Solutions Manual for

Modern Genetics

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PREFACE

The problems at the end of the chapters in Modern Genetics are an important part of the text. Working through the problems is an excellent way of reviewing the principles learned in each chapter. Moreover, the problems occasionally introduce additional bits of information considered too specialized or secondary for inclusion in the main part of the chapter, where they might distract from the main concepts.

We have tried to devise problems that will elicit from the student the type of reasoning that has been so helpful to the advance of the science and which is unique to genetics. We give the answers to the problems, and, where we feel it is useful, show how the answers may be reached. We hope that this will facilitate the process whereby students learn to think as geneticists, as well as provide self-testing for students working by themselves.

The answers have been tested in a large course jointly taught by both of us. The teaching assistants and students detected some errors and made other valuable suggestions that have been incorporated in this Manual. Any additional corrections or changes suggested by either students or instructors will be very much appreciated.

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Chapter 1
INTRODUCTION

1-1. The number of chromosomes would double every generation. The organism's descendants would have $8x2^5 = 256$ chromosomes after 5 generations, $8x2^{10}$ after 10 generations, and $8x2^{100}$ after 100 generations.

1-2. Similarities:
Chromosomes duplicate once in each process.
The same stages--prophase, metaphase, anaphase, telophase--occur in both.

Differences:

Mitosis	Meiosis
One cell division (two cell products)	Two cell divisions (four cell products)
Number of chromosomes unchanged (2N)	Number of chromosomes halved (N)
No pairing of homologous chromosomes	Pairing of homologous chromosomes at metaphase I
No recombination	Recombination of paternal and maternal chromosomes as well as of genes between homologous chromosomes

1-3. No, because the males are already haploid. Mitosis rather than meiosis occurs in spermatogenesis. (Meiosis, however, will occur in the females since these are diploid.)

1-4. All four cell types are meiotic products and, therefore, haploid with 23 chromosomes.

1-5. Cells with multiple sets of chromosomes arise through chromosome duplication without subsequent cell (or nuclear) division.

1-6. Sexually reproducing organisms will produce more variable progeny than asexual organisms. Meiosis ensures recombination of the paternal and maternal chromosomes as well as

recombination of the genes between homologous chromosomes. The progeny of an asexually reproducing organism will be genetically uniform (except for newly arisen mutations, which of course will also occur in the progeny of sexually reproducing organisms).

1-7. Two distinguishable kinds of gametes are possible for each such pair of chromosomes; hence $2^3 = 8$ distinguishable kinds of gametes are possible with three pairs. Designate the three pairs of chromosomes as follows: A_1A_2, B_1B_2, C_1C_2; the eight kinds of gametes are $A_1B_1C_1$, $A_1B_1C_2$, $A_1B_2C_1$, $A_1B_2C_2$, $A_2B_1C_1$, $A_2B_1C_2$, $A_2B_2C_1$, $A_2B_2C_2$.

2-1.

Cross:	AA x aa	AA x Aa	Aa x aa	Aa x Aa
Gametes:	A a	A $\frac{1}{2}$A, $\frac{1}{2}$a	$\frac{1}{2}$A, $\frac{1}{2}$a a	$\frac{1}{2}$A, $\frac{1}{2}$a $\frac{1}{2}$A, $\frac{1}{2}$a
Progeny:	Aa	$\frac{1}{2}$AA, $\frac{1}{2}$Aa	$\frac{1}{2}$Aa, $\frac{1}{2}$aa	$\frac{1}{4}$AA, $\frac{1}{2}$Aa, $\frac{1}{4}$aa

2-2. The fact that all progeny of the first cross is black suggests that black is dominant to albino and, moreover, that the black guinea pig is probably homozygous for the black allele. The black guinea pig of the second cross must have been heterozygous for the black and the albino alleles.

