THE MINUTE REACTION IN THE DEVELOPMENT OF *DROSOPHILA MELANOGASTER**

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INTRODUCTION

At the present time, studies on the relation between somatic character and gene involve many inferences from the end result to the nature of its production. The relative inaccessibility of the gene itself, and the great complexity of the developmental process, make a direct attack difficult.

Nevertheless, an investigation of the effects of different genes in combination with each other upon a given somatic character, may provide a fruitful orientation in the problem (see WRIGHT 1925, 1927). It seems likely that if one mutant gene modifies the effect of another, both of these genes are concerned in some way with the same process in development. If we make this assumption we may discover from experiments of the type suggested the fewest number of reactions possible in development from gene to character. The system arrived at is a logical one; it can be no more than the simplest scheme consistent with the data at hand. But it seems worth while to obtain the minimum requirements necessary for an explanation; in other words a set of conditions which must be met by any mechanism proposed.

In the following treatment, we shall use this method to analyze the interrelations of a group of mutants in *Drosophila melanogaster*. Essen-

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* The GOLTON AND MENDEL MEMORIAL FUND pays part of the cost of the accompanying tables.

tially the method followed is to determine by exclusion whether a given effect is primary, that is to say more immediately dependent upon the gene, or is due to a secondary reaction later in development. The rest of the genetic system is kept constant, and one may therefore disregard questions of genic balance (BRIDGES 1922).

It is a pleasure to acknowledge the many kindnesses of Professor T. H. MORGAN, DR. A. H. STURTEVANT, DR. C. B. BRIDGES, DR. HELEN REDFIELD, and DR. CURT STERN during the course of the work.

MATERIAL

The material used in these experiments is the group of dominant mutations known, because of their small bristles, as the Minutes. They were first discovered by BRIDGES in 1919 (BRIDGES and MORGAN 1923, figure 31, p. 206); since then so many have been found that this mutant type is one of the most frequent in Drosophila.

Many other characters than the bristles are affected in these mutants. The eyes are larger and rougher than normal; the wings are blunt in shape, sometimes beaded. Their venation is slightly plexus-like, and the fifth vein may stop short of the wing margin. Minute flies have weak legs, and a somewhat pale body color; the aristae may be reduced, the abdominal sclerites irregular. The postvertical bristles of the head are frequently missing, and other bristles (notably the alars) are occasionally duplicated. The total body size may be smaller than normal. Females are likely to be sterile, and are generally weaker than males. Most striking of all the characters of the Minutes, however, are the retardation of development and the elimination of chromosomes in somatic cells.

The loci of the Minutes were found to be scattered through the chromosomes (figure 1): sex-linked Minutes were found, as well as those located in the autosomes. The latter are lethal in homozygous condition, and correspondingly, no males of a sex-linked Minute survive. One very frequent type, which differs from the others in having a darker trident pattern and a closely knit wing texture, was found to be a deficiency for the small fourth chromosome (BRIDGES 1921). Other Minutes have been found to be sectional deficiencies—namely Minute-l, for arc and plexus in the second chromosome (MORGAN, BRIDGES and STURTEVANT 1925); Minute-30, deficient for crossveinless in the sex-chromosome (unpublished data of the writer); and Minute-IV, for rotated abdomen in chromosome IV (BRIDGES, unpublished). Some loci have mutated to Minute more than once, producing allelomorphic Minutes (unpublished data of STERN, BRIDGES, and the writer).

It is a striking fact that so many different loci should produce so similar somatic characters. Whether the production of the Minute character is the same in all cases, or whether the same end is reached by different means; or whether, indeed, the Minutes represent the same genic material or its absence at different loci, are immediate questions.

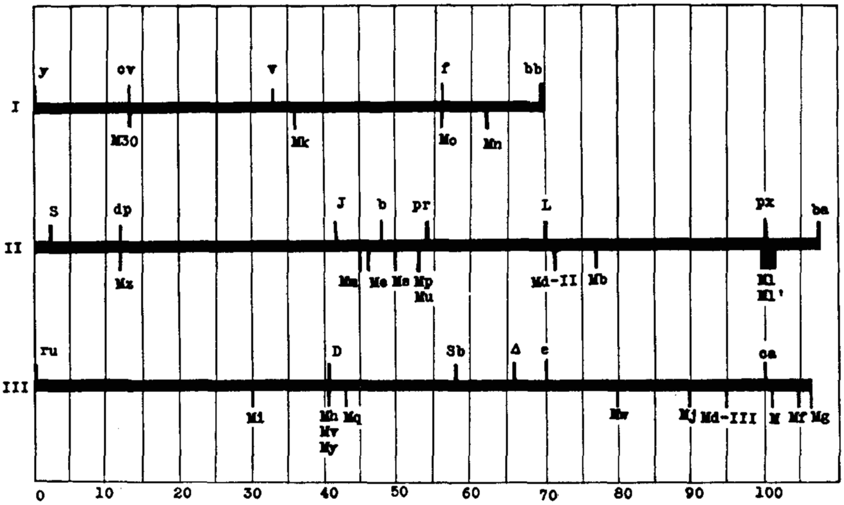

FIGURE 1.—Chromosome map, showing the loci of the Minutes and a few of the principal mutants of Drosophila.

TECHNIQUE

In all cases, where possible, the classes to be studied were identified by linked genes whose effects upon the Minutes were known and negligible. This is essentially a modification of the method originated by MULLER (1918) and STURTEVANT (1918) in their analyses of modifying factors, and since used extensively in Drosophila work (for example BRIDGES and MORGAN 1923). The value of this proceedure is obvious especially in cases where lethal ratios are to be studied (MULLER 1928).

Especially helpful in this work were dominants, lethal when homozygous, which are associated with crossover reducers (STURTEVANT 1926). For the second chromosome the mutant Curly, associated with crossover reducers for both limbs of the chromosome (WARD 1923), was used extensively. A Stubble stock, in which this dominant is associated with a crossover reducer for the right limb of chromosome III (STURTEVANT, unpublished) has been similarly useful for the third chromosome, particularly in the crosses with Delta.

The mutants employed in these experiments are described in table 1.

TABLE 1

Mutants used in the experiments. The dominants employed are indicated by a capital letter; these are all lethal when homozygous.

MUTANT	SYMBOL	CHIEF EFFECT	CHROMOSOME	LOCUS
black	b	Body color.	II	48.5
brown	b_w	Eye color.	II	105.0
	$l\ C_L\ C_R$	Lethal associated with crossover reducers for both limbs of III.	III	
	$l\ C_L$	Lethal with crossover reducer for left end of III.	III	
	$C_{III}\ l_{IIIa}$	Lethal in inverted section at right end of III.	III	
	C_{IIIRMo}	Crossover reducer for right end of III.	III	
cardinal	c_d	Eye color.	III	75.7
claret	c_a	Eye color.	III	100.7
curved	c	Wing shape.	II	75.5
Curly	C_y	Wing shape; associated with C_y are crossover reducers for II.	II	Left limb.
Delta	Δ	Wing venation.	III	66.2
Delta^3	Δ^3	"	III	66.2
Delta^4	Δ^4	"	III	66.2
Dichaete	D	Wing position, bristle number.	III	40.4
dumpy	d_p	Wing shape.	II	14.0
ebony	e	Body color; associated with a crossover reducer for right end of III.	III	70.7
ebony^4	e^4	Body color.	III	70.7
eosin	w^e	Eye color.	I	1.5
eyeless^2	e_y^2	Eye size.	IV	0.0
forked	f	Bristle shape.	I	56.8
forked^5	f^5	"	I	56.8
Hairless	H	Bristle number.	III	69.5
hairy	h	Number of hairs.	III	26.5
Intensifier	I	Intensifies effect of M_g.	III	48±
Jammed	J	Wing shape.	II	41.0
Minute	M	See text.	III	101.0
Minute-e	M_e	"	II	46±
Minute-g	M_g	"	III	106.2
Minute-h	M_h	"	III	40.4
Minute-j	M_j	"	III	90±
Minute-l	M_l	"	II	99.5–101.5
Minute-n	M_n	"	I	62±
Minute-o	M_o	"	I	56±
Minute-p	M_p	"	II	53±
Minute-s	M_s	"	II	50±
Minute-w	M_w	"	III	79.8
Minute-y	M_y	Allelomorph of Minute-h	III	40.4
Minute-z	M_z	See text.	II	14.0
Minute-l′	$M_{l'}$	Allelomorph of Minute-l.	II	100±

TABLE 1—*Continued*

MUTANT	SYMBOL	CHIEF EFFECT	CHROMOSOME	LOCUS
Minute-28	M_{28}	See text.	II	Right limb
Minute-IV	M_{IV}	"	IV	0.0
Pale-III	P_{III}	Translocation for II from plexus to the end of II.	III	80±
purple	p_r	Eye color.	II	54.5
plexus	p_x	Wing venation.	II	100.5
rough	r_o	Eye texture.	III	91.1
rudimentary^{14}	r^{14}	Wing shape.	I	54.5
sepia	s_e	Eye color.	III	26.0
scarlet	s_t	"	III	44.0
shaven	s_h	Bristle number.	IV	0.0
sooty	e^s	Slighter ebony allelomorph.	III	70.7
speck	s_p	Pigment at base of wing.	II	107.0
stripe	s_r	Pigment in thorax.	III	62.0
Star.	S	Eye texture.	II	1.3
Stubble	S_b	Bristle shape.	III	58.2
white-ocelli	w_o	Color of ocelli.	III	76.2

THE PRIMARY REACTIONS OF THE MINUTES

A simple test may be devised to determine the relationship of one Minute to another. If two Minutes, at different loci in the chromosomes, represent the same kind of primary effect, then their combination should give the same effect as either homozygous single type. That is, if different Minutes are due to the same genic material, or primary gene product, a summation of their effects should be obtained in combination. Then the expectation from such an assumption would be a lethal effect; since all Minutes are lethal when homozygous.

