Patterns of Inheritance

9

At some point in your life you must have wondered about your inherited physical characteristics. Why is your hair dark or light, curly or straight? Do your eyes look like your mother's, your father's, or like neither of them? How do your eyes and hair, your height, and the color of your skin compare to those of your parents and your siblings? What made you female or male? People have asked these kinds of questions for thousands of years, but we only began to get some answers in the mid-1800s, when Gregor Mendel started to experiment with inheritance in plants in his abbey garden. This chapter concerns the principles and patterns of inheritance.

Organizing Your Knowledge

Exercise 1 (Modules 9.1 – 9.4)

Web/CD Activity 9A *Monohybrid Cross*

These modules discuss the basic principles of heredity and introduce the vocabulary of genetics. Read the modules carefully, and then practice using the vocabulary by matching each phrase on the right with a word or phrase on the left.

A. Allele
B. Homozygous
C. Hybrid
D. Genotype
E. Segregation
F. F_2 generation
G. True-breeding
H. Heterozygous
I. Self-fertilization
J. Dominant
K. P generation
L. Monohybrid cross
M. Wild type
N. Phenotype
O. Cross
P. F_1 generation
Q. Recessive
R. Homologous chromosomes
S. Gene
T. Phenotypic ratio
U. Pangenesis
V. Cross-fertilization
W. Punnett square
X. Blending

____ 1. A unit that determines heritable characteristics
____ 2. Organisms that always produce offspring identical to parents
____ 3. The offspring of two different varieties
____ 4. When two alleles of a pair are different, the one that is masked
____ 5. An incorrect idea that acquired characteristics are passed on
____ 6. Parent organisms that are mated
____ 7. A diagram that shows possible combinations of gametes
____ 8. A breeding experiment that uses parents different in one characteristic
____ 9. One of the alternative forms of a gene for a characteristic
____ 10. Relative numbers of organisms with various characteristics
____ 11. An organism that has two different alleles for a characteristic
____ 12. Old idea that hereditary materials from parents mix in offspring
____ 13. An organism's genetic makeup
____ 14. Separation of allele pairs that occurs during gamete formation
____ 15. Fertilization of a plant by pollen from a different plant
____ 16. An organism that has two identical alleles for a characteristic
____ 17. Offspring of the P generation
____ 18. A characteristic most commonly found in nature
____ 19. What an organism looks like; its expressed traits
____ 20. Offspring of the F_1 generation
____ 21. When pollen fertilizes eggs from the same flower
____ 22. A hybridization
____ 23. When two alleles of a pair are different, the one expressed
____ 24. Where genes for a certain trait are located

Exercise 2 (Modules 9.3 – 9.4)

Web/CD Activity 9A *Monohybrid Cross*

Test your knowledge of Mendel's principles by answering the following questions. You may want to test your ideas on scratch paper.

1. A pea plant with green pods is crossed with a plant with yellow pods. All their offspring have green pods. (5)
   a. Which allele is dominant? Which allele is recessive?

   b. Using letters, what is the genotype of the green parent? The yellow parent?

   c. What are the genotypes of the offspring?

2. F_1 pea plants from the above cross are crossed. Use a Punnett square to figure out the genotypic and phenotypic ratios in the F_2 generation.
   a. Genotypic ratios:

   (5)

   b. Phenotypic ratios:

   show work

3. Two black mice mate. Six of their offspring are black and two are white. (4)
   a. What are the genotypes of the parents?

   b. For which offspring are you sure of the genotypes?

