STUDIES ON THE EFFECT OF X CHROMOSOME INVERSIONS ON CROSSING OVER IN THE THIRD CHROMOSOME OF DROSOPHILA MELANOGASTER

ARTHUR G. STEINBERG AND F. CLARKE FRASER[1]
McGill University, Montreal, Canada
Received July 14, 1943

INTRODUCTION

ALL present theories of crossing over tacitly assume that events in one tetrad (at least as far as crossing over is concerned) are independent of those occurring in the other tetrads of the cell. Yet as long ago as 1919 STURTEVANT suspected that the presence of a heterozygous inversion in one chromosome pair increases crossing over in a non-homologous pair of chromosomes. The effect was definitely established by SCHULTZ and REDFIELD (MORGAN, BRIDGES) and SCHULTZ 1932, 1933), who showed that in *Drosophila melanogaster* heterozygous inversions in the first and/or second chromosomes increase crossing over in the third chromosome and that heterozygous inversions in the first and/or third chromosomes increase crossing over in the second chromosome, and by GLASS (1933) who found that an inversion in the second chromosome increased crossing over in the third chromosome (this observation was independent of that of SCHULTZ and REDFIELD). Subsequently STEINBERG (1936) showed that crossing over was increased in the first chromosome in the presence of heterozygous inversions in the second and/or third chromosomes.

These experiments all involved an increase in crossing over in a tetrad which was not itself heterozygous for an inversion. STURTEVANT'S original observation was on a tetrad which was itself heterozygous for an inversion, although the increase in crossing over took place in an uninverted segment. He found that crossing over between the second chromosome mutants purple and curved, which was reduced to about one percent in the presence of the inversions carried in the second chromosome of the Nova Scotia stock, was increased to about 20 percent (that is, approximately the standard value) in the simultaneous presence of an inversion in the third chromosome. STURTEVANT'S observations were supported by GLASS'S report in 1933 that crossing over within the Plum inversion in the second chromosome was increased in the presence of an heterozygous inversion in the third chromosome. SIDEROW, SOKOLOW, and TROFIMOW (1936) in making use of GLASS'S observation for other purposes showed that heterozygous inversions in the second and third chromosomes increase crossing over in the X chromosome when it also is heterozygous for an inversion. These data are of particular interest because the regions of the X chromosome studied by these authors are similar to those studied by STEINBERG (1936) and may be compared with them. They will be discussed in this connection in a later section of this paper. The observations on *Drosophila melanogaster* were confirmed for *Drosophila pseudoobscura* by MACKNIGHT

[1] Holder of a Studentship from the NATIONAL RESEARCH COUNCIL OF CANADA.

(1937), who found that heterozygous inversions in the second and third chromosomes increased crossing over in the X chromosomes when they (the X chromosomes) were heterozygous for inversions in each of the arms.

SCHULTZ, MATHER, and STEINBERG and WHITE have each advanced working hypotheses to explain the above observations. SCHULTZ'S (MORGAN, BRIDGES, and SCHULTZ 1935) hypothesis involves the assumptions (a) that crossing over is a function of the twisting of the chromosomes about each other, (b) that the presence of an inversion in the heterozygous condition interferes with somatic pairing in the last premeiotic division of the pair of chromosomes bearing the inversion, and (c) that this will lead to "an increased likelihood of overlying contacts or twists near the spindle fiber of that pair of chromosomes when they do synapse in prophase; and this overlap will be correlated with a similar occurrence in another pair," thus resulting in increased crossing over in the latter pair. From this hypothesis it follows that the degree of disturbance in pairing is the factor which determines the extent of the interchromosomal effect of an inversion on crossing over. Hence one would expect to find a relationship between the length and position of an inversion in the chromosome on the one hand and the magnitude of its interchromosomal effect on the other.

MATHER'S (1936) hypothesis to explain the interchromosomal effect of inversions on crossing over involves the assumption that the total number of chiasmata in any given cell under fixed conditions is limited and that the tetrads within the nucleus compete for this limited number. If, therefore, one tetrad has fewer chiasmata than usual, the other tetrads in the cell may be expected to have more chiasmata than usual. On the basis of this hypothesis one would expect that those inversions which interfere most with crossing over within the tetrad bearing them would have the greatest interchromosomal effect on crossing over. It might be well to point out here that this hypothesis cannot explain the data involving an increase in crossing over caused by heterozygous inversions in a non-homologous tetrad which is also heterozygous for an inversion (see discussion of STURTEVANT, GLASS, *et al.* above). Although crossing over was measured in only one of the tetrads concerned, it must be clear that crossing over was increased in both tetrads. This necessitates an increase in the total number of chiasmata in the cell and therefore does not conform to MATHER'S hypothesis which involves competition among the tetrads for a fixed number of chiasmata.

The hypothesis proposed by STEINBERG and WHITE (1939) postulates that the interchromosomal effect of inversions on crossing over is physiological and not mechanical in nature. This was based on two points (a) the fact that many inversions are known to have physiological effects (position effect) and (b) the fact that the magnitude of the effect of an inversion on crossing over in a given non-homologous chromosome is directly proportional to the relative amount of the total chromatin of the cell contained in the affected chromosome (STEINBERG 1937). On the basis of this hypothesis no correlation between the size or position of the inversion in the chromosome and the magnitude of its effect would be expected.

The experiments reported below were designed to test these hypotheses.

MATERIALS AND METHODS

Crossing over was measured in the third chromosome by means of the "rucuca" complex of recessive markers. There follows a brief description of the mutants used; a more detailed description will be found in Drosophila Information Service No. 9. The wild type stock used was a strain of Oregon-R maintained in mass culture.

SYMBOL	NAME	LOCATION ON STANDARD 3RD CHROMOSOME MAP	DESCRIPTION
ru	roughoid	0.0	Eye rough and small
h	hairy	26.5	Extra hairs on wings
th	thread	43.2	Arista thread-like
st	scarlet	44.0	Eye-color bright scarlet
cu	curled	50.0	Wings upcurled
sr	stripe	62.0	Dark dorsal stripe
e^s	sooty	70.7	Body-color dark
ca	claret	100.7	Eye-color ruby

The crossover regions were numbered as follows:—

ru [1] *h* [2] *th* [3] *st* [4] *cu* [5] *sr* [6] e^s [7] *ca*

and will be referred to as such in the text unless otherwise indicated.

The effects of twelve different X chromosome inversions were tested. Table 1 lists these inversions, giving the cytological and where known the genetic positions of the left and right breaks.

TABLE 1

Description of the X Chromosome inversions used.

