PRACTICE PROBLEMS IN GENETICS PLUS SOLUTIONS

Problems Involving One Gene

1. In cats, long hair is recessive to short hair. A true-breeding (homozygous) short-haired male is mated to a long-haired female. What will their kittens look like?

2. Two cats are mated. One of the parent cats is long-haired (recessive allele). The litter which results contains two short-haired and three long-haired kittens. What does the second parent look like, and what is its genotype?

3. Mrs. And Mr. Smith both have widow's peaks (dominant). Their first child also has a widow's peak, but their second child doesn't. Mr. Smith accuses Mrs. Smith of being unfaithful to him. Is he necessarily justified? Why or why not? Work the genetics problem predicting the frequencies of the versions of this trait among their prospective children.

4. Mr. and Mrs. Jones have six children. Three of them have attached earlobes (recessive) like their father, and the other three have free earlobes like their mother. What are the genotypes of Mr. and Mrs. Jones and of their numerous offspring?

5. Mr. and Mrs. Anderson both have tightly curled hair. (The hair form gene shows incomplete dominance. There are two alleles, curly and straight. The heterozygote has wavy hair.) The Andersons have a child with wavy hair. Mr. Anderson accuses Mrs. Anderson of being unfaithful to him. Is he necessarily justified? Why or why not?

6. Two wavy haired people (one male and one female) marry and have eight children. Of these eight, how many would you expect to be curly haired, how many wavy haired and how many straight haired, assuming that the family follows the expected statistically predicted pattern? Suppose you examine the actual children and discover that three of the eight have curly hair. What do you suppose went wrong?

7. Basic body color for horses is influenced by several genes, on of which has several different alleles. Two of these alleles—the chestnut (dark brown) allele and a diluting (pale cream) allele (often incorrectly called 'albino')—display incomplete dominance. A horse heterozygous for these two alleles is a palomino (golden body color with flaxen mane and tail). Is it possible to produce a herd of pure-breeding palomino horses? Why or why not? Work the Punnett's square for mating a palomino to a palomino and predict the phenotypic ratio among their offspring.

8. In certain portions of the Jewish population, there is a genetic disease called Tay Sachs disease, which is fatal to infants within the first five years of life. This disease is caused by a recessive allele of a single gene. Why does this disease persist, even though it is **invariably** fatal long before the afflicted individual reaches reproductive age? (In other words, why doesn't the allele for Tay Sachs disease simply disappear?)

9. About 80% of the human population can taste the chemical phenolthiocarbamide (PTC), while the other 20% can't. This characteristic is governed by a single gene with two alleles, a tasting allele and a non-tasting allele. What does this statistic tell us about which allele (tasting or non-tasting) is dominant?

10. In fruit flies, the gene for wing shape has an unusual allele called 'curly' (designated 'Cy'). The normal (wild type) allele is designated 'cy.' A fly homozygous for cy (cy cy) has normal, straight wings. The heterozygote (Cy cy) has wings which curl up on the ends (and, incidentally, can't really fly). The homozygote for the Cy allele (Cy Cy) never hatches out of the egg. In other words, this allele is lethal in

the homozygous condition. If two curly winged flies are mated, and the female lays 100 eggs, predict the following, showing appropriate work:

a. How many eggs will produce living offspring?
b. How many straight winged flies do you expect among the living offspring?
c. What percentage of the living offspring do you expect to be curly winged like the parents?

11. In cattle, there is an allele called dwarf which, in the heterozygote, produces calves with legs which are shorter than normal. This, again, is a homozygous lethal (the homozygous dwarf calves spontaneously abort early or a stillborn). If a dwarf bull is mated to 400 dwarf cows, what phenotypic ratio to you expect among the living offspring?

Problems Involving Two Genes

1. A man with dark (dominant), curly (see problem I.5.) hair marries a woman with light, straight hair. Their daughter, who happens to have dark hair, marries a man with light, wavy hair. Answer the following questions about this dark-haired daughter and her family.
   a. Draw a Punnett's square for this marriage, and predict the phenotypic ratio among the offspring of the daughter and her husband.
   b. What is the chance that they will have a child with hair just like his or her father's?

2. In cats, again, black color is dominant to a special, temperature-sensitive albino gene which produces cats with dark legs, faces and tails (Siamese cats, in case you don't recognize it). A short haired (dominant) Siamese colored female is bred to a long-haired black male. They have eight kittens: 2 black, short-haired; 2 black, long-haired; 2 Siamese, short-haired; and 2 Siamese, long-haired. What were the genotypes of the two parents?

3. Elizabeth is married to John, and they have four children. Elizabeth has a straight nose (recessive) and is able to roll her tongue (dominant). John is also able to roll his tongue, but he has a convex (Roman) nose (dominant). Of their four children, Ellen is just like her father, and Dan is just like his mother. The other children—Anne, who has a convex nose, and Peter, who has a straight nose—are unable to roll their tongues. Please answer the following questions about this family.
   a. What are the genotypes of Elizabeth and John?
   b. Elizabeth's father was a straight-nosed roller, while her mother was a convex-nosed non-roller. What can you figure out about **their** genotypes?
   c. John's father was a straight-nosed roller, while his mother was a convex-nosed roller. What can you determine about their genotypes?
   d. Diagram the three described generations of this family in accepted pedigree form, including the phenotypes for these two traits.

4. If a pure-breeding (homozygous) black (dominant), long-haired (recessive) cat is mated to a pure-breeding Siamese, short-haired cat, and one of their male offspring is mated to one of their female offspring, what is the chance of producing a Siamese colored, short-haired kitten?

5. In horses, one which runs best in water (or in wet conditions) is called (WATER), and one which runs best in dry conditions is called (DRY). (WATER) is recessive to (DRY). A horse can also be either a trotter, which we will designate (GAIT) or a pacer, which we will designate (PACE). (PACE) is recessive to (GATE). We have mated two horses, a stallion named Halter-Man and a mare named Erlich-Mane. Halter-Man is a (WATER)(PACER), while Erlich-mane is a (DRY)(GAIT). One of Erlich-Mane's parents was a (WATER)(PACER). What are the chances of Erlich-Mane and Halter-Man producing a (WATER)(GAIT) foal (that's a baby horse, in case you didn't know)?