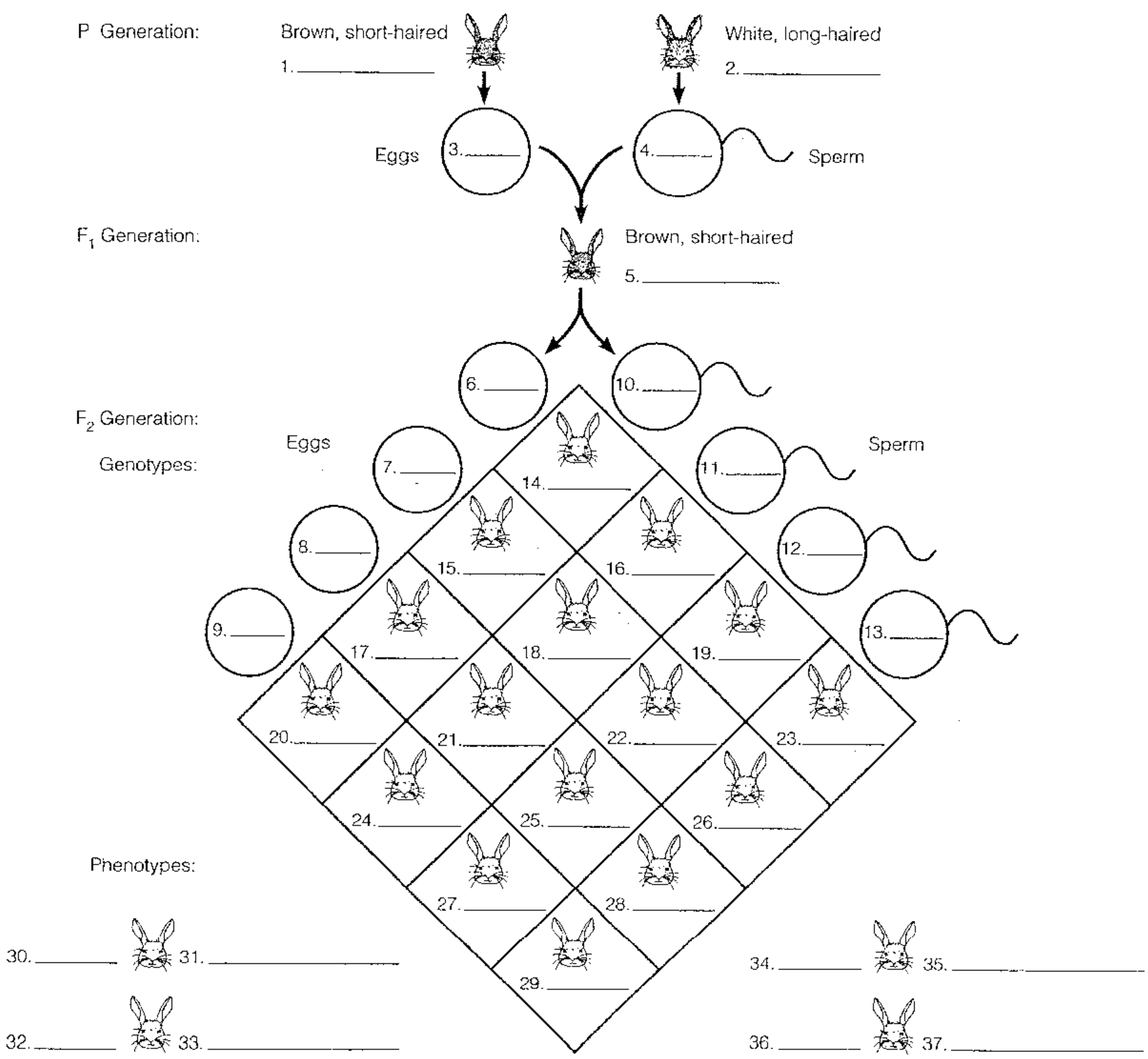
Exercise 3 (Module 9.5)

Web/CD Activity 9B *Dihybrid Cross*

Mendel studied the inheritance of two characteristics at once and found that each pair of alleles segregates independently during the formation of gametes. In other words, if a tall pea plant with purple flowers is crossed with a short plant with white flowers, some of their descendants can be tall with white flowers. The tall and purple alleles do not have to stick together—they are independent.

So far, the textbook has discussed inheritance in peas and dogs. Just to be different, let's look at a genetic cross involving rabbits. In rabbits, the allele for brown coat is dominant, the allele for white coat recessive. The allele for short fur is dominant, the allele for long fur recessive. Imagine mating a true-breeding brown, short-haired rabbit with a white, long-haired rabbit. Using Module 9.5 as a model, write the genotypes of rabbits and gametes in the P, F_1, and F_2 generations in the blanks in the Punnett square. You may want to modify the drawings to show the phenotypes of the rabbits in the F_2 generation. Then use the Punnett square to figure out the phenotypic ratios in the F_2 generation—the proportion of rabbits that you can expect to be brown and short-haired, brown and long-haired, white and short-haired, and white and long-haired. Write their phenotype and their proportions in the blanks at the bottom.

READ CAREFULLY



Exercise 4 (Module 9.6)

After reading this module on testcrosses, test your understanding by answering the following questions.

+ ?

1. Recall that brown coat color in rabbits is dominant and white color is recessive. Suppose you have a group of rabbits—some brown and some white.
   a. For which phenotype(s) do you know the genotype(s)?

   b. For which phenotype(s) are you unsure of the genotype(s)?

2. Using *B* and *b* to symbolize the brown and white alleles:
   a. What are the possible genotypes of a white rabbit in your group?

   b. What are the possible genotypes of a brown rabbit?