INVERSION	SALIVARY GLAND DATA		GENETIC DATA		REFERENCE
	LEFT BREAK	RIGHT BREAK	LEFT BREAK	RIGHT BREAK	
bb^{Df}	4D1–2	19F Df in 20 C-D	between *rb* and *rg*	between *car* and sp-a	STURTEVANT and BEADLE (1936) Salivaries—SUTTON Unpublished
dl-49	4D7-4E1	11F2–11F4	between *rb* and *cv*	between *fw* and *g*	STURTEVANT and BEADLE (1936) Salivaries—HOOVER (1938)
ClB	4A5	17A6	between *sc* and *bi*	between *sy* and *fu*	STURTEVANT and BEADLE (1936) Salivaries—HOOVER (1938)
sc^7	1B4	5D5	between *sc* and *svr*	between *cv* and *ct*	STURTEVANT and BEADLE (1936) Salivaries—SUTTON Unpublished
sc^8	1B2	20B+	between *ac* and *sc*	between *bb* and sp-a	STURTEVANT and BEADLE (1936) Salivaries—D.I.S. 9
y^4	1A	17	left of *y*	between *fu* and *da*	MULLER and PROKOFYEVA (1934) Salivaries—D.I.S.9
AM	8C17–8D1	16E2–16E3	near *lz*	between *B* and *Bx*	STONE and THOMAS (1935) Salivaries—HOOVER (1938)
sc^4	1B4	19F1–2	between *sc* and *svr*	between *car* and *bb*	STURTEVANT and BEADLE (1936) Salivaries—SUTTON Unpublished
AB	about 9F	13F1	near *v*	between *g* and *sd*	STONE and THOMAS (1935)
A99B	1D3–1E1	19D–19E	not determined		D.I.S. 12
sc^{260-14}	1B1.2–1B3.4	11D3–11D8	not determined		SUTTON (1943b)
B^{263-47}	16A1.2–16A4	beyond 20A1.2	not determined		SUTTON (1943a)

The plan of the experiments in all cases except those involving the *ClB* and *dl-49* inversions was as follows:—

P_1:-3, 4 or 5 rucuca ♀ ♀ ×4 or 5 Inversion-bearing ♂ ♂.

B.C.:-3 F_1 ♀ ♀ heterozygous for the inversion and rucuca×4 rucuca ♂ ♂.

In the case of the *ClB* and *dl-49* inversions the P_1 consisted of inversion bearing ♀ ♀ mated to rucuca ♂ ♂; otherwise the crosses were the same as in the other experiments. *ClB* ♀ ♀ were used for the obvious reason that no *ClB* ♂ ♂ survive; ♀ ♀ heterozygous for *dl-49* were used because of the low fertility exhibited by the *dl-49* ♂ ♂ of this stock.

In those cases in which the inverted chromosome carried markers which might interfere with the classification of any of the rucuca characters, only backcross flies not showing the markers were classified. Thus in the case of the sc^4 inversion which carries yellow, only the ♀ ♀ and non-sc^4 ♂ ♂ were classified; in the case of the y^4 inversion only the ♀ ♀ were classified; because the sc^7 and sc^8 inversions carried apricot, only the ♀ ♀ and non-apricot ♂ ♂ were classified; in the experiment involving the *dl-49* inversion only ♂ ♂ not carrying the *dl-49* inversion were classified because it is difficult to distinguish between *Hw* (Hairy-wing) carried by the *dl-49* inversion and *h* of the rucuca complex; in the *ClB* experiment the ♂ ♂ and the non-*ClB* ♀ ♀ were classified because of uncertainty in the classification of some eye colors in the presence of Bar. In all other cases all backcross offspring were classified.

In all cases the backcross generation was classified for nine days, including the first day of eclosion.

Throughout these experiments the standard cornmeal, agar, molasses food medium reinforced with dried brewer's yeast was used. All crosses were raised at 25°±0.2°C.

Further details of technique will be given in the appropriate places in the text.

DATA

Because the experiments were done in three groups to test different questions, and also for the sake of clarity, they will be presented in chronological order. The first set of data involved the following six inversions: bb^{D1}, *ClB*, *dl-49*, sc^8, sc^7, and y^4 (table 1). The raw data (except for the combining of the sexes) are given in table 10 at the end of the text. Table 2 shows the crossover values obtained in each region for each of the crosses and the percentage change which these values show with respect to those of the control. Table 3 presents the distribution of the strands among the various types of crossovers obtained and the χ^2 values derived from a comparison of each of the test crosses with the control.

Among the various methods which may be employed to compare control and test crossover values, that of comparing the strand distribution by means of 2×n contingency tables is the most direct, because each strand represents one tetrad and because the strand data are basic to the calculation of crossover frequencies. The χ^2 values listed in table 3 are derived from comparisons of each of the crosses with the control. For these calculations four and five point

TABLE 2

Comparison of test and control crossover values.

INVERSION TESTED	REGION 1 % CROSS-OVER	1 % CHANGE	2 % CROSS-OVER	2 % CHANGE	3 % CROSS-OVER	4 % CROSS-OVER	4 % CHANGE (INCLUDING REGION 3)	5 % CROSS-OVER	5 % CHANGE	6 % CROSS-OVER	6 % CHANGE	7 % CROSS-OVER	7 % CHANGE	MAP LENGTH	% CHANGE	TOTAL
Control (1)	24.8	—	21.1	—	1.0	5.6	—	13.9	—	10.6	—	38.0	—	115.0	—	2419
bb^{Df}	29.7	19.6	22.5	6.6	1.5	9.1	60.6	13.4	−3.6	9.3	−12.3	32.6	−14.2	118.1	2.7	2520
ClB	27.0	8.9	23.5	11.4	0.5	8.1	30.3	18.0	29.5	11.0	3.8	35.3	−7.1	123.4	7.3	2116
dl-49	26.6	7.3	23.8	12.8	0.8	7.8	30.3	16.8	20.9	11.3	6.6	39.0	2.6	126.1	9.7	1585
sc^{8}	24.7	−0.4	26.8	27.0	1.0	11.1	83.3	18.1	30.2	11.6	9.4	35.3	−7.1	128.6	11.8	1610
sc^{7}	27.6	11.3	25.7	21.8	1.1	8.5	45.4	16.6	19.4	12.0	13.2	37.7	−0.8	129.2	12.3	3116
y^{4}	24.9	0.4	24.1	14.2	1.3	14.4	137.8	21.5	54.7	11.4	7.5	35.4	−6.8	133.0	15.7	2711

crossover strands were grouped so that n (number of degrees of freedom) equals 4. In addition, many of the crossover values were compared with the appropriate control values in 2×2 contingency tables.

Five of the six inversions tested showed a significantly different strand distribution from that of the control (Inversions *ClB*, *dl-49*, sc^8, sc^7, and y^4 (table 3)). The deviation from the control values was in the same direction in every case—namely, a reduction in non-crossover strands, little or no change in the single crossover strands, and an increase in multiple crossover strands

TABLE 3

Classification of strands into crossover classes.