This argument, however, implies that the lethal effect is due to the same reaction as the Minute effect; an assumption which is plausible, but not necessarily true. But even if no lethal effect is observed, and there is no correlation between it and the Minute character, still, the combination of two Minutes should be more extreme than its components. For if the mechanism producing the Minute were identical in the two cases, a more extreme Minute should be produced by two in combination.

Combinations of twelve different Minutes (table 2) with each other were made in such a way that the class containing both Minutes was separable, by means of other characters than the Minutes, from the single Minute classes. This is necessary, because the low viability of the Minutes makes it inadvisable to trust to ratios.

The technique for the combinations with Minute-l deserves special mention. Minute-l, as has been noted above, is a sectional deficiency in the second chromosome. BRIDGES has found (MORGAN, STURTEVANT and BRIDGES 1927) that its effects are neutralized by a corresponding duplication known as Pale-III (BRIDGES and MORGAN 1923) which is attached to the third chromosome. Accordingly, a balanced stock is kept of eosin, Curly/Minute-l, Stubble/Pale-III (the Curly and Stubble chromosomes carrying crossover reducers), in which all but the heterozygotes for the second and third chromosomes are lethal combinations. This stock was used to avoid the high partial sterility of Minute-l females; unfortunately the sterility seems to be independent of the other Minute characteristics in this case, since the duplication does not cover the deficiency completely. Although the females of this stock were not Minute and were much improved in viability they were still as sterile as the usual Minute-l females. In the notation in the tables, both Pale-III and eosin are ignored; Minute-l Pale-III is tabulated as wild type.

TABLE 2

Combinations of the Minutes with each other.

1. M and M_e. $SbM/l\,C_L C_R$ ♀ × M_e/C_y ♂.

Culture	C_y	$C_y S_b M$	M_e	$M_e S_b M$
504	94	71	72	65
593	50	31	56	26
Total	144	102	128	91

2. M and M_g. $S_b M/l\,CL\,CR$ ♀ × $s_t I e^s M_g/S_b s_r CIIIRMo$ ♂.

Culture	S_b	$I M_g$	$S_b I M_g M$
499	65	81	51
581	60	52	46
Total	125	133	97

3. M and M_h. $s_e M_h H/l\,CL\,CR$ ♀ × $s_e M/e^s w_o r_o$ ♂.

Culture	+	$s_e M_h H M$	$M_h H$	M
477	136	101	78	104
558	132	94	93	115
Total	268	195	171	219

$s_e M_h H/l\,CL\,CR$ ♀ × $S_b M/l\,CL\,CR$ ♂.

Culture	$S_b M$	$M_h H$	$S_b M_h H M$	Crossovers
562	90	98	86	1

4. M and M_j. $S_b M/l\,CL\,CR$ ♀ × $M_j/S_b s_r CIIIRMo$ ♂.

Culture	S_b	M_j	$S_b M M_j$
503	141	94	58

5. M and M_l. w^e/w^e M_l/C_y $PIII/S_b s_r CIIIRMo$ ♀ × $H M/S_b s_r CIIIRMo$ ♂.

Culture	$C_y S_b$	$C_y S_b H M$	$C_y H M$	S_b	$H M$	$Ml S_b H M$
500	21	24	15	22	5	8

6. M and M_p. M_p/C_y ♀ × $S_b M/l\,CL\,CR$ ♂.

Culture	C_y	$C_y S_b M$	M_p	$M_p S_b M$	Crossovers
462	39	50	32	48	0
572	51	37	40	31	1
587	42	41	39	36	0
Total	132	128	111	115	1

7. M and M_w. $S_b M/l\,CL\,CR$ ♀ × $H\,M_w/l\,CL\,CR$ ♂.

Culture	$H\,M_w$	$S_b M$	$S_b H\,M_w M$
406	15	12	17
560	17	12	20
605	89	81	85
606	88	80	70
Total	209	185	192

8. M and M_y. $S_b M/l\,CL\,CR$ ♀ × $M_y/S_b s_r\,CIIIRMo$ ♂.

Culture	S_b	$S_b M_y M$	M_y
498	43	22	26
583	68	46	61
584	19	25	21
Total	130	93	108

9. M and Mz, M and M_{28}. $C_y M_{28}/Mz\,b$ ♀ × $S_b M/l\,CL\,CR$ ♂.

Culture	Mz	$M_z S_b M$	$C_y M_{28}$	$C_y M_{28} S_b M$
458	64	48	65	61
459	75	46	41	52
460	60	60	53	57
Total	199	154	159	170

10. M and Ml'. Ml'/C_y ♀ × $S_b M/l\,CL\,CR$ ♂.

Culture	C_y	$C_y S_b M$	M_l'	$M_l' S_b M$
461	77	71	89	84
573	69	44	65	77
574	83	60	71	89
Total	229	175	225	250

11. M_e and M_h. $s_e M_h H/l\,CL\,CR$ ♀ × M_e/C_y ♂.

Culture	C_y	$C_y M_h H$	M_e	$M_e M_h H$
516	59	43	59	47
598	55	43	60	55
599	49	24	37	24
Total	163	110	156	126

12. M_e and M_j. M_e/C_y ♀ × $M_j/S_b s_r\,CIIIRMo$ ♂.

Culture	$C_y S_b$	$C_y M_j$	$M_e S_b$	$M_e M_j$
582	70	26	52	30

13. M_e and M_l. $w^e/w^e\ Ml/C_y\ PIII/S_b s_r\,CII_r RMo$ ♀ × M_e/C_y ♂.

Culture	C_y	$C_y S_b$	$C_y M_e S_b, C_y Ml\,S_b$	$C_y M_e$	M_e	$M_e M_l S_b$	C_y/C_y
520	13	7	16	2	7	2	1

14. M_e and M_p. M_p/C_y ♀ × M_e/C_y ♂.

Culture	$C_y M_e, C_y M_p$	$M_p M_e$	C_y/C_y
510	165	79	20
591	67	32	11
Total	232	111	31

15.* M_e and M_w. $H\,M_w/l\,C_L C_R$ ♀ × M_e/C_y ♂.

Culture	C_y	$C_y H M_w$	M_e	$M_e H M_w$
585	30	29	29	18

16. M_e and M_z. $M_z b/C_y$ ♀ × $M_e/b\,p_r\,c$ ♂.

Culture	C_y	$C_y M_e$	$M_z b$	$M_e M_z$
350	48	47	45	52
351	25	22	22	18
352	18	17	12	13
Total	91	86	79	83

17. M_e and M_{28}. $C_y M_{28}/+$ ♀ × M_e/C_y ♂.

Culture	C_y	M_e	$C_y M_{28} M_e$
509	57	50	49
602	61	47	28
603	38	42	32
Total	156	139	109

18. M_e and M_l' M_e/C_y ♀ × M_l'/C_y ♂.

Culture	$C_y M_l' C_y M_e$	$M_e M_l'$
522	61	15
523	75	43
Total	136	58

19. M_g and M_w. $H\,M_w/l\,C_L C_R$ ♀ × $s_t\,I\,e^s\,M_g/S_b\,s_r\,CIIIRMo$ ♂.

Culture	S_b	$S_b H M_w$	$I M_g$	$H M_w M_g$
505	108	70	87	86
597	98	49	77	63
Total	206	119	164	149

20. M_g and M_l'. M_l'/C_y ♀ × $s_t\,I\,e^s\,M_g/S_b\,s_r\,CIIIRMo$ ♂.

Culture	$C_y S_b$	$C_y I M_g$	$M_l' S_b$	$M_l' I Mg$
507	48	55	68	57
594	53	33	72	68
595	44	26	42	35
Total	145	114	182	160

21. M_g and M_z, M_g and M_{28}. $C_y M_{28}/M_z b$ ♀ × $s_t\,I\,e^s\,M_g/S_b\,s_r\,CIIIRMo$ ♂.

Culture	$C_y M_{28} S_b$	$C_y M_{28} I M_g$	$M_z S_b$	$M_z I M_g$
580	34	44	79	79

22. M_h and M_l. A. $s_e M_h H/l\,C_L C_R$ ♀ × $w^e M_l/C_y\,PIII/S_b\,s_r\,CIIIRMo$ ♂.

Culture	C_y	$C_y S_b$	$C_y S_b M_h H$	$C_y M_h H$	$M_h H$	+	$S_b M_l$	$S_b M_l M_h H$
452	42	51	40	24	26	35	32	46
453	25	21	25	14	12	26	9	21
454	59	54	63	30	42	67	39	57
Total	126	126	128	68	80	128	80	124

B. $D/M_h s_t e^s$ ♀ × $M_l/S\, CL\, CR$ ♂.

Culture	SD	DM_l	SM_h	$M_h M_l$
X1	42	33	37	37
X2	36	32	27	33
X3	11	11	17	9
X4	35	27	37	34
949	45	31	30	30
950	14	18	13	16
951	21	13	21	24
952	6	9	7	6
Total	210	174	189	189

C1. $C_y/M_l\ s_t e^s/s_t e^s$ ♀ × $M_h s_t e^s/e^s$ ♂.