3. Suppose you wanted to find out the genotype of a brown rabbit. What color rabbit would you mate it with?

4. A brown buck (male) is mated with a white doe (female). In their litter of 11 young, six are white and five are brown. Using a Punnett square to check your answer, what is the genotype of the buck?

5. Use a Punnett square to figure out the ratio of brown and white offspring that would have been produced by the above mating if the brown buck had been homozygous.

6. If half the offspring from a testcross are of the dominant phenotype and half are of the recessive phenotype, is the parent of the dominant phenotype (but unknown genotype) homozygous or heterozygous?

7. If all the offspring from a testcross are of the dominant phenotype, is the parent with the dominant phenotype (but unknown genotype) homozygous or heterozygous?

Exercise 5 (Module 9.7)

Web/CD Activity 9C *Gregor's Garden*

NO

The rules of probability can be used to predict the flip of a coin, the drawing of a card from a deck, or the roll of a pair of dice. They also govern segregation and recombination of genes. Read Module 9.7 carefully, and then fill in the blanks below.

The probability scale ranges from 1_____ (an event that is certain not to occur) to 2_____ (an event that is certain to occur). The probabilities of all possible outcomes for an event must add up to 3_____. Imagine rolling a pair of dice, one die at a time. Each of the six faces of a die has a different number of dots, from one to six. If you roll a die, the probability of rolling a one is 4_____. The probability of rolling any number other than one is 5_____. The outcome of a given roll is unaffected by what has happened on previous rolls. In other words, each roll is a(n) 6________________ event.

If you roll two dice simultaneously, what is the probability of "snake eyes" (both ones)? The roll of each die is an independent event. The probability of such a compound event (both dice coming up ones) is the [7]______________ of the separate probabilities of the independent events. Therefore, the probability of rolling two ones is [8]____ × [9]_____ = [10]_____. This is called the rule of [11]______________.

This rule also governs the combination of genes in genetic crosses. The probability that a heterozygous (*Pp*) individual will produce an egg containing a *p* allele is [12]_____. The probability of producing a *P* egg is also [13]_____. If two heterozygous individuals are mated, what is the probability of a particular offspring being [14]____________ recessive (*pp*)? The probability of producing a *p* egg is ½. The probability of producing a *p* sperm is also ½. The production of egg and sperm are independent events, so to calculate their combined probability we use the rule of [15]______________. Thus the chance that two *p* alleles will come together at fertilization to produce a *pp* offspring is [16]____ × [17]____ = [18]____.

Back to the dice for a moment. What is the probability that a roll of two dice will produce a three and a four? There are two different ways this can occur. One die can come up a three and the other a four, or one can come up a four and the other a three. The probability of the first combination is $\frac{1}{6} \times \frac{1}{6} = \frac{1}{36}$. The probability of the second is also $\frac{1}{6} \times \frac{1}{6} = \frac{1}{36}$. According to the rule of [19]______________, the probability of an event that can occur in two or more alternative ways is the [20]______________ of the separate probabilities of the different ways. The probability of rolling a three and a four is therefore [21]_____ + [22]_____ = [23]_____.

Similarly, what is the probability that a particular offspring of two heterozygous parents will itself be heterozygous? The probability of the mother producing a *P* egg is [24]_____. The probability of the father producing a *p* sperm is also [25]_____. Therefore, the probability of a *P* egg and a *p* sperm joining at fertilization is [26]_____ × [27]_____ = [28]_____. Or a *p* egg and a *P* sperm could join. The probability of this occurring is also [29]_____. According to the rule of addition, the probability of an event that can occur in two alternative ways is the sum of the separate probabilities. Therefore, the probability of heterozygous parents producing a heterozygous offspring is [30]____ + [31]____ = [32]_____.

Exercise 6 (Module 9.8)

After you read this module, use the information in the illustration to solve the following problems. You will probably want to work out Punnett squares on scratch paper.

