

# Bio 102 Practice Problems

## Mendelian Genetics: Beyond Pea Plants

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### Short answer (show your work or thinking to get partial credit):

1. In four-o'clock flowers, red flower color (R) is incompletely dominant over white (r), and heterozygous plants (Rr) have pink flowers. What gametes will be produced by each parent in the following crosses, and what will be the phenotypes of the offspring?

a. Rr × RR

gametes:

Rr:  $\frac{1}{2}$  R,  $\frac{1}{2}$  r

RR: all R

offspring:

$\frac{1}{2}$  Rr (pink)

$\frac{1}{2}$  RR (red)

b. rr × Rr

gametes:

Rr:  $\frac{1}{2}$  R,  $\frac{1}{2}$  r

rr: all r

offspring:

$\frac{1}{2}$  Rr (pink)

$\frac{1}{2}$  rr (white)

c. RR × rr

gametes:

rr: all r

RR: all R

offspring:

all Rr (pink)

d. Rr × Rr

gametes:

Rr:  $\frac{1}{2}$  R,  $\frac{1}{2}$  r for each parent

offspring:

$\frac{1}{2}$  Rr (pink)

$\frac{1}{4}$  RR (red)

$\frac{1}{4}$  rr (white)

2. If a red-flowered four-o'clock is crossed with a white-flowered one:

a. What will be the flower color(s) of the  $F_1$ ? Of the  $F_2$ ?

A red-flowered four-o'clock (any red-flowered four-o'clock) has the genotype  $RR$ ; a white-flowered four-o'clock has the genotype  $rr$ . So, this cross is  $RR \times rr$ .

The  $F_1$  offspring will therefore all be  $Rr$ , all pink.

The  $F_2$  offspring (cross is  $Rr \times Rr$ ) will be  $\frac{1}{4} RR$ , red;  $\frac{1}{2} Rr$ , pink;  $\frac{1}{4} rr$ , white

b. What will be the flower color(s) of the offspring of a cross of the  $F_1$  with the red parent?

This cross is  $Rr \times RR$ , so we expect  $\frac{1}{2}$  the offspring to be red and  $\frac{1}{2}$  pink ( $\frac{1}{2} RR$  and  $\frac{1}{2} Rr$ )

c. What will be the flower color(s) of the offspring of a cross of the  $F_1$  with the white parent?

This cross is  $Rr \times rr$ , so we expect  $\frac{1}{2} Rr$  (pink) and  $\frac{1}{2} rr$  (white)

3. Suppose you sell flower seeds and you would like to sell packages of seeds which you can guarantee to produce all pink-flowered plants. How would you produce these seeds?

Simply cross a red-flowered plant ( $RR$ ) with a white-flowered plant ( $rr$ ). All the seeds will grow into  $Rr$  plants, which will be pink (but won't be pure-breeding, so your customers will have to come back for fresh seeds next year!).

4. In snapdragons, red flower color ( $R$ ) is incompletely dominant to white ( $r$ ), with heterozygous plants being pink. The broad-leaf allele ( $B$ ) is incompletely dominant over narrow leaves ( $b$ ), with the heterozygous plants having medium-width leaves. If a red-flowered, broad-leaved plant is crossed with a white-flowered, narrow-leaved one, what will be the appearance of the  $F_1$  and  $F_2$  plants?

This works exactly like a typical two-gene cross, except that heterozygous individuals have their own phenotypes.

The initial cross is  $RRBB \times rrb b$ , so the  $F_1$  is all  $RrBb$ , which gives the pink, medium phenotype.

Then, cross  $RrBb \times RrBb$ , and get:

$1/16 RRBB$ : red, broad

$1/8 RRBb$ : red, medium

$1/16 RRbb$ : red, narrow

$1/8 RrBB$ : pink, broad

$1/4 RrBb$ : pink, medium

$1/8 Rrbb$ : pink, narrow

$1/16 rrBB$ : white, broad

$1/8 rrBb$ : white, medium

$1/16 rrbb$ : white, narrow

5. In a paternity suit, where a woman claims that a particular man is the father of her child, the blood types of the three individuals are often tested to see if her claim could be correct. In each of the following cases, determine whether it is possible that the male is the father of the child:

a. Mother is type A, child is type B, alleged father is type A

No: mother is  $I^A i$  (because child didn't get A); father is  $I^A I^A$  or  $I^A i$ -no  $I^B$  allele anywhere

b. Mother is type A, child is type A, alleged father is type B

Yes: mother is  $I^A I^A$  or  $I^A i$ ; father could be  $I^B i$  and give an  $i$  allele to the child

c. Mother is type O, child is type O, alleged father is type A

Yes: mother and child are  $ii$ , but father could be  $I^A i$  and give an  $i$  allele to the child

d. Mother is type AB, child is type O, alleged father is type AB

No: mother is  $I^A I^B$ , child is  $ii$ --hey! this can't be the child's mother!! Looks like a scam!

e. Mother is type A, child is type O, alleged father is type AB

No: mother is  $I^A i$  and gives an  $i$  to the child, who is  $ii$ , but the father can't also give an  $i$ .

f. Mother is type A, child is type O, alleged father is type B

Yes: mother can be  $I^A i$  and father can be  $I^B i$ ; child can get both  $i$  alleles.

6. If a person of blood type AB marries one of type O, what will the blood types of their children be?

The O individual can contribute only  $i$  alleles to the children; the other parent can give  $I^A$  or  $I^B$ . So, the children should have a 50/50 chance of being  $I^A i$  or  $I^B i$ , type A or B.

7. If one parent is type A and the other is type B, but all four blood types are represented among the children, what were the genotypes of the parents?

If any child is  $ii$ , then each parent must have had an  $i$  allele. Therefore, the parents are  $I^A i$  and  $I^B i$ .

8. If both parents are type A but  $\frac{3}{4}$  of the children are type A and  $\frac{1}{4}$  are type O, what were the genotypes of the parents?

Again if any child is  $ii$ , then each parent had an  $i$  allele. Therefore, both parents are  $I^A i$ . We therefore expect about  $\frac{1}{4} I^A I^A$ ,  $\frac{1}{2} I^A i$  and  $\frac{1}{4} ii$ .

9. If one parent is type AB and the other is B, but  $\frac{1}{4}$  of the children are A,  $\frac{1}{4}$  AB and the rest B, what are the genotypes of the parents?

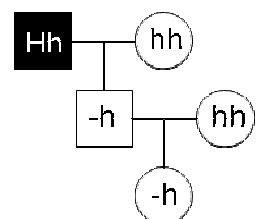
The only way for a type B parent to have any type A children is to have an  $i$  allele, so the B parent is  $I^B i$ . The AB parent can only be  $I^A I^B$ .