Culture	$C_y e^s$	$C_y M_h s_t e^s$	$M_l e^s$	$M_l M_h s_t e^s$
947	41	24	13	22
956	23	22	12	7
958	18	8	6	1
959	16	10	2	9
960	17	14	10	14
963	11	17	11	14
964	17	19	16	6
965	12	16	5	8
Total	155	130	75	81

2. Reciprocal of 1.

942	8	6	5	4
943	2	5	3	2
944	10	2	2	8
945	10	10	4	3
946	9	4	7	6
954	6	18	14	5
955	9	6	7	16
957	4	3	1	2
961	6	4	5	1
962	6	6	7	3
Total	70	64	55	50

23. M_h and M_p. $s_e M_h H/l\, CL\, CR$ ♀ × M_p/C_y ♂.

Culture	C_y	$C_y M_h H$	M_p	$M_p M_h H$
449	35	18	29	15
450	102	70	91	82
555	70	51	62	34
Total	207	139	182	131

24. M_h and M_w. $s_e M_h H/l\, CL\, CR$ ♀ × $M_w/S_b s_r CIIIRMo$ ♂.

Culture	S_b	$M_h S_b H$	M_w	$M_h H M_w$	Crossovers
467	62	52	33	63	..
575	97	71	59	68	1
576	67	50	53	39	..
577	59	60	59	61	..
Total	285	233	204	231	1

25. M_h and M_z, M_h and M_{28}. $C_y\,M_{28}/M_z\,b$ ♀ × $s_e\,M_h\,H/l\,C_L\,C_R$ ♂.

Culture	M_z	$M_z\,M_h\,H$	$C_y\,M_{28}$	$C_y\,M_{28}\,M_h\,H$
456*	127	101	92	81
472	67	91	75	68
473	75	80	69	40
474	59	36	53	49
Total	328	308	289	238

* Also $2C_y$, 1 H triploids; 1 intersex—see p. 389 of text.

$C_y/M_z\,b$ ♀ × $s_e\,M_h\,H/l\,C_L\,C_R$ ♂.

Culture	C_y	$C_y\,M_h\,H$	M_z	$M_z\,M_h\,H$
348	40	41	28	45
347	9	11	10	7
Total	49	52	38	52

26. M_h and M_l'. $s_e\,M_h\,H/l\,C_L\,C_R$ ♀ × M_l'/C_y ♂.

Culture	C_y	$C_y\,M_h\,H$	M_l'	$M_l'\,M_h\,H$	Crossovers
478	89	61	85	77	1
561	92	84	110	98	1
566	137	131	178	143	..
Total	318	276	373	318	2

27. M_j and M_w. $H\,M_w/l\,C_L\,C_R$ ♀ × $M_j/S_b\,s_r\,CIIIRMo$ ♂.

Culture	S_b	$S_b\,H\,M_w$	M_j	$H\,M_w\,M_j$
506	105	110	94	72

28. M_l and M_w. w^e/w^e M_l/C_y $PIII/S_b\,s_r\,CIIIRMo$ ♀ × $H\,M_w/l\,C_L\,C_R$ ♂.

Culture	C_y	$C_y\,S_b$	$C_y\,H\,M_w$	$C_y\,H\,S_b\,M_w$	+	$H\,M_w$	$M_l\,S_b$	$M_l\,S_b\,H\,M_w$
466	18	15	6	15	15	10	12	17
487	8	6	1	5	5	3	6	9
Total	26	21	7	20	20	13	18	26

29. M_l and M_y. M_l/C_y $PIII/S_b\,s_r\,CIIIRMo$ ♀ × $M_y/S_b\,S_r\,CIIIRMo$ ♂.

Culture	$C_y\,S_b$	$C_y\,S_b\,M_y$	$C_y\,M_y$	S_b	M_y	$M_l\,S_b\,M_y$
515	4	4	2	6	5	9
517	7	6	..	3	1	2
Total	11	10	2	9	6	11

30. M_l and M_z, M_l and M_{28}. w^e/w^e M_l/C_y $PIII/S_b\,s_r\,CIIIRMo$ ♀ × $C_y\,M_{28}/M_z\,b$ ♂.

Culture	$C_y\,S_b\,M_z$, $C_y\,M_{28}\,M_l\,S_b$	$C_y\,M_z$, $C_y\,M_{28}$	M_z	$M_z\,M_l\,S_b$
475	47	22	21	5
485	52	35	25	15
Total	99	57	46	20

31. M_p and M_w. $H\,M_w/l\,C_L\,C_R$ ♀ × M_p/C_y ♂.

Culture	C_y	$C_y\,H\,M_w$	M_p	$M_p\,H\,M_w$
482	95	112	111	110
557	81	66	103	59
564	85	69	88	77
Total	261	247	302	246

32. M_p and M_y. M_p/C_y ♀ × $M_y/S_b\ s_r\ CIIIRMo$ ♂.

Culture	$C_y S_b$	$C_y M_y$	$M_p S_b$	$M_p M_y$	Crossovers
511	60	63	72	55	..
589	63	47	71	56	..
592	33	39	34	23	1
Total	156	149	177	134	1

33. M_p and M_z. $M_z b/C_y$ ♀ × M_p/C_y ♂

Culture	$C_y M_z, C_y M_p$	$M_z M_p$	C_y/C_y
413	97	58	4
414	134	54	6
415	136	68	5
Total	367	180	15

34. M_p and M_{28}, M_p and M_z. M_p/C_y ♀ × $C_y M_{28}/b\ p_r$ ♂.

Culture	C_y	$C_y M_{28} M_p$	M_p
451	70	66	53
513	80	76	80
Total	150	132	133

$C_y M_{28}/M_z b$ ♀ × M_p/C_y ♂.

Culture	$C_y M_z$	$M_p M_z$	$C_y M_{28} M_p$
578	58	70	69
579	47	50	61
484	46	64	73
Total	151	184	203

35. M_p and M_l'. M_l'/C_y ♀ × M_p/C_y ♂.

Culture	$C_y M_l', C_y M_p$	$M_p M_l'$	C_y/C_y
471	214	97	3
556	210	123	11
565	293	148	11
604	258	149	3
Total	975	517	28

36. M_w and M_z, M_w and M_{28}. $H\ M_w/l\ CL\ CR$ ♀ × $C_y M_{28}/M_z b$ ♂.

Culture	$C_y M_{28}$	M_z	$C_y M_{28} H\ M_w$	$M_z H\ M_w$
463	93	109	89	96
464	84	86	73	76
465	116	119	85	118
Total	293	314	247	290

37. M_w and M_l'. M_l'/C_y ♀ × $H\ M_w/l\ CL\ CR$ ♂.

Culture	C_y	$C_y H\ M_w$	M_l'	$M_l' H\ M_w$
483	101	93	103	102
559	154	137	155	161
563	84	53	76	68
Total	339	283	334	331

38. M_y and M_l'. M_l'/C_y ♀ × $M_y/S_b\ s_r\ CIIIRMo$ ♂.

Culture	$C_y S_b$	$M_l' S_b$	$C_y M_y$	$M_l' M_y$	Crossovers
514	134	139	123	148	..
590	85	108	49	69	1
Total	219	247	172	217	1

39. M_y and M_z, M_y and M_{28}. $C_y M_{28}/M_z b$ ♀ × $M_y/S_b s_r$ *CIIIRMo* ♂

Culture	$C_y M_{28} S_b$	$M_z S_b$	$C_y M_{28} M_y$	$M_z M_y$
519	56	70	60	70
588	23	35	29	30
Total	79	105	89	100

40. M_z and M_l'. M_l'/C_y ♀ × $M_z b/C_y$ ♂.

Culture	$C_y M_l'$, $C_y M_z$	$M_l' M_z$	C_y/C_y
342	143	90	..
343	209	104	3
344	120	57	10
Total	472	251	13

41. M_z and M_{28}. $M_z b/C_y$ ♀ × $C_y M_{28}/+$ ♂.

Culture	C_y	M_z	$C_y M_{28} M_z$
345	107	88	95
346	96	62	76
Total	203	150	171

42. M_z and M_l', M_l' and M_{28}. $C_y M_{28}/M_z b$ ♀ × M_l'/C_y ♂.

Culture	$C_y M_z$	$M_z M_l'$	$C_y M_{28} M_l'$
476	92	83	99

M_l'/C_y ♀ × $C_y M_{28}/+$ ♂.

Culture	C_y	M_l'	$C_y M_{28} M_l'$	Crossovers
508	145	94	87	1
600	71	58	62	2
601	70	68	61	..
Total	286	220	210	3

Not one of the forty-nine combinations of Minutes at different loci was lethal. Unpublished experiments of the same sort carried out by STERN, and to some extent by BRIDGES, afford the same answer for six additional combinations. Moreover, the double Minutes were indistinguishable from the single ones except by the mutants used as markers. No summation of effects was visible in their appearance. The combination appears no more extreme than its more extreme component.

These two facts provide evidence against identity of the primary reactions of Minutes. Neither in their lethal effect, nor in their somatic effects, do different Minutes reinforce each other. Since the combination of two different Minutes is no more extreme than its components, it must be assumed either that each Minute produces its effect differently, or that we are concerned with an all-or-none reaction. The latter hypothesis will be considered presently; let us first examine the other characteristics of the Minutes in the combinations, to see whether or not they exhibit a cumulative effect.

The Minutes are known to affect the viability of Drosophila to a considerable extent. Table 3 compares the viability of the two single Minutes and their combination, in all those combinations of table 2 in which a non-Minute class was present. The measure of viability used was the ratio of the Minute to the non-Minute class; thus, the three Minute classes are each compared with the same non-Minute class, and an approximately common measure, from cross to cross, is obtained. The non-Minute class in most cases was either Curly or Stubble, so this ratio does not actually represent a comparison of Minute and wild type; but the present purpose is served equally well, although the ratios are somewhat higher. It will be seen that in all but a few cases, the viability of the combination is intermediate between the viabilities of the two com-

TABLE 3

Viability of Minutes as ratios to non-Minute classes.