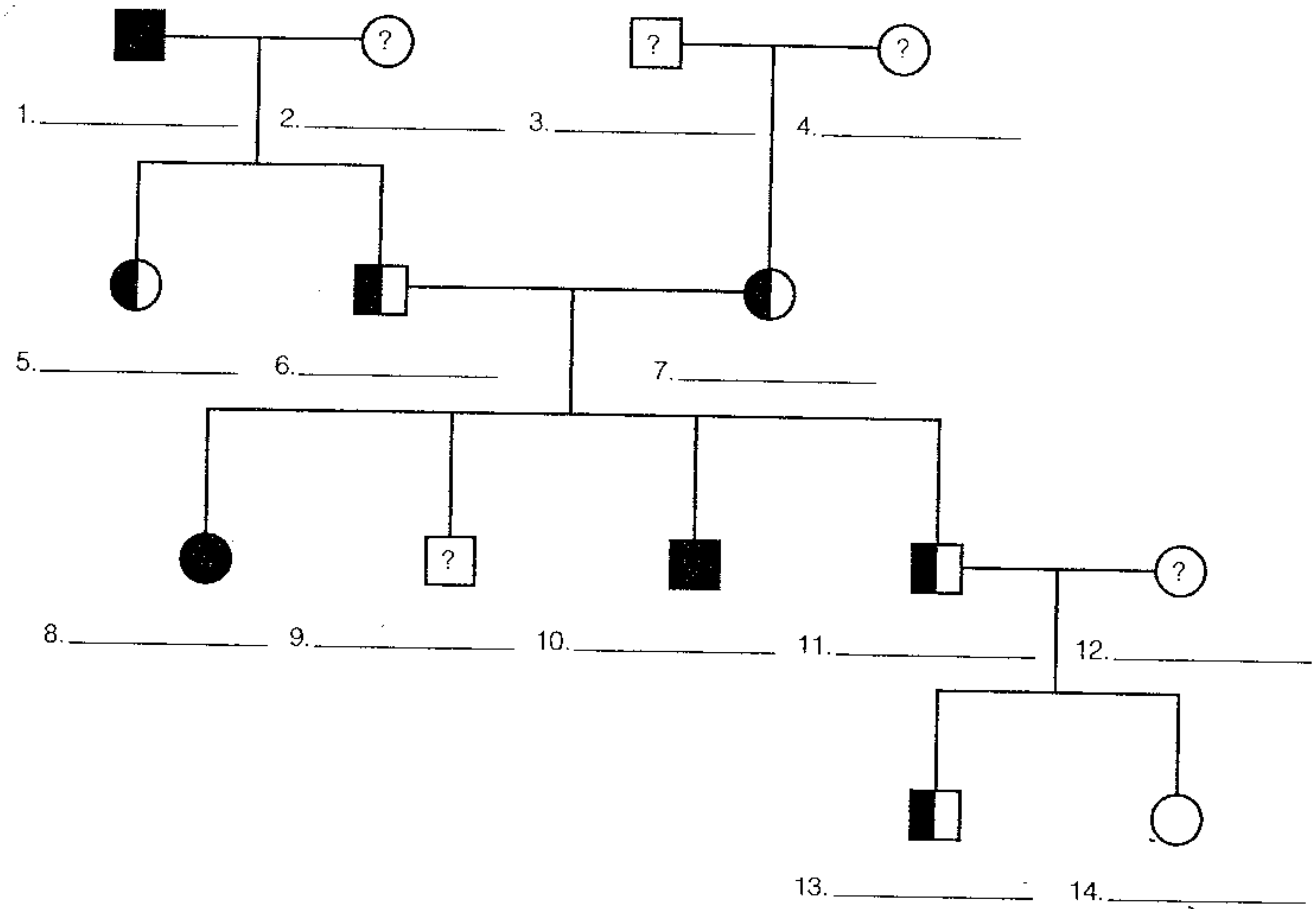
1. A man and woman, both without freckles, have four children. How many of the children would you expect to have freckles?

