GENETIC STUDIES OF THE SYRIAN HAMSTER

II. PARTIAL ALBINISM

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Received 10.vi.58

I. INTRODUCTION

THE present account of investigations with the Syrian hamster (*Mesocricetus auratus*) is a continuation of work reported earlier (Robinson, 1958b). The search for possible genetic linkage between the various colour mutants has been extended to include a new recessive allele (partial albinism or the "dark-eared albino") which was imported from the United States in 1955 (Robinson, 1957).

2. DESCRIPTION OF MUTANT ALLELES

A detailed description of the fur pigmentation of the normal Syrian hamster, and of the phenotypes engendered by the mutant alleles cream, ruby-eye and piebald, has been presented in the earlier paper. The following consists of new observations.

(i) Cream

The cream phenotype (symbol *e*) is produced by an inhibition of melanic pigmentation. The body fur is rich cream-yellow or yellow-orange. There is considerable variation between animals, much of which is determined by independent polygenes. The vestiges of melanin which remain upon the animal are confined to the eye, the dermis of ear pinnæ, the skin of the hip-gland and in the perineum. The development of this pigment in the skin is regular and corresponds to that present in the skin of the normal animal. In many crosses, however, there is a disturbance of melanin development in the pinnæ. The pigment appears to be laid down patchily if the erect pinnæ are viewed against a strong light. This condition of the ears has been termed "marbled" and is usually a transient stage to more or less normal pigmentation. In some creams, however, the marbled condition persists for a long period.

(ii) Ruby-eye dilute

The expression of ruby-eye (*ru*) is that of a typical eye and coat colour dilution. The pupil of the eye glows ruby in reflected light and the body fur is bluish-fawn. The male ruby-eye is either completely sterile or transiently fertile. Preliminary observations on this question have been given in the first paper. A more complete analysis on the sterility onset in the male has been communicated by Bruce (1958).

The ruby-eye hamster is less viable than the normal. The impaired vigour is apparent throughout life, being especially noticeable at parturition. The parturition death rate for the ruby-eye female is appreciably higher than that for the normal. The overall viability from the combined data of the previous paper at 21 days of age for *ruru* young is 0.5781 ± 0.0408 . The comparable viabilities for the two crosses of this paper are 0.5919 ± 0.0641 and 0.6178 ± 0.495 respectively, and are in general agreement. The previous data did not reveal a significant difference of viability between the sexes (0.0324 ± 0.0833). However, the present data reveal a significant difference (table 1). The mean difference is 0.1621 ± 0.0527 in favour of the female and is highly significant. In spite of the curiously discordant value of cross III for males, the five groups appear to be homogenous.

TABLE 1
Significance of sex differences of viability of ruby-eye hamsters at 21 days

Cross	♂	♀	Difference
I	0.4588	0.5077	-0.0489 ± 0.1359
II	0.5000	0.6106	-0.1106 ± 0.1246
III	0.8833	0.6853	0.1980 ± 0.1971
IV	0.4768	0.7066	$-0.2298 \pm 0.0934^*$
V	0.4824	0.7533	$-0.2709 \pm 0.0996^\dagger$

* significant † highly significant

The small inter-group differences yield an insignificant heterogeneity of $\chi^2_4 = 5.61$ ($P > 0.20$). Except for the aforesaid value, it is of interest to note that the viabilities for both sexes display a consistent rising trend. It is suggestive that the viability of ruby-eye is slowly improving through succeeding generations—the female at a significantly faster rate than the male. As part of the segregation data, the male *ruru* is a crossover class in the joint segregation of *ru* and *Y* (see next section), and it is conceivable that the shortage could be due to linkage between *ru* and *Y*, the male-sex differentiating segment of chromosome. Inspection of the complete segregations (table 7, columns 2 and 3) do not support the contention. The two complementary non-ruby-eye classes are not unbalanced.