If we use B to represent the black allele and b to represent the albino allele, the genotypes of the parents and progeny would be:

First cross BB x bb → Bb

Second cross Bb x bb → $\frac{1}{2}$Bb, $\frac{1}{2}$bb

2-3. These results are <u>not</u> consistent with the theory of pangenesis, which predicts albino offspring due to "albino determining particles" allegedly formed throughout the body. The results <u>are</u> consistent with Mendelian inheritance because the genotype of the female gametes (ova) is determined by the transplanted ovary.

2-4. The results suggest that black (B) is dominant over brown (b). The first female is likely to be BB, while the second is likely to be Bb. (The brown male is bb).

The expected offspring of the second female is:

Parents: Bb ♀ X bb ♂

Offspring: $\frac{1}{2}$Bb (black) and $\frac{1}{2}$bb (brown)

The chi-square test (see Table A.1) is made as follows:

	Black	Brown	Total
Observed (O)	14	10	24
Expected (E)	12	12	24
O-E	2	-2	0
$(O-E)^2$	4	4	
$(O-E)^2/E$	4/12	4/12	$\chi^2=8/12=0.67$

The hypothesis is accepted, because 0.67 < 3.84 (3.84 is the χ^2 value with 1 degree of freedom at the 0.05 level of significance--see Table A.2).

2-5. Because selfed green plants produce albino offspring, we infer (1) that albino (a) is recessive to green (A) and (2) that the green plants are heterozygous (Aa).

The expected progeny when a green heterozygous plant is selfed is:

$$\text{Aa } ♀ \quad \times \quad \text{Aa } ♂$$

$$\downarrow$$

$$\underbrace{\tfrac{1}{4}\,\text{AA} \quad \tfrac{1}{2}\,\text{Aa}}_{\tfrac{3}{4}\text{ green}} \qquad \underbrace{\tfrac{1}{4}\,\text{aa}}_{\tfrac{1}{4}\text{ albino}}$$

The chi-squares (calculated as in problem 2-4 or Table A.1) for the results are:

Parent

1 $\chi^2 = \frac{(38-36.75)^2}{36.75} + \frac{(11-12.25)^2}{12.25} = 0.17$

2 $\chi^2 = \frac{(26-27.75)^2}{27.75} + \frac{(11-9.25)^2}{9.25} = 0.44$

3 $\chi^2 = \frac{(42-40.5)^2}{40.5} + \frac{(12-13.5)^2}{13.5} = 0.22$

4 $\chi^2 = 0.06$

5 $\chi^2 = 0.24$

6 $\chi^2 = 0.80$

There is 1 degree of freedom (d.f.) in each case. Table A.2 shows that $\chi^2 = 3.84$ with 1 d.f. at the 0.05 level of significance. We accept our hypothesis because the χ^2 < 3.84 in every case.

2-6. The chi-square tests for the 3:1 and the 1:1 ratio give the following results

$$3{:}1 \quad \chi^2 = \frac{(22-22.5)^2}{22.5} + \frac{(10-7.5)^2}{7.5} = 1.11$$

$$1{:}1 \quad \chi^2 = \frac{(20-15)^2}{15} + \frac{(10-15)^2}{15} = 3.33$$

In both cases $\chi^2 < 3.84$, which is the value at the 0.05 level of significance with 1 d.f. Hence, neither hypothesis can be rejected.

If the male parent is Aa, a 3:1 ratio is expected in the offspring. If the male parent is aa (homozygous for the recessive albino allele), the expected ratio is 1:1.

2-7. A test cross of the farmer's dominant types (rose comb) to homozygous recessives (single comb) will reveal which among the dominant class are heterozygous because half of their progeny will be homozygous recessive (single comb) progeny. All progeny of the homozygous dominant individuals will show the dominant phenotype (rose comb) when the test cross is carried out.

2-8. Since a person never has this condition unless one of the parents had it, we know the atrophy is likely to be caused by a dominant allele.