INVERSION TESTED	ZEROS		SINGLES		DOUBLES		TRIPLES		QUADS		QUINTS		TOTAL	χ^2 (AGAINST CONTROL)
	N	%	N	%	N	%	N	%	N	%	N	%		
Control (1)	565	23.5	1107	45.8	576	23.8	160	6.6	11	0.5	0	0.0	2419	—
bb^{Df}	600	23.8	1078	42.8	649	25.8	173	6.9	19	0.8	1	0.0+	2520	6.9
ClB	453	21.4	893	42.2	610	28.8	144	6.8	15	0.7	1	0.0+	2116	17.8
dl-49	310	19.6	697	44.0	452	28.5	106	6.7	20	1.3	0	0.0	1585	23.3
sc^8	322	20.0	672	41.7	476	29.6	125	7.8	14	0.9	1	0.0+	1610	26.0
sc^7	567	18.2	1358	43.6	929	29.8	240	7.7	22	0.7	0	0.0	3116	40.9
y^4	495	18.3	1124	41.5	823	30.4	243	9.0	23	0.8	3	0.1	2711	55.1

When $n=4$; $P=0.05$ when $\chi^2=9.5$; $P=0.01$ when $\chi^2=13.3$

resulting in an increase in crossing over. The sixth inversion (bb^{Df}) did not show a significantly different strand distribution from that of the controls, $P>0.1$.

The χ^2 values listed in table 3 vary from 6.9 to 51.1 in more or less discrete steps which follow the same order of increasing magnitude as do the corresponding total map lengths listed in table 2. This relationship is to be expected, since the crossover values are derived from the strand data.

The data were examined to find whether or not any relationship existed between the size and position of the inversions and the effect on crossing over in the third chromosome. There is no correlation between size (either genetic or cytological) of the inversion and the magnitude of its interchromosomal effect. For example, the relatively short sc^7 inversion has a considerable effect on crossing over in the third chromosome, while the relatively long bb^{Df} inversion has no effect; also among those inversions with an effect, the short sc^7 and the long y^4 inversion each has a great effect on crossing over, while the long *ClB* and the short *dl-49* each has relatively little effect (tables 1, 2, 3). The only physical feature of the inversions which shows any correlation with the magnitude of the interchromosomal effect on crossing over is the position of the left break of the inversion. The closer this break lies to the left end of the chromosome the greater the magnitude of its interchromosomal effect on crossing over (tables 1, 2, 3). While no acceptable explanation of why such a relationship should exist was apparent, it was deemed advisable to test this relationship further. Accordingly, two other inversions, *AM* with its left break relatively far from the left end and sc^4 with its left break relatively close to the left end (table 1) were tested.

If the relationship between the position of the left end of the inversion and the magnitude of the interchromosomal effect on crossing over is real, it is to be expected that the *AM* inversion would have no effect on crossing over in the third chromosome, while the *sc*^{4} inversion would have a very large effect. The raw data are listed in table 10, the crossover values and their relative change with regard to the controls are in table 4, and the strand analysis is in table 5. The χ^2 values derived from a comparison of the strand distribution values of each of the test crosses with those for the control are 10.9 for the *AM* inversion and 11.1 for the *sc*^{4} inversion; with four degrees of freedom P falls between 0.05 and 0.02 ($\chi^2 = 11.7$ at $P = 0.02$). This indicates that the strand distributions may be different from those of the control, but nevertheless there is more than one chance in 50 in either case that the value of χ^2 derived will be exceeded. Comparison of the crossover values of each of the test crosses with those of the controls shows that the values are statistically identical in all cases. (Region 7 is not considered, because the control value for some unexplained reason is abnormally high as compared with the standard value (38.0 as compared to 30.0)). Because of this, the authors feel inclined to consider the strand distributions of the controls and tests to be the same. However, for the purpose of our present discussion the question of primary importance is not whether the strand distributions derived in the presence of the *AM* and *sc*^{4} inversions are the same as or different from those of the control, but "how do the values derived in the presence of these inversions compare with each other?" The strand distributions are statistically the same ($\chi^2 = 5.8$, $n = 4$, hence $P > 0.2$). χ^2 comparisons of *AM* and *sc*^{4} in each of the several crossover regions have not been made because (a) in all except regions 3–4 (regions 3 and 4 have been combined for purposes of statistical treatment because region 3 is so short) and 5, the crossover values are so close as to be obviously the same, (b) *sc*^{4} was compared with the control in region 3–4 and found to be the same ($P > 0.2$) and hence would also be the same as *AM*, and (c) *AM* was compared with the control in region 5 and found to be the same ($P > 0.2$) and therefore would not differ from *sc*^{4} (see the crossover values in table 4). Clearly these data do not conform to the original observation that the position of the left break of the inversion is related to the magnitude of the interchromosomal effect of the inversion on crossing over. No new physical relationship between the nature of the inversion and its interchromosomal effect was derived. It was felt therefore that further tests were desirable before any definite conclusions were drawn.

In order to simplify the technical problem of classification of the flies, a comparison of the individual crossover regions with the appropriate controls was made to see which regions were affected and which were not. Region 7 is of no value in these considerations because of its length, which allows for undetected crossovers, and also because of the abnormally high crossover value given by the controls. Region 1 is also of little value because of its length (26.5 units on the standard map); however, it should be noted in passing that the values obtained in region 1 in the presence of *AM* and *sc*^{7} give a P value of between 0.02 and 0.05 when compared with the control and that the value

TABLE 4

Comparison of crossover values (in presence of AM and sc^4) with control values.

INVERSION TESTED	REGION 1		2		3	4		5		6		7		MAP LENGTH	% CHANGE	TOTAL
	% CROSS-OVER	% CHANGE	% CROSS-OVER	% CHANGE	% CROSS-OVER	% CROSS-OVER	% CHANGE (INCLUDING REGION 3)	% CROSS-OVER	% CHANGE	% CROSS-OVER	% CHANGE	% CROSS-OVER	% CHANGE			
Control (1)	24.8	—	21.1	—	1.0	5.6	—	13.9	—	10.6	—	38.0	—	115.0	—	2419
AM	27.9	12.5	21.9	3.8	0.7	5.4	−7.6	15.3	10.1	10.4	−1.9	34.7	−8.7	116.3	1.1	1408
sc^4	25.4	2.4	22.2	5.2	0.5	7.1	15.1	13.8	−0.7	11.4	7.5	33.6	−11.5	114.0	−0.9	2006

derived in the presence of bb^{Df} gives a P value of much less than 0.01. In region 6 no value differed significantly from that of the controls. Region 3 is so short that small differences would be difficult to detect, and it therefore is not very useful. Thus, the only regions which give satisfactory information are regions 2, 3 and 4, and 5.

TABLE 5

Classification of strands into crossover classes.