The difference in relative viability of the sexes for ruby-eye is intriguing since a similar difference cannot be detected for piebald. The viability of piebald is much less than that of ruby-eye and, if the dissimilar sex viability is a consequence of an influence common to males (uterine environment), a similar effect should be patent for the piebald. This is not so, and it may be inferred, consequently, that the *ru* allele is sexually differentiated for some of its effects. This may take the form of sterility and probably reduced general vigour in the male. This may be obscured in practical breeding to some extent by the

extra stresses to which females are exposed from successive parturitions and lactations.

(iii) *Piebald*

The piebald (*s*) is an irregular form of recessive white spotting. Low-grade animals have the white pattern restricted to the foreface and breast while high-grade animals have extensive white areas on the body. Selective breeding has produced almost completely white specimens with small spots of coloured fur in the regions of the eye and ears and upon the hind quarters. In general, the progression of white is an antero-posterior direction with a tendency for a post-medial belt of white.

Animals homozygous for piebald are of reduced general stamina. At the recording age of 21 days the estimated viability is approximately 50 per cent. of the normal hamster. These losses are mainly attributable to intra-uterine death precipitated by (*a*) embryonic or foetal competition between normal and piebald, in which the latter succumb, and (*b*) developmental defects of the urino-genital system (see Orsini, 1952; Bock, 1953; and Foote, 1955). The defective development may extend to the vertebral column since the piebald individual may occasionally possess a bent or twisted tail. A piebald male, with a bent tail, was mated to two different non-piebald females, each having normal tails. The F_1 were normal coloured and with normal, straight tails, numbering 14 and 15 young, respectively. The F_2 of the first female segregated into 39 normal and 7 piebald, two of the latter having bent tails. The F_1 of the second female segregated into 38 normal and 7 piebald, one of the latter with a bent tail. The viability of piebald for the combined data is 0.5455 ± 0.0501 , not differing from expectation. The association of bent tail with the presence of piebald is highly significant, $\chi^2_c = 11.06$ ($P < 0.01$; with Yates' correction). It is conceivable, of course, that the occurrence of bent tail is due to developmental and parturitional hazards but this does not explain the association with piebald. An alternative explanation postulating a gene linked to piebald would require weak penetrance of the "bent tail" gene, in view of the low incidence of individuals with the abnormal tail vertebrae.

In view of the difference between the viability of the sexes for ruby-eye animals it is pertinent to enquire if such a difference may exist for the piebald. Crosses II and III showed a non-significant lower viability for the male, but in the present cross IV the tendency is reversed. The viability of the male sex is 0.3768 ± 0.0784 and that for the female, 0.2691 ± 0.0628 . Combining differences between viabilities for the three segregations gives the insignificant mean difference of 0.0451 ± 0.0621 in preference of the female. It may be mentioned that the differences were found from overall viabilities, which are lower than those given previously where an attempt was made to obtain estimates unbiased by the *ruruss* interaction.

(iv) *Partial albinism*

A mutation to an albinotic allele occurred in the United States, *circa* 1951-52. Adult animals, homozygous for the allele, have completely white fur and pink eyes but with pigmented ears. Pigment may form in certain regions of the skin in the fully mature animal, in the prepuce and scrotum of males and occasionally, not invariably, in the perineum of females. No pigment has been observed in the hip-gland. The intensity of pinnae pigmentation eventually attains that present in the normal but the amount in the genitals is reduced.

The young albinotic hamster at 21 days of age is completely devoid of pigment. By 26 days of age, however, the ear pinnae are distinctly tinged with pale grey, especially along the edges. By the thirty-first day the pinnae are suffused grey. The rate of pigment formation is initially rapid but slackens later. The age range for onset of ear pigmentation is from 24-28 days while the age range for the ear to qualify as suffused grey varied from 27-36 days. A correlation was noticed between early onset of the grey tinge and a rapid transition to suffused grey. While a correlation diagram portrayed a path of clustered entries about a regression line of slope, $b = 0.1360 \pm 0.0956$, the regression coefficient is subsignificant for a sample of 40 individuals. The eye colour of the young dark-eared albino is the light pink of a true albino. The eye colour of an adult animal is also that of complete albino, but some individuals appeared to have a ruby tint. The possibility that a few animals may have some pigment in the deeper layers of the eye should be recognised.