2-9. The observations given suggest that this form of the condition is due to homozygosis for a recessive allele. The parents (usually, first cousins) would be heterozygous for the recessive allele:

Aa X Aa

$\frac{1}{4}$ AA

$\frac{1}{2}$ Aa

$\frac{1}{4}$ aa (afflicted offspring)

2-10. A and B blood group alleles are co-dominant with respect to each other and dominant over the O allele. Therefore the only way an A type ♂ and B type ♀ can produce an O type child is if they both carry the O allele:

A allele = I^A

B allele = I^B

O allele = i

♂ \ ♀	I^B	i
i	I^Bi	ii
I^A	I^AI^B	I^Ai

So, we expect equal numbers of A, B, AB and O type children.

2-11. χ^2 values for Mendel's crosses for each of 7 characters based on 3:1 ratio are as follows

1 $\chi^2 = \frac{(5474-5493)^2}{5493} + \frac{(1850-1831)^2}{1831} = 0.26$

2 $\chi^2 = \frac{(6022-6017.25)^2}{6017.25} + \frac{(2001-2005.75)^2}{2005.75} = 0.01$

3 $\chi^2 = \frac{(765-696.75)^2}{696.75} + \frac{(224-232.25)^2}{232.25} = 0.39$

4 $\chi^2 = \frac{(651-643.5)^2}{643.5} + \frac{(207-214.5)^2}{214.5} = 0.35$

5 $\chi^2 = \frac{(882-885.75)^2}{885.75} + \frac{(299-295.25)^2}{295.25} = 0.06$

6 $\chi^2 = \frac{(428-435)^2}{435} + \frac{(152-145)^2}{145} = 0.45$

7 $\chi^2 = \frac{(787-798)^2}{798} + \frac{(277-266)^2}{266} = 0.61$

Each χ^2 value is less than 3.84, so the inheritance of the characters is not inconsistent with the 3:1 ratio predicted by Mendel's hypothesis.

2-12. Parents: BBRR X bbrr

Gametes: BR br

F_1 BbRr all black and rough

F_2		female gametes: 1/4 BR	1/4 Br	1/4 bR	1/4 br
	male gametes: 1/4 BR	BBRR	BBRr	BbRR	BbRr
	1/4 Br	BBRr	BBrr	BbRr	Bbrr
	1/4 bR	BbRR	BbRr	bbRR	bbRr
	1/4 br	BbRr	Bbrr	bbRr	bbrr

9/16 black rough
3/16 black smooth
3/16 albino rough
1/16 albino smooth

The offspring of the cross F_1 X albino smooth will be

Parents: BbRr X bbrr
↓ ↓
Gametes: 1/4 BR 1/4 Br br
1/4 bR 1/4 br

Progeny: 1/4 BbRr black rough
1/4 Bbrr black smooth
1/4 bbRr albino rough
1/4 bbrr albino smooth

2-13. Parents: B_R_ X bbR_
Offspring: B_R_ bbR_ B_rr bbrr
13 : 16 : 6 : 5

Considering the data locus by locus we see that 29 progeny were black and 21 were albino. This suggests that the black guinea pig must have been a heterozygote (Bb). Turning to the other locus we see 13+16 = 29 guinea pigs were rough coated while 6+5 = 11 were smooth. This approximately 3:1 ratio suggests both parents were heterozygotes at this locus (Rr).

Our hypothesis is that the parents had the following genotypes (the expected offspring are also given):

Parents: BbRr X bbRr

BbRr gametes:	bbRr gametes: 1/2 bR	1/2 br
1/4 BR	1/8 BbRR (black rough)	1/8 BbRr (black rough)
1/4 Br	1/8 BbRr (black rough)	1/8 Bbrr (black smooth)
1/4 bR	1/8 bbRR (albino rough)	1/8 bbRr (albino rough)
1/4 br	1/8 bbRr (albino rough)	1/8 bbrr (albino smooth)

That is, 3/8 black rough; 3/8 albino rough; 1/8 black smooth; and 1/8 albino smooth.