10. Huntington's disease (HD) is a rare human genetic disorder produced by a dominant allele. Symptoms of this fatal neurodegenerative disease typically are not seen until an individual is 30-50 years old. Suppose you are a genetic counsellor, and your client's grandfather died of HD. Her father is in his 40s and she is 20. She doesn't want to pass on the disease allele, and she knows that if she has HD, there's a 50-50 chance she'll pass it to her child.

a. Sketch your client's pedigree in the space to the right.

b. What is the probability that she will eventually develop HD?

Since HD is rare, we can assume the client's grandmother didn't have it and that the grandfather is heterozygous, even though these facts aren't given specifically. Her father had a 50/50 chance of getting the HD allele from the grandfather. *IF* the father has it (it's too early to tell for sure), then there's a 50-50 chance she inherited it. So, there's a  $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$  chance she'll get the disease.



11. In about 85% of humans (called "secretors"), the A or B blood type protein is found in saliva and other body fluids as well as in the blood. The other 15% do not have blood type proteins in the saliva ("nonsecretors"). If secretor (S) is dominant to non-secretor (s) and this gene assort independently of the A-B-O blood type gene, what proportion of the offspring from the following mating would have A, B or both blood type proteins in their saliva?

a. type AB, Ss × type AB, Ss (cross is  $I^A I^B Ss \times I^A I^B Ss$ )

1/4 of the offspring will get an ss combination, so they won't secrete any protein.

3/16 of the offspring will get  $I^A I^A$  and either SS or Ss, so they will secrete A protein

3/16 of the offspring will get  $I^B I^B$  and either SS or Ss, so they will secrete B protein

3/8 of the offspring will get  $I^A I^B$  and either SS or Ss, so they will secrete both proteins

b. type O, ss × type AB, Ss (cross is  $ii ss \times I^A I^B Ss$ )

1/2 of the offspring are ss and will have no protein in saliva

1/4 are  $I^A i Ss$  and will secrete A protein

1/4 are  $I^B i Ss$  and will secrete B protein

12. Suppose you are studying the genetics of cardinals (an appropriate topic for a North Central student, don't you think?). You notice that some cardinals have dark eyes, while others have blue eyes. How could you determine which allele is dominant, dark or blue? (Looking for an experiment here, not an answer to the question of which is dominant.)

The dominant allele is defined as the one that determines the phenotype of a heterozygous individual. To be certain of getting a heterozygous cardinal, you would first want to find or develop pure-breeding dark-eyed and blue-eyed lines. Then you'd simply cross two of these pure-breeding individuals and look at the phenotype of their  $F_1$  offspring, which would all be heterozygous. If they were dark-eyed, then dark is dominant; if blue-eyed, then blue is dominant (a third color would mean there was incomplete dominance).

13. Have you seen the purple ketchup that young kids think is cool? Eeeeew! But what if you could grow a purple tomato?—you could make a fortune! After combing through 100s of tomato fields, you find a single tomato plant that produces purple tomatoes. You carefully cross it with an ordinary, red tomato plant and find that half of the offspring are purple and half are red. Thinking you'll be able to find a pure-breeding purple tomato, you cross pairs of purple offspring. No matter how many crosses you make, though, you find that the offspring of purple x purple always come out mostly purple, but with a smaller number of red and a similar number that have an odd blue-ish color.

a. Give a genetic explanation for how purple color is produced.

Every time purple is crossed with purple, you get purple, red and blue. This suggests that purple is the phenotype for heterozygous plants, and that the purple color is produced by incomplete dominance.

Notice that it's an intermediate color sort of halfway between red and blue. Then, a purple x purple cross should give 1 red : 2 purple : 1 blue, which is what it sounds like you're getting.

b. Diagram the purple x red cross and the purple x purple cross to show that the results match those you expect based on your hypothesis. Be sure to define your symbols clearly.

$C^R$  = red,  $C^B$  = blue; heterozygous  $C^R C^B$  = purple

The purple x red cross is then  $C^R C^B \times C^R C^R$ , and results should be 1/2  $C^R C^R$  (red) and 1/2  $C^R C^B$  (purple)

The purple x purple cross is  $C^R C^B \times C^R C^B$  and gives 1/4  $C^R C^R$  (red), 1/2  $C^R C^B$  (purple), 1/4  $C^B C^B$  (blue)

14. Suppose you are interested in breeding varieties of flowers for gardeners. You have pure-breeding plants of a particular kind which produce red flowers and small leaves. You also have pure-breeding plants of the same species which have blue flowers and large leaves.

You ask your assistant to cross the two and to give you the results of F<sub>1</sub> and F<sub>2</sub> crosses. Unfortunately, he forgets to record the phenotype of the F<sub>1</sub> plants in his notebook, though he does remember that they all looked the same. There were 1000 F<sub>2</sub> plants, and the results were:

red flowers, large leaves - 62  
red flowers, small leaves - 188  
blue flowers, large leaves - 63  
blue flowers, small leaves - 187  
purple flowers, large leaves - 124  
purple flowers, small leaves - 376

a. Are we dealing with two separate genes (flower color and leaf size), or does one gene control both traits? How do you know?

There must be two separate genes. If there were only one gene, then the red flowers and small leaves would always be inherited together, as would blue flowers and large leaves. We see all the possible combinations in the actual offspring, so these must be two genes assorting independently.

b. Which alleles are dominant? How do you know?

If we look at the two traits separately, we see that there are 249 large-leaved plants and 751 small-leaved plants: very close to  $\frac{3}{4}$  small,  $\frac{1}{4}$  large. This is the ratio we expect from crossing two heterozygous parents if small leaves are dominant.

Looking at color, we see 250 red, 250 blue and 500 purple—exactly  $\frac{1}{4}$  red,  $\frac{1}{4}$  blue and  $\frac{1}{2}$  purple. This looks just like what we'd expect if there were incomplete dominance for this gene; heterozygous plants have the intermediate, purple phenotype.

c. What would the genotype and phenotype of the F<sub>1</sub> plants have been? (Remember, they all looked the same.)

Now we can assign some symbols. Since small is dominant over large, let's use **S** for the leaf size gene and let **S** = small and **s** = large. There is incomplete dominance for the color gene, so the best symbol might be **C** for color, with **C<sup>R</sup>** for red and **C<sup>B</sup>** for blue.

Using this system, the original parents are **C<sup>R</sup>C<sup>R</sup> SS** (pure-breeding red, small) and **C<sup>B</sup>C<sup>B</sup> ss** (pure-breeding blue, large). Crossing these produces F<sub>1</sub> offspring that are all **C<sup>R</sup>C<sup>B</sup> Ss** - heterozygous for both genes and phenotypically purple with small leaves.

d. You would like to sell seeds which will grow only plants with large leaves and purple flowers, because these are different from anything currently on the market. What parent plants would you cross to be sure of producing the correct seeds?

