be red or white in the purebred form.
But, in the hybrid form the flowers are pink and therefore show incomplete dominance.

This is an example of "_____ dominance"

15. What would be the possible outcomes resulting from a cross between pollen from a pink parent crossed with a red parent?

Symbols: ___ = _____
___ = _____
___ = _____

Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

16. What would be the possible outcomes resulting from a cross between pollen from a pink parent crossed with a white parent?

Symbols: ___ = _____
___ = _____
___ = _____

Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

Radishes may be long, oval, or round: long is dominant, round recessive, and oval a mixture of the two.

This is an example of "_____ dominance"

17. If a farmer crosses pollen from oval plants, with round plants, predict the outcomes.

Symbols: ___ = _____
___ = _____
___ = _____

Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

18 If that F1 generation is self-crossed, predict the phenotype ratios of the following F2 generation (Note notation!)

Symbols: ___ = _____
___ = _____
___ = _____

Cross **F1** _____ ♂ X **F1** _____ ♀

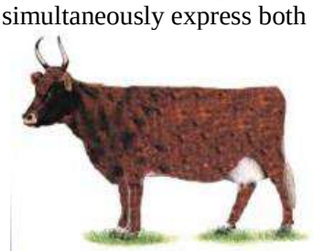
F2		

F1 Genotype Ratio:

F1 Phenotype Ratio:

Exceptions to Mendel's Laws: Codominance

Mendel had good fortune to study pea plants and not horses, cattle and dogs. "Codominance" is similar but different from "Incomplete Dominance". Codominance means that both alleles are dominant **AND** both alleles are expressed at the same time! There is no blending, instead there is a checkerboard or patchwork expression of both alleles. For example, Roan cattle simultaneously express both Red and White alleles.



Symbols are straightforward: We need two versions of "dominant" by using two versions of the same symbol. Obviously neither is lower nor upper case letters. In the case of coat color an appropriate symbol would be the capital letter "C". That means we could use two versions of "C" for red and for white alleles. The symbols then become:

C^RC^R = red C^WC^W = white C^RC^W = roan

19. If a farmer crosses a roan bull with a white cow, what will be the phenotype ratio of the F1 generation?

Symbols: ___ = _____
___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

If a farmer crosses a roan bull with a roan cow, predict the outcomes for the F1 generation?

Symbols: ___ = _____
___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

20 In a certain fish, blue scales and red scales are codominant. If a red fish is crossed with a blue fish, predict the F1 outcomes.

Symbols: ___ = _____
___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

Continuing with Mendel's Laws: Dihybrid Problems

21. Short fur in rabbits is dominant to long fur. What outcomes would you expect from a cross between two heterozygotes?

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

22. If black fur is dominant to white fur in rabbits What outcomes would you expect from a cross between two heterozygotes?

Symbols: ___ = _____
___ = _____

Cross P: _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

OK, let's do that all over again, but differently… this time let's do it all at once!

23 What phenotypic ratio would you expect from a dihybrid self-cross? That means the male gametes (sperm) are simultaneously carrying an allele for fur length and for coat color. Ditto the female gametes (eggs).

How many kinds of Sperm can the male dihybrid produce?

Answer: SB, Sb, sB, & sb

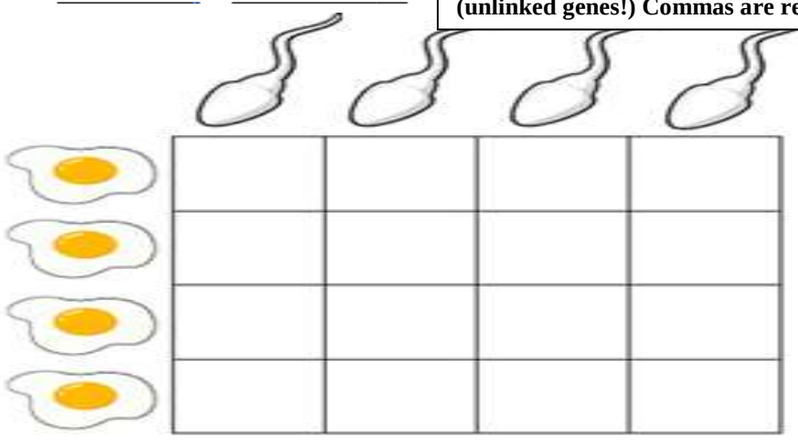
How many kinds of Eggs can the female dihybrid produce?

Answer: SB, Sb, sB, & sb

That means EACH gamete contains two alleles: One allele for fur length & One allele for fur color

Cross: Ss,Bb ♂ X Ss,Bb ♀

Notice the Notation for dihybrid crosses <u>assuming</u> "independent assortment" (unlinked genes!) Commas are required, when describing such a cross!