6. When a male pig from a line of true-breeding (homozygous) black, solid-hooved pigs was crossed to a female from a breed (homozygous) of red, cloven-hooved pigs, their several progeny all looked alike with regard to color and hooves. These progeny were all mated to members of the same breed as their red, cloven-hooved mother pig. The offspring from this final cross were: 11 black, cloven-hooved; 8 black, solid-hooved; 14 red, cloven-hooved; and 10 red, solid-hooved. For each of these two genes (coat color and hoof type) determine which allele is the dominant one. Explain your reasoning. What were the phenotypes of the progeny produced by the first mating in this problem?

7. In garden peas, long stems are dominant to short stems, and yellow seeds are dominant to green seeds. 100 long/yellow pea plants, all of which had one short/green parent, are interbred (bred to each other). 1600 progeny result. Please answer the following questions about these progeny.
   a. Assuming that these two genes are unlinked, about how many long/green pea plants would you expect to find among the offspring?
   b. What ratio of yellow to green seed color would you expect among the offspring?
   c. What would you expect the overall phenotypic ratio among the 1600 offspring to be (taking into consideration both traits)?

Problems Involving Sex Linkage

1. Plutonian Tickle-bellies have a sex determination system just like mammals. Hairy Snout is a holandric trait (carried on the Y chromosome). MyxRotcccc, a handsome male Tickle-belly, has lovely orange hair on his snout. He and his mate, OrgggWny, have six offspring, three boys and three girls. Please answer the following questions about this family.
   a. How many of MyxRotcccc's and OrgggWny's offspring have hairy snouts? Can you predict which ones?
   b. Their eldest son, Bob, marries and has a son. What is the chance that Bob's son will also have a hairy snout?
   c. JoKchew, MyxRotcccc's and OrgggWny's youngest daughter, marries a male who has a smooth, hairless purple snout. She has eight offspring, each one lovelier than the last, and all boys. What percentage of these offspring do you expect to have hairy snouts? Explain.

2. In fruit flies (*Drosophila*), one eye color gene is X-linked, with a recessive white allele and a dominant red allele. If white-eyed female flies are bred to red-eyed male flies, describe the expected offspring (assume all parental flies are true-breeding). What results do you expect if you do the **reciprocal cross** (reverse the phenotypes of the parent flies)?

3. Earl has normal color vision, while his wife Erma is colorblind. . Colorblindness is an X-linked trait, and the normal allele is dominant to the colorblindness allele. If they have a large family, in what ways should the colorblindness trait affect their children?

4. Ethan is colorblind. His wife, Edna, is homozygous for the normal color vision allele. If they have eight children, how man of them would you expect to be colorblind? Using Punnett's squares, derive and compare the genotypic and phenotypic ratios expected for the offspring of this marriage and those expected for the offspring of the marriage described in III.3.

5. Marian's father is colorblind, as is her maternal grandfather (her mother's father). Marian herself has normal color vision. Marian and her husband, Martin, who is also colorblind, have just had their first child, a son they have named Mickey. Please answer the following questions about this small family.
   a. What is the probability that this child will be colorblind?
   b. Three sources of the colorblindness allele are mentioned in this family. If Mickey is colorblind, from which of these three men (Marian's grandfather, Marian's father, or Martin) did he inherit the allele?

c. Using proper pedigree format, diagram the available information about the four generations of this family described, assuming that Mickey is colorblind.
d. If Martin were not colorblind, how would this affect the prediction about Mickey?

6. In cats, there is a coat color gene located on the X chromosome. This gene is a different gene from the black/Siamese gene discussed in earlier problems. This gene has two alleles—orange and black. A heterozygous cat has tortoiseshell color (a splotchy mixture of orange and black). Predict the genotypic and phenotypic frequencies among the offspring of the following crosses. Pay careful attention to the **genders** of the offspring.
   a. Black female X Orange male
   b. Orange female X Black male
   c. Tortoiseshell female X Black male
   d. Tortoiseshell female X Orange male

Problems Involving Genes With Multiple Alleles

1. In a particular family, one parent has Type A blood, the other has Type B. They have four children. One has Type A, one has Type B, one has Type AB, and the last has Type O. What are the genotypes of all six people in this family?

   NOTE: The ABO blood type gene has three alleles. $\mathbf{I^A}$ and $\mathbf{I^B}$ are codominant; **i** (for Type O) is recessive to both.

2. Refer to problem I.3. Mrs. Smith has blood type A. Mr. Smith has blood type B. Their first child has blood type AB. Their second child has blood type O. **Now** is Mr. Smith justified? What are Mr. and Mrs. Smith's genotypes for these two genes?

3. In a recent case in Spokane, Washington, a young woman accused a soldier of being the father of her child. The soldier, of course, denied it. The soldier's lawyer demanded that blood types be taken to prove the innocence of his client. The following results were obtained: Alleged father, Type O. Mother, Type A. Child, Type AB. The court found the soldier guilty on the basis of the woman's remarkable memory for dates and details that apparently eliminated all other possible fathers.
   a. What are the possible genotypes for these three people?
   b. Do you agree with the court's decision? Why or why not?

4. It was suspected that two babies had been exchanged in a hospital. Mr. and Mrs. Jones received baby #1 and Mr. and Mrs. Simon received baby #2. Blood typing tests on the parents and the babies showed the following:

Mr. Jones: Type A Mrs. Jones: Type O	Mr. Simon: Type AB Mrs. Simons: Type O
Baby #1: Type A	Baby #2 Type O

   Were the babies switched? How do you know whether they were or they weren't?

5. A man with type O blood marries a woman with Type AB blood. Among their children, what proportion would you expect to have blood types like one or the other of these parents? What proportion would have expect to have blood types different from both parents? Explain.