CROSS	SINGLE MINUTES				COMBINATION
1	M_a	.89	M	.71	.63
2	M	..	M_g	1.06	.78
3	M	.82	M_h	.64	.73
4	M	..	M_j	.66	.41
6	M	.97	M_p	.84	.87
8	M	..	M_y	.83	.72
10	M_l'	.98	M	.77	1.09
11	M_e	.96	M_h	.68	.77
12	M_e	.75	M_j	.37	.43
15	M_w	.97	M_e	.97	.60
16	M_e	.95	M_z	.87	.91
17	M_{28}	..	M_s	.89	.70
19	M_g	.79	M_w	.58	.72
20	M_l'	1.25	M_g	.79	1.10
22*a*	M_h	1.02	M_l	.63	.98
b	M_h	.90	M_l	.83	.90
c1	M_h	.84	M_l	.48	.52
c2	M_h	.91	M_l	.77	.72
23	M_p	.88	M_h	.67	.63
24	M_h	.82	M_w	.72	.81
25	M_h	1.06	M_z	.78	1.06
26	M_l'	1.17	M_h	.87	1.00
27	M_w	1.05	M_j	.90	.69
31	M_p	1.16	M_w	.91	.91
32	M_p	1.14	M_y	.95	.86
34	M_{28}	..	M_p	.89	.88
37	M_l'	.99	M_w	.84	.98
38	M_l'	1.13	M_y	.79	.99
41	M_{23}	..	M_z	.74	.84
42	M_{23}	..	M_l'	.77	.73

ponents. Considering the heterogeneity of the stocks used, probable errors are meaningless here, and accordingly have not been computed. But the result is significant as a first approximation, and accords with the absence of a cumulative effect in the appearance of the combinations. No summation of the viability effect is found.

Another measure of the effect might be found in the partial female sterility: since Minutes are frequently relatively female-sterile, a greater percentage of the females of combinations might be expected to be sterile than of the single Minute females. It will be noted that most of the crosses for combinations of Minute-28 and Minute-z involve the use of females which are combinations of both. No unusual sterility was noted. In fact, Minute-28 has been used to balance stocks of Minute-z and Minute-e. Here again no cumulative effect is observed.

We may consider the retardation of development caused by Minutes. A rough preliminary experiment indicated that the differences in this respect between Minute-h and Minute-l were appreciably large (table 4, A). Accordingly, stocks were synthesized which were made fairly homogeneous for modifying factors by continued crosses of the Curly, Minute-h and Minute-l stocks to a closely inbred stock of sooty (described by LI, 1927). At the end of nine generations the stocks were alike in their sex and fourth chromosomes, and in all of the third chromosome except a region of about fourteen units. The second chromosome was less uniform, and the Curly classes are least reliable, since the crossover reducers associated with Curly prevented the introduction of second chromosome sections from the sooty stock.

These stocks were unfortunately highly sterile; particularly so, it seemed, in the experimental crosses (table 2, cross 22B). Consequently, still another experiment was performed in which, although the stocks were not uniform, the modifiers present were different enough from those in the other experiments to constitute a check (table 2, cross 22 C).

Table 4 shows the time of development in days, of the different classes in these experiments. No great accuracy is claimed; but it is obvious that there is no summation of the effects of the two Minutes. Furthermore, the combination seems to develop, in the two more accurate experiments, more nearly at the rate of the more extreme component. This relationship should prove interesting in further experiments.

Parallel with the decrease in rate of development, the viability is lowered, except possibly in the case of Star Minute-h in experiment C. Such a relationship is perhaps to be expected; although other factors may be involved than those correlated with total time of development.

Thus, when we consider the grade of character development of the combinations, their viability, their degree of female-sterility and their rate of development, we find that two Minutes in combination do not reinforce one another. Corroboration of this is found even more strikingly in combinations of three Minutes (table 5); no summation is observed even here. As regards Minute characters the fly which carries three Minutes looks exactly like his single Minute brothers.

TABLE 4

Mean time of development of Minute-h, Minute-l, and of their combination.

Experiment A	$C_y S_b$	$C_y M_h S_b H$	$M_l M_h S_b H$	$S_b M_l$
Days	3.9±.3	4.5±.2	5.0±.2	6.6±.2
Viability	..	1.02	.98	.63
Experiment B	$S D$	$S M_h$	$M_l M_h$	$D M_l$
Days	4.8±.1	6.0±.1	5.8±.1	5.7±.1
Viability	..	.90	.90	.83
Experiment C	$C_y e^s$	$C_y M_h s_t e^s$	$M_l M_h s_t e^s$	$M_l e^s$
Days 1)	3.0±.0	5.0±.1	4.8±.1	4.8±.1
2)	3.3±.1	4.0±.2	4.8±.2	4.8±.2
Viability 1)	..	.84	.52	.48
2)	..	.91	.72	.77

TABLE 5

Combinations of three Minutes.

A. M, M_h and M_{28}. $S_b M/l\,CL\,CR$ ♀ × $C_y M/+\ s_e M_h H/+$ ♂.

Culture	+	$C_y M_{28}$	$M_h H$	$S_b M$	$C_y M_{28} S_b M$	$C_y M_{28} M_h H$	$M_h S_b H M$	$C_y M_{28} M_h S_b H M$
531	27	19	24	14	9	19	15	21
547	52	44	60	38	36	41	61	43
550	12	8	10	15	13	5	9	3
551	43	42	44	45	41	34	51	34
552	81	54	50	56	49	41	46	39
Total	215	167	188	168	148	140	182	140

B. M_h, M_w and M_{28}. $M_w/S_b s_r\,CIIIRMo$ ♀ × $C_y M_{28}/+\ S_e M_h H/+$ ♂.

Culture	S_b	$C_y M_{28} S_b$	$M_h H S_b$	M_w	$C_y M_{28} M_h H S_b$	$C_y M_{28} M_w$	$M_h H M_w$	$C_y M_{28} M_h H M_w$
562	20	0	25	9	17	14	23	16
553	28	12	16	19	21	10	20	14
Total	48	22	41	28	38	24	43	30

There are cases known (Minute-dII and Minute-dIII, and the intensifier of Minute-g) in which two genes interact to produce a Minute. But we may leave these in a different category for the present, since they are obviously special cases.

These experiments, then, exclude the hypothesis that the Minutes are caused by the same simple primary reaction; for such an hypothesis to be tenable, their effect in combination must be cumulative. But if the assumption is added that the Minute-producing reaction is of the all-or-none type, then it is possible that once over the necessary threshold, no further action is possible, and thus no summation effect is observed. On this hypothesis the lethal effect in homozygous condition is due to a different reaction than is the Minute effect. The differences between Minutes might be due to the time when the threshold is passed, thus to the duration of the reaction; and the tendency of the combination to approach the characteristics of its more extreme component would fit quite neatly with these assumptions.

We may test this as follows: there exist duplications covering certain Minutes which are deficiencies. Among these are Triplo-IV, which covers the deficiency Minute-IV, and is, of course, a duplication with respect to the deficiency Haplo-IV; and Pale-III, which has been mentioned above as a suppressor of Minute-l. Now if the Minutes are caused by an all-or-none reaction of the sort postulated above, these duplications, which suppress two of the most extreme Minutes, should suppress Minutes at other loci. Table 6 gives combinations of Triplo-IV with seven Minutes. The balanced stock of Triplo-IV (MORGAN, STURTEVANT and BRIDGES 1926) in which the three fourth chromosomes contain Minute-IV, shaven, and shaven, was used; consequently half the Triplo-IV flies produced in the experiment were without Minute-IV but might carry the other Minute. In no case were the introduced Minutes suppressed by Triplo-IV. The same relation is obvious in the combinations of Minutes with Pale-III (given in table 2, crosses 5, 13, 22, 28, 29, and 30). These are the experiments involving combinations of Minute-l referred to above. The Curly not-Stubble classes of these crosses contain the Pale-III duplication, and do not contain Minute-l.

In neither of these experiments was any suppression of the introduced Minute to be seen. The combination of a Minute and Triplo-IV, or of a Minute and Pale-III, was merely a superposition of the Minute features upon the characters of the duplication. Even the least extreme Minutes tested—Minute-p and Minute-e, for example—which under any quantitative scheme should certainly be suppressed by these suppressors of the more extreme Minutes, showed no signs of suppression.

We may conclude, then, that on the basis of this evidence, the all-or-none hypothesis postulated is untenable. But we may further test this, to make the proof more rigorous.

The presence of an additional normal allelomorph suppresses a Minute when the rest of the chromosome system is simple diploid. This we have seen to be true in the case of Triplo-IV and Pale-III (also MORGAN, STURTEVANT and BRIDGES 1926, 1927). This suppression is also found in triploid Drosophilas.

It was found by BRIDGES (unpublished data) that some apparently normal triploid females regularly produce Minute diploid offspring.

TABLE 6

Combinations of Triplo-IV and Minutes.

1. $M.\ 3IV$ ♀ × $S_b M/l\,CL\,CR$ ♂.

Culture	$+, 3IV$	$S_b M, S_b M\,MIV, S_b M\,3IV$	MIV
661	16	19	10

2. $M_h.\ 3IV$ ♀ × $s_e M_h H/l\,CL\,CR$ ♂.

Culture	$+, 3IV$	$M_h H, M_h H\,3IV$	MIV
655	89	95	41

3. $M_p.\ 3IV$ ♀ × M_p/C_y ♂.

Culture	$C_y, C_y\,3IV$	$M_p, M_p\,3IV$	$C_y\,MIV$
662	94	144	36

4. $M_l'.\ 3IV$ ♀ × C_y/M_l' ♂.