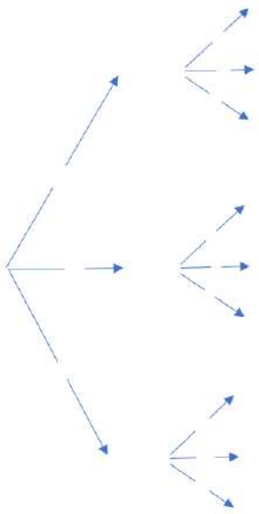
F1 Genotype Ratio:

F1 Phenotype Ratio:

There must be an easier way! https://www.ncbi.nlm.nih.gov/books/NBK21812/

One solution is to break down a big problem into two smaller problems.
Let's work with the two Punnett Square you already constructed for fur length and fur color.

24. Find the genotype ratio of the F1



This is VERY important:

When doing Probability trees, make sure the **DENOMINATORS** stacked on top of each other, **ALWAYS** remain **IDENTICAL**

ex 1/4, 2/4, 1/4

Two genes mean you require two Punnet Squares, to determine ratios to be expressed as fractions

Symbols: ___ = _____
___ = _____

Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

Symbols: ___ = _____
___ = _____

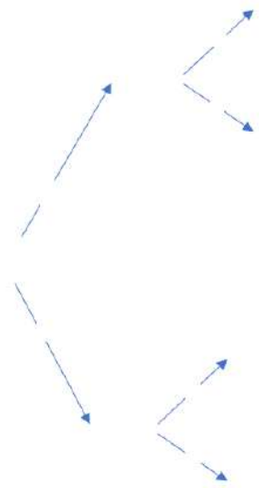
Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

25 Again, using the same Punnett Squares above, this time predict the phenotype ratio for the same cross:



You just determined the genotype and phenotype ratios for a "Dihybrid Self-cross". On a separate sheet of paper, employ the same technique to determine the genotype and phenotype ratios for:

26 A dihybrid test-cross between a short-furred black male and a long-furred white female. (refer to question #14)

Before starting: which parent must be the dihybrid? _____

What must be the genotype of the father? _____

What must be the genotype of the mother? _____

You are working with two genes: therefor make two Punnett Squares (one for each gene) and then construct the two probability trees (one for genotype and one for phenotype)

What is the genotype ratio for this dihybrid test-cross? _____

What is the phenotype ratio for this dihybrid test-cross? _____

Again, why are test crosses very useful? _____

Mendelian Genetics: Product and Sum Rules

Directions: For each of the following problems, calculate the probability of the offspring for the given crosses using the sum and product rules. For these problems, it would be a good idea to limit Punnett squares to single gene crosses.

The genetic notation for either Aa or AA result in the same phenotype indicated $\overline{A}$ or alternatively as **A__**

27. A male with genotype Aa is crossed with a female with genotype Aa.
What is the probability the F1 offspring would have the same phenotype as the father?

28. A male with genotype Aa Bb is crossed with a female with genotype Aa bb.

What is the probability the F1 offspring would have genotype aa Bb?

29 What is the probability the above cross will generate an $\overline{aB}$ phenotype

30. A male with genotype Aa bb Cc is crossed with a female with genotype Aa Bb CC.

What is the probability the offspring will have the same genotype as the father?

What is the probability the offspring will have the same phenotype as the father?

Exceptions to Mendel's Laws. Blood Types = multiple alleles combined with codominance.

Blood Antigens are weird! It is possible to have an immune response to blood antigens, even if you have never been exposed to those antigens before. That is important to understand. https://www2.palomar.edu/anthro/blood/ABO_system.htm

The ABO blood group antigens remain of prime importance in transfusion medicine—they are the most immunogenic of all the blood group antigens. The most common cause of death from a blood transfusion is a clerical error in which an incompatible type of ABO blood is transfused. The ABO blood group antigens also appear to have been important throughout our evolution because the frequencies of different ABO blood types vary among different populations, suggesting that a particular blood type conferred a selection advantage (e.g., resistance against an infectious disease.)

Antigen "A" and Antigen "B" are oligosaccharide chains that project above the Red Blood Cell (RBC) surface. These chains are attached to proteins and lipids that lie in the RBC membrane. "O" for all intents and purposes means no antigen is being presented.

Each biological parent donates one of their two ABO alleles to their child. A mother who is blood type O can only pass an O allele to her son or daughter. A father who is blood type AB could pass either an A or a B allele to his son or daughter. This couple could have children of either blood type A (O from mother and A from father) or blood type B (O from mother and B from father).