Any large-leaved plant has the genotype **ss**; any red-flowered plant is **C<sup>R</sup>C<sup>R</sup>** and any blue-flowered one is **C<sup>B</sup>C<sup>B</sup>**. Therefore, you could cross any red-flowered plant with large leaves with any blue-flowered plant with large leaves and be certain that the cross is **C<sup>R</sup>C<sup>R</sup> ss x C<sup>B</sup>C<sup>B</sup> ss** and that all offspring will be **C<sup>R</sup>C<sup>B</sup> ss**, purple-flowered with large leaves.

15. Blood typing is often used in paternity cases (where there is a dispute about whether a particular man is the father of a child) as a preliminary screening method to rule out some possible fathers.

a. You are the judge in a paternity suit where the mother is not sure which of three men is the father of her child. You order blood tests for everyone and get these results:

Mother: type A  
Child: type B  
Mr. X type B  
Mr. Y: type O  
Mr. Z: type AB

Based on these results, can any of these men be eliminated (are there any who cannot be the father)? If so, which one(s)? Briefly explain your reasoning.

To be type B, the child must be  $I^B I^B$  or else  $I^B i$ . If the mother is type A, she has to be  $I^A i$ , because if she were  $I^A I^A$  she would've given an  $I^A$  allele to the child. The child therefore must've gotten  $i$  from the mother and must be  $I^B i$ . This means the father must have contributed an  $I^B$  allele. Either Mr. X ( $I^B I^B$  or  $I^B i$ ) or Mr. Z ( $I^A I^B$ ) could've done this, but Mr. Y (who has to be  $ii$ ) couldn't have. He can be eliminated.

b. Suppose you also get results for a second, separate blood antigen: the Rh factor. This factor is controlled by a separate gene, with only two alleles: positive and negative (positive is dominant over negative). Those results are as follows:

Mother: negative  
Child: positive  
Mr. X: negative  
Mr. Y: positive  
Mr. Z: positive

Based on this additional information, can anyone else be eliminated as the possible father? If so, which one(s) now cannot be the father? Explain briefly.

Suppose we use  $R$  for positive and  $r$  for negative. If the mother is negative, she is homozygous recessive ( $rr$ ), because this is a recessive trait. The child is positive and must've gotten a negative allele from the mother, so the child is heterozygous ( $Rr$ ). This means the father must've contributed a positive allele. Mr. X cannot do this, because he is also  $rr$ , so he can be eliminated.

c. Given all the information above, can you say for sure that one of these men is the father? Explain why or why not.

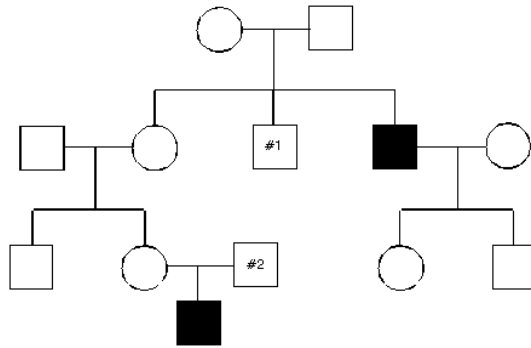
Of the three, only Mr. Z can be the father. However, we don't know that he is the father: any man who has type B or AB blood and is Rh+ could be the father.

16. In a separate paternity suit, a Type O woman accuses a Type A man of being the father of her Type AB child. After double-checking that the blood-type data are correct, you throw the case out of court and have the woman held for questioning! Why?

Something very odd is going on here: this woman cannot be the child's mother! If she's type O, then she's  $ii$ ; the child is  $I^A I^B$  and therefore couldn't have gotten either allele from this mother. It looks like a case of fraud.

17. For the traits shown in each of the following human pedigrees, state whether the most likely mode of inheritance is dominant or recessive. Base your decision only on the information given, and briefly state your evidence. If there's not enough information to decide between the two possibilities, say so. Then give the genotype for the two numbered individuals in each pedigree.

a.



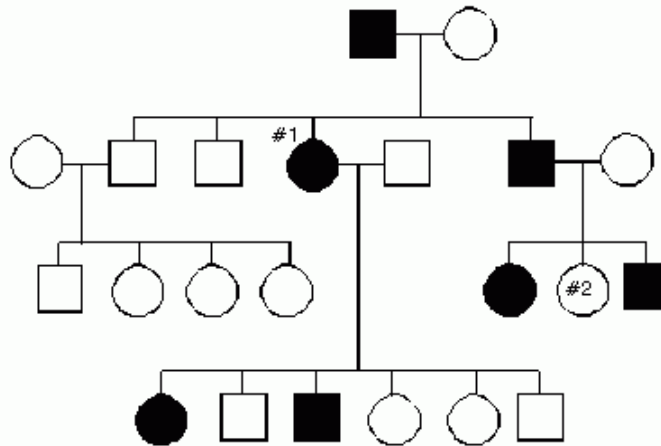
Mode of inheritance: dominant or [recessive](#)?

Evidence: [affected children have two unaffected parents.](#)

Genotype of #1: [Aa or AA \(can also be written A-\)](#)

Genotype of #2: [Aa](#)

b.



Mode of inheritance: dominant or recessive? [Dominant is the best answer.](#)

Evidence: [All affected children have at least one affected parent.](#)

Genotype of #1: [Aa](#)

Genotype of #2: [aa](#)

It is not [impossible](#) that this pedigree shows a recessive trait. If so, however, then all of the affected individuals would have to be [aa](#), and each of their unaffected parents would have to be a carrier, [Aa](#). This is pretty unlikely unless the recessive trait is extremely common; however, you would get full credit if you said you couldn't decide between dominant and recessive and explained how this could work. If, however, you were told that the disease was rare, then it would have to be dominant in this case.

18. Your friend is interested in breeding chickens, and he has recently acquired a pair of unusual, expensive blue-gray birds. He wants to breed the birds and sell the offspring. Unfortunately, when he mates his birds, he is surprised to find that the offspring are not all blue-gray! Instead, he gets the results below. Knowing that you are an Expert Geneticist, he comes to you for advice.

6 blue-gray males  
5 blue-gray females  
3 black males  
4 black females  
4 white males  
3 white females  
(25 total offspring)

a. Based on these results, how do you think the blue-gray color is inherited (dominant/recessive, sex-linked/autosomal, one gene/multiple genes)? Justify your conclusion.

This looks like incomplete dominance. There are three phenotypes, and blue-gray is intermediate between black and white. There is no difference between males and females, so no reason to suspect sex linkage. And it looks like just one gene, since the results fit a 1:2:1 pattern expected for incomplete dominance rather than a 9:3:3:1 pattern expected for two genes.

b. Why didn't your friend get all blue-gray offspring?