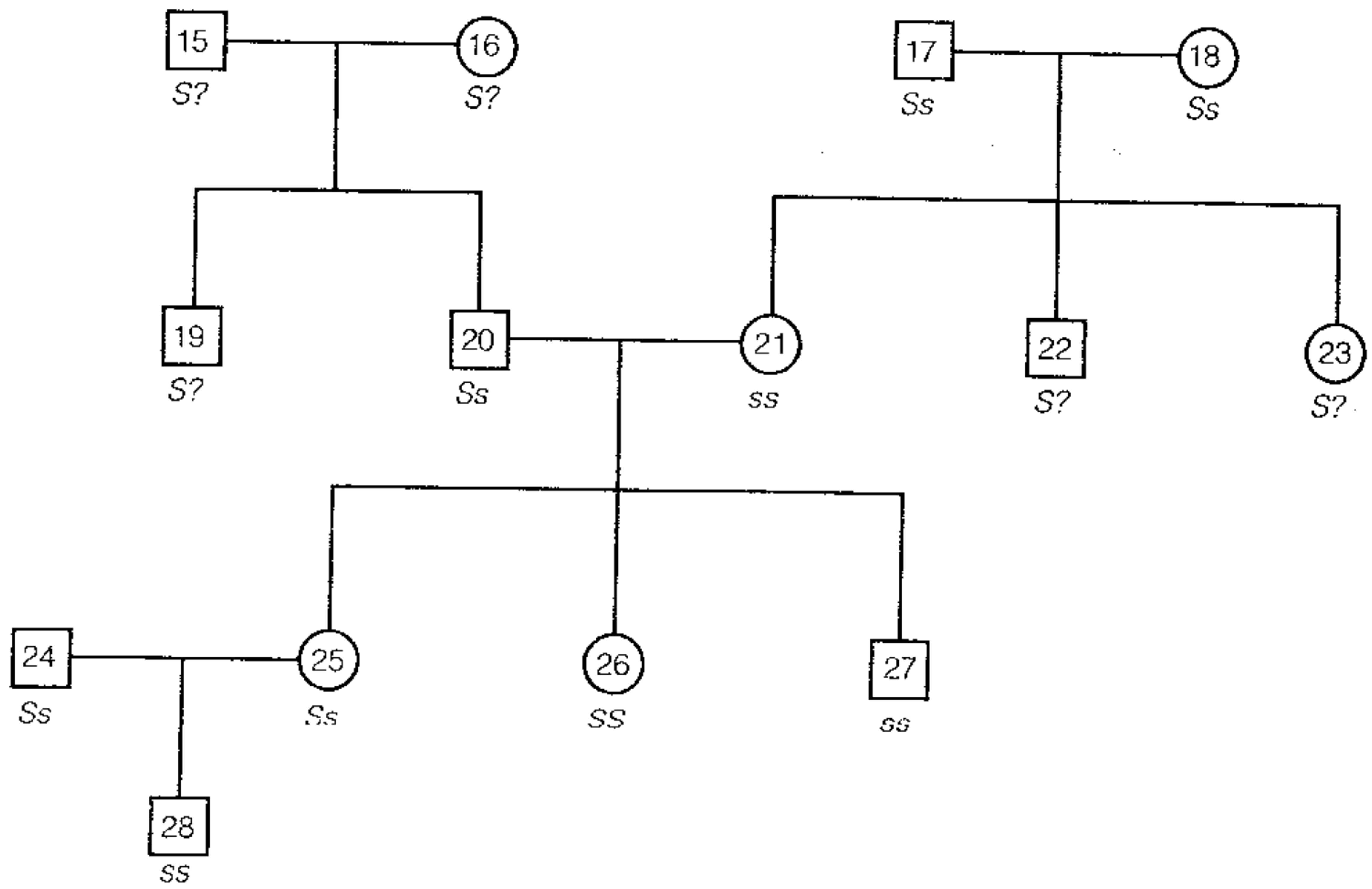
2. Both Fred and Wilma have widow's peaks. Their daughter Shirley has a straight hairline. What are Fred and Wilma's genotypes?

3. A man and woman both have free earlobes, but their daughter has attached earlobes. What is the probability that their next child will have attached earlobes?

Exercise 7 (Module 9.8)

Family trees called pedigrees are used to trace the inheritance of human genes. The two pedigrees below show the inheritance of sickle-cell disease (described in Modules 9.14 and 9.15), which is caused by an autosomal recessive allele. In the first pedigree, the square and circle symbols are colored, as far as genotypes are known. Fill in the genotypes—*SS*, *Ss*, or *ss*—below the symbols. Use question marks to denote unknown genotypes. Complete the second pedigree by coloring in the symbols, following the rules described in Module 9.8. Again denote unknowns with question marks.





Amy asked, "What exactly is PKU? Is it a serious problem?"

Sharon explained that PKU, short for [7]________________, is an inherited inability to break down an ________________ called phenylalanine. "The phenylalanine can build up in the blood and cause mental retardation. As I said, don't start worrying yet. We can test your fetus. If PKU is detected early, retardation can be prevented by putting the child on a special [9]______________, low in phenylalanine."

Amy asked, "How will you test the baby?"

"We'll have to perform [10]________________—taking a sample of the [11]______________ fluid. We can check for PKU by testing for certain chemicals in the fluid itself. While we're at it we will culture some of the fetal [12]________________ from the fluid and do a [13]________________—take a picture of the chromosomes—to check for [14]______________ syndrome. It will take a couple of weeks to culture the cells. Or we could get the karyotype results right away by using a newer technique called [15]__________________ sampling. The placenta cells we sample with this technique are [16]______________ more rapidly, so—"

Greg interrupted. "Wait a minute. Do you have to get samples? Can't you just do [17]______________ imaging to look at the baby? Doctor Portillo did that before Kelly was born."