Culture	$C_y, C_y\,3IV$	$M_l', M_l'\,3IV$	$C_y\,MIV$
660	112	135	47

5. $M_w.\ H\,M_w/l\,CL\,CR$ ♀ × $3IV$ ♂ (and reciprocal cross).

Culture	$+, 3IV$	$H\,M_w$	MIV
665	97	128	20
666	86	126	23
Total	183	254	43

6. $M_z.\ 3IV$ ♀ × $M_z b/C_y$ ♂.

Culture	$C_y, C_y\,3IV$	$M_z, MIV, M_z\,MIV, M_z\,3IV$	$C_y\,MIV$
663	70	57	15
664	79	88	20
Total	149	145	35

7. $M_{28}.\ 3IV$ ♀ × $C_y M_{28}/CIIL\,b\,p_r$ ♂.

Culture	$+, 3IV$	$C_y M_{28}, C_y M_{28}\,MIV, C_y M_{28}\,3IV$	MIV
683	28	37	14

This indicated that a single dose of a Minute was recessive to two normal allelomorphs in the triploid parent. REDFIELD found this to be true also for Minute and Minute-h, in the course of crossing over studies in triploids.

This relationship in triploids presents us with the opportunity of making the experiment converse to that involving the use of suppressors. For, if the same all-or-none reaction is concerned in all Minutes, two different Minutes should reinforce each other in triploids. Since each is recessive by itself—that is to say, cannot in triploids reach the threshold of our postulated all-or-none reaction—and if it is the same reaction concerned for each one of the Minutes, they should interact to produce a Minute triploid.

Before considering this experiment we may examine certain preliminary experiments which should be performed to make the argument valid. In the first place, how general is the recessive condition for Minutes in triploids? To answer this, experiments were performed in such a way that triploids and intersexes containing the Minute were separable by other mutants from the non-Minute classes. Curly in the second chromosome, and Dichaete, Hairless and Stubble in the third, were useful since they are themselves dominants distinguishable in triploids. In all cases except in certain crosses involving Minute-w, the Minutes tested were completely recessive in classes containing two normal allelomorphs and one Minute. Such triploids, intersexes and supermales appeared normal (table 7). Furthermore, when such normal appearing triploids were tested, they yielded Minutes.

TABLE 7

Minutes which are recessive in single dose in triploids and intersexes.

A. M. 3N ♀ × $S_b M/l C_L C_R$ ♂.

	3N		Intersexes		Supermales		2N	
Culture	S_b	+	S_b	+	S_b	+	$S_b M$	+
C7	4	1	3	9	1	..	12	12
C8	3	1	5	7	..	1	4	10
C24	..	1	6	3	..	..	6	16
C25	..	1	5	3	..	..	3	7
C26	..	3	7	7	..	..	11	20
Total	7	7	26	29	1	1	36	65

B. M_h (and see table 10). $s_e h/s_e h/s_e h$ ♀ × $h M_h s_t/l C_L$ ♂.

	3N		Intersexes		Supermales		2N	
Culture	h	+	h	+	h	+	$h M_h$	+
C105	1	1	4	4	..	..	4	12
251	1	1	13	9	..	..	20	21
253	1	..	10	13	..	..	24	23
254	3	..	15	17	..	1	27	37
264	1	1	1	9	..	..	14	15
Total	7	3	43	52	..	1	89	108

C. M_l. 3N ♀ × w^e M_l/C_y ♂.

	3N		Intersexes		Supermales		2N	
Culture	C_y	+	C_y	+	C_y	+	C_y	M_l
99	7	4	21	15	..	1	56	46

D. M_s. 3N ♀ × M_s/C_y ♂.

	3N		Intersexes		Supermales		2N	
Culture	C_y	+	C_y	+	C_y	+	C_y	M_s
C122	4	4	9	20	4	..	35	18

E. M_z 3N ♀ × $M_z b/C_y$ ♂.

	3N		Intersexes		Supermales		2N	
Culture	C_y	+	C_y	+	C_y	+	C_y	M_z
59	2	1	6	6	..	..	9	11

F. M_l'. 3N ♀ × M_l'/C_y ♂.

	3N		Intersexes		Supermales		2N	
Culture	C_y	+	C_y	+	C_y	+	C_y	M_l'
82	4	5	6	10	2	2	21	10
83	5	6	9	7	1	..	19	18
C114	1	2	8	11	..	1	31	35
Total	10	13	23	28	3	3	71	63

G. M_{28}. 3N ♀ × $C_y M_{28}/+$ ♂.

	3N		Intersexes		Supermales		2N	
Culture	C_y	+	C_y	+	C_y	+	$C_y M_{28}$	+
C117	3	3	9	10	..	1	33	34

In certain crosses, in the presence of a section of the third chromosome close to Minute-w, this Minute behaved as a semi-dominant (table 8). The bristles were slightly shorter, the wings blunt, and in general the Minute characters were partially manifested. In other crosses, involving Minute-w in a different background chromosome, this semi-dominance was not exhibited. STERN (unpublished data) has observed a similar recessive effect in his cultures of Minute-w in triploids.

It should be noted that wild type triploids occasionally manifest characters like those mentioned above: short bristles, blunt, brittle-textured wings which are of a brownish color, reduced aristae and an intensified trident pattern. Accordingly, the semi-dominance of Minute-w in the crosses just discussed may not be due to this Minute but to a modifier which also affects normal triploids. But these modified wild-type triploids are not completely 3N, but contain only two fourth chromosomes, due, presumably, to a process of non-disjunction. The evidence for this is various. For example, mitotic figures of triploids frequently show only two fourth chromosomes (BRIDGES, unpublished). Moreover, according to data of BRIDGES, few eyeless triploids or eyeless intersexes survive—a result which is easily interpreted as "exaggeration" of eyeless due to a deficiency of the fourth chromosome. The occasional slight appearance of Minute-like characters in triploids is to be explained in the same way, as due to a loss of a fourth chromosome which thus produces effects approaching those seen in Haplo-IV. Finally, BRIDGES finds that on crossing triploids to Triplo-IV males for several generations, until the triploids again have three fourth chromosomes, these Haplo-IV characteristics are no longer to be found.

TABLE 8

The dominance of a single dose of M_w *in triploids.*

A. 3N ♀ × $e^s M_w/S_b s_r CIIIRMo$ ♂.

	3N		Intersexes		Supermales		2N	
Culture	S_b	M_w	S_b	M_w	S_b	M_w	S_b	M_w
C52	2	1	3	1	..	..	12	15

B. 3N ♀ × $D e^s M_w/l\, CL\, CR$ ♂.

	3N		Intersexes		Supermales		2N	
Culture	$D M_w$	+	$D M_w$	+	$D M_w$	+	$D M_w$	+
C60	2	6	6	12	..	1	12	31
C62	..	2	3	6	1	2	5	14
C63	4	1	1	7	..	1	8	36
C115	4	5	6	13	2	4	13	36
C119	2	2	18	23	2	3	19	41
Total	12	16	34	61	5	11	57	158

C. 3N ♀ × $H M_w/CIII\, lIIIa$ ♂.

	3N		Intersexes		Supermales		2N	
Culture	$H M_w$	+	$H M_w$	+	$H M_w$	+	$H M_w$	+
C118	3	4	10	9	..	..	26	27
C121	1	2	7	16	1	14	17	24
675	2	1	4	11	..	..	14	14
Total	6	7	21	36	1	14	57	65

It should be noted immediately that the apparent partial dominance of "Haplo-IV" provides a difficulty for the all-or-none hypothesis from another angle. One might still, however, postulate different thresholds in triploids, and one might do so with some plausibility.

We may examine this question by considering the effect of two doses of a single Minute in triploids. By so doing, we create a legitimate measure of the threshold in the triploid system itself.

It is known that triploids with only one fourth chromosome die (unpublished data of BRIDGES). This lethal effect is due to the Minute portion of the fourth chromosome, as is evidenced by the following experiment. We may assume that Minute-IV, a deficiency for rotated abdomen in the fourth chromosome, represents the Minute portion of Haplo-IV. If wild-type triploids, containing two fourth chromosomes, are crossed to Minute-IV males, half of their progeny will contain Minute-IV. The triploids and intersexes among this progeny will then contain only a single normal allelomorph of the fourth chromosome Minute, and according to the results of BRIDGES, should die; or they might conceivably be Minute, if the extent of the deficiency had an influence on the lethal effect in the crosses of triploids to Haplo-IV. Table 9A shows the results of such an experiment. No Minute triploids or intersexes appeared; and on being tested, the wild type triploids gave no Minute offspring (table 9B). This indicates that diplo-IV triploids containing Minute-IV

TABLE 9

A. Crosses of Minute-IV males to normal triploids. 3N ♀ × MIV ♂.

CULTURE	3N *MIV*	3N +	INTERSEXES *MIV*	INTERSEXES +	2N + ♀	2N +♂	2N *MIV* ♀	2N *MIV* ♂
925	..	3	..	5	17	2	6	..
926	..	..	..	2	4	..	10	..
927	..	..	..	..	4	..	7	1
928	..	..	..	2	12	3	5	..
929	..	..	..	7	11	2	13	2
970	..	1	..	4	12	2	4	1
971	..	..	..	1	8	1	4	..
972	..	5	..	7	25	2	19	4
Total	..	9	..	28	93	12	68	8

B. Crosses of triploids from A to wild-type males.

CULTURE	3N	INTERSEXES	SUPERSEXES ♀	SUPERSEXES ♂	2N ♀	2N ♂
934	2	10	..	..	30	2
935	4	12	..	..	32	8
937	2	8	..	..	25	4
938	4	22	..	..	31	3
976	8	34	..	..	68	6
977	6	23	..	1	33	3
978	3	14	..	1	48	4
979	4	20	..	..	43	3
Total	33	143	..	2	310	33

C. Ratio of intersexes to females, and of triploids to males, in A and B.

	INTERSEXES/FEMALES	TRIPLOIDS/MALES
A	.18	.45
B	.46	1.00
A/B	.39	.45

do not survive. Moreover, the ratio between intersexes and females, and between males and triploid females (classes which, except for their viability, should be equal) was in the crosses to Minute-IV only half of what it was in the tested triploid daughters (table 9C), which establishes the fact that diplo-IV triploids and diplo-IV intersexes containing Minute-IV do not survive. The responsibility for the lethal effect of the absence of two fourth chromosomes in triploids is definitely placed with the section producing the Minute character.