6. You are a scientist performing the first analysis of the genetic basis for the inheritance of flower color in a certain species of wildflower. You begin your investigation by observing that there are four different flower colors in the local wild population: white, red, blue and purple. Your first assumption

(hypothesis) is that you are looking at the effects of a single gene, so operate under that assumption. You collect a variety of samples of all colors, take them back to your greenhouse, and begin making crosses. Remember, you are crossing members of a wild population—you have no idea whether any of your plants are homozygous or heterozygous. Here are the various results you observe:

White X White	All offspring always produce white flowers.
Red X Red	In some matings, all offspring produce red flowers. In other matings, some of the offspring produce red flowers, some white, with red flowering offspring outnumbering white flowering offspring.
Blue X Blue	In some matings, all offspring produce blue flowers.. In other matings, some of the offspring produce blue flowers, some white with blue flowering offspring outnumbering white flowering offspring.
Purple X Purple	Always produces a mixture of red, blue and purple flowering offspring, with purple most frequent, followed by red and blue in roughly equal numbers,
White X Red	In some matings, all offspring produce red flowers. In other matings, some of the offspring produce red flowers, some white. Red and white occur in roughly equal numbers..
White X Blue	In some matings, all offspring produce blue flowers. In other matings, some of the offspring produce blue flowers, some white. Blue and white occur in roughly equal numbers..
White X Purple	Always produces roughly equal numbers of blue flowering offspring and red flowering offspring.
Red X Blue	Always produces purple offspring, but in some matings also produces red and/or blue offspring, and/or white offspring
Red X Purple	Always produces red and purple offspring, sometimes mixed with blue.
Blue X Purple	Always produces blue and purple offspring, sometimes mixed with red.

a. How many alleles are governing flower color in this plant? What color does each of these alleles produce (in other words, what colors are your homozygous plants)?
b. Explain the dominance relationships among your alleles, and explain the results of each of the crosses described above.

NOTE: This problem has a relatively high difficulty level.

7. A woman has a daughter. There are three men whom she claims might have been the father of the child. The judge in the paternity court orders that all three men, the child, and the mother have blood tests. The results are: mother, Type A; Daughter, Type O; Man #1, Type AB; Man #2, Type B; Man #3, Type O. The mother claims that this proves that Man #3 must be the little girl's father.
   a. Is the mother correct? Why or why not?
   b. The judge isn't satisfied, so he asks for the medical records of the people involved. He discovers that the little girl is colorblind. Men #'s 1 and 2 are also colorblind; Man #3 has normal color vision, as does the mother. (NOTE: Colorblindness is X-linked and recessive.) Assuming that one of these three men **must** be the father, can you now determine which of the three it is?

8. Another woman has the same problem. Her blood type is A, her child's is B. She again has three candidates for fatherhood. Their blood types are: Man #1, B; Man #2, AB; Man #3, O. Based on blood types, the mother says it must have been #1.
   a. Do you agree? Why or why not?
   b. This child, a son this time, is also colorblind. The only one of the men in question to share this characteristic is #2. The mother is not colorblind. Can you now determine who the father of the little boy is, assuming it must be one of these men? Explain your answer.

Problems Involving Gene Interactions

1. In cats, there is a gene which produces ticked fur (bands of different colors on each hair) called Agouti (H). The recessive allele (h) for this gene produces hair which is a solid color from end to end. In addition, there is a coat color gene which has a recessive albino allele (a) which, in the homozygote, prevents the production of any coat color pigment, resulting in a white cat with pink eyes, the traditional albino. Note that this problem has described two completely different genes. These genes are unlinked. An albino female cat is mated to a solid brown male cat. All of their offspring are Agouti. The males and females among these offspring are allowed to freely intermate, producing a flock of F_2 kittens. Predict the phenotypic ratio for fur color among these many grandkittens.

2. In *Drosophila* (fruit flies), the wild type eye color, brick red, is actually produced by the deposition of two pigments in the eyes, a dull brown pigment and a brilliant red pigment. These two pigments are produced by the action of two different, non-allelic (and non-linked) genes. Each of these genes has two alleles, a dominant one which causes normal the production of the pigment controlled by the gene, and a recessive one which is defective, and causes none of that pigment to be produced. Thus, a normal eye-color fruit fly must have at least one dominant allele for each of these genes.

   If a fly is homozygous for the defective, recessive allele of the gene which produces the brown pigment, that fly will have only the brilliant red pigment in its eyes. This condition is called "cinnabar." For this reason, the gene responsible for producing the brown pigment is called the "cinnabar" gene (genes are often named for the effect their mutant alleles have on the phenotype). The symbol for this gene is a two-letter symbol, cn. The dominant allele is **Cn** and the recessive allele is **cn**. Careful with this symbol. Never separate the c's from the n's. So a cinnabar-eyed fly would have the genotype **cn cn**.

   If a fly is homozygous for the defective, recessive allele of the gene which produces the brilliant red pigment, that fly will have only the dull brown pigment in its eyes. This produces "brown" eyes, so this gene is called the "brown" gene. The symbol for this gene is br. The dominant allele is **Br**, the recessive **br**. A brown-eyed fly would be **br br**. Again, be careful not to separate the b and the r.

   Note that all flies have two alleles for **each** of these genes, so the cinnabar eyed fly would actually have the genotype **cn cn Br Br** or **cn cn Br br**, and the brown eyed fly would actually have the genotype **Cn Cn br br** or
   Cn cn br br.

   A mating is made between a **Cn Cn br br** fruit fly and a **cn cn Br Br** fruit fly. 200 offspring result (the F_1). These offspring are allowed to freely interbreed, and produce 40,000 (whew! Whatever happened to population control!) offspring (the F_2).
   a. What color eyes did the original parents have?
   b. What were the genotypes and phenotypes of the F_1 offspring?
   c. What color eyes do the **cn cn br br** flies have?
   d. What phenotypic ratio do you predict among the F2 offspring?

Solutions for Practice Problems in Genetics

NOTE: When a genotype is listed as, for example, A_, it means that the second allele is unknown. The actual genotype may be AA or Aa.

Problems Involving One Gene

1. First assign symbols for the alleles, following the rules and conventions. For example, the letter "L" could be used for this gene. The symbols would thus be L for the dominant short allele and l for the recessive long allele. The problem tells you that the parents are both homozygous (the short-haired one because you are told it is true-breeding, the long haired one because it has the recessive characteristic, which automatically makes it homozygous). So here's your mating:

Mating:	ll	X	LL
Gametes:	Only l		Only L
Offspring:	All Ll; All short-haired		

2. From problem 1 you already know the dominance here. Go ahead and use the same symbols.

Mating:	ll	X	??
Gametes:	Only l		?
Offspring:	Short haired: Ll Long-haired: ll		

Since the known parent is ll, it contributes a recessive allele to all offspring. So the final phenotype of the kittens is actually determined by the unknown parent. Since some of the kittens are short-haired, they must have received the dominant allele from this unknown parent. The kittens who are long-haired must have received the recessive allele from the unknown parent. So that parent must be Ll, and must be short-haired.