"We really can't check chromosomes or PKU by just looking at the fetus with ultrasound. Amy is over [18]______________ years old, so I think it is important to get a sample of amniotic fluid so we can check for Down syndrome. I'm sure everything will be okay, but it's best to be prepared. Plus, the karyotype will answer another question I'm sure you are eager to know the answer to—whether you are going to have a boy or a girl."

Exercise 10 (Modules 9.11 – 9.16)

Web/CD Activity 9D *Incomplete Dominance*

(10)

These modules discuss examples of inheritance that are a bit more complex than the simple patterns of heredity observed by Mendel. After reading the modules, see if you can match each description with a pattern of inheritance. Choose from:

A. incomplete dominance
B. multiple alleles
C. codominance
D. pleiotropy
E. polygenic inheritance

_____ 1. There are three different alleles for a blood group—I^A, I^B, and i—but an individual has only two at a time.

_____ 2. Crosses between two cremello (off-white) horses always produce cremello offspring. Crosses between chestnut (brown) horses always result in chestnut offspring. A cross between chestnut and cremello horses produces palomino (a golden-yellow color somewhat intermediate between chestnut and cremello) offspring. If two palominos are mated, their offspring are produced in the ratio of 1 chestnut : 2 palominos : 1 cremello.

_____ 3. The sickle-cell allele, *s*, is responsible for a variety of phenotypic effects, from pain and fever to damage to the heart, lungs, joints, brain, or kidneys.

_____ 4. In rabbits, an allele for full color *(C)* is dominant over an allele for chinchilla *(c')* color. Both full color and chinchilla are dominant over the white allele *(c)*. A rabbit can be CC, *Cc'*, *Cc*, *c'c'*, *c'c*, or *cc*.

_____ 5. In addition to the A and B molecules found on the surface of red blood cells, humans also have M and N molecules. The genotype L^ML^M produces the M phenotype. The genotype L^NL^N gives the N phenotype. Individuals of genotype L^ML^N have both kinds of molecules on their red blood cells, and their phenotype is MN.

_____ 6. If a red shorthorn cow is mated with a white bull, all their offspring are roan, a phenotype that has a mixture of red and white hairs.

_____ 7. Independent genes at four different loci are responsible for determining an individual's HLA tissue type, important in organ transplants and certain diseases.

_____ 8. A recessive allele causes a human genetic disorder called phenylketonuria. Homozygous recessive individuals are unable to break down the amino acid phenylalanine. As a consequence, they have high levels of this substance in their blood and urine, reduced skin pigmentation, lighter hair than their normal brothers and sisters, and often some degree of mental impairment.

_____ 9. When graphed, the number of individuals of various heights forms a bell-shaped curve.

_____ 10. Chickens homozygous for the black allele are black, and chickens homozygous for the white allele are white. Heterozygous chickens are gray.

Exercise 11 (Module 9.16)

Genetic testing, or screening, is a rapidly growing component of health care. Match each of the following descriptions with a category of genetic tests.