If there is incomplete dominance and blue-gray is the intermediate color, then any blue-gray bird is heterozygous. There is no way to get pure-breeding blue-gray birds.

If we let  $C^B$  represent black and  $C^W$  represent white, then the blue-gray birds are  $C^B C^W$ . Crossing two of these gives  $\frac{1}{4} C^B C^B$ , black;  $\frac{1}{2} C^B C^W$ , blue-gray, and  $\frac{1}{4} C^W C^W$ , white, which is very close to what was observed.

c. If your friend wants to be sure of getting all blue-gray offspring, what parents should he mate, and why?

Any black bird will be  $C^B C^B$  (the only way to get black), and any white bird will be  $C^W C^W$  (the only way to get white). Crossing these two would give all  $C^B C^W$  blue-gray offspring.

19. A pure-breeding plant with red flowers, yellow seeds, square stems, and serrated leaves with white veins is crossed with a pure-breeding plant having white flowers, pink seeds, round stems and smooth-edged leaves with green veins. All the offspring have red flowers, pink seeds, square stems, and serrated leaves with yellow veins.

a. If these offspring are crossed with each other and 1000  $F_2$  plants are obtained, how many of the offspring should have yellow seeds?

Let's look only at seed color. Pure-breeding yellow was crossed with pure-breeding pink, and the  $F_1$  (heterozygous) plants had pink seeds. Therefore, pink is dominant.

If  $P$ =pink and  $p$ =yellow, the  $F_1$  offspring are  $Pp$  and the  $F_2$  cross ( $Pp \times Pp$ ) should give  $\frac{3}{4} P-$  (pink) and  $\frac{1}{4} pp$  (yellow).  $\frac{1}{4}$  of 1000 is 250 offspring.

Notice that it doesn't matter what the other traits are;  $\frac{1}{4}$  of all the offspring will still have yellow seeds.

b. How many of the offspring should have yellow veins?

Now looking only at vein color, pure-breeding white crossed with pure-breeding green gave all yellow veins. This sounds like incomplete dominance: the heterozygote has a phenotype in between the two homozygous phenotypes.

If  $C^G$  = green and  $C^W$  = white, then the  $F_1$  are  $C^G C^W$  and the  $F_2$  should be  $\frac{1}{4} C^G C^G$  (green),  $\frac{1}{2} C^G C^W$  (yellow) and  $\frac{1}{4} C^W C^W$  (white).  $\frac{1}{2}$  of 1000 is 500 offspring.



20. A brown-haired woman has a blonde-haired child. She claims that her second husband, who has brown hair, is the father. However, her first husband, a blonde, believes the child must be his and sues his ex-wife for custody. The judge in the case orders blood typing for all the parties involved. The results are as follows:

	<b>Mother</b>	<b>Child</b>	<b>1<sup>st</sup> Husband</b>	<b>2<sup>nd</sup> Husband</b>
blood type	A	O	AB	B
hair color	brown	blonde	blonde	brown

- a. Based on the results of the blood typing, which husband would the judge decide was the father of the child? Explain (your explanation should include genotypes!).

The child's genotype must be **ii** (only way to get O). The first husband's genotype must be  $I^A I^B$ , so he can't contribute an **i** allele and therefore can be ruled out. The second husband could be  $I^B i$ , so he could be the father. The judge will therefore decide in favor of the second husband.

- b. The first husband probably never studied genetics and thinks it's impossible for two brown-haired people to have a blonde-haired child. Can you give him a clear, simple explanation of how this is possible?

Each individual has two forms of each gene (alleles), and a child gets one of his/her from each parent. Some alleles are dominant, meaning they will mask the effect of other alleles. Brown hair is caused by a dominant allele, so someone can have brown hair but carry a blonde allele in addition to the brown allele. If two of these brown-haired carrier parents have a child, the child can get one blonde allele from each and come out blonde.

- c. Although blood typing is helpful in resolving paternity disputes, it is impossible to say with certainty that a particular man is the father of a child based on blood-type results. Explain.

Blood typing can sometimes rule out a possible father (as in the case of husband #1), but it can never say with certainty who is the father. In this case, it could be husband #2, but it could also be any man with an  $I^A i$ ,  $I^B i$  or **ii** genotype.

21. Suppose you are studying the genetics of cardinal flowers (yes, it's a real flower: *Lobelia cardinalis*—a good research topic for an NCC student, right?). You cross a pure-breeding red flower and a pure-breeding white flower and get all red offspring. But, to your surprise, in the  $F_2$  generation, you get 1875 red and 125 white...far from the 3:1 ratio you expected. How would you explain these results? Diagram the  $F_2$  cross and show which genotypes result in which phenotypes.

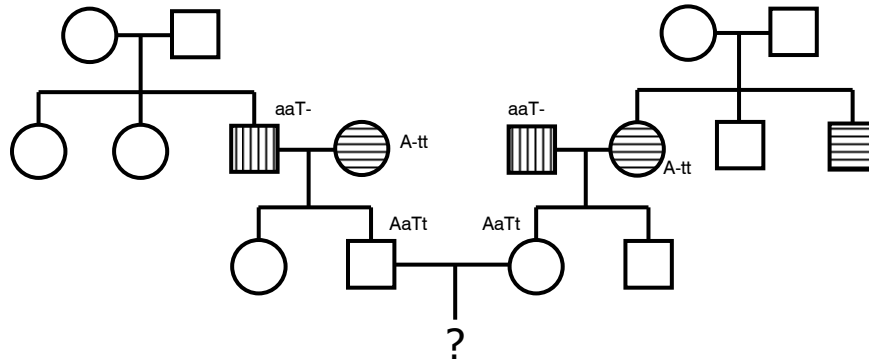
1875:125 is a perfect 15:1 ratio ( $2000/16 = 125$ ). Any cross that comes out in "16ths" must involve 2 genes (a variation of 9:3:3:1), so this looks like there are two genes involved in flower color and there is some kind of epistasis.

So, if we just call the genes A and B, then the pure-breeding parents must have been AABB (red) and aabb (white)...the  $F_1$  is all red, so we know that the white alleles of both genes must be recessive.

Now, the  $F_2$  must be AaBb x AaBb, and (as with any  $F_2$ ) cross, we get genotype ratios of 9/16 A-B-, 3/16 A-bb, 3/16 aaB- and 1/16 aabb.

How can this come out 15:1? Well, if only aabb is white (that is, if you have to be homozygous recessive for both genes to be white), then 1/16 of the offspring are white and all the rest are red.

22. The following pedigree shows the inheritance of two human genetic disorders. Symbols with vertical stripes indicate individuals who have alkaptonuria (an inherited metabolic disorder), and symbols with horizontal stripes indicate individuals who have tyrosinemia (an inherited enzyme deficiency).