These observations strongly suggest that the present mutant of the hamster is that of a thermo-sensitive allele of the albino locus, comparable to the allele primarily responsible for the phenotype of the "albino" guinea-pig, Himalayan rabbit or Siamese cat. For this reason the symbol proposed for the allele is c^d . It will be noted that other extremities of the body in the hamster, the nose, feet and tail, are not pigmented as is the case for the rabbit and cat. The three alleles of the guinea-pig (c^a), rabbit (c^h) and cat (c^s) differ in the degree of pigment formation. The Siamese cat allele allows more pigment to be formed than is usually found in either the "albino" guinea-pig or Himalayan rabbit. The Siamese cat usually has pigment in the dorso-lateral regions. In the guinea-pig and rabbit this is rare, while in the hamster it is unknown. It is probable that the hamster allele c^d permits less pigment to manifest than the respective alleles of the rabbit and cat. This comparison assumes, of course, the usual (*i.e.* most frequent) polygenic background for pigment expression of the mutant for each species. Additional evidence for exact placing of partial albinism may be found from the effect of the homologous alleles upon the development of yellow pigment. The cat gene allows some yellow pigment upon the extremities (the red-pointed Siamese) while the guinea-pig (Wright, 1915), rabbit (Robinson, 1958*a*, pp. 268-269) and hamster alleles do not. Ranking the four mutants for amount

of pigmentation typically expressed, gives the probable order $c^s > c^h > c^d > c^a$.

It should perhaps be mentioned that the fullest expression of himalayanism is dependent upon the combination of the albinistic allele with non-agouti (a). Thus, the Himalayan rabbit is of genotype aac^hc^h . This mutant allele is unknown in the hamster. The appearance of non-agouti in the hamster would probably result in a more typically acromelanic phenotype. Black pigment is present in the ears but not on the legs or tail, and this is probably the reason why the ears only are coloured. The amount of melanic pigmentation formed upon the more exposed, cooler parts of the body (ear pinnae, prepuce and scrotum) is comparable to that found in the normal phenotype. It would be desirable if some direct experiments could be performed to establish the nature of the differential thermal thresholds for various sectors of the body. This has been accomplished by Iljin and Iljin (1930) for the cat and by numerous experiments for the rabbit (Robinson, 1958a, pp. 240-246).

The gene for partial albinism is epistatic to most of the other colour mutants; only when the usual dark ear colour is modified may the presence of another mutant allele be assumed. The e allele usually has no effect upon ear colour and, consequently, animals of genotype c^dc^dE — and c^dc^dee are indistinguishable. This is not invariably the case, however, for some ee hamsters display a tardy development of ear melanism, the “marble” ear. This is paralleled by some c^dc^dee animals, in which event the ear colour tends towards a patchwork grey. Three of these “grey-eared albinos” were tested by mating to cream. The resulting litters consisted of twenty-one young, all cream. It is unfortunate that the expression of greyiness is too variable for reliable identification of the genotype c^dc^dee . Prepuce and scrotal pigmentation are not affected by e and both the dark-eared albino (c^dc^dE — or c^dc^dee) and the grey-eared albino (c^dc^dee) display similar genital pigment. The ear colour of the ruby-eye hamster is peach-grey, produced by a sharp reduction in skin pigmentation throughout the whole body. In combination with c^d , the reduction appears to be enhanced. The genotype c^dc^druru is a “synthetic albino” with almost flesh-coloured ears and genitals. The ear colouring varies from clear pink to peach-grey but not attaining the degree of peach-grey found in the non-albinotic ruby-eye. The reason for this is not obvious, but it is suggestive that the thermal threshold of melanin production in c^dc^druru animals may be higher than that in c^dc^dRu —. The genotype $c^dc^deeruru$ is also a synthetic albino.

