VARIATIONS OF LINKAGE IN RATS AND MICE

W. E. CASTLE AND W. L. WACHTER[1]

Bussey Institution, Harvard University, Forest Hills, Boston, Massachusetts

In the common brown rat (*Mus norvegicus*) there occurs a linkage system of three genes; that is, there occur in this species three characters which show with relation to one another the phenomena of coupling and repulsion in heredity. Two characters are said to be coupled in heredity when they have a tendency to stay together generation after generation, and they are said to exhibit repulsion when they have a tendency to keep apart. In general, two linked characters show coupling when they are inherited from the same parent in the same gamete and repulsion when they are inherited from different parents and so in different gametes. It is supposed that linked genes lie in the same chromosome. If this explanation is correct, it follows that in the brown rat there occur, in a common chromosome, genes for the three recessive characters, albinism, red-eyed yellow and pink-eyed yellow. With a view to learning more about the behavior of linked genes in heredity, an intensive study has been made of this case.

Everyone is familiar with the common white rat, an albino variety of *Mus norvegicus*, which has long been in captivity as a pet and is now extensively used as a laboratory animal. Its coat is practically without pigment (a creamy white) and its eyes are pink. Albinism is a simple Mendelian recessive character. Consequently albino rats produce only albino offspring.

The two yellow varieties are of more recent origin. They were discovered in England only a few years ago. They are identical with each other in appearance except for the eye color, which in one variety is similar to the albino, being practically without pigment and so showing a pink reflection from the blood in the retina. This variety is known as pink-eyed yellow. In the other variety the eye contains considerable black pigment (though less than is found in black or gray rats), consequently the eye has a dull red color and the variety is called red-eyed yellow. Fanciers call it black-eyed yellow.

The yellow varieties behave in exactly the same way as the albino in crosses with the fully pigmented black or gray varieties. Each is a simple recessive character and so breeds true as soon as isolated.

When the albino variety is crossed with one of the yellow varieties, or when the yellow varieties are crossed with each other, gray or black offspring are obtained fully or nearly[2] as heavily pigmented as wild rats. This result shows that the three recessive variations are all different in nature and are really complementary.

When an F_2 generation is produced from one of these crosses it contains more of the recessive (grandparental) types and fewer of the dark type of F_1 than the percentage expected when two recessive characters are independent in their inheritance. This suggests linkage, and when more exact tests are made it is indeed found that linkage occurs in every case, though its strength is different in each case.

The linkage between albinism and red-eyed yellow is strongest of all. If an albino is crossed with a red-eyed yellow rat, gray F_1 young are obtained. These mated with each other produce an F_2 generation of albino, gray, and red-eyed yellow rats. Now if albinism and red-eyed yellow were independent (not linked), half the F_2 albinos should transmit yellow and so would produce yellow young when crossed with yellows. Also half of the F_2 yellow rats should transmit albinism and so would produce albino young when mated with albinos. In reality, we had to test several hundred F_2 albinos and red-eyed yellows before we found one that transmitted *both* albinism and red-eyed yellow. From such "cross-over" individuals a stock of double-recessive individuals was in time obtained which enabled us to determine more precisely the crossover percentage. The procedure was as follows. An F_1 individual was mated with a double-recessive individual or individuals and the young were examined at birth as to their eye color, note being made of how many had light eyes (destined to be either albinos or red-eyed yellows) and how many had dark eyes (the F_1 type). *Those having dark eyes would theoretically equal half the total number of crossover gametes produced by the F_1 parent.* For, if we designate the albino character by c and the red-eyed yellow character by r, then the gametes which unite to form the F_1 individual are cR and Cr. The F_1 individual will form gametes ordinarily of these same two types, but exceptionally (as crossovers) of the types CR and cr. The double-recessive individuals mated with the F_1 individual will produce only gametes cr in formula, which, united with the four kinds of gametes

[2] Crosses of the two yellow varieties with each other produce lighter grays than either cross of albino with yellow.

produced by the F_1 mate, will produce a double-dominant combination necessary for the production of dark eyes, only when united with the CR crossover type of gamete. In matings of F_1 with double recessive individuals, 12,587 young have been produced, of which 18 were dark-eyed, indicating the occurrence of twice 18, or 36 crossover gametes, a percentage of 0.28 (see table 1). In testing F_2 individuals for evidence of

TABLE 1

Summary of data on linkage in rats and mice.