The possible ABO alleles for one parent are in the top row and the alleles of the other are in the left column. Offspring genotypes are shown in black. Phenotypes are red.

Parent Alleles →	A	B	O
A	AA (A)	AB (AB)	AO (A)
B	AB (AB)	BB (B)	BO (B)
O	AO (A)	BO (B)	OO (O)

If you need some practice with this concept, go to this link: http://www.biology.arizona.edu/human_bio/problem_sets/blood_types/inherited.html

Following the "labeling rules" we already agreed upon above; we shall now adopt the following convention:

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

In your own worlds explain the following:

Blood type O can be described as a "universal donor" because: _____
_____

Blood type AB can be described as a "universal recipient" because: _____
_____

31. A blood-type B father and a blood-type A mother have a blood-type O child. From this information, predict all the different blood-types their children could possibly have:

Symbols: ___ = _____
___ = _____

Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

It is a good idea to write a quick pedigree off to the side when doing blood type problems

B ? ♂ x A ? ♀

⇩

O O

Clearly both parents were "carriers" for allele "O"! Now you can proceed with the Punnett Square.

Tom Mueller RHS

32 A woman with type A blood is claiming that a man with type AB blood is the father of her child, who is also type AB. Could this man be the father? Show the possible crosses; remember the woman can have AO or AA genotypes.

Symbols: ___ = _____
___ = _____

Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

— — ♂ X — — ♀

⇩

— —

Symbols: ___ = _____
___ = _____

Cross **P:** _____ ♂ X _____ ♀

F1		

F1 Genotype Ratio:

F1 Phenotype Ratio:

— — ♂ X — — ♀

⇩

— —

By now you should realize that you really do not need Punnett Squares.

Solve the following problems:

33. A man with type AB blood is married to a woman with type O blood. They have two natural children, and one adopted child. The children's blood types are: A, B, and O. Which child was adopted?

34 A man with type B blood marries a woman with type A blood. They have six children, all with type AB blood. What are the most **LIKELY** genotypes of the father, mother, and children? Is there any other **UNLIKELY** answer possible?

Rh blood group antigens are different than ABO antigens. When born without the Rh antigen, the body does not automatically make antibodies against it. Instead, a person with Rh negative blood needs to be 'sensitized' before he or she will start to produce antibodies to the Rh antigen. That can be a problem if a mother is Rh-negative and the father is Rh-positive. Delivery at the end of pregnancy can be a painful business, where the mother's immune system could become exposed to baby's antigens. If an Rh-negative mother is sensitized to Rh antigens, future pregnancies could miscarry when the mother mounts an immune response to the fetus' RH antigens. https://www2.palomar.edu/anthro/blood/Rh_system.htm

A Father with blood type B Rh+ and a mother with blood type A Rh- have a daughter with blood type O Rh-

35 What can you determine about the parents' genotypes and daughter's genotypes?

36 Is there a possibility the mother has been sensitized to Rh?

37 How many different genotypes could their children be?

Mendelian Genetics: Chi Square Analysis

Directions: Use the Chi Square Equation to analyze if the data supports the independent assortment or if there is a variable not being accounted for in the data.

Use the critical values table here to do the problems below. *

Degrees of Freedom (df)					
Probability (p)	1	2	3	4	5
0.05	3.84	5.99	7.82	9.49	11.1
0.01	6.64	9.21	11.3	13.2	15.1
0.001	10.8	13.8	16.3	18.5	20.5

38 In peas, yellow seeds (Y) are dominant over green (*y*) seeds. In a cross between two plants both heterozygous for seed color, the following was observed. Does the data fit the predicted phenotypical ratio?

- Yellow = 4352
- Green = 1497

Critical value chosen = _____ (always done beforehand!)

Null Hypothesis:

Phenotype	Observed (O)	Expected (E)	O - E	$(O-E)^2$	$(O-E)^2/E$
					$\sum \frac{(O-E)^2}{E} =$

According to statistics:

As much as we can conclude from statistics:

39 In the garden pea, yellow color is dominant to green, and inflated pod shape is dominant to the constricted form. Both of these traits should independently assort during a dihybrid cross. The progeny of a Dihybrid Testcross generated the following numbers:

- 643 yellow, inflated
- 558 green, inflated
- 654 yellow constricted
- 561 green, constricted

Do the data above support a conclusion that these genes assort independently?
Support your answer using Chi-square analysis.

Critical value chosen = _____ (always done beforehand!)