We may consider the lethal threshold of Minutes in the autosomes other than the fourth. This will be the more convincing, the more viable the Minute that is used; accordingly, we shall consider the case of Minute-h, one of the less extreme Minutes. The primary consideration being the easy identification of the double Minute individuals by other characters than those resulting from the Minute, two stocks were prepared, in which Minute-h was associated with different markers. These stocks were sepia Minute-h Hairless/l *CL CR*, and hairy Minute-h scarlet/l *CL*. Males of the latter stock were crossed to sepia hairy triploids. The hairy not-Minute individuals in the offspring were triploids or intersexes containing Minute-h. Such triploids were mated to sepia Minute-h Hairless/l *CL CR* males; their Hairless triploid and intersex progeny should be the double Minute class sought, barring the negligible class due to crossing over between sepia and hairy, and between these loci and Minute-h. In these cultures (table 10) only one Hairless intersex appeared; it was quite normal, and undoubtedly represented a crossover.

TABLE 10

The death of $M_h/M_h/+$ *triploids and intersexes.* $h\ M_h\ s_t/s_e\ h/s_e\ h$ ♀ × $s_e\ M_h\ H/l\ CL\ CR$ ♂.

	3N			INTERSEXES			SUPERMALES			2N			
CULTURE	*H*	s_eH	+	*H*	s_eH	+	*H*	s_eH	+	s_eM_hH	M_h	+	M_hH
C106	..	..	..	..	1	8	..	1	3	8	7	6	1
292	..	1	4	..	3	24	..	..	2	17	12	14	..
296	..	1	1	1	11	24	..	..	..	28	10	26	..
306	..	..	..	..	3	14	..	..	..	12	7	12	..
310	..	..	2	..	7	16	..	..	1	19	13	26	..
334	..	1	..	..	1	1	..	..	..	1	2	6	..
Total	..	3	7	1	26	87	..	1	6	85	51	90	1

Thus, we may consider it established that the lethal threshold for Minute-h is passed with two doses of the Minute in triploids. The same point was determined as follows for Minute-w. Hairless triploids, containing Minute-w in the Hairless chromosome, were obtained and mated to Minute-w/Stubble males. Those triploids and intersexes containing two doses of the Minute should be Hairless: no such individuals were found (table 11). Moreover, in this cross Minute-w was completely recessive. The numbers are regretably low, but they are sufficient to prove the point that for Minute-w also a double dose is lethal in triploids.

TABLE 11

The death of $M_w/M_w/+$ *triploids and intersexes.* $H\ M_w/+/+$ ♀ $\times M_w/S_b\ s_r\ CIIIRMo$ ♂.

	3N			INTERSEXES			2N				
CULTURE	S_b	+	$S_b H$	S_b	+	$S_b H$	S_b	M_w	$S_b H M_w$	$S_b H$	$H M_w$
703	1	2	..	11	7	6	28	22	7	3	1
723	1	..	1	5	4	7	18	17	5	..	..
Total	2	2	1	16	11	13	46	39	12	3	1

The facts are then as follows: two doses of a Minute are lethal in a triploid, one dose is recessive, and the triploids we have used contain only two fourth chromosomes. Since this is the case, the combination of two different Minutes in a triploid should provide decisive evidence as regards the all-or-none hypothesis. For each of the two Minutes is lethal by itself in double dose, and therefore we should expect, if their action were the same, that the combined effects of single doses of each should pass at least the Minute threshold.

It may be noted that the very fact that the Minutes are recessive in triploids with two fourth chromosomes is itself evidence of this kind. For we have already shown that the absence of the portion of the fourth chromosome correlated with the Minute effect is also correlated with the lethal effect of only one fourth chromosome. And hence, in a triploid containing a Minute and only two fourth chromosomes, we are truly dealing with a combination of Minutes. We may go further, however, and consider combinations of Minutes in triploids—a situation which amounts to combinations of three Minutes.

For Minute-w and Minute-h, the technique was similar to that employed in testing for the lethal effect. Normal triploids were crossed to sepia Minute-h Hairless males. The Hairless triploids in their progeny were mated to Minute-w/Stubble males. These should give triploids and intersexes which are Hairless not-Stubble and contain both Minutes. The Hairless not-Stubble classes did not show Minute characteristics and came through as well as any of the other classes, being completely viable (table 12). The result is an especially striking one because these double Minute classes showed the same phenotypes of check characters as the classes which were expected but did not appear in the test for the lethal effect of two doses of Minute-w. In that case the Hairless class with two doses of the same Minute was missing in the triploids and intersexes, and in this case, where two different Minutes are involved, the Hairless class survives and appears normal. No cumulative effect whatsoever is seen.

TABLE 12

The combination of M_h and M_w in triploids. $s_e M_h H/l$ CL CR/+ ♀ × $M_w/S_b s_r$ CIIIRMo ♂.

	3N				INTERSEXES				2N					
CULTURE	S_b	H	$S_b H$	+	S_b	H	$S_b H$	+	$M_h H M_w$	M_w	S_b	$M_h S_b H$	$S_b H$	$M_h S_b$
700	1	..	..	..	1	4	6	4	11	8	7	..	3	3
706	..	..	1	..	2	5	2	5	5	13	15	6	3	3
796	..	..	..	..	3	5	4	..	4	7	12	5	..	1
797	1	..	..	..	1	4	3	2	5	6	7	3	2	..
814	1	2	2	1	6	13	11	2	12	16	8	6	2	2
852	..	3	1	..	2	6	5	1	9	9	10	4	2	2
Total	3	5	4	1	15	37	31	14	46	59	59	24	12	11

Similar evidence was obtained in combinations of Minute and Minute-h. These were obtained by crossing sepia Minute-h Hairless/sepia hairy/sepia hairy triploids to sepia Minute/ebony white-ocelli rough males. The sepia Hairless triploids and intersexes in their progeny should be the combination desired, excepting rare crossovers. In the two cultures raised, no such triploids were obtained; but intersexes of the specified composition had normal bristles, and showed no signs of being Minute.

Likewise, Minute-h and Minute-28 do not reinforce each other in combination in triploids. This was seen as the result of a new occurrence of triploidy in one of the cultures (456) of the experiment designed to produce the combination of these two Minutes in the diploid condition (table 2, cross 25). Curly Hairless individuals were found which were not Minute, although they should have been so by virtue of the linkage of Minute-28 to Curly, and of Minute-h to Hairless. These individuals proved to be triploids containing both Minutes. Since they represented a new occurrence of triploidy, they probably had three fourth chromosomes, and so were really a combination of only two Minutes. The case is incidentally interesting as a matter of technique; for it is obvious that by the appropriate use of Minutes, triploidy may be detected very easily whenever it occurs.

We may consider one other combination—that of Minute and Minute-s. In this case, normal triploids were crossed to Stubble Minute/1 *Cl Cr* males, and the Stubble triploids among their progeny were mated to Minute-s/Curly males. The Stubble triploids and intersexes resulting should be the combination desired, except for a few crossovers between Stubble and Minute. None of these appeared Minute; and one of them, when tested, showed that Minute was still linked to Stubble.

TABLE 13

The non-cumulative effect of M and Ms in triploids and intersexes. $S_b\ M/+/+$ ♀ × M_s/C_y ♂.

	3N				INTERSEXES				SUPERMALES				2N					
CULTURE	S_b	C_yS_b	+	C_y	S_b	C_yS_b	+	C_y	S_b	C_yS_b	+	C_y	M_sS_bM	C_yS_bM	M_s	C_yM	C_y	C_yS_b
C30	5	3	..	..	10	8	6	4	..	..	3	..	7	7	10	..	22	1
C31	2	1	1	..	5	2	2	1	..	..	..	..	2	5	2	1	5	3
C33	..	..	3	..	3	..	6	..	1	..	..	..	3	8	16	4	9	2
C34	1	..	1	..	7	3	5	1	..	..	..	..	2	2	7	1	15	3
C40	3	2	..	..	6	6	6	3	..	..	..	1	9	5	11	3	10	1
Total	11	6	5	..	31	19	25	9	1	..	3	1	23	27	46	9	61	10

All of the facts, then, militate against the identity of the primary reaction producing the Minute character in different Minutes. The excess normal allelomorph of one Minute will not suppress any other; nor will two Minutes combine together in triploids to produce the Minute character, when one is insufficient to do so. This means that the primary reactions must be different; and not only quantitatively but qualitatively. For if the differences were quantitative, one might expect the suppressor of a given Minute to be effective with all those which are less extreme than the one in question. This is not so: for the two duplications tested suppress two of the most extreme Minutes known—Minute-l and Haplo-IV—and in no case were they effective with other less extreme Minutes. Moreover, these experiments rule out completely the hypothesis that the same all-or-none reaction is at work in different Minutes.

It should be pointed out here that superficially the Minutes offer a tempting field for quantitative explanation of the type employed by GOLDSCHMIDT (1927); but, as we have seen, such an explanation is untenable in application to the primary reactions producing Minutes.