3. Again, assign symbols. A good choice here would be W for widow's peak and w for no widow's peak. As both parents here have the dominant trait, they must each have at least one W. Their first child obviously inherited this allele from at least one of them, as he also possesses a widow's peak. The second child does not, and thus must be ww. But note that there is no evidence here that prevents us from assuming that both of these parents could be carrying hidden recessive w alleles, so Mr. Smith is not justified. Here's the Punnett's Square, assuming these two are truly the parents of both children:

	W	w
W	WW	Ww
w	Ww	ww

Genotypic ratio predicted: 1 WW : 2 Ww : 1 ww
Phenotypic ratio predicted: 3 Widow's Peak : 1 No Widow's Peak

4. Assign symbols. A good choice: E for free earlobes and e for attached earlobes. This problem is a simple exercise in pedigree analysis. All of the individuals with attached earlobes must be ee. All of the individuals with free earlobes must be E_. In this particular case, the E_ parent has children who have attached earlobes, so that parent must have a little e, and is thus Ee. And all of the children have one parent with attached earlobes, so they must also all have at least one little e, and are thus Ee. So the

answer is, Mr. Jones is ee, Mrs. Jones is Ee. The three children with attached earlobes are ee, and the three with free earlobes are Ee.

5. Assign symbols. Be careful with this one, as your alleles have incomplete dominance. It isn't a good idea to use capital and lower case letters, since that convention predisposes us to think in terms of complete dominance. One good choice would be to us superscripts: C^1 for curly; C^2 for straight. Because this gene's alleles have incomplete dominance, everyone's genotype is revealed by his or her phenotype, so our curly-haired parents must both be C^1C^1. The child with wavy hair must be C^1C^2. So Mr. Anderson **is** justified. Of course, there is a small (very small) possibility that Junior's straight-hair allele could have arisen as a new mutation, but other hypotheses are more likely.

6. Same gene as above, so use the same symbols you chose there. This is a simple monohybrid cross.

	C^1	C^2
C^1	C^1C^1	C^1C^2
C^2	C^1C^2	C^2C^2

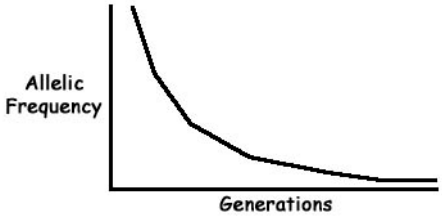
Genotypic Ratio: 1 C^1C^1 : 2 C^1C^2 : 1 C^2C^2
Phenotypic Ratio: 1 Curly : 2 Wavy : 1 Straight
This phenotypic ratio predicts that ¼ of the offspring should be curly-haired, ½ should be wavy haired and ¼ should be straight-haired. So of the eight children, our prediction would be 2 with curly hair, 4 with wavy hair and 2 with straight hair. The answer to the question, "What went wrong?" is "Nothing." What solving the problem does for us is make a statistical prediction, but every new conception is a new toss of the coins—statistical predictions are only really useful for large sample sizes. So it is very normal for a group as small as a family to show frequency distributions which don't match statistical expectations.

7. The answer to the question proposed by the problem should be simple. A palomino horse is always a heterozygote. There is no actual "palomino" allele—you only get this phenotype by having two **different** alleles for a gene. So your palominos can never be "pure-breeding" because they can never be homozygous. Choosing P^1 (chestnut) and P^2 (dilute allele) for our two alleles, here's the Punnett's Square for palomino mated to palomino:

	P^1	P^2
P^1	P^1P^1	P^1P^2
P^2	P^1P^2	P^2P^2

Genotypic Ratio: 1 P^1P^1 : 2 P^1P^2 : 1 P^2P^2
Phenotypic Ratio: 1 Chestnut : 2 Palomino : 1 Dilute

8. No human who is homozygous for the Tay Sachs allele ever reproduces, but the heterozygotes are just fine. So the reason this allele persists, and doesn't vanish from the population, is that it survived in heterozygotes. The typical frequency pattern for an allele like this is that it decreases if the allele is fairly common, but the more rare it becomes, the slower the decrease becomes. This is because the more rare the alleles is in the population as a whole, the higher the percentage of the alleles will be found in heterozygotes, and the more unusual it will become for two heterozygotes to mate with each other. So the frequency reduction pattern typically looks something like this:



Note that the graph tails into what's called an asymptote. This means that it approaches but never reaches zero. The more rare the allele gets, the less selective pressure there is against it (because such a high percentage of the remaining alleles are tied up in heterozygotes) that the background mutation rate is high enough to balance the selection rate, and the overall frequency remains constant.

9. This is a trick question. The answer is, "Nothing." Dominance isn't about frequency, it's about biochemistry. Though very often the dominant version of a trait is much more common in a species, this isn't always true. For example, in human blood types the only recessive allele is the allele for Type O, and this is the **most** common of human blood types.

10. This is a case of Pseudodominance. The mating described is a simple monohybrid cross, represented by this Punnett's Square:

	Cy	cy
Cy	CyCy	Cycy
cy	Cycy	cycy

Genotypic ratio predicted: 1 CyCy : 2 Cycy : 1 cycy

a. Be a bit careful here. Pay attention to precisely what each question is asking for. This part is asking "how many?" The problem specifies 100 eggs laid. All CyCy eggs have the lethal combination of alleles, so they will never hatch. Thus our living offspring will only total 75.
b. Again, the question asks "how many?" The living flies will have the phenotypic ratio 2 Curly : 1 straight. Simple math tells us that there should thus be 25 straight winged flies.
c. This part asks "what percentage?" 2/3 of the living offspring would be expected to be curly winged, so that would mean 66.7% curly.