INVERSION TESTED	ZEROS		SINGLES		DOUBLES		TRIPLES		QUADS		TOTAL	χ^2 (AGAINST CONTROL)
	N	%	N	%	N	%	N	%	N	%		
Control (1)	565	23.5	1107	45.8	576	23.8	160	6.6	11	0.5	2419	
AM	326	23.2	609	43.3	395	28.1	74	5.3	4	0.3	1408	10.9
sc^4	463	23.1	905	45.1	536	26.7	97	4.8	5	0.2	2006	11.1

When n=4; P=0.05 when χ^2=9.5; P=0.01 when χ^2=13.3.

Four additional X chromosome inversions were tested—namely B^{263-47}, *A99b*, sc^{260-14} and *AB* (table 1). Although the rucuca stock was used as in the previous eight experiments, only *h*, *th*, *cu*, and *sr* were followed. The crossover regions and their equivalents in the earlier experiments are as follows:

New region	Old region	Markers
1	2	*h-th*
2	3 and 4	*th-cu*
3	5	*cu-sr*

Because more than a year had elapsed since the experiments were begun, a new set of controls was studied. The raw data of these crosses (except for a grouping of the sexes) are listed in table 11. The crossover values and the strand analyses are listed in tables 6 and 7, respectively. (For the purposes of χ^2 analyses the double and triple crossover strands were combined.)

TABLE 6

Comparison of Crossover values.

INVERSION TESTED	REGION 1		REGION 2		REGION 3		MAP LENGTH	% CHANGE	TOTAL
	% CROSSOVER	% CHANGE	% CROSSOVER	% CHANGE	% CROSSOVER	% CHANGE			
Control (2)	21.2	—	6.0	—	12.9	—	40.1	—	3918
B^{263-47}	19.8	−6.6	7.3	21.7	14.6	13.2	41.7	4.2	2124
A99b	21.3	0.5	7.0	16.7	14.9	15.5	43.2	7.7	2145
sc^{260-14}	23.9	12.7	7.2	20.0	14.7	14.0	45.8	14.2	2505
AB	25.1	18.4	9.9	65.0	16.4	27.1	51.4	28.2	2144

TABLE 7

Classification of strands into crossover classes.

INVERSION TESTED	ZEROS		SINGLES		DOUBLES		TRIPLES		TOTAL	χ^2 (AGAINST CONTROL)
	N	%	N	%	N	%	N	%		
Control (2)	2511	64.09	1245	31.77	160	4.08	2	0.05	3918	—
B^{263-47}	1326	62.43	712	33.52	83	3.91	3	0.14	2124	1.3
A99b	1333	62.14	701	32.68	108	5.03	3	0.14	2145	4.4
sc^{260-14}	1492	59.56	882	35.21	128	5.11	3	0.12	2505	14.3
AB	1187	55.36	815	38.01	139	6.48	3	0.14	2144	50.1

When n=2; P=0.05 when $\chi^2=6.0$; P=0.01 when $\chi^2=9.2$.

By rearranging the data of the first nine crosses on the basis of the four markers followed in the last five crosses, it is possible to obtain direct comparisons. The crossover values of the rearranged data are given in table 8, the strand distributions are given in table 9.

The first and second sets of controls when compared in this way are found to be statistically identical in each of the three crossover regions and also with regard to the strand distribution. Therefore there was no change in the rucuca or Oregon-R stocks during the course of these experiments. Of the four inversions tested two were very short; one (*AB*) is located in the central region of the X chromosome, the other (B^{263-47}) in the proximal region of the X chromosome. The former had a marked effect on crossing over in the third chromosome, the latter had none. The remaining two inversions were relatively long; one (*A99b*) includes the entire active region of the X chromosome, the other

TABLE 8

*Comparison of test crossover values with control values.**

REGION		CONTROL (1)	SC^4	AM	$BB^{D/}$	DL-49	CLB	SC^7	SC^8	Y^4
1	% crossover	21.1	22.2	21.9	22.5	23.8	23.5	25.7	26.8	24.0
	% change	—	5.2	3.8	6.6	12.8	11.4	21.8	27.0	18.5
2	% crossover	6.5	7.5	6.1	9.6	8.5	8.6	9.1	11.9	15.3
	% change	—	15.4	−6.2	47.7	30.8	32.3	40.0	83.1	135.4
3	% crossover	13.9	13.8	15.3	13.4	16.8	18.0	16.6	18.1	21.5
	% change	—	−0.7	10.1	−3.6	20.9	29.5	19.4	30.2	54.7
	Map length	41.5	43.5	43.3	45.6	49.1	50.1	51.4	56.8	60.8
	% change	—	4.8	4.3	9.9	18.3	20.7	23.9	36.9	46.5

* Note new region 1=old region 2; new region 2=old regions 3 and 4; new region 3=old region 5.

In recasting data, crossover strands involving regions 3 and 4 simultaneously were treated as non-crossovers in new region 2.

TABLE 9

Classification of strands into crossover classes.
(Data of table 10 arranged on basis of three regions only.)

	CONTROL (1)		*sc*^{4}		*AM*		*bb*^{D1}		*dl-49*		*ClB*		*sc*^{7}		*sc*^{8}		*y*^{4}	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
0	1541	63.7	1240	61.8	867	61.6	1506	59.8	905	57.1	1188	56.1	1717	55.1	831	51.6	1346	49.6
1	755	31.2	660	32.9	473	33.6	886	35.1	586	37.0	798	37.7	1198	38.4	637	40.2	1094	40.4
2	119	4.9	105	5.2	68	4.8	123	4.9	91	5.7	128	6.0	197	6.3	129	8.0	259	9.6
3	4	0.17	1	0.06	0	0.00	5	0.20	3	0.19	2	0.10	4	0.12	3	0.19	12	0.44
Total	2419		2006		1408		2520		1585		2116		3116		1610		2711	
χ^2				1.6		2.6		8.8		17.5		26.9		41.8		60.8		114.4

When n=2; P=0.05 when χ^2=6.0; P=0.01 when χ^2=9.2

(sc^{260-14}) about the distal half. *A99b* had no effect while sc^{260-14} caused a significant increase in crossing over in the third chromosome.

The data derived from these four inversions combined with those derived from the eight previously tested make it abundantly clear that neither the size nor the position with respect to the ends of the chromosome nor the combination of these two morphological features of an inversion are related to the interchromosomal effect of inversions on crossing over.

DISCUSSION

For convenience of discussion two aspects of the problem of the interchromosomal effect of inversions on crossing over may be distinguished: (a) the nature of the effect—that is, the magnitude and distribution of the increased crossing over from region to region of the affected chromosome—and (b) the relationship between the effect (its magnitude and distribution) and the nature of the inversion causing it. The two aspects are of course intimately related, and the one cannot be measured without the other.