Null Hypothesis:

Phenotype	Observed (O)	Expected (E)	O - E	$(O-E)^2$	$(O-E)^2/E$
					$\sum \frac{(O-E)^2}{E} =$

According to statistics:

As much as we can conclude from statistics:

Exceptions to Mendel's Laws. Sex Chromosomes vs Autosomal Chromosomes

Females have the Genotype XX and males have the Genotype XY

Use a Punnett Square to indicate why sex ratios are generally 1 Female: 1 Male

Cross: _____ ♂ X _____ ♀

Genotype Ratio:

Phenotype Ratio:

Sex Chromosomes X & Y pose interesting exceptions to Mendel's Laws. If a trait is X-linked: mothers can be heterozygous or homozygous for the trait. Father's can only be hemizygous. That means. Females can be "carriers" for an X-linked trait. Males can never be "carriers" for an X-linked trait: they express the only trait they have got on their one X-chromosome.

X-linked traits are always shown as superscripts on a Capital X in either upper or lower case indicating the dominant or recessive genotype.

For example: $\mathbf{X^R}$ would indicate an X-linked dominant allele for eye color Red for a particular gene
& X^r would indicate an X-linked recessive allele for eye color White for the same gene

40. In Drosophila, the gene for red eyes, R is dominate for the gene for white eyes, r. This gene is X-linked. Determine the possible genotype and phenotype ratios expected from a cross between,

(a) heterozygous female and red-eyed male,
(b) a heterozygous female and a white-eyed male,
(c) a homozygous dominate female and a red-eyed male
(d) a homozygous dominate female with a white-eyed male.

(a)

Cross: _____ ♂ X _____ ♀

	X	Y
X		
X		

Genotype Ratio:

Phenotype Ratio:

(b)

Cross: _____ ♂ X _____ ♀

	X	Y
X		
X		

Genotype Ratio:

Phenotype Ratio:

(c)

Cross: _____ ♂ X _____ ♀

	X	Y
X		
X		

Genotype Ratio:

Phenotype Ratio:

(d)

Cross: _____ ♂ X _____ ♀

	X	Y
X		
X		

Genotype Ratio:

Phenotype Ratio:

41. In humans the allele for normal blood clotting, B is dominant to the allele for hemophilia, b. This is a sex-linked trait found on the X chromosome. The last Tsar of Russia (Nicholas II) did not have hemophilia. His wife (Alexandra) also did not have hemophilia. They had a hemophiliac son, and four normal daughters. What is/are the probable genotype(s) for each member of the family?

Tsar Nicholas _____
Empress Alexandra _____
Daughter Olga Nikolaevna _____
Daughter Tatiana Nikolaevna _____
Daughter Maria Nikolaevna _____
Daughter Anastasia Nikolaevna _____
Son Alexei Nikolaevich _____

In cats, the X-linked gene for calico (multicolored) cats is codominant. Females that receive a B and an R gene have black and orange splotches on white coats. Males can only be black or orange, but never calico. That means Males can have two different genotypes and females can have three different genotypes. Remembering the rules for writing codominance symbols above, solve the following crosses:

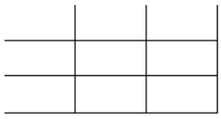
Calico Cats are X-linked mosaics.
Roan Cattle are autosomal-linked mosaics.

Tom Mueller RHS

42 Show the cross of a female calico cat with a black male cat?

Symbols: ___ = _____ ___ = _____
___ = _____ ___ = _____
___ = _____

Cross: _____ ♂ X _____ ♀



Genotype Ratio:

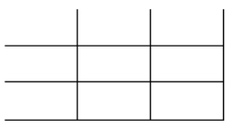
Phenotype Ratio:

a. What percentage of the kittens will be black and male? _____
b. What percentage of the kittens will be calico and male? _____
c. What percentage of the kittens will be orange and female? _____
d. What is the probability a kitten will be calico and female? _____
e. What is the probability an F1 female will be calico? _____ (careful now… your answer will be different than d.)

43. Show the cross of a female black cat with a male orange cat.

Symbols: ___ = _____ ___ = _____
___ = _____ ___ = _____
___ = _____

Cross: _____ ♂ X _____ ♀



Genotype Ratio:

Phenotype Ratio:

44 In humans the gene for normal color vision ***C***, is dominant to the gene from red-green color blindness, ***c***. This trait is sex-linked and found on the X chromosome.
The autosomal gene for brown eyes, **B**, is dominant to the gene for blue eyes, **b**.

Calculate the probable genotype and phenotype ratios of the children born to a blue-eyed woman who is heterozygous for color vision and a heterozygous brown-eyed man who is colorblind.