GENES CONCERNED	GAMETES TESTED	CROSSOVER GAMETES	PERCENT CROSSOVERS	NATURE OF CROSS	SOURCE OF DATA
Albinism and red-eyed yellow in rats.............	434	1	0.46±1.62	Repulsion	CASTLE 1919
	270	5	1.85±2.05	Repulsion	DUNN 1920
	12,587	36	0.28±0.42	Repulsion	New data
Total..............	13,291	42	0.31±0.41		
Red-eyed yellow and pink-eyed yellow in rats.....	4,746	870	18.33±0.69	Repulsion and coupling	CASTLE 1919
Albinism and pink-eyed yellow in rats..........	90	19	21.10±3.55	Repulsion	CASTLE 1919
	32,735	6438	19.66±0.26	Repulsion	New data
Total..............	32,825	6457	19.67±0.26		
Albinism and pink-eye in mice..................	3,418	482	14.10±0.81	Repulsion	CASTLE 1919
	3,331	503	15.10±0.82	Coupling	DUNN 1920
	3,880	568	14.64±0.76	Coupling	New data
Total..............	10,629	1553	14.61±0.46		

crossing over (CASTLE 1919, DUNN 1920), in the preliminary work, the occurrence was noted of 6 crossovers among 704 gametes which entered into the production of 352 tested individuals. This is less than one percent of crossovers. Combining the data from the F_2 tests, with those obtained from back-crosses, we have 42 indicated crossovers in 13,291 gametes, or 0.31 ± 0.41 percent, which in round numbers is one-third of one percent of crossovers. The numbers are large enough to show that crossing over between these two genes is a rare event.

A word might be said as to the statistical significance in this case of the calculated crossover percentage, which is slightly less than its probable

error. Does this mean that doubt exists as to the occurrence of crossing over between the two genes? By no means. The demonstration of the existence of a single F_2 individual, which transmitted in the same gamete both yellow and albinism, would constitute incontrovertible proof that crossing over had occurred. Six such individuals were obtained. The probable error in this case indicates merely the likelihood that, on the repetition of the experiment, crossovers would again be obtained in comparable numbers.

The probable errors throughout this paper are based on the convenient tables prepared and distributed privately by Dr. R. A. EMERSON in 1922. In the use of these tables in our work, the probable error has been based, not as ordinarily on the total population studied, but on *half* the total population, for the reason that the observed number of crossovers was really that of the half population, since one of the two theoretically equal classes of crossovers was not identified. This procedure increases considerably the probable error, over what it would otherwise be in populations of the size recorded.

Between the genes for pink-eyed yellow and for red-eyed yellow, the crossover percentage is 18.33 ± 0.69 (data of CASTLE 1919), based on tests of 4746 gametes produced by F_1 males and females.

The linkage is least between the genes for albinism and pink-eyed yellow. Back-crosses of F_1 animals of both sexes with double recessive individuals have been studied very extensively in this case. They indicate that of 32,735 gametes produced by F_1 animals, 6438 were crossovers. This is a crossover percentage of 19.66 ± 0.26. Combining with these figures data reported by CASTLE (1919) on tests of 90 F_2 animals, which gave an indicated crossover percentage of 21.10 ± 3.55, we have for this linkage relation, data on 32,825 gametes produced by F_1 animals, giving a crossover percentage of 19.67 ± 0.26.