All the inversions tested showed the same pattern of effect on crossing over in the third chromosome (that is, when any effect was observed). The greatest increase in crossing over occurred in the region of the centromere and fell off sharply on either side (tables 2 and 4). SCHULTZ and REDFIELD (MORGAN, BRIDGES, and SCHULTZ 1932, 1933) reported the same type of distribution of effect in the second and third chromosomes. They observed no difference in the pattern of effect on the third chromosome of inversions in the first and second chromosomes, nor did they observe any differences between the effect of the *ClB* inversion and the Payne inversions on crossing over in the second chromosome. From all these data it appears that the autosomes always respond in the same way to the interchromosomal stimulus of inversions on crossing over. This is not true of the X chromosome, which shows a different pattern of increase in the presence of the Curly inversions from that which it shows in the presence of the Payne inversions (STEINBERG 1936).

The increase in crossing over observed in the third chromosome is associated with a decrease in non-crossover strands and an increase in single and multiple crossover strands. This relationship is most clearly illustrated in tables 7 and 9 where only the three most affected regions are considered, but masked in tables 3 and 5 where all seven regions are considered, because four of the seven regions are either not affected at all or are affected to only a very slight extent. The increased frequency of multiple crossovers may be the result of reduced interference or may be due to a proportional increase of single and multiple crossovers resulting from an increase in crossing over without any change in interference. If interference has been reduced, the frequency of multiple crossover strands relative to the frequency of single crossover strands should be increased. If, on the other hand, interference has not been affected, the frequency of multiple crossover strands relative to the frequency of single crossover strands should remain unchanged. The changed relationship may not be discernible when all seven regions are considered because of the masking effect of the four unaffected regions; however, if only the three most affected regions are considered it should be easily recognized.

A preliminary survey of the data in table 9 indicated that in all except the cross involving the y^4 inversion the ratio of single crossover to multiple crossover strands was statistically the same. Accordingly a χ^2 test for homogeneity was made in a 2×8 contingency table involving the strand data of the original set of controls and that of seven of the first eight inversions (y^4 being omitted); $\chi^2=8.3$, $n=7$, and $P\approx0.30$; hence there is no change in interference. The strand distribution derived in the presence of the y^4 inversion was tested against the control strand distribution in a 2×2 table; $\chi^2=33.2$, $n=1$, $P<<<0.01$, indicating a considerable change in interference. The change is obviously a reduction, since the frequency of multiple crossover strands relative to single crossover strands is greatly increased. The test for homogeneity when repeated with the y^4 inversion included gave a χ^2 value of 29.0, $n=8$, $P<<0.01$. The remaining four inversions were tested against the second set of controls (table 7) in a 2×5 contingency table; $\chi^2=8.8$, $n=4$, $P>0.05$ but <0.1, indicating no change in interference.

The data published by STEINBERG (1936) involving the effect of the Curly and Payne inversions, singly and combined, on crossing over in the X chromosome were tested in the same manner. In each of the three tests $P<<<0.01$, indicating a marked decrease in interference. This was recognized in the earlier publication where, although no statistical tests were made, it was pointed out that there was a considerable increase in multiple crossover strands and only a slight increase in single crossover strands in the presence of the inversions either singly or combined. SIDEROW, SOKOLOW, and TROFIMOW (1936) studied the effect of inversions in the second and third chromosomes on double crossing over within the inverted portion of X chromosomes heterozygous for an inversion. In each of two experiments (one involving In(1) *sc*^{9} the other In(1) *ClB*) the test cross showed a five-fold increase in crossing over as compared to the control value. This magnitude of increase is the same as that obtained by STEINBERG (1936) and indicates that SIDEROW, SOKOLOW, and TROFIMOW's data also involve a great reduction in interference.

Unfortunately SCHULTZ and REDFIELD'S data are not published in a form which would permit an analysis of interference changes in their experiments.

It is clear that the increase in crossing over caused by heterozygous inversions in another pair of chromosomes is realized in two different ways. The first method involves a reduction of non-crossover strands and a concomitant reduction in interference. This type of effect is the only one thus far to be observed in the X chromosome, and it has been observed in the third chromosome only in the presence of the y^4 inversion. The second method involves a general increase in crossing over with no accompanying change in interference. This type of increase in crossing over has been observed in the third chromosome in all cases involving an increase, except that associated with the presence of the y^4 inversion.

It will be noted that a tetrad analysis of the data has not been attempted, although an extensive analysis of this type was made in the senior author's earlier paper (STEINBERG 1936). This is so because the work of HEARNE and HUSKINS (1935), HUSKINS and NEWCOMBE (1941), and of LINDEGREN and LINDEGREN (1937, 1939) cast doubt on one of the basic assumptions involved

in the derivation of the formulae upon which the tetrad analysis is based—namely, that the chromatids which cross over at one level do not influence those which cross over at other levels.

We turn now to a discussion of the data in the light of the three hypotheses advanced to explain the interchromosomal effect of heterozygous inversions on crossing over. SCHULTZ's hypothesis requires a correlation between the degree of disturbance of somatic pairing in the last premeiotic division within the chromosome pair heterozygous for the inversion and the interchromosomal effect of the inversion on crossing over. The only direct way of measuring the degree of disturbance of somatic pairing is of course cytological observation of the last premeiotic division. If SCHULTZ's hypothesis is correct, the disturbance in somatic pairing should affect the pairing not only of non-homologous chromosomes but also that of the chromosome pair heterozygous for the inversion. This disturbance should be reflected in the extent to which crossing over is affected in the chromosome pair heterozygous for the inversion and hence should afford an indirect measurement of the degree of disturbance in somatic pairing caused by heterozygous inversions. Seven of the twelve X chromosome inversions utilized in these experiments were studied by STURTEVANT and BEADLE (1936) with regard to their effect on crossing over within the inverted and the uninverted portions of the chromosomes. STURTEVANT and BEADLE's findings are summarized below.

INVERSION	EFFECT ON CROSSING OVER WITHIN THE INVERTED PORTION	EFFECT ON CROSSING OVER WITHIN THE UNINVERTED PORTION	
		TO LEFT OF INVERSION	TO RIGHT OF INVERSION
sc^7	Decreased	*	Decreased
dl-49	Decreased	Decreased	Decreased
ClB	Probably decreased	Decreased	Decreased
sc^4	Little or possibly no effect	*	*
sc^8	Little or possibly no effect	*	*
bb^{Df}	Little or possibly no effect	Decreased	*
y^4	Little or possibly no effect	*	Decreased

* No uninverted section in which crossing over occurs in normal flies is present, and therefore no tests can be made.