Partial albino homozygous for piebald (c^dc^dss) may occasionally reveal the genotype by the presence of flesh-coloured spots on the ears. Since the ear pinnae are often unspotted, even in high-grade piebalds, this is an unreliable guide. The steep reduction in body weight could be used as an indicator of homozygosity of piebald. At 21 days of age the mean weight of piebalds is approximately 77 per cent. of that of

non-piebald. These two features may discriminate the piebald albino in special instances but perhaps not with sufficient accuracy for critical segregation analysis.

It has been observed that the various mutants appear to be associated with small differences of temperament. The dark-eared albino appears to be neutral in this respect. Defining the normal as standard, the cream is a more placid animal (on the average), while the ruby-eye and piebald are more nervous. The piebald is more irascible than the ruby-eye. The roster would be, therefore, for increasing nervousness: cream < normal $\simeq$ albino < ruby-eye < piebald. Finally, in the crosses so far completed, the c^d allele appears to be fully penetrant, and individuals homozygous for it, of normal viability.

TABLE 2
Data from experimental crosses

Cross	Type	CERu		CcRu		CEru		Ceru		c^dRu		c^dru	
		♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
IV	$YERusc^d/XeruSC \times YERusc^d/XeruSC$	S 136 s 17	137 10	38 8	43 5	27 1	36 5	6 0	7 0	59 64	7 13		
V	$YERuc^d/XeruC \times YERuc^d/XeruC$	346	348	108	106	45	82	28	32	172	209		

3. ANALYSIS OF SIMULTANEOUS SEGREGATION

Two series of matings have been completed involving the joint segregation of c^d with e , ru and s . The results of the two crosses (IV and V) are summarised by tables 2 and 3. The segregation of cross IV is partitioned as rows into normal (S) and piebald (s) as combined with the genotypes heading the columns. In addition to the gene symbols proposed above, the symbols Y and X are employed as representing the differential segments of the sex chromosomes. The segregation of a mutant allele may display a sex association which could be interpreted as partial sex-linkage. For analytical convenience, Y is treated as a dominant gene. Where two dominant genes enter the cross from the same parent, this is taken as coupling association. All the young were sexed and classified for coat colour at 21 days, except for the identification of c^dc^dRu- and c^dc^druru , where the ear colour distinction was deferred to between 40 and 50 days of age. Unfortunately, this separation of the two albinotic types could not be made for cross V. Estimation of the parameters for the theoretical genotypes underlying the observed segregation is achieved by maximum likelihood scores. Iterative correction factors were applied until the parameters converged sufficiently. The required variances were found by inversion

of the respective information matrices. The inviability which accompanies the segregation of *ru* and *s* is symbolised by *v* and *u*, respectively, and the crossover value by *p*.

TABLE 3
Classification of data for segregation analysis

Cross	Mating Type	Loci		Phenotypic classes				Total
		<i>a</i>	<i>b</i>	<i>AB</i>	<i>aB</i>	<i>Ab</i>	<i>ab</i>	
IV	CII	<i>e</i>	<i>ru</i>	300	94	69	13	476
	RII	<i>e</i>	<i>s</i>	336	94	73	13	476
	RII	<i>e</i>	<i>c^d</i>	369	107	143	65	619
	CIB	<i>e</i>	<i>Y</i>	181	42	188	6	476
	RII	<i>ru</i>	<i>s</i>	354	76	40	6	476
	RII	<i>ru</i>	<i>c^d</i>	394	82	123	20	619
	CIB	<i>ru</i>	<i>Y</i>	258	41	259	61	619
	CII	<i>s</i>	<i>c^d</i>	430	46	143	20	619
	RIB	<i>s</i>	<i>Y</i>	207	26	223	77	476
	RIB	<i>c^d</i>	<i>Y</i>	233	66	243	77	619
V	CII	<i>e</i>	<i>ru</i>	694	127	214	60	1095
	RII	<i>e</i>	<i>c^d</i>	821	274	381	138	1476
	CIB	<i>e</i>	<i>Y</i>	391	136	430	138	1095
	RII	<i>ru</i>	<i>c^d</i>	908	187	381	114	1476
	CIB	<i>ru</i>	<i>Y</i>	454	73	454	209	1095
	RIB	<i>c^d</i>	<i>Y</i>	527	172	568	209	1476