These figures clearly indicate that the order of the genes, if linear, is (1) albinism, (2) red-eyed yellow and (3) pink-eyed yellow, since the greatest crossover percentage occurs between albinism and pink-eyed yellow, which makes them the end genes of the series. Before we discuss the evidence for the linearity or non-linearity of the arrangement of the three genes, it will be necessary to consider the relation of sex to the crossover percentage, since in the data already given in summary fashion, male and female parents were unequally represented.

In all the rat linkages, as also in the linkage studied in mice, F_1 females give a higher crossover percentage than males give. See table 2. In the case of albinism and red-eyed yellow, F_1 females have given a crossover

TABLE 2

Data on the frequency of crossing over in the two sexes of rats and mice.

GENES CONCERNED	SEX OF PARENT	GAMETES TESTED	CROSSOVER GAMETES	PERCENT CROSSOVERS	NATURE OF CROSS	SOURCE OF DATA
Albinism and red-eye in rats..........	Female	3,759	20	0.53 ± 0.78	Repulsion	New data
	Male	8,828	16	0.18 ± 0.50	Repulsion	New data
Total.........		12,587	36	0.28 ± 0.42		
Red-eye and pink-eye in rats.......	Female	2,683	549	20.46 ± 0.92	Repulsion and coupling	CASTLE 1919
	Male	2,063	321	15.55 ± 1.04	Repulsion and coupling	CASTLE 1919
Total.........		4,746	870	18.33 ± 0.69		
Albinism and pink-eye in rats.......	Female	11,480	2518	21.93 ± 0.44	Repulsion	New data
	Male	21,255	3920	18.39 ± 0.32	Repulsion	New data
Total.........		32,735	6438	19.66 ± 0.26		
Albinism and pink-eye in mice......	Female	2,789	444	15.92 ± 0.90	Repulsion and coupling	DUNN 1920
	Male	3,683	503	13.65 ± 0.78	Repulsion and coupling	DUNN 1920
	Female	556	106	19.06 ± 2.02	Coupling	New data
	Male	3,324	462	13.89 ± 0.82	Coupling	New data
	Female	3,345	550	16.44 ± 0.82		Combined data
	Male	7,057	965	13.77 ± 0.57		Combined data
Total.........		10,352	1515	14.63 ± 0.47		

percentage of 0.53 ± 0.78, while males have given 0.18 ± 0.50 percent. In the cross of albino with pink-eyed yellow, F_1 females have given 21.93 ± 0.44 percent of crossovers, whereas males have given 18.39 ± 0.32, a difference of more than three percent between the sexes. As regards the relation of pink-eyed yellow to red-eyed yellow, F_1 females have given 20.46 ± 0.92 percent crossovers, and males have given 15.55 ± 1.04 percent. The probable errors are greater in the last case than in either of the others because fewer young were produced.

The data obtained from mice are entirely consistent with those given by rats. In the cross of albino with pink-eyed colored mice, F_1 females have given a crossover percentage of 16.44 ± 0.82 and F_1 males 13.77 ± 0.57 percent, a difference of nearly three percent. All the data are consistent with the view that in rats and mice a pair of chromosomes containing genes for albinism and pink-eyed colored coat cross over somewhat more freely in females than in males. This being the case, it is legitimate to compare only crossover percentages obtained from the same sex.

On the theory of linear arrangement of the genes, the crossover percentage between the most distant genes in a linkage system should approximate the sum of the intermediate linkages from gene to gene. That is, AC should equal $AB+BC$, when the order of the genes is ABC. The facts in the present case are in harmony with this theory. Calling the three genes c(albinism), r (red-eyed yellow), and p (pink-eyed yellow), we should have $cr+rp=cp$. Substituting the observed, we have for males, $0.18+15.55=18.44$, which is greater than the actual sum of the first two terms (15.73) by 2.71 percent, but the sum of the three probable errors is 1.86 percent, more than half of the observed deviation. In the case of females the equation would read $0.53+20.46=21.93$, which again is greater than the true sum of the first two terms (20.99), although the discrepancy is not so great, being 0.94, the sum of the three probable errors being 2.14. In each case $AC>AB+BC$, yet the difference is no greater than random sampling might produce. The linear arrangement theory is tenable in the case.