The χ^2 value (with 4-1 = 3 d.f.) is:

$$\chi^2 = \frac{(13-15)^2}{15} + \frac{(16-15)^2}{15} + \frac{(6-5)^2}{5} + \frac{(5-5)^2}{5} = 0.53$$

Since $0.53 < 7.82$ we do not reject our hypothesis.

2-14. (1) $vg^+ \_\_ st^+ \_\_$ X vg vg st st

The occurrence of approximately equal numbers of all four progeny types suggests that the wild-type parents are heterozygous at each locus. A chi-square test that the parental genotypes are: vg^+ vg st^+ st X vg vg st st (and therefore that we will find a 1:1:1:1 ratio among progeny) follows:

$$\chi^2 = \frac{(178-156)^2}{156} + \frac{(164-156)^2}{156} + \frac{(142-156)^2}{156} + \frac{(140-156)^2}{156} =$$

$= 6.41$, with 3 degrees of freedom.

Since $6.41 < 7.82$, we do not reject our hypothesis.

(2) $vg^+ \_\_ st^+ \_\_$ X $vg^+ \_\_ st^+ \_\_$

The absence of scarlet eye in the progeny suggests that at least one parent is homozygous for the red-eye allele. The 3:1 ratio of long to vestigial wings suggests that both

parents are heterozygous at that locus: vg^+ vg st^+ st^+ X vg^+ vg st^+ __.

The expected progeny types from these parents will occur in a 3:0:1:0 ratio.

$$\chi^2 = \frac{(364-353.25)^2}{353.25} + \frac{(107-117.75)^2}{117.75} = 0.98, \text{ with 3 d.f.}$$

Because $0.98 < 7.82$, we consider the observations consistent with our hypothesis.

(3) vg^+ __ st^+ __ X vg^+ __ st^+ __

A ratio approximating 3:1 for each locus suggests that both parents are heterozygous at each locus: vg^+ vg st^+ st X vg^+ vg st^+ st. The prediction of this model is that the offspring phenotypes will appear in a 9:3:3:1 ratio

$$\chi^2 = \frac{(309-303.75)^2}{303.75} + \frac{(107-101.25)^2}{101.25} + \frac{(95-101.25)^2}{101.25} + \frac{(29-33.75)^2}{33.75} =$$

$= 1.47$, with 3 d.f.

Again the data fit our hypothesis.

2-15.

	Experiment	Parental Genotypes
P = one pod allele	1	PPNn X ppNn
p = three pod allele	2	PpNN X ppnn
N = normal leaf allele	3	Ppnn X ppNn
n = wrinkled leaf allele	4	PpNn X ppNn
	5	PpNn X Ppnn

2-16. See Table 2.2:

Gene pairs	# gamete types	Genotypes	Phenotypes
1	$2^1 = 2$	3	2
2	$2^2 = 4$	$3^2 = 9$	4
3	$2^3 = 8$	$3^3 = 27$	8
5	$2^5 = 32$	$3^4 = 81$	32
7	$2^7 = 128$	$3^5 = 243$	128

2-17. Aa Bb Cc Dd X Aa Bb Cc Dd

Since genes assort independently, the probability of obtaining a particular 4-locus genotype is simply the <u>product</u> of the probabilities of obtaining each single locus genotype.

(1) 1/4 X 1/4 X 1/4 X 1/4 = 1/256
(2) 1/4 X 1/4 X 1/2 X 1/2 = 1/64
(3) 1/2 X 1/2 X 1/2 X 1/2 = 1/16

2-18. See Table 2.5:

$$\frac{n(n+1)}{2} = \frac{7x8}{2} = 28$$

2-19. See Table 2.5. The <u>proportion</u> of all possible genotypes that are homozygotes is $n/\frac{n(n+1)}{2} = \frac{2}{n+1}$

With 3 alleles: 2/(3+1) = 1/2
With 5 alleles: 2/(5+1) = 1/3
With 6 alleles: 2/(6+1) = 2/7