GENETIC MODIFIERS OF MINUTES

We are confronted here by a situation in which many *different* primary reactions produce a *closely similar* secondary effect. But we may analyze this similarity. If we consider the modifiers of the Minutes, and we observe whether or not all Minutes react in a similar way to a given modifier, we may trace this similarity further back in development. For it is a plausible assumption, that if two mutants give the same interaction with a given factor, either genetic or environmental, there is a similar stage in their development. On the basis of this assumption we shall proceed to analyze the reactions of the Minutes with certain genetic modifiers.

Delta and its allelomorphs

In general the Minutes differ from each other in their behavior with modifiers only as regards the degree of the reaction. Qualitatively, the combinations of Minutes with other mutant characters are very similar to each other. That is, in spite of the differences in the primary causes of Minutes, their subsequent behavior in development must be very similar; so much so that superficially they present the characteristics of a system of multiple allelomorphs.

The best evidence for this is derived from the experiments with the mutants at the Delta locus (BRIDGES and MORGAN 1923, figure 29, p. 197). These are quite different in appearance from the Minutes. They affect the same parts of the body as the Minutes, but in quite a different way—almost in the opposite direction. In Delta the eyes are small and quite rough, the bristles are stout, sometimes duplicated, and there are extra hairs on the thorax. The legs are short and thick, and the sex comb in the male is large. In addition, the body color is quite dark; but the most striking effect is presented by the wings. These are sometimes spread, with thick veins frayed out to deltas at the wing margin, and are of a granular texture.

The same effects are present, but to a less degree, in the slighter allelomorphs Delta^3 and Delta.^{4} There is one distinct difference between these and Delta: in both Delta^3 and Delta^4 there occurs a thickening at the crossveins. This is particularly striking in Delta,^{4} which does not exhibit the deltas at the wing margin. It will be noted that these effects are, as stated above, superficially opposite in sign to those of the Minutes. One might, then, reasonably expect to find that Delta and Minute neutralize each other in combination, in the same way as Delta and Hairless do

(BRIDGES, 1922). The combination of Delta and certain Minutes, however, proves almost entirely lethal.

In these experiments, usually Delta/Stubble stripe *CIIIRMO* females were mated to Minute males. In their progeny, all of the not-Stubble individuals are Delta, with the exception of a very few crossovers in the presence of heterozygous *CIIIRMO*. Half of these Delta flies should be Minute. These Delta Minutes constitute the missing class in the cultures presented in table 14. There are a few survivors which will be discussed later.

TABLE 14

Minutes which are lethal with Delta.

A. M_w. 1. $\Delta/CIII\,lIIIa$ ♀ × $M_w/S_b\,s_r\,CIIIRMo$ ♂.

Culture	$\Delta\ S_b$	S_b	M_w	$\Delta\ M_w$
272	69	87	28	..
280	89	78	59	..
Total	158	165	87	..

2. $\Delta/S_b\,s_r\,CIIIRMo$ ♀ × $M_w/e\,CIII$ ♂.

Culture	Δ	S_b	$S_b\,M_w$	$\Delta\ M_w$	Crossovers
B3	100	111	70	..	..
379	44	52	21	..	2
380	24	26	17	..	2
381	31	26	30	..	1
Total	199	215	138	..	5

3. $M_w/e\,CIII$ ♀ × $\Delta/S_b\,s_r\,CIIIRMo$ ♂.

Culture	Δ	S_b	$S_b\,M_w$	$\Delta\ M_w$
B2	76	71	48	..

4. $M_w/e\,CIII$ ♀ × $\Delta/CIII\ lIIIa$ ♂.

Culture	Δ	+	M_w	$\Delta\ M_w$
69	66	41	15	..

B. M_h. 1. $M_h/l\,CL$ ♀ × $\Delta/S_b\,s_r\,CIIIRMo$ ♂.

Culture	Δ	S_b	$S_b\ M_h$	$M_h\ \Delta$
B14	63	56	64	..
B15	58	54	54	..
B18	12	18	17	1
Total	133	128	135	1

TABLE 14—*Continued*

2. $\Delta/S_b s_r CIIIRMo$ ♀ $\times h M_h s_t/l CL$ ♂.

Culture	Δ	S_b	$M_h S_b$	$M_h\Delta$	Crossovers
395	68	58	54	10	1
396	54	52	44	..	..
397	19	13	25	3	1
Total	141	123	123	13	2

C. M_y (M_y is an allelomorph of M_h). 1. $\Delta/S_b s_r CIIIRMo$ ♀ $\times M_y/l CL$ ♂.

Culture	Δ	S_b	$M_y S_b$	$M_y \Delta$	Crossovers
361	21	23	20	..	..
363	95	84	47	..	4
364	58	59	42	..	..
Total	174	166	109	..	4

D. M. 1. $\Delta/S_b s_r CIIIRMo$ ♀ $\times s_e M/e^A w_o r_o$ ♂.

Culture	Δ	S_b	$S_b M$	ΔM	Crossovers
386	12	5	3	..	..
387	12	20	17	..	3
388	54	50	55	..	3
389	27	28	42	2	..
Total	105	103	117	2	6

E. M_j. 1. $\Delta/S_b s_r CIIIRMo$ ♀ $\times M_i/e^s r_o c_a$ ♂.

Culture	Δ	S_b	$M_j S_b$	ΔM_j	Crossovers
B6	39	33	36	..	13
369	82	56	36	..	4
538	107	104	74	..	2
543	92	94	44	..	..
544	86	57	15	..	..
Total	406	344	205	..	19

F. M_l. 1. $\Delta/S_b s_r CIIIRMo$ ♀ $\times M_l/b_w s_p$ ♂.

Culture	Δ	S_b	$M_l S_b$	$M_l \Delta$	Crossovers
402	34	48	34	..	..
403	65	60	40	..	..
527	29	47	22	..	..
533	87	109	93	..	..
534	76	73	50	..	1
Total	291	337	239	..	1

TABLE 14—*Continued*

G. M_s. 1. $\Delta/S_b s_r CIIIRMo$ ♀ × M_s/C_y ♂.

Culture	$C_y \Delta$	$C_y S_b$	$M_s S_b$	$M_s \Delta$
B26	64	65	70	2

H. M_s. 1. $\Delta/S_b s_r CIIIRMo$ ♀ × $M_z b/C_y$ ♂. (Culture 374 was the reciprocal.)

Culture	$C_y \Delta$	$C_y S_b$	$M_s S_b$	$M_s \Delta$	Crossovers
374	20	14	26	..	..
375	50	44	47	3	2
376	86	65	83	1	3
377	12	9	14	..	..
Total	168	132	170	4	5

I. M_{28}. 1. $\Delta/S_b s_r CIIIRMo$ ♀ × $C_y M_{28}/+$ ♂.

Culture	Δ	S_b	$C_y M_{28} S_b$	$C_y M_{28} \Delta$	Crossovers
391	32	35	34	..	..
392	70	57	39	..	5
393	30	36	43	..	..
394	95	73	61	..	..
Total	227	201	177	..	5

J. M_o. 1. $M_o f/r^{14}$ ♀ × $\Delta/S_b s_r CIIIRMo$ ♂.

			♀		♂
Culture	Δ	S_b	$S_b M_o$	$M_o \Delta$	Non-M_o
409	45	61	74	1	79
410	7	13	6	..	6
411	7	8	8	..	10
412	6	7	8	..	6
541	12	14	15	2	22
542	51	48	41	16	62
Total	128	151	152	19	185

K. M_n. M_n/f^5 ♀ × $\Delta/S_b s_r CIIIRMo$ ♂.

			♀		♂
Culture	Δ	S_b	$S_b M_n$	$M_n \Delta$	Non-M_n
405	40	44	25	3	73
406	30	23	22	2	31
407	13	16	14	2	31
408	30	32	36	2	69
Total	113	115	97	9	204

This effect is known to be due to Delta, and not to some dominant modifier of either character, since different stocks of both Delta and Minute were used in the cases of Minute-w and of Minute-h. Furthermore, reciprocal crosses were made in some instances (table 14, A and B), and the same result was obtained; a maternally inherited effect is, therefore, not responsible.

Not all Minutes are lethal with Delta, however; those which are known to be least extreme in other crosses, as regards the usual characters of Minutes, survive in combination with Delta (table 15). This makes it probable that the difference between the two groups is a difference between the Minutes, and not simply a difference in modifying factors. Moreover, another stock of Minute-IV was used, besides that recorded in table 15, and the same non-lethal result was obtained (table 22B).

The Delta-Minute Combination

For most combinations, the missing Delta Minute class was found dead in pupa cases on the paper of the culture medium. When these pupae were dissected, fully formed imagoes were discovered, which exhibited many abnormalities, all of which were extreme cases of the effects of Delta or of Minute. Some flies that were not too badly distorted were able to emerge. Such a one, typical of many observed, is the Delta Minute-z individual of figure 2.

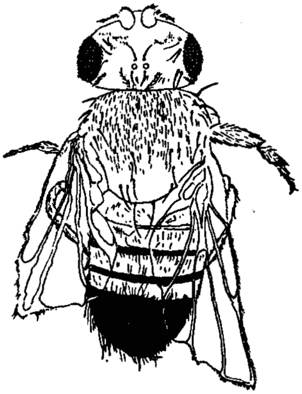

FIGURE 2.—The combination of Delta and Minute-z.

One of the most striking effects is a shortening of the legs. The tarsus, which is primarily affected, is sometimes reduced to half the size of the tibia. The femur is bent like a bow; the two effects on the legs taken together, make the animal decidedly bowlegged. One pair of legs (ordin-

Table 15

Minutes which are not lethal with Delta.