A literal interpretation of the chromosome theory might lead one to the conclusion that in this case homologous chromosomes are *longer* in females than in males, but such a suggestion can scarcely be considered seriously. There is a difference in the physiology of maturation in ova and in spermatogonia. In Drosophila *no* crossing over occurs in males, though the chromosomes certainly have appreciable length in the male. On the contrary, in silk-moths crossing over occurs *only* in males, though the chromosomes are probably quite as long in the egg as in the sperm-cell. In rats and mice it is evident, at least in the case of one pair of chromosomes, that crossing over occurs a little more freely in females than in males, but there is no reason to think that the arrangement or spacing of the genes is different in the two sexes.

Aside from sex, we have investigated two other factors which might conceivably influence the amount of crossing over, namely, the age of the parent, and seasonal conditions, in particular, temperature. Both these investigations have yielded negative results. There was some indication

of a rise in the crossover percentage in litters born in the warmer months, July, August and September, but fuller investigation failed to substantiate the suggestion. Age of the parent and size of the litter also exert no discoverable effect on the crossover percentage. Differences in the crossover percentages given by different male F_1 individuals have also been sought but largely without success. The crossover percentages of individual male parents fluctuate in a typical curve of error, and selection of extreme individuals has had no racial effect. Hence, we conclude that such fluctuation has no genetic significance, but is due solely to random sampling.

TABLE 3

Crossover percentages between albinism and pink-eyed yellow among the young sired by males of known age in months.

AGE OF SIRE IN MONTHS	YOUNG WITH LIGHT EYES	YOUNG WITH DARK EYES	TOTAL YOUNG	PERCENT CROSSOVERS	P. E.	DEVIATION FROM AVERAGE	DEV. P. E.
3	880	78	958	16.28±	1.54	−1.81	1.17
4	1963	194	2157	17.98±	1.02	− .11	.10
5	2081	209	2290	18.24±	.99	+ .15	.15
6	2029	215	2244	19.16±	1.00	+1.07	1.07
7	2220	249	2469	20.17±	0.96	+2.08	2.16
8	1838	187	2025	18.47±	1.05	+ .36	.34
9	1658	181	1839	19.68±	1.11	+1.59	1.43
10	1302	126	1428	17.64±	1.24	− .45	.36
11	1231	104	1335	15.58±	1.31	−2.51	1.91
12	927	81	1008	16.07±	1.50	−2.02	1.34
13	759	60	819	14.65±	1.67	−3.44	2.06
14	567	64	631	20.28±	1.90	+2.19	1.15
15	400	30	430	13.95±	2.30	−4.04	1.74
16	263	32	295	21.69±	2.78	+3.60	1.29
17	176	10	186	10.75±	3.50	−7.34	2.97
18	69	4	73	10.95±	5.55	−7.14	1.28
19	29	3	32	18.75±	8.43	+ .66	.08
20	22	3	25	24.00±	9.50	+5.91	.62
21	5	2	7				
Total	18,419	1832	20,251	18.09	0.33		

Table 3 shows the crossover percentage among the young sired by F_1 males of known age from three to twenty-one months old. The average crossover percentage among the 20,251 young, was 18.09±0.33. It was slightly lower than the average when the sires were three and four months old, then above the average for the next five months, again below the average for the next four months, and then oscillated between high and low average values. No consistency is shown in the deviations for young

or old sires. In no month does the deviation from the general average reach three times the probable error. In only three months does it exceed twice the probable error, and these are widely scattered, being in the seventh, thirteenth and seventeenth months, respectively. Accordingly, the observed deviations are without statistical significance, being satisfactorily accounted for as the results of random sampling alone.

TABLE 4

Crossover percentages between albinism and pink-eyed yellow among the young of F_1 females of known age in months.