- a. Based on the information here, is alkaptonuria a dominant trait or a recessive trait? Give specific evidence to justify your conclusion.

This must be a recessive trait. We see children who have alkaptonuria born to parents who do not. The only way for this to happen is for both parents to be carriers of a recessive trait and therefore not show it.

- b. Based on the information here, is tyrosinemia a dominant trait or a recessive trait? Give specific evidence to justify your conclusion.

This must be a recessive trait. We see children who have tyrosinemia born to parents who do not. The only way for this to happen is for both parents to be carriers of a recessive trait and therefore not show it.

- c. What is the chance that the couple at the bottom of the pedigree will have a child (indicated by the question mark) who has both alkaptonuria and tyrosinemia?

Each of the parents has a parent who has alkaptonuria. If we designate the alkaptonuria allele as **a**, then each parent has an **aa** parent; therefore, each of them must have inherited one **a** allele. We know their genotypes are **Aa** and not **aa** because they're not affected.

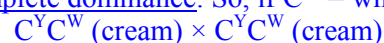
Similarly, each of the parents has a parent who has tyrosinemia. Therefore, both of them are carriers for this trait. If **t** represents the tyrosinemia allele, both are **Tt**

Now, we have the cross **AaTt x AaTt**. This is an ordinary dihybrid cross, and in a dihybrid cross, we expect 1/16 of the offspring to be homozygous recessive for both traits, **aatt**. Thus, there is **one chance in 16** of having a child with both diseases.

23. You buy a cream-colored guinea pig, and you like its color so much that you decide to breed it and sell the offspring (guinea piglets?). So, you buy a second cream-colored animal, but to your surprise, after several litters, you get 15 cream pigs but also 8 yellow and 6 white!

- a. Based on these results, briefly explain how color is inherited in guinea pigs and diagram the cross between the two cream animals. Be sure to define symbols.

There are three phenotypes, and the ratio is approximately 1:2:1, so it seems likely that cream (an intermediate phenotype) results from incomplete dominance. So, if  $C^W$  = white and  $C^Y$  = yellow, then the cross is:



$$\begin{array}{l} \downarrow \\ \frac{1}{4} C^Y C^Y \text{ (yellow)} \\ \frac{1}{2} C^Y C^W \text{ (cream)} \\ \frac{1}{4} C^W C^W \text{ (white)} \end{array}$$

- b. Is there any cross that would always yield cream-colored animals?

Sure. Just cross any yellow ( $C^Y C^Y$ ) with any white ( $C^W C^W$ )  $\rightarrow$  all  $C^Y C^W$  (cream).

24. In mice, coat color is determined by a gene, *B*, which has black and brown alleles. Black is completely dominant over brown. However, there is a second gene, *C*, which also affects color. Mice must have at least one dominant allele of this gene in order to show any color (black or brown); if they do not, they're white.

- a. A pure-breeding brown mouse is crossed with a mouse that is homozygous recessive for both genes. What are the genotypes and phenotypes of these two parents?

A pure-breeding brown mouse must be homozygous for brown (*bb*) and also homozygous dominant for color (*CC*). Its genotype is therefore *bbCC*.

The homozygous recessive is *bbcc*, and since it has no *C* allele, it has no color and is white.

- b. What are the genotypes and phenotypes of their  $F_1$  offspring?

The *bbCC* parent makes only *bC* gametes; the *bbcc* parent makes only *bc* gametes. Crossing these gives *bbCc*  $F_1$  offspring, all brown.

- c. If two of the  $F_1$  mice are crossed, what will be the phenotypes of their offspring, and in what proportions?

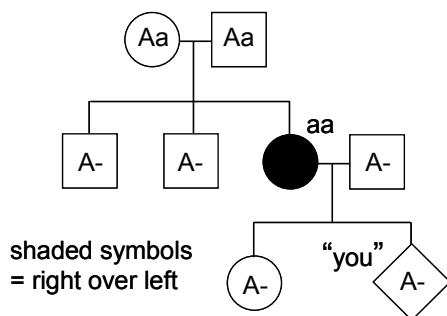
Now, cross *bbCc* x *bbCc*. Each parent makes  $\frac{1}{2}$  *bC* gametes and  $\frac{1}{2}$  *bc* gametes. This gives us a 4x4 Punnett square:

		<i>bC</i>	<i>bc</i>
<i>bC</i>		<i>bbCC</i> (brown)	<i>bbCc</i> (brown)
<i>bc</i>		<i>bbCc</i> (brown)	<i>bbcc</i> (white)

$\frac{3}{4}$  of the offspring will be brown, and  $\frac{1}{4}$  white.

25. Suppose you decide to further investigate the genetics of leg-crossing. You interview your maternal grandparents, your mother and father, your mother's two brothers and your sister. Your mother is the only one in the family who prefers right over left; everyone else prefers left over right.

- a. Draw the leg-crossing pedigree for your family.  
 b. Explain how leg-crossing is inherited, giving evidence from the pedigree.  
 c. Show the genotypes of your family members on the pedigree.



It looks like right-over-left is a recessive trait: your mother shows this trait, but neither of her parents does. This can only happen if she's homozygous recessive and her parents are both carriers. Everyone else in the pedigree has at least one dominant allele, but we can't be sure if they're homozygous or heterozygous.

26. Cystic fibrosis (CF) produces multiple defects throughout the body, including thickened lung mucus and lack of digestive enzymes. These different symptoms (phenotypes) could result from defects in two individual genes, or they could be different effects of a defect in one gene.

It is difficult to get enough offspring from humans of known genotypes to study a problem such as this genetically, but mice also get CF-like disease and can be used as model organisms. Suppose we have pure-breeding mice that show both the lung mucus phenotype and the digestive enzyme phenotype. The offspring from a cross between these mice and pure-breeding normal mice do not have any CF symptoms. How would you find out if these two phenotypes are due to a single gene or to two separate genes?

To attack this problem, diagram two separate crosses: one assuming that there is a single gene and one assuming that there are two separate genes. For each, show the symbols you will use and the genotypes and phenotypes of parents and offspring. Show clearly how the results of these two crosses would be different.

Pure-breeding CF mice crossed with pure-breeding normal mice show no symptoms, so we know the CF gene(s) have to be recessive.