11. This problem is again a pseudodominance problem. The mating is a simple, monohybrid cross.

D = dwarf
D = normal

	D	d
D	DD	Dd
d	Dd	dd

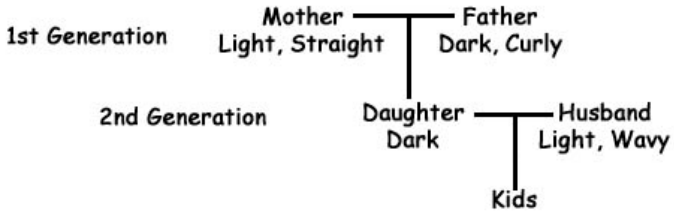
Genotypic ratio predicted: 1 DD : 2 Dd : 1 dd
Phenotypic ratio predicted: 2 dwarf : 1 normal
Note that the DD offspring, which are dead, do not figure into the phenotypic ratio. Also note that, though this question gave you the total number of calves, it **didn't** ask you "how many?" It asked for the phenotypic ratio.

Problems Involving Two Genes

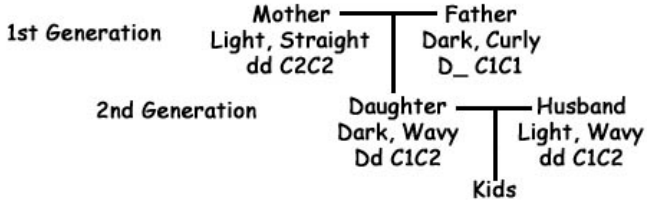
1. The straight/curly gene was already introduced in Section I. Solving this problem first involves some pedigree analysis, then the simple mechanics of solving a straightforward genetics problem. First step, assign symbols:

D = Dark C1 = Curly
D = Light C2 = Wavy

Now figure out the parents' genotypes. Here's what we're told:



First problem—we know the daughter's hair is dark, but is it straight, wavy or curly? The alleles of this gene have incomplete dominance, which means that straight-haired Mom and curly-haired Dad are both homozygous. That means that the daughter must be a heterozygote, and thus have wavy hair. Her husband must also be a heterozygote. For hair color, Dark is dominant to light. That means that anyone in the pedigree with light hair is homozygous. The daughter has a mother with light hair, so she must be a heterozygote. We don't have enough information to figure out whether the father is homozygous or heterozygous. So here's what we've figured out:



So the mating is Dd C1C2 X dd C1C2. Next step is to figure out the different kinds of gametes each of these parents can make.

Mother	Father
D C1	d C1
D C2	d C2
d C1	
d C2	

Note that the father only makes two kinds of gametes because he is homozygous for the D/d gene. The next step is the Punnett's Square:

	D C1	D C2	d C1	d D2
d C1	Dd C1C1	Dd C1C2	dd C1C1	dd C1C2
d C2	Dd C1C2	Dd C2C2	dd C1C2	dd C2C2

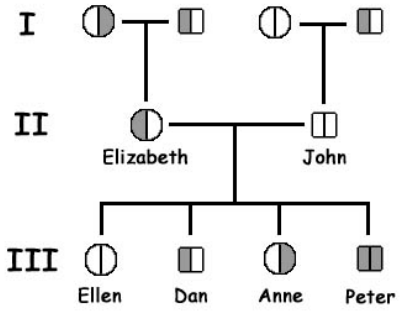
Genotypic Ratio: 1 Dd C1C1: 2 Dd C1C2: 1 Dd C2C2: 1 dd C1C1: 2 dd C1C2: 1 dd C2C2

Remembering that our hair form gene has *incomplete dominance* our phenotypic ratio will be:
1 dark curly : 2 dark wavy : 1 dark straight : 1 light curly : 2 light wavy : 1 light straight.

The father's hair is light and wavy, so the chance that a child will have hair like his is 2/8 (or 1/4).

2. This is a simple pedigree analysis problem. We have two genes. For the color gene, black is dominant to Siamese. For the hair length gene, short is dominant to long. Our parents are a short-Siamese female and a long-black male. The only parts of their genotypes in question are her second hair length allele and his second color allele. A Siamese cat is always homozygous, as is a long-haired cat (second rule of pedigree analysis). Their litter of kittens includes babies with all combinations of color and hair length. Note that the numbers (in this case 2 of each kind of kitten) are immaterial. What matters is **what** colors these parents can produce. Rules 3 and 4 help us figure out the rest of everyone's genotypes. Since they have some kittens who are Siamese (and thus must be homozygous), the black parent must be carrying that recessive allele, so he's heterozygous. Since they have some kittens who are long-haired (and must be homozygous), the short-haired parent must be carrying that recessive allele. Since Mom is homozygous for Siamese and Dad is homozygous for long hair, all of the kittens must carry at least one allele for each of these traits. So the black kittens are heterozygous, and the short-haired kittens are heterozygous as well.

3. Again, this begins with a simple pedigree analysis problem.
   a. Using the Rules for Pedigree analysis, we can figure out that Elizabeth is homozygous for straight nose, and heterozygous for tongue rolling (because her children include non-rollers). John is heterozygous for both nose and tongue rolling (because their children include both straight noses and non-rollers).
   b. Because Elizabeth has a straight nose, her mother must be heterozygous for noses. Elizabeth only got **one** of her straight nose alleles from her father; the other had to come from her mother. We know Elizabeth is heterozygous for tongue rolling, which means that she got a rolling allele from one parent and a non-rolling allele from the other. Mom had to give her the non-rolling allele, so she got the rolling allele from Dad. **However** this does not allow us to conclude that her father was homozygous for tongue rolling. Rule #5 tells us that we may not guess about his second allele, and we don't have enough information to figure it out.
   c. The only thing we can figure out about John's parents is that his father was homozygous for straight nose. We know only that they have at least one dominant allele for the other genes in question, but nothing about John helps us figure out whether they are hiding recessives or not.
   d. For our little pedigree, we will designate that the left side of each symbol represents nose shape and the right side represents tongue rolling. Open symbols represent the dominant phenotypes and shaded symbols represent recessive phenotypes. As always, circles are females and squares are males. In constructing a pedigree "mating pairs" are connected by a horizontal line. Offspring are connected by a descending vertical line. Siblings are connected by horizontal brackets. So here's our pedigree:



4. Once again, we begin with some pedigree analysis to figure out everyone's genotypes. A bit of rumination reveals that this problem describes a nearly classic dihybrid cross. "Pure breeding" is a euphemism for "homozygous," so all of the original parents are homozygous. We mate a bbLL cat to a BBll cat, producing a bunch of BbLl kittens as an F1. The problem then instructs us to create an F2 by mating the kittens to each other. Here's this mating:

Parents: BbLl X BbLl
Gametes: BL BL
Bl Bl
bL bL
bl bl

	BL	Bl	bL	bl
BL	BBLL	BBLl	BbLL	BbLl
Bl	BBLl	BBll	BbLl	Bbll
bL	BbLL	BbLl	bbLL	bbLl
bl	BbLl	Bbll	bbLl	bbll

Genotypic Ratio:
1 BBLL 2 BbLL
1 BBll 2 Bbll
1 bbLL 2 BBLl
1 bbll 2 bbLl
4 BbLl

Phenotypic Ratio: 9 Black Short : 3 Black Long : 3 Siamese Short : 1 Siamese Long
The actual question is, "what is the chance of producing a Siamese, short kitten?" The answer is 3/16.

5. Sorry about the rather dated joke in this question. This problem involves two genes. First step: assign symbols for the alleles.
First gene: W = Dry (dominant); w = Water
Second gene: P = Gate (dominant); p = Pace
Using pedigree analysis, we figure out that Halter-Man is wwpp and Erlich-Mane is WwPp. So here's our mating:

WwPp X wwpp
Gametes:
WP wp
Wp
wP
wp

Genotypic Ratio of Offspring: 1 WwPp : 1 Wwpp : 1 wwPp : 1 wwpp
Phenotypic Ratio of Offspring: 1 Dry-Gate : 1 Dry-Pace : 1 Water-Gate : 1 Water-Pace
The question asked is, what is the chance of producing a Water-Gate foal. Answer: 1/4 or 25%.

6. This is a reasoning problem. The issue is understanding dominance. We begin by mating two true-breeding pigs, one black with solid hooves and one red, with cloven hooves. They produce offspring, which are not described. Note that you know these offspring should all look alike with respect to these

traits, because they are the product of the mating of two homozygous parents. These undescribed offspring are then bred back to pigs which are genetically just like the red, cloven parent pig. This is called a "back cross," though strictly speaking a back-cross should literally mean mating back to the parent. The various offspring from the back-cross are described, and you are asked to determine dominance for the alleles of these two genes.

The first thing to note here is that the numbers of each offspring class are completely irrelevant. The only thing that matters in this kind of problem is what **kinds** of offspring result from that back cross. Recall that one of the parents of this second generation of offspring is definitely homozygous for red and homozygous for cloven, just as the original female was. This means that this parent contributed a red allele and a cloven allele to **every** one of the offspring. And yet, some of the offspring are black and some have solid hooves. This is possible only if black is dominant to red and if solid is dominant to cloven.

7. As is so often true for genetics problems, this begins with pedigree analysis. Assign symbols to the alleles, such as L for long (dominant) and t for short, and Y for yellow (dominant) and y for green. Always make sure you assign legal symbols, meaning that they must be different versions of the same symbol. (In other words, assigning T for tall and s for short is illegal.) As our tall, yellow plant had a short, green parent, it must be heterozygous for both genes. Thus, this is a dihybrid cross. Here's the mating:

Parents: LlYy X LlYy
Gametes: LY LY
Ly Ly
lY lY
ly ly

	LY	Ly	lY	ly
LY	LLYY	LLYy	LlYY	LlYy
Ly	LLYy	LLyy	LlYy	Llyy
lY	LlYY	LlYy	llYY	llYy
ly	LlYy	Llyy	llYy	llyy

Genotypic Ratio:
1 LLYY 2 LlYY
1 LLyy 2 Llyy
1 llYY 2 LLYy
1 llyy 2 llYy
4 LlYy

Phenotypic Ratio: 9 Long Yellow : 3 Long Green : 3 Short Yellow : 1 Short Green

a. Out of 1600 offspring, 300 (3/16) would be expected to be Long Green.
b. This question asks about only one of the genes. You would expect a 3 Yellow : 1 Green ratio.

c. 9 Long Yellow : 3 Long Green : 3 Short Yellow : 1 Short Green. Note that you would never present the numbers without the descriptions. 9:3:3:1 is never the correct answer to this kind of question.

Problems Involving Sex Linkage

1. Holandric traits are possessed by only males and passed only from father to son. To **all** sons.
   a. They have three sons. All three would have hairy snouts; none of their three daughters would.
   b. Again, this is holandric. The probability is 100% that any of Bob's sons will have hairy snouts.
   c. Lovely JoKchew and her husband will never had hairy-snouted sons. JaKchew can't carry the trait, even though her father had it. And her husband doesn't have a hairy snout, and thus can't pass that trait to any of his sons.

2. In the first mating, we know the females are all homozygous because the white allele is recessive. The male is **hemizygous**, meaning that he has only one allele for this gene, and that allele in this case is the red allele. The traditional symbol for this gene is the letter w: W for red; w for white. So here's the mating:

Mating:	ww	X	WY
Gametes:	Only w		W Y

Note that the "Y" substitutes for the second allelic symbol for the male parent.

	w
W	Ww
Y	wY

Genotypic Ratio: 1 Ww : 1 wY
Phenotypic Ratio: 1 Red eyed female : 1 white eyed male
Note that this mating demonstrates one feature of many matings involving X-linkage—the phenotypic ratio for the males is different from that for the females, so the gender must be included in the phenotypic ratio.

Here's the Reciprocal cross:

Mating:	WW	X	wY
Gametes:	Only W		w Y

	W
w	Ww
Y	WY

Genotypic Ratio: 1 Ww : 1 WY
Phenotypic Ratio: All red eyed
Note that this pair of crosses demonstrates another key feature of matings involving X-linkage—reciprocal crosses often give different results.

3. Here's this mating, where C = normal color vision and c = colorblind:

Mating: cc X CY

Gametes: Only c C Y

	c
C	Cc
Y	cY

Genotypic Ratio: 1 Cc : 1 cY
Phenotypic Ratio: Daughters all normal color vision, sons all colorblind.