_____ 1. Confirms or rules out whether an individual has a particular genetic disorder

_____ 2. Helps determine a person's risk for developing a particular disorder in the future

_____ 3. Determines whether an individual has a potentially harmful recessive allele

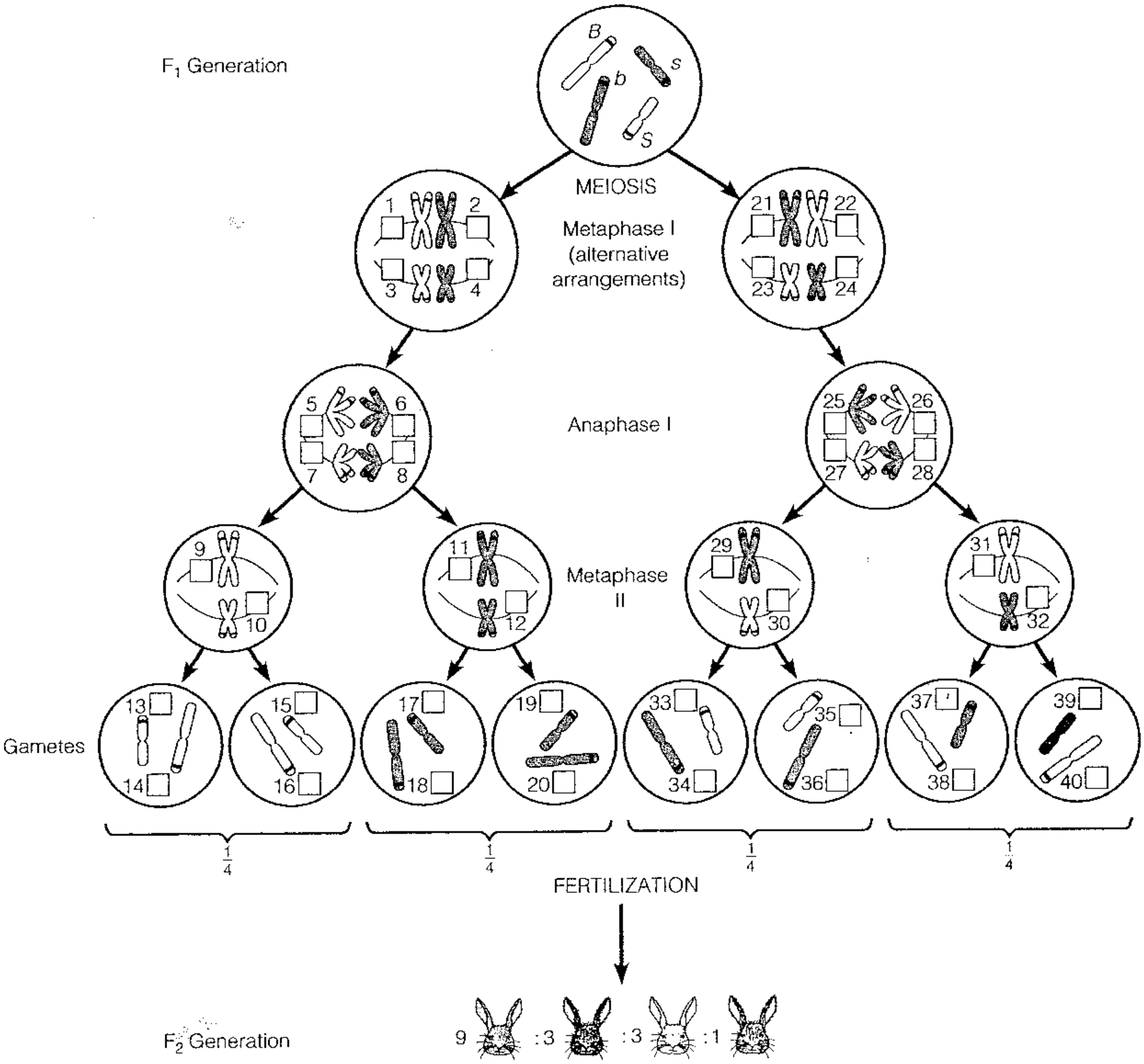
_____ 4. Catches inherited disorders immediately after birth

A. newborn screening
B. diagnostic testing
C. prediction testing
D. carrier testing

Exercise 12 (Module 9.17)

Genes are located on chromosomes. Genes undergo segregation and independent assortment because the chromosomes that carry them undergo segregation and independent assortment during meiosis. The illustration below is similar to that in Module 9.17. It shows how alleles and chromosomes are arranged in an F_1 rabbit and how meiosis sorts the alleles into their gametes. The diagram below shows only the chromosomes. Put a letter (*B*, *b*, *S*, or *s*) in each of the numbered boxes to show how segregation and independent assortment of chromosomes cause segregation and independent assortment of alleles.

(20)



Exercise 13 (Modules 9.18 – 9.20)

Web/CD Activity 9E *Linked Genes and Crossing Over*

These three modules discuss the inheritance of linked genes—genes on the same chromosome. Their pattern of inheritance is inconsistent with Mendel's "rules," but they illustrate important principles of chromosome structure and behavior. After reading the modules, match each of the observations below with the statement that explains the observation. Take your time; this exercise is not easy.

Observations

____ 1. When two heterozygous round yellow peas are crossed, their offspring are produced in a 9:3:3:1 ratio (9 round yellow : 3 round green : 3 wrinkled yellow : 1 wrinkled green).

____ 2. When two peas heterozygous for purple flowers and long pollen are crossed, the expected 9:3:3:1 ratio is not seen. The ratio is close to 3 purple long : 1 red round. Similarly, when a fruit fly with red eyes and long wings *(SsCc)* is crossed with a fly with scarlet eyes and curled wings *(sscc)*, offspring are not produced in the expected 1:1:1:1 ratio. Most offspring are red long and scarlet curled.