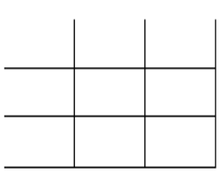
Introduction to Pedigrees:

45. The polled (hornless) trait in cattle is dominant. The horned trait is recessive. A certain polled bull is mated to three cows.

Cow A, which is horned gives birth to a polled calf.
Cow B, also horned, produces a horned calf.
Cow C, which is polled, produces a horned calf.

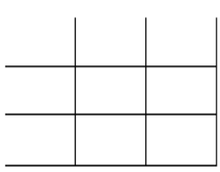
Symbols: ___ = _____
___ = _____

Cross: _____ ♂ X _____ ♀



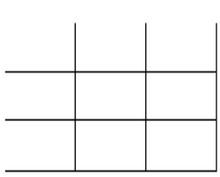
Symbols: ___ = _____
___ = _____

Cross: _____ ♂ X _____ ♀



Symbols: ___ = _____
___ = _____

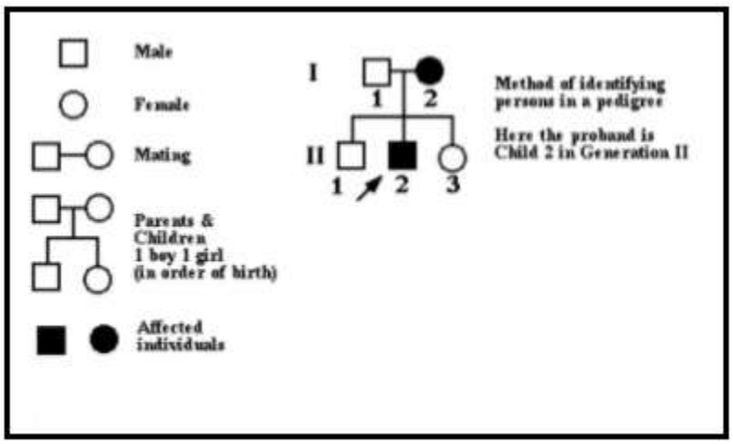
Cross: _____ ♂ X _____ ♀



Name the genotypes of all parents and show the Punnett squares and possible genotypes of each offspring resulting from the cross.

Bull _____
Cow A _____ calf: _____
Cow B _____ calf: _____
Cow C _____ calf: _____

There has to be an easier way!



You will need to learn some new symbols.

The information provided in the pedigree to the left is insufficient to determine whether or not the trait in question is either recessive or dominant.

The information provided in the pedigree to the left is insufficient to determine whether or not the trait in question is X-linked or Autosomal.

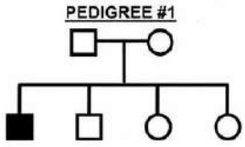
Y-linked is ruled out.

Ensure you understand all that before proceeding.

Directions: Analyze each pedigree and try to figure out which type of inheritance the disorder follows. Make sure to look at male/female ratios, who might be a carrier, who doesn't have the disease, etc.

46

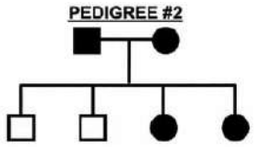
PEDIGREE #1



Could this trait be inherited as a simple…?			If yes, then suggest a genotype **Father** x **Mother**
a. Autosomal Recessive?	Yes	No	_____ x _____
b. Autosomal Dominant?	Yes	No	_____ x _____
c. X-Linked Recessive?	Yes	No	_____ x _____
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

47

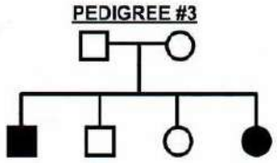
PEDIGREE #2



Could this trait be inherited as a simple…?			If yes, then suggest a genotype **Father** x **Mother**
a. Autosomal Recessive?	Yes	No	_____ x _____
b. Autosomal Dominant?	Yes	No	_____ x _____
c. X-Linked Recessive?	Yes	No	_____ x _____
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

48

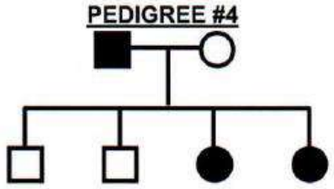
PEDIGREE #3



Could this trait be inherited as a simple…?			If yes, then suggest a genotype **Father** x **Mother**
a. Autosomal Recessive?	Yes	No	_____ x _____
b. Autosomal Dominant?	Yes	No	_____ x _____
c. X-Linked Recessive?	Yes	No	_____ x _____
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