AGE IN MONTHS	DARK-EYED YOUNG	LIGHT-EYED YOUNG	TOTAL YOUNG	PERCENT CROSSOVERS	P. E.	DEVIATION FROM AVERAGE	DEV. / P. E.
3	435	71	506	28.06	2.12	+6.50	3.06
4	920	110	1030	21.36	1.49	−0.20	0.14
5	1260	121	1381	17.52	1.28	−4.04	3.15
6	986	117	1103	21.21	1.44	−0.35	0.24
7	1148	157	1305	24.06	1.32	+2.50	1.89
8	961	117	1078	21.70	1.45	+ .14	0.09
9	834	108	942	22.92	1.55	+1.36	0.90
10	665	84	749	22.43	1.74	+0.87	0.50
11	600	67	667	20.09	1.85	−1.47	0.79
12	420	50	470	21.27	2.20	−0.29	0.13
13	407	34	441	15.42	2.27	−6.14	2.70
14	327	44	371	23.72	2.47	+2.46	0.87
15	188	24	212	22.64	3.28	+1.08	0.32
16	161	24	185	25.94	3.51	+4.38	1.24
17	91	9	100	18.00	4.77	−3.56	0.74
18	47	5	52	19.23	6.61	−2.33	0.35
19	5	1	6				
20	5	0	5				
Total	9460	1143	10,603	21.56	0.46		

Table 4 contains similar data on the crossover percentage given by F_1 females. Neither old nor young females give percentages consistently high or low. The deviations from the average crossover percentage reach three times the probable error in two months and exceed twice the probable error in a third month, but are of doubtful statistical significance in any case.

Table 5 shows the variation in crossover percentage among individual F_1 parents. Sixty-one different males included in this table produced from 30 to 591 young each. The crossover percentages among these young range from 9.03 to 32.42, average 18.39 ± 0.32. The deviations from the average are less than the probable error in 31 cases, lie between once

TABLE 5

Summary of the young sired by individual F₁ males heterozygous for albinism and pink-eyed yellow.

MALE BRED IN CAGE NUMBER	TOTAL YOUNG	PERCENT CROSSOVERS	P. E.	DEVIATION FROM AVERAGE	DEV. P. E.
151	83	28.91	5.20	+10.52	2.02
153	387	24.28	2.42	+ 5.89	2.43
155	548	17.51	2.04	− 0.88	0.43
157	451	18.18	2.24	− 0.21	0.09
159	245	19.59	3.04	+ 1.20	0.39
183	62	22.58	6.06	+ 4.19	0.69
185	498	20.40	2.14	+ 2.01	0.93
187	251	17.52	3.00	− 0.87	0.29
189	535	16.82	2.06	− 1.57	0.76
191	389	14.91	2.41	− 3.48	1.44
193	387	21.18	2.42	+ 2.79	1.15
195	509	16.89	2.11	− 1.50	0.71
200	166	24.09	3.70	+ 5.70	1.64
241	522	13.02	2.09	− 5.37	2.56
243	410	24.87	2.36	+ 6.48	2.73
245	177	18.07	3.57	− 0.32	0.09
247	376	15.42	2.46	− 2.97	1.20
249	386	15.02	2.43	− 3.37	1.38
251	425	14.11	2.31	− 4.28	1.85
253	291	21.30	2.79	+ 2.91	1.04
255	376	19.14	2.46	+ 0.75	0.30
257	351	21.65	2.54	+ 3.26	1.28
259	487	19.30	2.16	+ 0.91	0.42
261	504	16.66	2.12	− 2.33	1.09
265	367	13.62	2.49	− 4.77	1.91
267	227	23.78	3.16	+ 5.39	1.70
269	433	19.87	2.29	+ 1.48	0.64
271	214	23.37	3.26	+ 4.98	1.52
273	502	19.12	2.13	+ 0.73	0.34
275	231	18.18	3.13	− 0.21	0.06
277	361	17.72	2.51	− 0.67	0.26
279	362	23.20	2.51	+ 4.81	1.90
303	432	18.98	2.29	+ 0.59	0.25
305	241	22.40	3.07	+ 4.01	1.30
307	307	18.89	2.72	+ 0.50	0.18
309	331	18.12	2.62	− 0.27	0.10
311	305	14.42	2.73	− 3.97	1.45
313	177	9.03	3.57	− 9.36	2.62
315	478	23.43	2.18	+ 5.04	2.31
329	262	13.74	2.95	− 4.65	1.57
331	365	17.53	2.49	− 0.86	0.34
333	309	18.12	2.71	− 0.27	0.10
335	367	13.62	2.49	− 4.77	1.91
337	451	16.85	2.24	− 1.54	0.68
341	287	12.54	2.81	− 5.85	2.08
343	30	13.33	8.71	− 5.06	0.58