C = coupling, R = repulsion, I = intercross, B = backcross, for the respective alleles.

(i) Cross IV

This segregation is an F_2 generation from $YXEERuRussc^dc^d \times XXeeruruSSCC$. The regular segregation ratios display considerable disturbance and inspection of table 2 reveals a deficiency of both *ru* and *ss* zygotes.

	χ^2	d.f.	P
<i>e</i> segregation . . .	1.61	1	>0.20
<i>ru</i> „ . . .	23.98	1	<0.001
<i>s</i> „ . . .	62.19	1	<0.001
<i>c^d</i> „ . . .	1.19	1	>0.20
sex „ . . .	0.71	1	>0.30

Estimation of the recombination fraction for the ten possible gene-pair comparisons is complicated by the impaired viability of segregants homozygous for *ru* and *s*. The three comparisons $e-c^d$, $e-Y$ and c^d-Y , have the inviability apportioned over complementary crossover and non-crossover classes and estimation is straightforward. For the

remaining comparisons a simultaneous estimation with either v or u is unavoidable.

Simultaneous segregation of c^d and s is marred by the inviability of ss segregants and by the epistasis of c^d to s . The probabilities of the three classes are as follows ($P = (1-p)^2$), with the values of $p = 0.4036 \pm 0.0946$ and $u = 0.3912 \pm 0.0355$ as the solution of the derived maximum likelihood functions.

	CS	Cs	$c^d c^d$
Expectation . . .	$\frac{2+P}{3+u}$	$\frac{u(1-P)}{3+u}$	$\frac{1-P+uP}{3+u}$
Observation . . .	430	46	143

Examination of previous data upon the joint segregation of ru and s has suggested that the inviability of each may interact in the double recessive $rurus$. These animals are very feeble, their weight at 21 days is 45 per cent. of normal, and their prenatal death rate may be greater than that of a simple compound of the prenatal rate for $ruru$ and ss alone. Representing x as the viability of $rurus$ (chance of survival of the phenotype = xvu), the observed segregation would be produced by the following values $v = 0.6441 \pm 0.0814$, $u = 0.3390 \pm 0.0565$ and $x = 0.6987 \pm 0.3184$; x does not differ significantly from unity. The method of calculation of x and its sampling variance is given in the preceding paper, where x is significant. However, in all of the data to hand, the $rurus$ individuals constitute a crossover class. In consequence it has not been possible to decide if the shortage in this class is due (a) to the inviability interaction or (b) to linkage between ru and s .

(ii) Cross V

The second cross is similar to the first, but without piebald, and the resultant F_2 generation is shown by tables 2 and 3. Statistical examination of the single gene ratios disclosed the usual deficiency of $ruru$ individuals. There is also a deficiency of males which just exceeds the conventional 5 per cent. level of significance. This may be a chance deviation but the tests for a sex association between the mutants indicate that the deficiency is concentrated in the phenotypic class $YXruru$. The male ruby-cyc is a crossover class in the $ru-Y$ comparison and the recombination fraction computed is significant ($\chi^2_1 = 5.84$; table 7, line 5). That the association is not due to genetic linkage with the Y segment of chromosome is shown by the same table. The two complementary non-ruby-eye classes are of exact equality which is scarcely to be expected with linkage. The association between ru and Y revealed by the combined estimate of p , which just attains the

border-line of significance ($\chi^2_1 = 3.85$, table 7, total), is probably due to the excess mortality of *ruru* males.