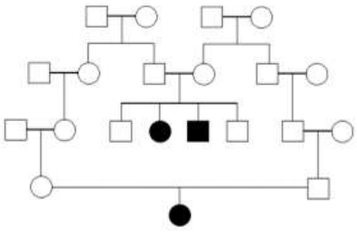
49

PEDIGREE #4



Could this trait be inherited as a simple…?			If yes, then suggest a genotype **Father** x **Mother**
a. Autosomal Recessive?	Yes	No	_____ x _____
b. Autosomal Dominant?	Yes	No	_____ x _____
c. X-Linked Recessive?	Yes	No	_____ x _____
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

50



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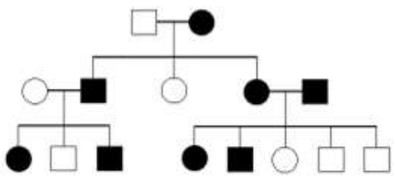
			If yes, then suggest a genotype **Father** x **Mother**
a. Autosomal Recessive?	Yes	No	_____ x _____
b. Autosomal Dominant?	Yes	No	_____ x _____
c. X-Linked Recessive?	Yes	No	_____ x _____
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

51



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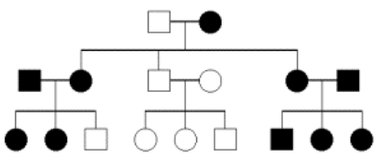
c. X-Linked Recessive?	Yes	No	_____ x _____
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

52



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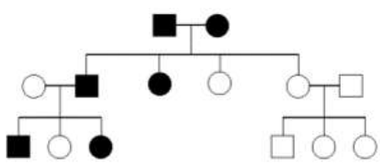
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

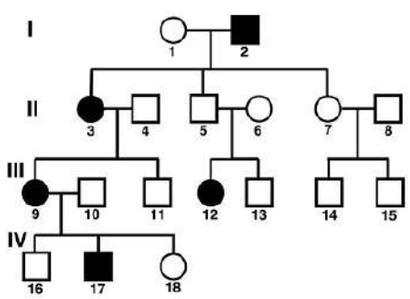
53



Could this trait be inherited as a simple…?

			If yes, then suggest a genotype **Father** x **Mother**
a. Autosomal Recessive?	Yes	No	_____ x _____
b. Autosomal Dominant?	Yes	No	_____ x _____
c. X-Linked Recessive?	Yes	No	_____ x _____
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

54



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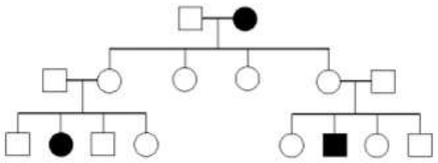
55



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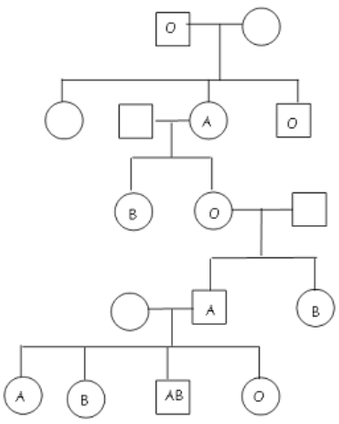
d. X-Linked Dominant?	Yes	No	_____ x _____
e. Y-Linked?	Yes	No	_____ x _____

56

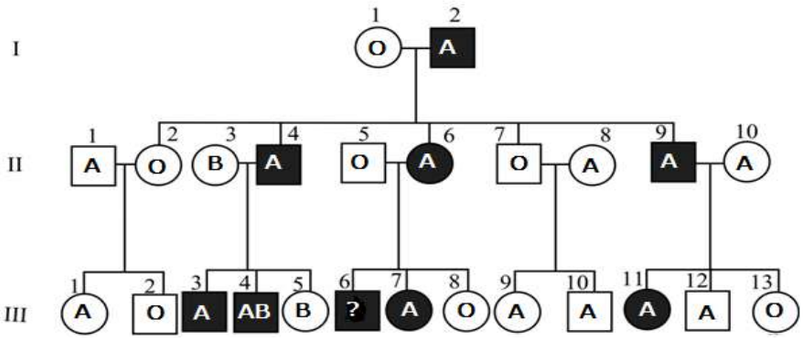


Use your powers of deduction to determine the Genotypes of each individual.

Write genotypes immediately under their respective individual.

Do not forget that "?" can be a correct answer for one or both alleles or for phenotype.