From these data it follows that crossing over is affected by the inversions in the following order of decreasing magnitude: $dl\text{-}49 \geqq ClB > sc^7 > bb^{Df} \geqq y^4 > sc^4 = sc^8$. Presumably the degree of disturbance experienced in somatic pairing in the last premeiotic division would follow the same seriation. However, the relative magnitude of the effect of these inversions on crossing over in the third chromosome follows no such seriation (tables 2, 3, 4, 5, 7, 8). For example, both sc^4 and sc^8 are very long inversions and have little or no effect on crossing over in the X chromosome, yet sc^8 has a considerable effect on crossing over in the third chromosome, while sc^4 has no effect; y^4 is a long inversion and has little or no effect on crossing over in the X chromosome, while *ClB* is of medium

length and reduces crossing over in the X chromosome to a very great extent; nevertheless, the y^4 inversion causes a significantly greater increase in crossing over in the third chromosome than does the *ClB* inversion; on the other hand, although the *ClB* inversion has a much greater effect on crossing over in the X chromosome than does the sc^4 inversion, it has a significantly greater effect on crossing over in the third chromosome. When to this group of seven inversions we add the *AM* and *AB* inversions, which STONE and THOMAS (1935) have shown to cause a considerable reduction in crossing over in the X chromosome, and the *A99b* and sc^{260-14} inversions, which probably have little or no effect, and the B^{263-47} inversion, which probably has a considerable effect on crossing over in the X chromosome, the breakdown of a correlation between the effect of an inversion on crossing over in the X chromosome and its effect on crossing over in the third chromosome becomes complete. From these considerations it follows that SCHULTZ's hypothesis must be abandoned.

MATHER's theory of "competitive pairing" (the name is an unfortunate one, since it has already been used much more appropriately by DOBZHANSKY (1934) to describe his hypothesis (DOBZHANSKY 1931, 1932) concerning the competition between the portions of rearranged chromosomes for pairing with their homologues) requires an inverse correlation between the effect of an inversion on crossing over within the tetrad heterozygous for it and its effect on crossing over in a non-homologous tetrad. The discussion presented above relative to SCHULTZ's hypothesis is also pertinent to MATHER's hypothesis and leads to the same conclusion—namely, that this hypothesis also does not explain the data.

There is one type of data involving an interchromosomal effect on crossing over which may be explained by MATHER's hypothesis. SCHULTZ (MORGAN, BRIDGES, and SCHULTZ 1935) and STEINBERG coincidentally (see introduction STEINBERG 1941) found that crossing over in the autosomes was greatly increased when measured in the exceptional offspring of XXY ♀ ♀ (that is, daughters arising from XX eggs and sons from no-X eggs). BRIDGES (1916) has shown that the X chromosomes in XX eggs are non-crossover chromosomes. Hence the increase in crossing over observed in the autosomes of daughters arising from XX eggs and sons arising from no-X eggs is associated with the absence of crossing over in the X chromosomes. While this phenomenon may be explained on the basis of MATHER's hypothesis, the explanation is not the only one which fits the data and need not be the correct one. It is possible nevertheless that the increase in crossing over observed in the autosomes of the exceptional offspring of XXY ♀ ♀ is due to a different underlying mechanism from that concerned with the increase in the crossing over arising in the presence of heterozygous X chromosome inversions, since the latter increase is not necessarily associated with a decrease in crossing over in the X chromosomes.

STEINBERG and WHITE'S (1939) hypothesis requires that no relationship exist between the length or position of the inversion relative to the chromosome ends and the interchromosomal effect of the inversion on crossing over. They suggested that the interchromosomal effect of inversions on crossing over was

due to an unspecified physiological effect caused by the inversion. It was pointed out that many inversions are known to cause physiological effects.

It is now clear that most of the physiological (mutational) effects associated with inversions are due to position effects. Furthermore, neither the position of the inversion relative to the chromosome ends, nor the size of the inversion are related as such to the position effect resulting from the inversion. It has been demonstrated above that neither of these two factors are related to the interchromosomal effect of inversions on crossing over. Earlier experiments (see SCHULTZ in MORGAN, BRIDGES, and SCHULTZ 1932, 1933, 1935; STEINBERG 1937, *et al.*) have shown that the increase in crossing over is affected in all chromosomes of the nucleus. STEINBERG (1937) showed that the relative magnitude of the effects exhibited by the various chromosomes cannot be explained as a simple function of the chromosome lengths. He showed that the magnitude of the increase in crossing over per unit map length of a given chromosome was a function of the total chromatin of the cell contained in that chromosome. For these reasons the present authors postulate that the interchromosomal effect of inversions on crossing over is the result of a position effect.

Position effects may be classified into two groups (with some possible exceptions which will be discussed below): (a) those which arise as the result of the transference of a locus which ordinarily lies close to the heterochromatic region to a euchromatic region (for example the cubitus interruptus and light loci) and (b) those which arise as the result of the transference of a locus which ordinarily is situated in a euchromatic region to a heterochromatic region (for example, the white and brown loci). A group of possible exceptions is constituted of those position effects which arise as a result of translocations or inversions in which both breaks occur in euchromatic regions. However, PROKOFYEVA (1939) and KAUFMANN (1939) have shown that interstitial heterochromatic regions exist within the euchromatic regions of the X chromosome. It is conceivable that the latter group of position effects simply involve transfers from euchromatic regions to interstitial heterochromatic regions and vice versa and hence are not exceptions at all. It is our belief that the position effect leading to a change in crossing over arises exactly as do all other position effects and is subject to the same influences that they are. If this is so, the presence of a Y chromosome should enhance or decrease the interchromosomal effect of inversions on crossing over just as it enhances the position effect of some loci (the cubitus interruptus group) and decreases that of others (the brown group). Furthermore some translocations should show an interchromosomal effect on crossing over (for example, a II–III translocation may effect crossing over in the first chromosome, etc.), and others should not, depending upon the regions involved.

No predictions can be made with regard to the role of homozygous inversions on crossing over in non-homologous chromosomes, since it has been shown that some position effects have no expression in the homozygous condition (cubitus interruptus, etc.), while others do (some mottled whites, etc.); nevertheless

such experiments are worth doing, since they may contribute new facts to help our understanding of the problem.

Despite the many theories evolved to explain the mechanism of crossing over, we are still far from an understanding of its basic nature. One difficulty lies in the fact that the present techniques used to study crossing over have about reached the limit of their usefulness without giving us the information needed to solve the problem. It is to be hoped that further studies of the relationship postulated in this paper between the interchromosomal effect of inversions on crossing over and the position effect phenomenon will lead to a further insight into the problem of crossing over.

SUMMARY

The effects of 12 different X chromosome inversions (table 1) on crossing over in the third chromosome were measured.

Eight of the inversions caused an increase in crossing over in the third chromosome, while the remaining four had no effect on crossing over in the third chromosome (tables 7 and 9).