	χ^2	d.f.	P
<i>e</i> segregation . .	0.0003	1	> 0.98
<i>ru</i> „ . .	36.65	1	< 0.01
<i>c^d</i> „ . .	0.52	1	> 0.30
sex „ . .	4.12	1	< 0.05

The outcome of tests for possible linkage between the six gene-pair comparisons are tabulated in table 4. The assessment of independent segregation for the pair *ru*—*c^d* is complicated by epistasis of *c^d* to *ru*

TABLE 4
Estimated recombination fractions (*p*) and viabilities (*v* or *u*)

Cross	Loci	<i>p</i>	<i>v</i> or <i>u</i>
IV	<i>e</i> — <i>ru</i>	0.5477 ± 0.0386	0.6244 ± 0.0578
	<i>e</i> — <i>s</i>	0.5640 ± 0.0447	0.3209 ± 0.0498
	<i>e</i> — <i>c^d</i>	0.5756 ± 0.0595	
	<i>e</i> — <i>Y</i>	0.4349 ± 0.0397	
	<i>ru</i> — <i>s</i>	0.4544 ± 0.0578	$\left\{ \begin{array}{l} v \\ u \end{array} \right.$ 0.5933 ± 0.0854 0.3128 ± 0.0508 0.5919 ± 0.0641 0.5919 ± 0.0641 0.3912 ± 0.0355 0.3209 ± 0.0498
	<i>ru</i> — <i>c^d</i>	0.4786 ± 0.0343	
	<i>ru</i> — <i>Y</i>	0.4383 ± 0.0396	
	<i>s</i> — <i>c^d</i>	0.4036 ± 0.0946	
	<i>s</i> — <i>Y</i>	0.4396 ± 0.0516	
	<i>c^d</i> — <i>Y</i>	0.5186 ± 0.0348	
V	<i>e</i> — <i>ru</i> {	♂ 0.4062 ± 0.0392 *	0.4824 ± 0.0608 0.7533 ± 0.0789
	♀	0.4635 ± 0.0338	
	<i>e</i> — <i>c^d</i>	0.4993 ± 0.0393	
	<i>e</i> — <i>Y</i>	0.5151 ± 0.0262	
	<i>ru</i> — <i>c^d</i>	0.4305 ± 0.0915	0.5525 ± 0.0827 0.6178 ± 0.0495
	<i>ru</i> — <i>Y</i>	0.4288 ± 0.0295 *	
	<i>c^d</i> — <i>Y</i>	0.5237 ± 0.0225	

* Significant, see text.

and the lower inviability of *ru*. Three phenotypic classes can be distinguished and the theoretical probabilities of these are as shown for the *s*—*c^d* comparison of cross IV, with *v* substituted for *u* and $P = p^2$. The values of *p* and *u* satisfying the maximum likelihood functions are 0.4305 ± 0.0915 and 0.5525 ± 0.0827 , respectively. The analysis for random segregation of the genes in the comparison *ru*—*c^d* is apparently not interfered with by the sex difference in viability of *ruru*, as witnessed by the insignificantly low value of $\chi^2_1 = 0.52$. This is not the case for the comparison *e*—*ru*, where the segregation data, pooled for both sexes, have the significant χ^2_1 value of 5.73. Analysis of the data for each sex separately discloses that the lower viability of the male is the source of the disturbance ($\chi^2_1 = 5.80$, table 4, line 12).

(iii) *Combination of Data*

For each of the contrasted pairs of mutants, estimates of the recombination fraction can be made more precise by suitable amalgamation of the data. For many of the gene pairs, data from both crosses of this paper may be used to augment that from the first paper. The combination is effected by summing the maximum likelihood scores (with due regard to sign) and the amount of information regarding p , yielded by each cross. The amount of information (I) is derived as the reciprocal of the variance for $p = 0.5$. The score (S) and standard error (s) of p are also found for $p = 0.5$.