57



"Hood Syndrome" is a very rare condition with reduced fingernails and toenails together with elbow and knee deformities as well as kidney problems

This pedigree shows the transmission of Hood Syndrome together with ABO Blood Types. One Blood Type is unknown.

a) Do you have enough information to determine whether Hood Syndrome is a dominant or a recessive condition? Explain your reasoning.

b) You are then told that Hood Syndrome is a very rare condition and when patients with this syndrome marry an unafflicted spouse, their offspring, on average have a 50% chance of acquiring the syndrome. Does this information change your answer to a)?

c) Does this pedigree provide evidence of genetic linkage between Hood syndrome & ABO Blood types? Explain

d) Using H vs h to represent alleles at the Hood locus and I^A I^B and i to represent ABO alleles, write the genotypes for I-1 & I-2 as well as their five children in Generation II

e) Explain why III-11 has Hood Syndrome but III-12 does not. Provide possible genotypes for these two individuals.

f) Given your understanding of Hood Syndrome genetics; what is the most likely Blood Type for III-6? Explain.

g) Is Blood Type O even possible for III-6? (Hint: do next section before answering)

Exceptions to Mendel's Laws. Gene Linkage

William Bateson was the famous scientist who "rediscovered" Mendel, and who invented the term "Genetics" and who (together with Reginald Punnett) was the first to recognize that some genes are linked. In fact, numerous genes are found on the same chromosome. Genes on same chromosome are described as being in same Linkage Groups and inherited together. For example, red hair and freckles are closely linked; you rarely get one without the other. That said, unlinked genes can also occur on the same chromosome. For example: three of Mendel's genes were on chromosome #4.
http://www.prism.gatech.edu/~gh19/b1510x/pealocus.gif

58. In *Drosophila*, the gene for eye color (A), wing shape (B), and body color (C) are all found on the same chromosome. The following crossover frequencies for these genes were determined by & trihybrid test-cross experiments. Determine the sequence of genes A, B, and C on a chromosome. There are two correct answers:

Genes	Crossover Frequency
A & B	12%
A & C	6%
B & C	18%

59 The following chart shows the crossover frequencies for some genes on an autosome of another organism. Determine the sequence of genes

Genes	Crossover Frequency
W & S	8%
C & W	3%
C & B	5.5%
C & S	11%
B & S	5.5%

60 The following chart shows the crossover frequencies for some genes on an autosome of another organism. Determine the sequence of genes

Genes	Crossover Frequency
A & B	15%
B & C	45%
B & D	40%
A & D	25%

60 Alfred Sturtevant was an undergraduate student who decided to cuff an important homework assignment which was going to count heavily towards his final mark. He arranged the following crossover gene frequencies collected while studying Drosophila. Bar-shaped eyes are indicated by the (B) allele, and carnation eyes are indicated by the allele (C). Fused veins on wings (F), leg length (C), and scalloped wings (D) are located on the same chromosomes. Construct a chromosome map.

Genes	Crossover Frequency
A & B	24.0%
A & C	8.0%
C & D	2.0%
A & F	16.0%
F & B	8.0%
D & F	6.0%

61 You have realized by now that constructing maps is easy if you are lucky enough to be provided the flanking outside markers allowing you to map everything in between. Life is not always so easy! This problem does not provide you the flanking outside markers. You have been provided enough data to construct three overlapping linkage maps. Just employ the same rationale as before: identify two outside flankers and then locate the interior marker in between.

Do that three times, identify the overlap and then construct map; Start with A & C, & A & D… then C & D

Genes	Crossover Frequency
A & C	8%
A & D	10%
B & D	14%
B & F	8%
C & D	2%
C & F	8%
D & F	6%

62 **P**: dihybrid Cute/Dumb ♂ X ugly/smart ♀ .
This is a dihybrid test-cross. ugly is recessive to Cute & smart is recessive to Dumb and genes linked!
That means, symbols with cross need to be written differently.
How did we know the two genes must be linked? _____

Cross: $\frac{C\ D}{c\ d}$ ♂ X $\frac{c\ d}{c\ d}$ ♀

Notice the notation for linked genes is different than for unlinked genes (refer to the cross in question #23)

Understand that mapping requires test-crosses!

F1:

Cute/Dumb	Cute/smart	ugly/Dumb	ugly/smart
458♂ & 461♀	38♂ & 43♀	42♂ & 37 ♀	462♂ & 459♀

How did the data permit us to indicate the linkage pattern, indicated in the cross?

What else can you deduce from the data?

63 **P**: Again, a dihybrid test cross Cute/Dumb ♂ X ugly/smart ♀ Data is different! Indicate the cross:

Cross: _____ ♂ X _____ ♀

F1:

Cute/Dumb	Cute/smart	ugly/Dumb	ugly/smart
38♂ & 43♀	458♂ & 461♀	462♂ & 459♀	42♂ & 37 ♀

How did you know to write the cross "the same but different"?

What else can you deduce from the data?