4. This is the reciprocal for the cross in Number 3.

Mating: CC X cY

Gametes: Only C c Y

	C
c	Cc
Y	CY

Genotypic Ratio: 1 Cc : 1 CY
Phenotypic Ratio: All normal color vision
The question asks, if they have eight children, how many of them would you expect to be colorblind? The answer is, "none."

5. Again, we start with pedigree analysis. Marian is a heterozygote. We know this because she herself is not colorblind, but her father was. As a male gives his one and only X chromosome to any female offspring, she must have inherited his colorblindness allele, which is on his X chromosome. For Marian, her maternal grandfather's colorblindness is immaterial. The X she inherited from her mother must carry the dominant normal color vision allele. Martin, Marian's husband, had the colorblindness allele on his only X chromosome.
   a. The probability that Mickey will be colorblind is 0.5 (50%). A son inherits his X chromosome from his mother, and Marian has one with the C allele and one with the c allele. He has an equivalent chance of receiving either one.
   b. Mickey's colorblindness allele came from Marian's father (via Marian herself, of course; you don't inherit anything from grandparents—it all comes from parents). Mickey's direct source of the allele was Marion, and see above for the explanation of why Marian does not carry her mother's father's c allele. Mickey didn't get it from Martin, his father, because he had to get his Y chromosome from Martin, and the Y chromosome has no allele for this gene on it.
   c. It wouldn't. Martin has nothing to do with Mickey being or not being colorblind. It's all up to Marian.

6. This problem is simply a series of four matings involving X-linkage.
First task: assign symbols. It's not a good idea to use capital and lower case letters for this one, as there is no dominant allele. One suggestion would be B = Black and B' = Orange. Remember that BB' will be tortoiseshell.

a. First mating: Black female (BB) x Orange male (B'Y). This one is simple. All female offspring will be BB' and all male offspring will be BY. Female kittens will be tortoiseshell, male kittens will be black.
b. Second mating: Orange female (B'B') x Black male (BY). This is familiar territory. This is the reciprocal of the first mating. Again, it's easy. All female kittens are BB' (tortoiseshell) and all male kittens are B'Y (orange).
c. Third mating: Tortoiseshell female (BB') x black male (BY).

	B	B'
B	BB	BB'
Y	BY	B'Y

Genotypic Ratio: 1BB : 1 BB' : 1BY : 1 B'Y
Phenotypic Ratio: 1 Black Female : 1 Tortoiseshell Female : 1 Black Male : 1 Orange Male
d. Fourth mating: Tortoiseshell female (BB') x Orange male (B'Y)

	B	B'
B'	BB'	B'B'
Y	BY	B'Y

Genotypic Ratio: 1BB' : 1 B'B' : 1BY : 1 B'Y
Phenotypic Ratio: 1 Tortoiseshell Female : 1 Orange Female : 1 Black Male : 1 Orange Male

Problems Involving Genes with Multiple Alleles

1. First, we need to figure out the genotypes of these parents. Again, pedigree analysis tells us that they must both be heterozygous, and hiding i (Type O) alleles behind their I^A (Type A) and I^B (Type B) alleles. The evidence for this is the fact that one of their children is Type O. As i is recessive, this means that each parent must possess an i allele. The Type AB child must be I^AI^B, as these two alleles are codominant with each other. The Type A child must be I^Ai because the Type B parent has no second I^A to contribute. Same for the Type B child, as the Type A parent has no I^B allele to contribute.

2. Mr. Smith still has no evidence to support infidelity on the part of his wife. If each of them is heterozygous, they could easily produce a child with type O blood, and of course, they can have a Type AB child.

3. One can only hope this judge was never reelected.
   a. The mother's genotype is I^A_ where we don't have any information to provide the second allele. The child must be I^AI^B and the accused man must be ii. The father of this child must have contributed that I^B allele.
   b. You should disagree with the court's decision. A type O person can't be the parent of a Type AB child because that child must receive I^A from one parent and I^B from the other, and a person who is Type O possesses neither of those alleles. It doesn't matter how good the woman's memory seems to be. She's wrong.

4. A puzzle like this one is generally a matter of elimination, and this one is no exception. The key to determining whether these babies were switched or not is to look for impossible parent/child connections. In this case, the problem is that Mr. Smith, who is Type AB, can't be the father of a Type O baby, because the I allele for Type O is recessive, and the child must receive it from both parents. The I^A and I^B alleles are codominant, so a person with Type AB blood can't be carrying an O allele.

5. By now, you should be able to answer this one easily. In a mating between Type O (ii) and Type AB (I^AI^B), none of the children will have the same blood type as either parent. All will have blood types different from both parents. The children can be either I^Ai (Type A) or I^Bi (Type B), but never Type O or Type AB. For one of their children to be Type O, both parents must contribute the i allele, and the Type AB parent doesn't have any. For any of their children to be Type AB, they would have to inherit the I^A from one parent and the I^B from the other, and the Type O parent possesses neither of these alleles.

6. This is a challenging question which requires good logic skills to solve. You've been provided with results from all possible matings. Remember that you are mating wild plants, and you have no idea whether your plants are homozygous or heterozygous for anything.

   a. Let's begin with the obvious and make a preliminary guess that there are four alleles for this gene, one for white, one for red, one for blue and one for purple. Because we have no idea whether our plants are homozygous or heterozygous, and because we collected a lot of plants ;^) we can assume that at least **some** of our matings would be between homozygotes. If we have four alleles, some of our White x white should thus produce only white; some of our red x red should produce only red; some of our blue x blue should produce only blue; and some of our purple x purple should produce only purple. These would be the matings which just happened to be between two homozygotes. Looking at our data, we see that everything looks good until we check out the purple x purple matings. These matings never produce **any** purple offspring. This would argue that the purple color is not due to a purple allele, but to the interaction between some of our other alleles. And this conclusion is borne out be observing what **is** produced when we mate purple x purple—a mixture of purples, reds and blues. So here's a new hypothesis: red and blue alleles are incompletely dominant, and the heterozygote is purple.

   b. Now consider the white. The results for mating white to white are quite different from the results of mating red to red or blue to blue. When red is mated with red, sometimes some of the offspring have **white** flowers. Same for blue mated to blue. But white mated to white never produces any color other than white in the offspring. These observations argue strongly that white is a recessive allele.