If there is a single gene:

C = normal, c = CF

Parents: CC (pure-breeding normal) x cc (pure-breeding CF)

F<sub>1</sub> would be all Cc, phenotypically normal

F<sub>2</sub> (Cc x Cc) would be:  $\frac{3}{4}$  C- ( $\frac{1}{4}$  CC and  $\frac{1}{2}$  Cc), phenotypically normal  
 $\frac{1}{4}$  cc, CF symptoms (both lung and digestive)

If there are two genes:

l = thick lung mucus, L = normal

e = lack of digestive enzymes, E = normal

Parents: LLEE (pure-breeding normal) x llee (pure-breeding CF)

F<sub>1</sub> would be all LI Ee, phenotypically normal

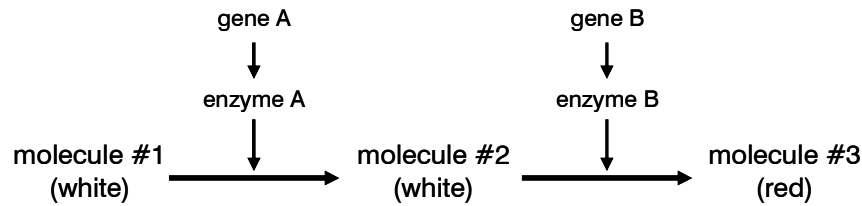
F<sub>2</sub> (LI Ee x LI Ee) would be:  $\frac{9}{16}$  L- E-, phenotypically normal  
 $\frac{3}{16}$  L- ee, normal for lungs but lacking digestive enzymes  
 $\frac{3}{16}$  ll E-, normal for digestive enzymes but thick mucus  
 $\frac{1}{16}$  ll ee, both CF symptoms

In an F<sub>2</sub> cross, if there were two genes for the two symptoms, then you would see separation of the two phenotypes (due to independent assortment). If there were only one gene, all mice would either have CF or be fully normal.

27. Diseases like cystic fibrosis and Tay-Sachs disease aren't caused by bacteria or viruses that you can "catch;" if you have one of these diseases, you inherited it and were born with it. In some cases, we can use drugs to treat these diseases (that is, reduce their symptoms), but we cannot cure the diseases with drugs (that is, there will never be a time when the patient can stop taking the drugs and be disease-free). What would we have to be able to do in order to cure one of these diseases?

Change at least one allele of the gene from the recessive to the dominant in the homozygous recessive individual who's afflicted with the disease.

28. A certain kind of flower is red because of a red pigment that requires two different genes. Gene A encodes an enzyme which catalyzes the conversion of colorless molecule #1 into a second colorless molecule, #2. The enzyme encoded by gene B catalyzes conversion of molecule #2 into a red pigment, molecule #3. Both enzymes must be working in order to make the red pigment, as shown below:



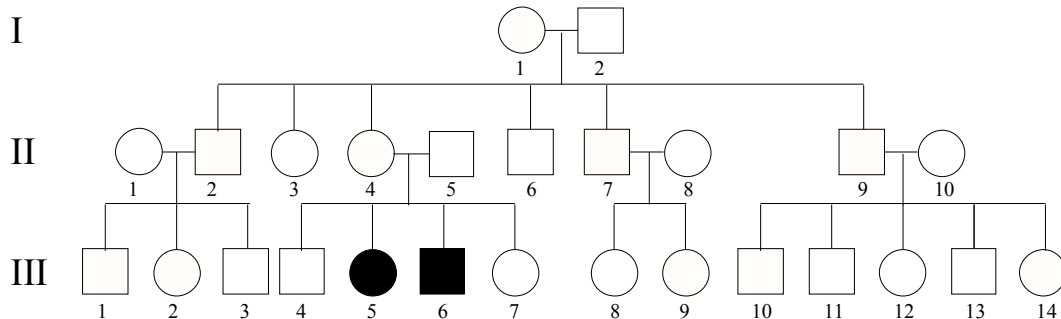
A pure-breeding white-flowered plant that produces no functional enzyme A or B is crossed with a pure-breeding red-flowered plant. Predict the phenotypes and ratios of the F<sub>2</sub> offspring.

Making red pigment requires both enzymes, so at least one functional copy of each gene. Non-functional alleles are usually recessive, so a functional copy of gene A would be the **A** allele and the non-functional version would be **a**. Similarly, **B** is the functional allele for gene B and **b** is non-functional.

Now, we can say that any plant that has at least one dominant allele for each gene, **A-B-**, will be red, and every other genotype (**aa** with anything and **bb** with anything) will be white.

The original pure-breeding plants are **AABB** (red) and **aabb** (white). Their F<sub>1</sub> offspring will have to be all **AaBb** (red). The F<sub>2</sub> cross then produces 9/16 **A-B-** (red) and 3/16 **aaB-** + 3/16 **A-bb** + 1/16 **aabb** or a total of 7/16 white.

29. A pedigree for Gaucher disease, a human genetic disorder resulting in anemia and problems with liver and spleen function, is shown below.



- a. Gaucher disease is caused by a recessive allele. Give specific evidence from the pedigree that supports this conclusion.

Individuals III-5 and III-6 are affected, but neither of their parents (II-4 and II-5) is. Affected children of unaffected parents is the best evidence for a recessive trait.

- b. If we assumed that the Gaucher allele is extremely rare in the population, could it actually be a dominant allele? Explain why or why not, using specific evidence from the pedigree.

No, it could not. Individuals III-5 and III-6 would have to have received at least one dominant disease allele each, meaning that at least one of their parents (II-4 or II-5) had an allele to give, and if this were the case then II-4 or II-5 would've had the disease.

- c. What is the genotype of each of the following individuals:

- (i) II-4 **Aa**
- (ii) II-5 **Aa**
- (iii) I-2 **Aa or AA**

30. A man is accused of being the father of a child. In court, he swears he has never slept with the child's mother. The judge orders a blood test for all the parties. The man's blood type is A, the mother's is B, and the baby's is O.

a. Could this man be the father of the child? Explain, showing genotypes.

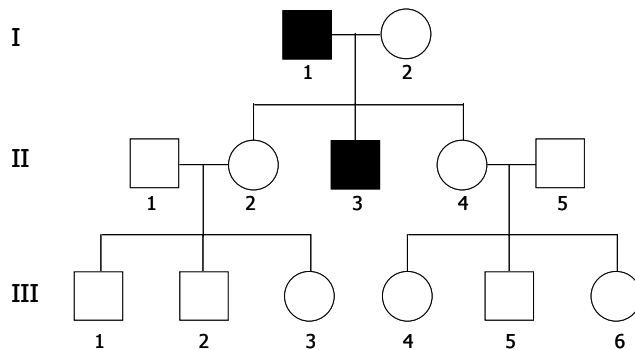
Yes, he could. The baby's genotype is  $ii$ , so the mother's must've been  $I^B i$  in order for her to donate a recessive  $i$  allele. The father's genotype could be  $I^A i$ , and he could then also give a recessive  $i$  allele.

b. What do you think the judge will do next?

The blood test shows that this man could be the father but can't determine if he is the father (that is, it could be someone entirely different who also has an  $i$  allele). DNA testing could make this determination.

31. The human pedigree below is for myotonic dystrophy, a rare genetic disease which begins with muscle weakness and progresses until the patient has difficulty controlling any muscular movements.

a. Is this disease most likely to be due to a dominant allele or a recessive allele? Give specific evidence.