TABLE 5 (continued)

Summary of the young sired by individual F_1 males heterozygous for albinism and pink-eyed yellow.

MALE BRED IN CAGE NUMBER	TOTAL YOUNG	PERCENT CROSSOVERS	P. E.	DEVIATION FROM AVERAGE	DEV. P. E.
343[a]	90	15.55	5.03	− 2.84	0.56
345	323	19.19	2.65	+ 0.80	0.30
347	551	21.41	2.03	+ 3.02	1.48
349	591	17.25	1.96	− 1.14	0.58
351	562	17.08	2.01	− 1.31	0.65
353	230	11.30	3.14	− 7.09	2.25
355	342	16.95	2.58	− 1.44	0.55
357	184	16.30	3.52	− 2.09	0.59
359	298	26.17	2.76	+ 7.78	2.81
361	581	14.11	1.98	− 4.28	2.16
363	371	18.86	2.47	+ 0.47	0.19
365	305	13.11	2.73	− 5.28	1.93
369	475	32.42	2.19	+14.03	6.40
263	341	15.83	2.58	− 2.56	0.99
493	137	17.51	4.06	− 0.88	0.21
Total	21,324	18.39	0.32		

TABLE 6

Summary of the young produced by groups of 3 or 4 F_1 females heterozygous for albinism and pink-eyed yellow.

REARED IN CAGE NUMBER	TOTAL YOUNG	PERCENT CROSSOVERS	P. E.	DEVIATION FROM AVERAGE	DEV. P. E.
161	219	9.13	3.22	−12.56	3.90
162	252	27.72	3.00	+ 6.03	2.01
163	220	21.81	3.22	+ 0.12	0.03
164	312	28.20	2.70	+ 6.51	2.41
165	174	12.74	3.62	− 8.95	2.47
166	208	21.15	3.31	− 0.44	0.13
167	252	19.84	3.00	+ 0.15	0.05
168	119	20.16	4.35	− 1.53	0.35
169	127	23.62	4.22	+ 1.93	0.45
170	222	19.81	3.20	− 1.88	0.58
171	505	24.55	2.12	+ 2.86	1.34
172	208	19.23	3.31	− 2.46	0.74
174	193	24.87	3.42	+ 3.18	0.92
175	228	21.05	3.16	− 0.64	0.20
176	190	24.21	3.46	+ 2.52	0.72
177	272	22.05	2.89	+ 0.36	0.12
178	225	28.44	3.17	+ 6.75	2.13
179	183	19.67	3.52	− 2.02	0.57
180	249	17.67	3.02	− 4.02	1.33
281	174	19.54	3.62	− 2.15	0.59
282	253	15.01	2.99	− 6.68	2.23
283	112	14.28	4.51	− 7.41	1.64

TABLE 6 (continued)

Summary of the young produced by groups of 3 or 4 F₁ females heterozygous for albinism and pink-eyed yellow.