   So here's our final hypothesis about this gene. We have three alleles, red, blue and white. Red and blue are incompletely dominant, with the hybrid having purple flowers, and white is recessive to both red and blue. Now let's look at all of the matings and test our hypothesis. We'll use the symbols C1 for red, C2 for blue and c for white.

White X White	cc x cc All white
Red X Red	C1C1 x C1C1 All red C1c X C1C1 All red C1c X C1c 3 Red : 1 White
Blue X Blue	C2C2 x C2C2 All Blue C2c X C2C2 All Blue C2c X C2c 3 Blue : 1 White
Purple X Purple	C1C2 X C1C2 1 Red : 2 Purple : 1 Blue
White X Red	cc X C1C1 All Red cc X C1c 1 Red : 1 White
White X Blue	cc X C2C2 All Blue cc X C2c 1 Blue : 1 White
White X Purple	cc X C1C2 1 Red : 1 Blue
Red X Blue	C1C1 X C2C2 All Purple C1c X C2C2 1 Purple : 1 Blue

	C1C1 X C2c 1 Purple : 1 Red C1c X C2c 1 Purple : 1 Red : 1 Blue : 1 White
Red X Purple	C1C1 X C1C2 1 Red : 1 Purple C1c X C1C2 2 Red : 1 Blue : 1 Purple
Blue X Purple	C2C2 X C1C2 1 Blue : 1 Purple C2c X C1C2 2 Blue : 1 Red : 1 Purple

7. Yet another paternity challenge based on blood type.
   a. The mother is incorrect. The mother must be L^Al of course, because otherwise she couldn't have a child who is ll. Certainly man #3, who is also ll, is a possible father. But there's no means to eliminate Man #2 with the information given. He could be L^Bl, and thus have provided the second recessive allele for the child.
   b. The new information excludes Man #3. Because colorblindness is an X-linked recessive, any colorblind girl must have a colorblind father. She has to be homozygous for colorblindness, and he has only one X chromosome to give her, Thus the X he gave his daughter must have the colorblindness allele on it. As he only **has** one X chromosome, that means he must **be** colorblind. So among these three men, the only possible candidate for paternity would be #2.

8. The mother (Type A) must be L^Al, and her son must be L^Bl. He received his l allele from her.
   a. The father of this child must be able to contribute an LB allele, so #1 is certainly a candidate. But so is #2.
   b. If a male child is colorblind, he inherited his colorblindness from his mother. His father contributed a Y chromosome, and colorblindness is on the X chromosome. The only X he has he got from his mother. So this additional information does not clarify this situation.

Problems Involving Gene Interactions

1. In the original mating, the female is albino, the male solid brown. The kittens are all agouti. This tells you that the albino female cat carries the agouti allele. (It's possible she's homozygous, but you don't know for sure. The male is possibly homozygous for the normal allele of the albino gene, but again you don't really know for sure.) The agouti offspring are all heterozygous for both genes. They are not albino, but inherited an albino allele from their mother; they are agouti, but inherited a solid allele from their father. So this problem has set up a traditional dihybrid cross. Assign B/b to the alleles for the Agouti/brown gene and A/a to the alleles for the albino gene.

Parents: BbAa X BbAa
Gametes: BA BA
Ba Ba
bA bA
ba ba

	BA	Ba	bA	ba
BA	BBAA	BBAa	BbAA	BbAa
Ba	BBAa	BBaa	BbAa	Bbaa
bA	BbAA	BbAa	bbAA	bbAa
ba	BbAa	Bbaa	bbAa	bbaa

Genotypic Ratio:

1 2

BBAA BbAA

1 BBaa 2 Bbaa

1 bbAA 2 BBAa

1 bbaa 2 bbAa

4 BbAa

Phenotypic Ratio: Ostensibly, this appears to be a traditional 9:3:3:1 phenotypic ratio, but if you consider carefully the meaning of "phenotype," you can see that it's a bit different. Albino cats have white fur, regardless of whether the agouti gene "says" to be agouti or solid. So the actual phenotypic ratio is:

9 Agouti : 3 Solid Brown : 4 White (Albino)

2. This is a slightly different kind of situation. Here we have a "normal" condition which is actually produced by the interaction of two different genes. This is probably far, far more common than is obvious, but in this particular case it's very clear. The wild type eye color of *Drosophila* requires action of two genes, and each of these can have a mutation which incapacitates it. In this problem, we set up the classic Mendelian two-gene mating scheme:

Cn = wild
cn = cinnabar
Br = wild
br = brown

First mating:

Cn Cn br br X cn cn Br Br

Offspring genotype: All Cn cn Br br

Offspring phenotype: All wild type

Second MatingParents: Cn cn Br br X Cn cn Br br

Gametes: Cn A Cn A

Cn a Cn a

cn A cn A

cn a cn a

	Cn Br	Cn br	cn Br	cn br
Cn Br	Cn Cn Br Br	Cn Cn Br br	Cn cn Br Br	Cn cn Br br
Cn br	Cn Cn Br br	Cn Cn br br	Cn cn Br br	Cn cn br br
cn Br	Cn cn Br Br	Cn cn Br br	cn cn Br Br	cn cn Br br
cn br	Cn cn Br br	Cn cn br br	cn cn Br br	cn cn br br

Genotypic Ratio:

1 Cn Cn Br Br | 2 Cn cn Br Br

1 Cn Cn br br | 2 Cn cn br br

1 cn cn Br Br | 2 Cn Cn Br br

1 cn cn br br | 2 cn cn Br br

4 Cn cn Br br

Phenotypic Ratio: 9 Wild : 3 Cinnabar : 3 Brown : 1 White (cinnabar-brown)

a. The first parent (Cn Cn br br) had brown eyes. The second parent (cn cn Br Br) had cinnablar eyes.
b. All F1 flies were Cn cn Br br, and all had wild type eye color.
c. cn cn br br flies have white eyes (they have neither pigment in their eyes).
d. Phenotypic Ratio: 9 Wild : 3 Cinnabar : 3 Brown : 1 White (cinnabar-brown)