It could be recessive ( $mm \times Mm$  in generation I), but this would require an affected individual to find a carrier to marry—unlikely if it's a rare trait. So it's most likely dominant. You got credit if you said it was recessive and had a good explanation, however, please remember that being rare is not good evidence that something is recessive!

b. Assign appropriate symbols for the alleles of this gene.

If it's dominant, then  $M$  = myotonic dystrophy and  $m$  = normal would be fine, or any other single letter you'd like to choose. If you said it's recessive, then they'd be reversed.

c. What is the genotype of person #II-3?

If it's dominant, then this person must be  $Mm$  (because the mother, I-2, is  $mm$ ).

If you said it's recessive, then this person would be  $mm$ .

d. What is the genotype of person #III-4?

If it's dominant, then this person must be  $mm$  (because unaffected).

If you said it's recessive, then she would be  $M-$ : we don't know if II-4 was  $Mm$  or  $MM$ .

32. While working at your summer job as a campus groundskeeper (mmmm...love those humid summer afternoons!), you notice that among all the ordinary short, yellow marigolds there is one exceptionally tall plant with bright red flowers.

Thinking you could make some money by selling an unusual plant variety, you do a cross between the tall, red plant and a short, yellow plant. The results are a little disappointing—in fact, you get no red offspring at all and only some of your offspring are tall:

457 short marigolds with orange flowers  
439 tall marigolds with orange flowers

- a. Looking at plant height, give the genotypes of the parents and the genotypes and phenotypes of the offspring. Don't forget to define your symbols.

Because we got  $\frac{1}{2}$  tall and  $\frac{1}{2}$  short, then either the tall or the short parent must be heterozygous. One answer, then, is that the tall parent is heterozygous ( $T = \text{tall}$ ,  $t = \text{short}$ ; genotype is  $Tt$ ) and the short parent is homozygous ( $tt$ ), leading to half tall ( $Tt$ ) and half short ( $tt$ ) offspring. This is actually the most likely answer, since one tall flower in a field of short flowers isn't likely to have gotten a mutation in both alleles of the height gene.

But, you can't determine for sure which is dominant in this problem, so it would also be correct to say that the tall parent is homozygous ( $S = \text{short}$ ,  $s = \text{tall}$ ; genotype is  $ss$ ) and the short parent is heterozygous ( $Ss$ ), again leading to half tall ( $ss$ ) and half short ( $Ss$ ) offspring.

- b. Looking at flower color, give the genotypes of the parents and the genotypes and phenotypes of the offspring. Don't forget to define your symbols.

Here, we crossed red with yellow and got all orange. This sounds like a case of incomplete dominance, since we have a third phenotype which seems to be intermediate between the other two. If so, then the red and yellow parents must both have been homozygous ( $C^R = \text{red}$ ,  $C^Y = \text{yellow}$ —notice the superscript symbols that are standard for incomplete dominance—with parents  $C^R C^R \times C^Y C^Y$ ). All the offspring would then be  $C^R C^Y$  and the intermediate heterozygous color is orange.

- c. In order to make your commercial venture a success, you need a reliable way to obtain seeds that will grow tall, red marigolds. What plants could you cross that would always give you tall, red offspring, and how would you obtain these parents?

If you want all tall, red offspring, you'd have to ensure that both parents in your cross were homozygous for both the tall and red traits. If you said that tall is recessive, this is easy, because any tall plant is homozygous and any red plant is homozygous. If, however, you said that tall is dominant, then a tall, red plant will be homozygous for red but might not be homozygous for tall. To be sure, you'd want to do a testcross: cross the tall red with a short plant and see if any offspring came out short. If not, it's homozygous tall and would be a good parent to produce seeds.

33. In gerbils, fur color is controlled by two different genes. One gene determines how much black pigment is produced; there are two alleles, producing black and tan colors. These two alleles show incomplete dominance, and heterozygotes are brown. A second gene determines whether any pigment (of any color) is produced: at least one dominant allele of this gene is required in order for gerbils to be black, brown or tan; otherwise, they are white. This second gene is sex-linked.

- a. What would be the most appropriate symbols to use for the two alleles of the first gene (controlling black, brown and tan colors)?

The black-brown-tan gene is not sex-linked, so we can use ordinary letters. However, it does show incomplete dominance, so we don't want to use B and b, or we won't realize there's incomplete dominance going on. B and T would also be a mistake, because that violates the one-gene-one-letter rule. So, it would be best to use a single letter to represent the gene, such as maybe F for fur, and use capital superscripts to show the two incompletely dominant alleles:

$F^B$  = black allele,  $F^T$  = tan allele (then the  $F^B F^T$  genotype gives brown fur by incomplete dominance)

- b. What would be the most appropriate symbols to use for the two alleles of the second gene (controlling whether any pigment is made)?

This gene is sex-linked, so we need to use X to indicate that it's on the X chromosome. We could use the letter C (for color) to represent this gene, and since colored is dominant over white, we'd have:

$X^C$  = color allele (dominant),  $X^c$  = white allele (recessive)

- c. What would be the genotype of a black male gerbil?

The only way to get black is  $F^B F^B$ , and at least one  $X^C$  allele is necessary to show this color. Since it's a male, it can only have one X chromosome and thus only one  $X^C$  allele:  $F^B F^B X^C Y$

- d. What would be the genotype of a white female gerbil that had one black parent and one tan parent?

The only way to get white in a female is with two recessive  $X^c$  alleles (since she has two X chromosomes). Since  $X^c X^c$  results in white no matter what alleles there are for the other gene, her phenotype doesn't help us with the F alleles. But we know that she had a black parent, which must have been  $F^B F^B$ , and a tan parent, which must have been  $F^T F^T$ , so she must have gotten one black allele and one tan allele (heterozygous). Therefore, she's  $F^B F^T X^c X^c$

- e. If these two gerbils are mated, what genotypes will you expect among their offspring, and in what proportions?

The cross is  $F^B F^B X^C Y \times F^B F^T X^c X^c$ . We can use an ordinary Punnett square to show how the gametes are formed and combined, so long as we keep track of males and females:

The genotypes expected are the ones shown in the square, with each one occurring  $\frac{1}{4}$  of the time.

	$F^B X^C$	$F^B Y$
$F^B X^c$	$F^B F^B X^C X^c$	$F^B F^B X^c Y$
$F^T X^c$	$F^B F^T X^C X^c$	$F^B F^T X^c Y$

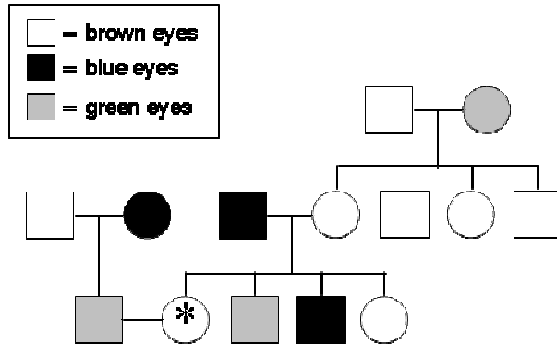
- f. What phenotypes will you expect, and in what proportions?