Of those inversions which caused an increase in crossing over in the third chromosome, all except the y^4 inversion did so without reducing the interference value. In the presence of the y^4 inversion interference is greatly reduced. These observations were contrasted with those of the Senior author on the effect of autosomal inversions on crossing over in the X chromosome in which it was found that a marked decrease in interference occurred in each of the three test crosses.

There is no relation between the size of the inversion, nor its position relative to the chromosome ends, nor its effect on crossing over in the X chromosome and the magnitude of its effect on crossing over in the third chromosome.

The data were examined in the light of the three hypotheses (SCHULTZ, MATHER, and STEINBERG and WHITE) which had been advanced to explain the interchromosomal effect of inversions on crossing over; only that of STEINBERG and WHITE was found adequate. This hypothesis, which in its original form ascribed the interchromosomal effect of inversions on crossing over to an unspecified physiological (mutational) effect of inversions, has been modified to state that the interchromosomal effect of inversions is due to a position effect.

TABLE 10

Number and types of offspring derived from each of the various crosses listed below.

REGION	CONTROL (1)		bb^{D1}		*dl-49*		*ClB*		sc^{7}		sc^{8}		y^{4}		*AM*		sc^{4}	
	ru	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*
0	206	359	282	318	143	167	210	243	232	335	145	177	221	274	140	186	182	281
1	134	90	171	135	80	66	108	101	167	101	76	47	103	100	85	57	123	94
2	101	93	116	96	67	60	87	80	168	118	85	66	108	85	68	53	78	104
3	6	1	5	6	3	2	2	1	7	3	2	2	5	7	0	4	0	2
4	14	20	28	37	20	20	23	35	31	41	24	25	62	46	8	22	18	26
5	44	61	57	54	36	45	60	59	85	91	28	55	84	89	31	46	36	51
6	58	54	36	45	28	37	43	43	56	83	36	35	44	43	26	24	41	49
7	188	243	143	149	117	116	116	135	167	240	76	115	159	189	80	105	123	160
1.2	14	14	23	28	8	16	20	11	18	31	19	14	24	26	7	6	8	13
1.3	0	2	2	3	0	0	1	0	3	1	0	0	0	2	1	1	0	0
1.4	9	6	17	21	7	7	9	9	12	10	5	14	18	13	3	5	2	9
1.5	25	20	23	27	13	14	31	21	38	25	17	18	44	18	17	18	16	22
1.6	21	13	16	19	16	13	17	15	28	26	15	6	31	19	16	15	22	24
1.7	83	58	86	57	54	44	67	56	142	78	42	38	67	57	63	46	55	62
2.3	0	0	1	0	1	0	0	0	0	1	0	1	1	1	0	0	0	0
2.4	1	5	10	10	2	3	3	3	13	11	8	6	12	16	3	4	8	8
2.5	20	19	17	14	15	16	30	23	36	27	14	19	33	37	13	18	21	19
2.6	22	11	18	18	14	10	27	12	31	31	13	11	23	22	8	12	17	16
2.7	61	57	64	50	46	38	65	49	100	70	51	35	73	48	40	33	59	43
3.4	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0
3.5	3	0	0	0	0	0	1	0	0	0	1	2	1	1	0	0	0	0
3.6	1	0	0	1	0	0	0	1	2	0	1	0	2	1	0	1	1	1
3.7	0	0	2	1	0	1	1	0	1	3	2	1	1	4	1	0	1	2
4.5	4	2	1	4	7	3	0	5	7	6	7	8	17	20	0	3	5	7
4.6	2	4	4	3	1	4	2	3	2	4	0	5	7	8	0	2	4	2
4.7	12	15	19	15	10	9	19	13	22	28	16	17	27	30	4	7	10	13
5.6	0	3	1	0	0	4	1	0	2	3	2	2	3	7	2	1	1	3
5.7	23	24	27	21	24	34	30	42	22	53	26	21	45	38	10	21	14	29
6.7	9	13	16	10	12	5	11	12	20	22	9	10	12	12	4	10	5	14
1.2.3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
1.2.4	0	1	1	1	0	1	0	2	2	0	0	0	3	5	0	0	0	1
1.2.5	5	5	3	2	1	5	4	1	8	4	7	3	3	2	0	1	0	2
1.2.6	2	5	4	2	1	1	4	3	3	5	3	3	3	5	2	2	2	1
1.2.7	10	13	13	6	10	13	9	7	16	24	9	14	6	12	6	4	7	5
1.3.4	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1.3.5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

1.3.6	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0
1.3.7	1	0	0	0	0	0	0	1	0	2	0	0	2	1	1	1	1	0
1.4.5	2	3	2	3	0	2	4	0	4	3	1	1	6	7	1	0	0	2
1.4.6	0	0	0	0	0	0	2	4	2	1	2	1	1	2	2	0	1	0
1.4.7	3	7	5	17	3	8	8	7	13	13	5	6	7	12	0	5	7	3
1.5.6	3	4	3	0	1	1	0	0	3	1	2	0	5	3	1	2	1	1
1.5.7	18	10	10	18	10	4	15	9	29	10	8	5	19	16	4	7	10	7
1.6.7	7	4	8	9	2	4	7	4	8	6	2	1	9	1	6	4	2	2
2.3.4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.7	0	2	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
2.4.5	2	1	0	0	0	0	0	1	0	2	1	1	6	5	0	0	1	0
2.4.6	1	0	0	1	0	1	1	0	2	1	2	2	2	3	1	0	2	0
2.4.7	7	3	2	4	1	2	3	2	4	12	1	4	5	10	3	1	0	2
2.5.6	1	0	0	1	0	0	0	1	4	4	1	3	3	0	1	1	2	0
2.5.7	10	7	8	24	9	9	11	16	16	15	13	10	21	18	7	7	10	7
2.6.7	6	4	7	5	6	5	5	4	5	3	2	2	7	8	3	1	4	2
3.4.5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
3.4.6	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
3.4.7	0	1	0	1	0	0	0	0	0	5	1	0	0	1	0	0	1	0
3.5.6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3.5.7	0	3	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0
3.6.7	0	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0
4.5.6	0	0	0	0	1	0	0	0	1	0	1	0	0	1	0	0	0	0
4.5.7	3	2	3	1	1	1	3	1	1	2	0	3	2	7	0	0	1	2
4.6.7	0	1	0	0	1	0	1	1	1	1	2	1	4	2	0	0	4	0
5.6.7	1	0	0	0	0	0	0	0	1	1	0	0	0	3	0	0	0	2
1.2.3.7	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1.2.4.5	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0
1.2.4.6	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
1.2.4.7	1	0	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	1
1.2.5.6	0	0	0	0	0	1	0	1	0	1	0	2	1	0	0	0	0	0
1.2.5.7	3	0	2	2	0	3	1	5	4	3	1	0	0	4	0	2	1	0
1.2.6.7	0	0	1	0	3	3	1	0	1	3	1	0	0	2	0	0	0	0
1.3.4.5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.3.4.7	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.3.5.7	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
1.3.6.7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1.4.5.6	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
1.4.5.7	0	1	0	1	1	1	1	0	1	1	1	1	4	4	0	1	0	1
1.4.6.7	0	1	1	0	0	0	1	1	1	1	2	0	0	1	0	0	0	0
1.5.6.7	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
2.3.4.5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3.4.7	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