The conclusions from the analysis of the combination data are shown by table 5. The total score and information will be useful for

TABLE 5
Summary of extent of linkage tests

Loci	p	s	S	I	Phase balance	Closest linkage
$e - ru$	0.477	0.018	-73.3333	3168.5913	75	0.465
$e - s$	0.487	0.028	-17.1111	1281.9118	61	0.445
$e - c^d$	0.522	0.033	20.8885	930.9622	0	0.436
$e - Y$	0.491	0.018	-28.0000	3254.2076	81	0.466
$ru - c^d$	0.473	0.033	-24.9835	938.1825	0	0.436
$ru - Y$	0.466	0.017	-113.3333 *	3331.9701	100	0.466
$s - c^d$	0.407	0.084	-12.8133	138.0122	100	0.335
$s - Y$	0.510	0.031	10.6667	1028.4231	0	0.439
$c^d - Y$	0.522	0.019	61.9999	2793.3332	0	0.463

* significant, see text

future amalgamations. Column six is an index of phase balance, conveniently tabulated as the percentage of the amount of information contributed by segregations in coupling linkage. Perfect balance is shown by the index 50, and possesses the implication that certain inviability interactions between genotypes which could pass undetected are, on the average, cancelled out. The last column gives the closest linkage compatible with the collated data and computed as $0.5 - 1.96s$. Table 6 arranges the χ^2 analysis for homogeneity.

Table 7 presents in detail the effect of the sex difference in viability of *ruru* animals upon the $ru - Y$ comparison. Consideration of the complete segregation would infer a genetic linkage ($p = 0.4660 \pm 0.0173$), if it were not for the inviability. Although the totals are significantly disturbed, this is probably a consequence of the reduced viability of $YXruru$, a crossover class. Consideration of the two non-ruby-eye classes supports the inviability suggestion, for in these the departure from random segregation is negligible ($p = 0.5289 \pm 0.0307$). This last estimate of p utilizes about 32 per cent. of the total information available for p but is compensated by the absence of bias.

The result of analyses of the three $ru - s$ segregations cannot distinguish between (a) an inviability interaction of genes *ru* and *s* in the

class *ruruss*, producing a larger than expectation of prenatal death of these animals, or (b) genetic linkage. For this reason, the *ru-s* pair are omitted from table 5. Crosses II and III show considerable dis-

TABLE 6
Homogeneity analysis of the segregations

Loci	Deviation from random assortment		Homogeneity		
	χ^2_i	<i>P</i>	χ^2	d.f.	<i>P</i>
<i>e-ru</i>	1.69	>0.10	7.22	4	>0.10
<i>e-s</i>	0.24	>0.50	4.94	2	>0.05
<i>e-c^d</i>	0.47	>0.30	1.14	1	>0.20
<i>e-Y</i>	0.24	>0.50	6.13	3	>0.10
<i>ru-c^d</i>	0.66	>0.30	0.25	1	>0.50
<i>ru-Y</i>	3.85 *	<0.05	6.60	4	>0.10
<i>s-c^d</i>	1.19	>0.20	...	...	...
<i>s-Y</i>	0.11	>0.70	3.46	2	>0.10
<i>c^d-Y</i>	1.38	>0.20	0.02	1	>0.95

* significant, see text

TABLE 7
Effect of differential viability of ru upon linkage analysis of ru-Y segregation

Cross	Segregation				Linkage analysis	
	<i>RuY</i>	<i>RuX</i>	<i>ruY</i>	<i>ruX</i>	Four classes χ^2_i	First two classes χ^2_i
I	170	195	26	33	0.02	1.71
II	110	113	55	69	0.83	0.04
III	180	197	53	45	1.33	0.77
IV	258	259	41	61	2.43	0
V	454	454	73	114	5.84 *	0
Total	1172	1218	248	322	3.85 *	0.89
Homogeneity (d.f. = 4)					6.60	1.63