Females will always be colored (getting an  $X^C$  from the father), and half will be black and the other half tan.

Males will always be white, getting an  $X^c$  from the mother.



34. Human eye color is actually much more complicated than the simple brown-dominant-over-blue model you may have seen before. Eye color can be partly explained by looking at two different genes, *bey* and *gey*. There are two alleles of the *bey* gene, brown (*B*) and blue (*b*), and brown is completely dominant over blue. There are also two alleles of the *gey* gene, green (*G*) and blue (*g*). The green allele is completely dominant over the blue *gey* allele. However, the two genes interact as follows: (1) if there is at least one brown *bey* allele, eyes will be brown even if there is a green *gey* allele, and (2) if there is at least one green *gey* allele, eyes will be green as long as there's no brown *bey* allele.



a. What is the probability that the woman marked with the asterisk (\*) has the genotype  $BbGg$ ?

We know her blue-eyed father is  $bbgg$ , so for the *bey* gene, she has to be  $Bb$  (she has brown eyes). She has both blue-eyed and green-eyed siblings, so her mother must have been  $Gg$  for the *gey* gene. This means she has a 50% ( $\frac{1}{2}$ ) chance of being  $Gg$ .

b. If this is actually her genotype, what is the probability that she'll have a green-eyed child?

Her husband's mother has blue eyes, and his are green, so he must be  $bbGg$ . The cross is then  $bbGg \times BbGg$ . From this cross,  $\frac{1}{2}$  the offspring should be  $bb$ , and  $\frac{3}{4}$  either  $Gg$  or  $GG$ , so the probability is  $\frac{3}{8}$  that the child will be either  $bbGg$  or  $bbGG$  and have green eyes.

**True or False? Read carefully: a question is false unless it is completely true!**

- T**  **F**  1. If heterozygous individuals have a distinct phenotype that is intermediate between the two homozygous phenotypes, we define this as incomplete dominance.
- T**  **F**  2. Mendel's rules of inheritance are useful in studying some genes, but they don't work if there are more than two alleles in the population or if dominance is incomplete.
- T**  **F**  3. A testcross can be used to determine the genotype of an unknown organism.
- T**  **F**  4. Recessive human traits can be easily recognized in a pedigree because they are rare.
- T**  **F**  5. For some traits, such as blood type, individuals can have three alleles of a gene, instead of the normal two.
- T**  **F**  6. The  $\chi^2$  test can be used to evaluate a genetic hypothesis. If the  $p$ -value calculated from  $\chi^2$  is  $>0.05$ , the hypothesis is correct.
- T**  **F**  7. Individuals have two alleles for most genes. However, for some genes, an individual can have three or more alleles.
- T**  **F**  8. If an individual heterozygous for the sickle-cell anemia allele makes two kinds of hemoglobin protein, one normal and one misfolded, this would be an example of codominance.
- T**  **F**  9. The A-B-O blood groups illustrate two important genetic complexities that Mendel didn't anticipate: multiple alleles and incomplete dominance.
- T**  **F**  10. Although epistasis and incomplete dominance result in different ratios than in Mendel's pea-plant crosses, Mendel's two laws still apply to these situations.
- T**  **F**  11. The chi-squared test ( $\chi^2$ ) is used to evaluate a genetic hypothesis; the  $p$ -value tells you how likely it is that your hypothesis is correct.
- T**  **F**  12. In a pedigree, a trait which shows up in an individual and in one of his/her parents must be a dominant trait.
- T**  **F**  13. The larger the  $\chi^2$  value, the less well the actual data fit the results predicted by a genetic hypothesis.
- T**  **F**  14. A man with blood type O could not be the father of a type A child.
- T**  **F**  15. A man with blood type AB could not be the father of a type O child.
- T**  **F**  16. Standard deviation measures how accurate data are.

- T**  **F**  17. Dominant traits occur more commonly than recessive traits.
- T**  **F**  18. Co-dominance would not change the genotype ratios of an  $F_2$  cross, but would produce a phenotype ratio of 1:2:1 rather than 3:1.
- T**  **F**  19. One gene can produce multiple phenotypic effects, or two or more genes may combine to produce a single inheritable characteristic.
- T**  **F**  20. Simple traits obey Mendel's two laws, but inheritance of more complicated traits involving incomplete dominance, multiple alleles or epistasis cannot be predicted using simple Mendelian genetics.
- T**  **F**  21. A child with blood type AB+ is born to an A- mother. A man with type O+ blood could NOT be the father of this child.
- T**  **F**  22. For some genes, an individual can have three or more alleles.
- T**  **F**  23. One character can be controlled by multiple genes. This is known as pleiotropy.
- T**  **F**  24. For a genetic disease caused by a dominant allele, there are no carriers.
- T**  **F**  25. Recessive traits are usually rare.
- T**  **F**  26. Filled-in symbols in pedigrees represent individuals that show a recessive trait.
- T**  **F**  27. Recessive traits are very rare, because it is necessary to inherit two recessive alleles in order to show the trait phenotypically.
- T**  **F**  28. If a woman who has a genetic disease and is heterozygous for the disease allele marries a man who does not have the disease, there is a 50-50 chance their first child will have the disease.
- T**  **F**  29. In incomplete dominance, a heterozygous individual has a phenotype which is intermediate between the two homozygous phenotypes.

### Matching:

1. Below are results from some crosses, some of which would have surprised Mendel a bit. Match each with the term that best describes what's going on.

<u>B</u>	Two pure-breeding parents are crossed. All offspring have a phenotype that is different from either parent.	a. complete dominance b. incomplete dominance
<u>C</u>	A child with blood type AB is born to a type A parent and a type B parent.	c. codominance d. overdominance
<u>E</u>	A child with blood type O is born to a type A parent and a type B parent.	e. multiple alleles f. dihybrid cross
<u>A</u>	In a cross between two parents with the same phenotype, $\frac{3}{4}$ of the offspring resemble the parents and $\frac{1}{4}$ do not.	g. can't happen

### Fill in the blank:

1. If an individual's two alleles for a given gene are different, we say that individual is **heterozygous**. If we're interested in a recessive trait, this individual could be considered a(n) **carrier**, because he/she would not show the trait but could pass it on.
2. If the offspring of two pure-breeding parents have a phenotype which is intermediate between the two parent phenotypes, we say this gene shows **incomplete dominance**.