TABLE 10—*Continued*

REGION	CONTROL (1)		*bb*^{Df}		*dl-49*		*ClB*		*sc*^{7}		*sc*^{8}		*y*^{4}		*AM*		*sc*^{4}	
	ru	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*	*ru*	NON-*ru*
2.4.5.6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2.4.5.7	1	0	1	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0
2.4.6.7	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	1
2.5.6.7	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
3.4.5.7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3.4.6.7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5.6.7	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1.2.4.6.7	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0
1.4.5.6.7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
2.3.5.6.7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.4.5.6.7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Totals	1150	1269	1271	1249	779	806	1071	1045	1547	1569	794	816	1356	1355	668	740	908	1098
Grand Totals	2419		2520		1585		2116		3116		1610		2711		1408		2006	

TABLE 11

Raw data derived from the last four inversions tested and their control (data of the two sexes is combined).

INVERSION TESTED	CROSSOVER REGIONS																TOTAL
	0		1		2		3		1.2		1.3		2.3		1.2.3		
	h	NON-*h*	*h*	NON-*h*	*h*	NON-*h*	*h*	NON-*h*	*h*	NON-*h*	*h*	NON-*h*	*h*	NON-*h*	*h*	NON-*h*	
Control (2)	1126	1385	356	327	90	94	179	199	16	17	62	51	7	7	1	1	3918
AB	476	711	229	190	76	74	110	136	17	20	44	35	13	10	2	1	2144
A99b	526	807	196	166	53	53	95	138	12	12	37	30	8	9	0	3	2145
sc$^{260-14}$	606	886	240	243	60	70	122	147	17	16	32	48	9	6	1	2	2505
B$^{263-47}$	345	981	222	125	62	63	81	159	8	7	31	25	6	6	1	2	2124

LITERATURE CITED

BRIDGES, C. B., 1916 Non-disjunction as proof of the chromosome theory of heredity. Genetics **1**: 1–52, 107–163.

DOBZHANSKY, TH., 1931 The decrease of crossing over observed in translocations, and its probable explanation. Amer. Nat. **65**: 214–232.

1932 Studies on chromosome conjugation. I. Translocations involving the second and the Y chromosomes of *Drosophila melanogaster*. Z.i.A.V. **60**: 235–286.

1934 Studies on chromosome conjugation. III. Behavior of duplicating fragments. Z.i.A.V. **68**: 134–162.

GLASS, H. B., 1933 A study of dominant mosaic eye-color mutants in *Drosophila melanogaster*. II. Tests involving crossing over and non-disjunction. J. Genet. 28: 69–112.

HEARNE, C. MARIE, and C. L. HUSKINS, 1935 Chromosome pairing in *Melanoplus femur-rubrum*. Cytologia **6**: 123–147.

HOOVER, MARGARET E., 1938 Cytogenetic analysis of nine inversions in *Drosophila melanogaster*. Z.i.A.V. **74**: 420–434.

HUSKINS, C. L., and H. B. NEWCOMBE, 1941 An analysis of chiasma pairs showing chromatid interference in *Trillium erectum* L. Genetics **26**: 101–127.

KAUFMANN, B. P., 1939 Distribution of induced breaks along the X chromosome of *Drosophila melanogaster*. Proc. Nat. Acad. Sci. **25**: 571–577.

LINDEGREN, C. C., and G. LINDEGREN, 1937 Non-random crossing over in Neurospora. J. Hered. **28**: 105–113.

1939 Non-random crossing over in the second chromosome of *Neurospora Crassa*. Genetics **24**: 1–7.

MACKNIGHT, R. H., 1937 Crossing over in the sex chromosome of racial hybrids of *Drosophila pseudoobscura*. Genetics **22**: 249–256.

MATHER, K., 1936 Competition between bivalents during chiasma formation. Proc. Roy. Soc. Lond. B **120**: 208–227.

MORGAN, T. H., C. B. BRIDGES, and J. SCHULTZ, 1932 The constitution of the germinal material in relation to heredity. Carnegie Inst. Washington Year Book **31**: 303–307.

1933 The constitution of the germinal material in relation to heredity. Carnegie Inst. Washington Year Book **32**: 298–302.

1935 The constitution of the germinal material in relation to heredity. Carnegie Inst. Washington Year Book **34**: 284–291.

MULLER, H. J., and A. A. PROKOFYEVA, 1934 The individual gene in relation to the chromomere and the chromosome. Proc. Nat. Acad. Sci. **21**: 16–26.

PROKOFYEVA-BELGOVSKAYA, A. A., 1939 Cytological mechanism of mosaicism and of chromosome rearrangement. C. R. Acad. Sci. U.R.S.S. **22**: 270–273.

SIDEROW, B. N., N. N. SOKOLOW, and I. E. TROFIMOW, 1936 Crossing over in Heterozygoten Inversionen. I. Einfaches crossing over. Genetica **18**: 291–312.

STEINBERG, A. G., 1936 The effect of autosomal inversions on crossing over in the X chromosome of *Drosophila melanogaster*. Genetics **21**: 615–624.

1937 Relations between chromosome size and effects of inversions on crossing over in *Drosophila melanogaster*. Proc. Nat. Acad. Sci. **23**: 54–56.

1941 Studies on Modifier of Bar. A mutant which affects the expression of the Bar mutation of *Drosophila melanogaster*. Genetics **26**: 440–451.

STEINBERG, A. G., and E. C. WHITE, 1939 The failure of host genotype to affect crossing over in an implanted ovary in *Drosophila melanogaster*. Amer. Nat. **73**: 91–93.

STONE, W., and I. THOMAS, 1935 Crossover and disjunctional properties of X chromosome inversions in *Drosophila melanogaster*. Genetics **17**: 170–184.

STURTEVANT, A. H., 1919 Inherited linkage variations in the second chromosome. Carnegie Inst. Washington Publ. **278**: 305–341.

STURTEVANT, A. H., and G. W. BEADLE, 1936 The relations of inversions in the X chromosome of *Drosophila melanogaster* to crossing over and disjunction. Genetics **21**: 554–604.

SUTTON, EILEEN, 1943a Bar eye in *Drosophila melanogaster:* a cytological analysis of some mutations and reverse mutations. Genetics **28**: 97–107.

1943b A cytogenetic study of the yellow-scute region of the X chromosome in *Drosophila melanogaster*. Genetics **28**: 210–217.