In your own words: explain the following terms:

Dihybrid-test cross in Coupling: _____

Dihybrid-test cross in Repulsion: _____

Final Word on Introductory Genetics: EMPHASIS is on the word "introductory!"

A little knowledge is a dangerous thing! Sometimes – students can be traumatized by wondering whether their parents must have lied and that students must have been adopted… or other such conjectures.

Warning: Students must understand that Mendel's Rules have exceptions AND that those exceptions have exceptions.

Students should be alerted there is much to Genetics which cannot be addressed in high school Biology, including the notion of "Penetrance"

Meanwhile, could a child with blood type AB have a father whose blood-type is O? Rarely – very rarely, but Yes!

… or could two blue-eyed parents have a brown-eyed child? Rarely – very rarely, but Yes!

http://genetics.thetech.org/ask/ask413 & http://genetics.thetech.org/how-blue-eyed-parents-can-have-brown-eyed-children

The answer to both questions are an emphatic "Yes".

WHY?!

Because the rules of Mendelian Genetics are in fact in the exception to the rule!

http://anthro.palomar.edu/mendel/mendel_3.htm

Let's leave something for university. Here endeth the lesson.

Tear-off sheet for teachers

By way of pedagogic suggestion:

When first broaching Punnett Squares: student understanding is greatly aided by drawing paternal alleles listed inside "Swimming Sperm" which "swim to the top" and maternal contribution listed to the left of the Punnett Square inside two concentric circles representing "Eggs sunny-side up" - "on the side"

Introduced in such fashion: the inside squares of the Punnett intuitively represent "fertilization events" when aided by such visuals.

Students will quickly forgo the need for such visuals but once EVERYONE adopts the routine of drawing paternal contributions above and maternal contributions to the side, a great hurdle has been overcome when work is done collaboratively and quizzes are marked in class.

This "POGIL-like" package should take about one to two weeks (not including other activities) and was written with the intention that students work together in groups while teacher operates as "guide on the side"

IMHO, once a package leaves the classroom – it cannot serve as evaluation for mastery on an individual basis.

That is where daily quizzes come in (especially important in Genetics and again IMHO -other may disagree - each to xsr own).

By way of suggestion: each Genetics class could commence with a quiz (marked in class) which probes understanding of what students were supposed to have mastered the previous day. That effort keeps both teacher and students honest. To repeat: this was by way SUGGESTION only… teaching styles differ and "one size does not fit all".

That all said, this package serves the same purpose as the "examples" provided in a math textbook.

Teachers will need to provide other exemplars to their students in class.

Good place to start: http://www.hhmi.org/biointeractive/mendelian-genetics-probability-pedigree-and-chi-square-statistics

IMHO – there are not enough exemplars of each question category (especially towards the end) to permit student mastery.

Questions regarding the mechanism of dominance vs recessive will arise in class. Those teaching Advanced/AP/IB may have already taught some of the various mechanisms without realizing it!

Do Calico Cats exhibit codominance? If so what does that tell us about codominance? Mosaicism Events occur early in fetal development when individual cells commit to expression of either the maternal or paternal chromosome (or gene). X-chromosome Barr Body formation is just one such mechanism. Imprinting and Epigenetics can provide illustrative examples of similar mechanisms of "mosaic commitment" early in fetal development. Mosaics can be Sex-linked or autosomal.

On the topic of mechanisms of dominant vs recessive alleles:

When considering Human Genetic diseases - 90% of all can be traced to mutations which lie outside protein coding regions! Furthermore, those mutations were just as likely to be dominant as recessive… or incomplete dominant… or co-dominant! One mechanism of Incomplete dominance could be "gene dosage" or "Haplosufficiency" of protein product.

However; again, many such mutations map outside the protein reading frame. That means, dominance is not just about the allele for a functional protein providing corrective "backup" for a defective allele.

Again. many teachers have already introduced many alternate mechanisms in class without realizing it! An easy example would be the Lac Operon, where mutation of the Operator "region" leaves the Operon constitutively "on". That would be an example of "dominance". (Classical Geneticists speak of mutations in "cis" and in "trans".)

So where does this leave us as far as explaining the various versions of "dominance" to our students at a high school level?

Students can understand that genes interact:

…most traits are governed by more than one gene AND most genes affect more than one trait! This is important!

Meanwhile, many genes do not code for protein products. For example, X-chromosome inactivation requires RNA transcripts which never are translated into protein. These RNA transcripts incompletely "paint" the X-chromosome thereby inactivating "painted regions". (segue to RNAi)

Bottom line – much of what we observe as Dominance vs. Recessive has to do with Regulatory genes, not the Proteome.

Hope any of that was helpful.

Tom Mueller RHS