REARED IN CAGE NUMBER	TOTAL YOUNG	PERCENT CROSSOVERS	P. E.	DEVIATION FROM AVERAGE	DEV. P. E.
284	84	14.28	5.20	− 7.41	1.42
285	225	24.00	3.17	+ 2.31	0.73
286	88	11.36	5.08	−10.33	2.03
287	48	16.66	6.88	− 5.03	0.73
288	301	21.26	2.74	− 0.43	0.15
289	59	20.33	6.16	− 1.36	0.22
290	323	24.42	2.65	+ 2.73	1.03
291	82	24.39	5.27	+ 2.70	0.51
292	106	7.54	4.63	−14.15	3.05
295	185	16.21	3.50	− 5.48	1.56
296	303	25.08	2.74	+ 3.39	1.23
297	265	22.66	2.92	+ 0.97	0.33
298	183	22.95	3.52	+ 1.26	0.35
299	109	22.01	4.55	+ 0.32	0.07
300	302	21.19	2.74	− 0.50	0.18
301	252	23.80	3.00	+ 2.11	0.70
302	112	17.85	4.51	− 3.84	0.85
318	219	23.74	3.22	+ 2.05	0.63
319	185	24.86	3.50	+ 3.17	0.90
319ᵃ	63	12.69	5.96	− 9.00	1.51
320	332	15.66	2.62	− 6.03	2.30
325	230	21.73	3.14	+ 0.04	0.01
333	69	26.08	5.70	+ 4.39	0.77
371	338	22.48	2.59	+ 0.79	0.30
372	294	25.16	2.78	+ 3.47	1.24
373	287	20.20	2.47	− 1.49	0.60
374	140	17.14	4.03	− 4.55	1.12
375	140	15.71	4.03	− 5.98	1.48
376	68	23.52	5.78	+ 1.83	0.31
377	68	29.41	5.78	+ 7.72	1.33
378	281	32.02	2.84	+10.33	3.63
379	253	28.45	2.99	+ 6.76	2.26
380	295	22.37	2.77	+ 0.68	0.24
Total	11,186	21.69	0.45		

and twice the probable error in 19 cases, lie between twice and three times the probable error in 10 cases, and exceed three times the probable error in only one case, that of the male bred in cage 369 which sired 475 young. He is credited with a very large number of crossovers, 6.4 times the probable error. His case alone suggests a possibly significant deviation from the average. As soon as it was recognized that this male was giving an unusually high crossover percentage, he was given additional mates and subsequent litters of young were examined with especial care. It

was found that he was heterozygous, not for ordinary albinism but for its allelomorph, ruby-eye, and one of his double-recessive mates also contained one dose of ruby-eye with one of ordinary albinism. Homozygous ruby-eyed young resulted from this mating and it is possible that in the earlier litters, which were destroyed at birth, some of these ruby-eyed young may have been classed as dark-eyed. Accordingly, all litters of this female were excluded from the total, but still the percentage of dark-eyed young credited to this male was abnormally high. To see whether the peculiarity of this male would be inherited by his descendants, several of his doubly heterozygous sons were mated with double recessive females. Such matings produced a total of 351 young with an indicated crossover percentage of 17.37 ± 3.00, a perfectly normal result. Apparently the male had not transmitted his peculiarity to any of his sons. The question whether ruby-eye gives a crossover percentage different from that of its allelomorph, ordinary albinism, is being investigated further.

An F_1 male which in his earlier litters had given only seven percent of crossovers was also made an object of special study, but two months later the percentage had risen to fifteen and it showed subsequently no tendency to return to its earlier low amount. Random sampling seems an adequate explanation of the peculiar early result.

SUMMARY

1.   Three genes of the common rat, which belong to a common linkage system, are apparently linear in their arrangement. The order of the genes is *crp*.

2.   The crossover percentages for these genes are regularly higher among the gametes of F_1 females than of F_1 males. The same is true for two linked genes of the house mouse, possibly homologous with genes *c* and *p* of the rat.

3.   No evidence has been obtained that the crossover percentage varies with age of the parent, or temperature or other seasonal conditions, either in rats or in mice.

4.   Variations in crossover percentages given by different male parents are capable of explanation as due to chance alone, except possibly in the case of one individual which, however, did not transmit the peculiarity to his sons.

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