* significant, see text

turbance from random assortment ($\chi^2_1 = 13.34$ and 9.14 , respectively), but cross IV does not ($\chi^2_1 = 0.63$). The three crosses yield a total χ^2_3 of 23.12 ($P < 0.01$), which may be partitioned into deviation from random segregation of $\chi^2_1 = 17.35$ ($P < 0.01$) and heterogeneity between crosses of $\chi^2_2 = 5.77$ ($P > 0.05$). The heterogeneity χ^2_2 is large but is not significant. The weighted mean recombination fraction is $p = 0.3183 \pm 0.0342$ and is highly significant. At this junction it is not considered worthwhile to strive for a more accurate estimate of p . Attempts are in progress to improve the stamina of *ruruss* animals,

healthy individuals of which are necessary to produce an F_2 generation with *ru* and *s* segregating in opposite linkage phase (coupling) to the data so far obtained. The decision of linkage versus inviability interaction may be left open until suitably balanced data are procured.

4. DISCUSSION

The segregation data collected to date are sufficient to establish that the four mutant genes *e*, *ru*, *s* and *c^a* assort independently of each other and of sex. There is the possibility of linkage between *ru* and *s* but from other available evidence it is probable that the association is due to the enhanced inviability of one of the crossover classes (namely *ru**ru**ss*). The remoter possibility of linkage between *ru* and *X* is also more probably due to a sex-differentiated inviability of a crossover class.

The question may be posed, what is the probability of detection of linkage in the hamster with four mutants? Green (1951) has proposed a formula for the computation of such probabilities given certain prior assumptions. The primary assumption is that the gene content of individual chromosomes do not differ too widely and, therefore, the probability of a mutant residing upon any chromosome is approximately the reciprocal of the haploid number. The Syrian hamster possesses 44 chromosomes (Husted, Hopkins and Moore, 1945; Matthey, 1952; Sachs, 1952; and Sheaffer, 1955), two of which are the sex determiners. It is probable that, except for weak sex-linkage, an association with sex would be noticed early in the study of a new mutant. Thus the probability may be found for the existence of at least one linkage among 4 genes for 21 autosomes. The probability is 26 per cent., hence it is not unduly surprising that no linkage has been uncovered. As a point of interest, the number of mutants necessary for the probability of linkage to exceed that of no-linkage is 6, but the probability is then merely 54 per cent. Green points out that unequal distribution of genes upon the chromosomes would in its effects appear to decrease the number of chromosomes. The above probability is perhaps, as a consequence, an underestimate. On the other hand, modal chiasma frequency per bivalent must be considered and this would tend to produce some very weak linkages at least, if not effective chromosome groups of pseudo-independent genes, depending upon the strength of localisation of the chiasmata. This would tend to reduce the above probability.

Since the formal genetics of the Syrian hamster has scarcely begun, it is urged that the collection of breeding data, which involves gene segregation amenable to linkage study, be published in full for future amalgamations (see Robinson, 1956). The possibility of weak sex-linkage should not be overlooked. This information may be compactly arranged in the manner of table 2 if pressure of other work prevents immediate analysis.

5. SUMMARY

1. A new mutant, partial albinism, is described, and the results of tests for linkage with other mutants and with sex are presented. No evidence for linkage could be found.

2. A critical collation of available segregation data for four mutant genes failed to disclose positive evidence for genetic linkage, either between the genes or with sex.

3. The joint segregation of two genes (ruby-eye, piebald) is disturbed but this could be due either to linkage or to an inviability interaction.

4. Since hamster genetics is in its infancy, a plea is made for the publication of all segregation data which could yield information upon weak linkage.

Acknowledgment.—I am indebted to Mr G. T. C. Gore for kindly recording the animals which constitute cross V.

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