2-20. The first parent exhibits the dominant phenotypes for each one of the four traits; the second parent exhibits the recessive phenotype for each one of the four traits. Because the F_1 individuals all exhibit the dominant phenotype for all four traits, it follows that the first parent must have been <u>homozygous</u> dominant at each locus. If we represent the four dominant alleles as A, B, C, D and the four recessive alleles as a, b, c, d, the cross is:

Parents AA BB CC DD X aa bb cc dd

F_1 Aa Bb Cc Dd

Crosses of F_1 individuals with homozygotes for all four recessive alleles give the 16 possible kinds of phenotypes in approximately equal proportions. This suggests that the four genes assort independently.

The cross F_1 X F_1 will produce the 16 phenotypes in the following expected ratios (see page 44-45):

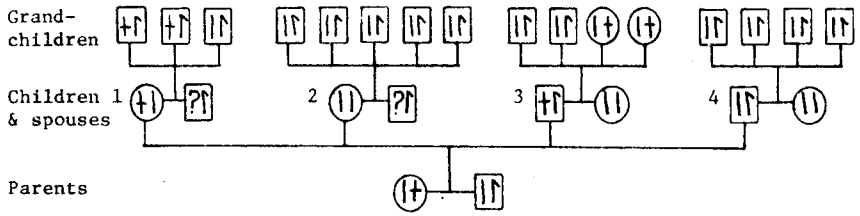
1.	Wild color = dominant at all four loci	$\frac{3}{4}x\frac{3}{4}x\frac{3}{4}x\frac{3}{4}$* = 81/256
2.	Black = one recessive, three dominants	1X3X3X3 = 27/256
3.	Spotted agouti = one recessive, three dominants	1X3X3X3 = 27/256
4.	Rubi agouti = one recessive, three dominants	1X3X3X3 = 27/256
5.	Dilute agouti = one recessive, three dominants	1X3X3X3 = 27/256
6.	Spotted black = two recessives, two dominants	1X1X3X3 = 9/256
7.	Rubi black = two recessives, two dominants	1X1X3X3 = 9/256
8.	Dilute black = two recessives, two dominants	1X1X3X3 = 9/256
9.	Spotted, dilute agouti = two recessives, two dominants	1X1X3X3 = 9/256
10.	Ruby, dilute agouti = two recessives, two dominants	1X1X3X3 = 9/256
11.	Spotted, rubi agouti = two recessives, two dominants	1X1X3X3 = 9/256
12.	Spotted, dilute black = three recessives, one dominant	1X1X1X3 = 3/256
13.	Ruby, dilute black = three recessives, one dominant	1X1X1X3 = 3/256
14.	Spotted, ruby, black = three recessives, one dominant	1X1X1X3 = 3/256
15.	Spotted, ruby, dilute agouti = three recessives, one dominant	1X1X1X3 = 3/256
16.	Spotted, ruby, dilute black = four recessives	1X1X1X1 = 1/256

*Note that (1) the denominators of the multipliers have been omitted for simplicity from the second to the sixteenth phenotype; (2) the recessive phenotypic traits are underlined.

Chapter 3
THE CHROMOSOMAL BASIS OF HEREDITY

3-1. Work by inference, from progeny to progenitors.

Key: □ = male; ○ = female
| = normal X chromosome; ┼ = X chromosome with color-blind allele
Y = Y chromosome; ? = either | or ┼



Comments: The first daughter(1) has color-blind as well as normal sons; therefore, she must have been heterozygous for the color-blind and the normal allele.

The second daughter (2) is probably homozygous for the normal allele, because none of the five sons is color blind.

The first son (3) is color blind and hence carries the color-blind allele. Because his sons as well as his daughters have normal vision, their mother is likely to be homozygous for the normal allele.

The second son (4) has normal vision and hence carries the normal allele. His wife is likely to be homozygous for the normal allele since all their four sons have normal color vision.

3-2. Work by inference, from parents to progeny.

Key: | = normal X chromosome; ┼ = X chromosome with hemophilia allele