____ 3. When two heterozygous purple long peas are crossed, most of their offspring are purple and long or red and round. But a very small number of offspring are purple and round or red and long. Similarly, when the *SsCc* and *sscc* fruit flies are mated, nearly all their offspring are *SsCc* and *sscc*. However, a small number of offspring (about 6% of the total) are *Sscc* and *ssCc*.

____ 4. When a fruit fly with red eyes and long wings *(SsCc)* is crossed with a fly with scarlet eyes and curled wings *(sscc)*, 94% of their offspring are *SsCc* and *sscc*, and 6% are *Sscc* and *ssCc*. In other words, the recombination frequency between the *s* and *c* alleles is 6%. When a fly with red eyes and pale body *(SsEe)* is crossed with a fly with scarlet eyes and ebony body, 27% of their offspring are *Ssee* and *ssEe*. The recombination frequency between alleles *s* and *e* is 27%.

____ 5. When a fly with long wings and pale body *(CcEe)* is crossed with a fly with curled wings and ebony body *(ccee)*, 21% of their offspring are *Ccee* and *ccEe*. The recombination frequency between alleles *c* and *e* is 21%.

Explanations

A. The greater the distance between two genes, the greater the opportunity for crossing over to occur between them. If crossing over is more likely, more recombinant offspring will result. If two genes are farther apart, the recombination frequency will be greater between them.

B. Pairs of alleles on different chromosomes segregate independently during gamete formation. They follow Mendel's principle of independent assortment. In other words, genes for different traits on different chromosomes do not tend to "stick together" when passed on to offspring.

C. If two genes are on the same chromosome, or linked, they tend to be inherited together. Alleles on the same chromosome do not segregate independently. They tend to "stick together," violating Mendel's principle of independent assortment.

D. Recombination frequencies can tell you how far apart genes are on a chromosome. If you know the distance from *a* to *b*, the distance from *a* to *c*, and the distance from *b* to *c*, you can map the sequence of genes on the chromosome.

E. Homologous chromosomes cross over during meiosis and exchange segments. This recombines linked genes into assortments not seen in the parents.

Exercise 14 (Module 9.21)

What determines an individual's sex? Sex is generally determined by genes and chromosomes, but the process of sex determination works differently in different species. Match each group of organisms below with their system of sex determination.

A. Most plants, including peas, corn
B. Humans, fruit flies, some plants
C. Ants, bees
D. Earthworms, snails
E. Some butterflies, birds, fishes
F. Grasshoppers, crickets, roaches

____ 1. Females are ZW, males ZZ.
____ 2. Females are diploid, males haploid.
____ 3. Females are XX, males XO (one X).
____ 4. Hermaphroditic; all produce eggs and sperm.
____ 5. Females are XX, males XY.
____ 6. Monecious; all produce both eggs and sperm.

Exercise 15 (Modules 9.22 – 9.23)

Web/CD Activity 9F *Sex-Linked Genes*

(16)

Genes located on the sex chromosomes—called sex-linked genes—determine many traits unrelated to maleness or femaleness. Red-green color blindness is a recessive sex-linked trait in humans. After reading Modules 9.22 and 9.23, see if you can describe the inheritance of color blindness by filling in the blanks below.

The genes for normal color vision and red-green color blindness, like most human sex-linked traits, are carried on the 1________________ chromosome. A capital letter *C* represents the 2________________ allele for normal vision; a small *c* represents the color-blindness allele. A male with normal color vision has the genotype 3________________. (Because these genes are carried on the *X* chromosome, their symbols are shown as superscripts on the letter *X*.) A color-blind male has the genotype 4________________.

A color-blind male will transmit the allele for color blindness to all his 5________________ but none of his 6________________. This is because only his daughters inherit his 7________________ chromosome, and only his 8________________ chromosome is passed to all his sons. All the children of a color-blind male and a homozygous dominant female will have normal color vision. Their sons will inherit only the normal vision allele, but their daughters will be 9________________ of the color-blindness allele, thus possessing the genotype 10________________.

A heterozygous female carrier transmits the color-blindness allele to 11________________ of her offspring. If she and a male with normal vision have children, 12________________ of their sons will be normal and 13________________ will be color blind. 14________________ of their daughters will be normal, because they inherit at least one dominant allele from their 15________________. But half these daughters will be 16________________ of the color-blindness trait, because they inherit the color-blindness allele from their mother.

Color blindness is much more common in men than in women. If a man inherits a single color-blindness allele from his 17________________, the gene will be expressed and he will be color blind. Because a man has only one 18________________ chromosome, whatever genes it carries are seen in the man's phenotype. If a woman inherits just