A. M_e. $\Delta/S_b s_r CIIIRMo$ ♀ × $M_e/b\ p_r c$ ♂.

Culture	Δ	S_b	$M_e S_b$	$M_e \Delta$
353	24	41	35	12
354	33	36	39	8
355	101	87	62	62
356	19	22	16	..
Total	177	186	152	82

B. M_g. $\Delta/S_b s_r CIIIRMo$ ♀ × $s_t I e^s M_g/e^s r_o c_a$ ♂.

Culture	Δ	S_b	$S_b I M_g$	$\Delta I M_g$	Crossovers
382	73	80	36	32	3
383	75	46	78	63	5
384	81	92	57	65	1
385	4	14	11	3	..
Total	233	232	182	163	9

C. M_p. $\Delta/S_b s_r CIIIRMo$ ♀ × M_p/C_y ♂.

Culture	$C_y \Delta$	$C_y S_b$	$M_p S_b$	$M_p \Delta$
365	11	14	16	10
366	47	48	50	42
367	55	78	73	67
368	105	86	98	97
Total	218	226	237	216

D. M_l'. $\Delta/S_b s_r CIIIRMo$ ♀ × M_l'/C_y ♂.

Culture	$C_y \Delta$	$C_y S_b$	$M_l' S_b$	$M_l' \Delta$	Crossovers
371	29	35	22	7	1
372	15	25	19	2	..
373	41	53	43	22	..
532	63	64	73	36	..
Total	148	177	157	67	1

E. MIV. $\Delta/S_b s_r CIIIRMo$ ♀ × $MIV/+$ ♂.

Culture	Δ	S_b	$S_b\ MIV$	$\Delta\ MIV$	Crossovers
357	96	112	86	52	1
358	9	8	5	..	..
359	36	40	39	3	..
360	21	17	25	4	1
Total	162	177	155	59	2

arily the last pair) may be more affected than the others. The wings are often scalloped, and are always extreme Delta, exhibiting both the thickening at the crossveins and the deltas at the margin to a marked degree. The texture of the wing is very brittle, since the thinness characteristic of Minutes is combined with the granular nature of the Delta wing.

The eyes in the least extreme forms are very rough. In the more extreme cases, they are like those of Lobe, and one or the other may be very much reduced. The ocelli are affected in some cases; either they are all fused together, as occasionally happens with Delta, or one of them may be missing. In the individual figured only two ocelli were present.

The bristles of the combination were constantly larger than Minute bristles, and were frequently duplicated. Furthermore, the irregular additional hairs on the thorax, typical of Delta, were characteristically present in Delta Minutes.

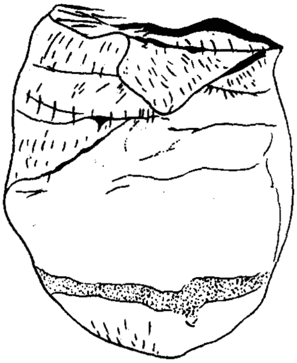

FIGURE 3.—Abdomen of a Delta Minute-h combination, dissected out of the pupa case.

One character of the combination remains to be described. In extreme cases, the abdomen was incompletely chitinized; irregular patches, marking the boundaries of unchitinized areas, were visible through the walls of the pupa cases. An abdomen of this kind, from a Delta Minute-h individual, is shown in figure 3. This effect in the combination is really a marked intensification of a characteristic of Minutes, that is the tendency towards irregularity in the chitinization of abdominal sclerites.

Intensification of the characters of Delta and Minute occurs not only in the lethal combinations, but also in those which survive. In all cases the venation effect of Delta is enhanced, the eyes are roughened, and the legs shortened. Minutes-e and -p, moreover, show an occasional eyeless-like condition in combination with Delta. In other words, the difference between the two types of combination is one of degree, and not one of kind.

For even in the non-lethal group, the Delta Minutes are usually less viable than the Minutes which are not Delta. This indicates that the lethal effect and the intensification described above, may both be due to the same cause. How close the relationship is, we shall consider later. But it may be remarked here, that even in the lethal group, there are also differences. The more extreme the Minute, the earlier the lethal effect. In some cases—Minute-j being the most striking—no Delta Minute pupae were found, but in those cultures a few puparia were discovered whose contents were not fully formed imagoes, but decayed undifferentiated tissue. This may be interpreted to mean that the combination dies at an earlier stage in these instances—a significant fact, in view of the extreme character of the Minutes concerned.

We may throw further light on this question if we consider the effects produced by combining Minutes with the less extreme allelomorphs of Delta. If the Minutes really differ only quantitatively, we should find that the less extreme Minutes of the group lethal with Delta, survive with the slighter Delta allelomorphs. Moreover, these combinations should be like those combinations of Minute with Delta which survive.

In other words, we have at our command two of the factors affecting a reaction in development; and we may vary either of them, keeping the other constant. We have already seen, that if we keep Delta constant, the Minutes vary quantitatively from each other. The results of varying Delta, with the Minute constant, follow.

The effects of Delta^3 and Delta^4

The experiments with Delta^3 were somewhat complicated by the fact that only after they were completed was Delta^3 known to be involved instead of Delta. A cross of Minute-w to a new stock thought to be Delta showed no lethal effect. The supposed Delta Minutes were like those which had already been seen in a cross of Minute-w to Delta^3 (table 16).

Accordingly, a series of location tests was carried out, to test whether a dominant modifier of the reaction was present, or whether Delta^3 were really involved (table 17). When it was found (see table 17) that a third chromosomal factor must be involved, a comparison of the combination of this Delta and Hairless, and that of Delta^3 and Hairless, was made. The two were found to be the same, and both were less extreme than the Delta Hairless combination, in that no deltas at all remained at the wing

TABLE 16

The non-lethal effect of Delta^3 *upon Minute-w.*

A. $e^s M_w/S_b s_r CIIIRMo$ ♀ $\times \Delta^3/CIII\ lIIIa$ ♂.

Culture	$\Delta^3 S_b$	S_b	M_w	$\Delta^3 M_w$
A520	36	31	18	10
A524	19	12	14	13
A527	54	57	37	9
A541	77	80	26	24
Total	186	180	95	56

B. $\Delta^3/S_b s_r CIIIRMo$ ♀ $\times e^s M_w/l\ CLCR$ ♂.

Culture	Δ^3	S_b	$S_b M_w$	$\Delta^3 M_w$
A525	64	64	53	34
A533	106	106	75	50
A544	119	147	109	62
Total	289	317	237	146

TABLE 17

The non-lethal effect of Delta^3 *upon Minute-w.*

A. $M_w/e\ CIII$ ♀ $\times \Delta^3/s_t S_b s_r CIIIRMo$ ♂.

Culture	Δ^3	S_b	$S_b M_w$	$\Delta^3 M_w$
B51	59	50	43	35
B52	36	53	34	22
B53	37	34	30	38
B55	21	26	20	15
B56	47	47	48	34
B58	45	43	45	40
B61	30	37	10	4
Total	275	290	230	188

B. $M_w/e\ CIII$ ♀ $\times \Delta^3/s_t S_b s_r CIIIRMo\ e_y^2/e_y^2$ ♂.

Culture	Δ^3	S_b	$S_b M_w$	$\Delta^3 M_w$
339	55	62	36	23
340	49	54	39	25
341	30	41	18	22
Total	134	157	93	70

C. $M_w/e\ CIII$ ♀ $\times S/+\ \Delta^3/H$ ♂.

Culture	$S \Delta^3$	Δ^3	$S H$	H	$S H M_w$	$H M_w$	$S\Delta^3 M_w$	$\Delta^3 M_w$
444	33	28	18	41	19	40	27	28
445	30	21	22	35	22	26	24	19
446	30	25	24	38	25	20	22	16
447	37	18	15	60	36	44	34	29
Total	130	92	79	174	102	130	107	92

TABLE 18

The effect of Delta³ upon Minutes which are lethal with Delta.

A. M_j. 1. $\Delta^3/s_t S_b s_r CIIIRMO$ ♀ × $M_j/e^s r_0 c_a$ ♂.

Culture	Δ^3	S_b	S_bM_j	Δ^3M_j
B30	31	26	7	..
435	102	87	63	..
Total	133	113	70	..

2. $\Delta^3/s_t S_b s_r CIIIMRO$ ♀ × $M_j/S_b s_r CIIIRMO$ ♂.

Culture	Δ^3S_b	S_bM_j	Δ^3M_j
827	59	54	1

B. M_l. $\Delta^3/s_t S_b s_r CIIIRMo$ ♀ × $M_l/b_w s_p$ ♂.

Culture	Δ^3	S_b	$M_l\ S_b$	$M_l\ \Delta^3$	Crossovers
B33	81	87	16	2	1
B34	109	121	18	..	1
433	112	102	94	35	..
434	70	66	47	4	1
438	54	69	25	11	..
Total	426	445	200	52	3

C. M. $\Delta^3/s_t S_b s_r CIIIRMo$ ♀ × $s_e M/e^s w_o r_o$ ♂.

Culture	Δ^3	S_b	$S_b\ M$	$\Delta^3\ M$	Crossovers
437	25	26	27	18	..
440	58	62	67	53	1
441	69	59	43	50	..
Total	152	147	137	121	1

D. Mo. $M_o f/r^{14}$ ♀ × $\Delta^3/s_t S_b s_r CIIIRMo$ ♂.

Culture	Δ^3	S_b	♀ $S_b\ M_o$	$\Delta^3\ M_0$	♂ Non-M_o
B44	39	49	43	34	105
B45	40	31	32	35	35
B46	14	16	20	16	35
Total	93	96	95	85	175

E. M_n. M_n/f^5 ♀ × $\Delta^3/s_t S_b s_r CIIIRMo$ ♂.

Culture	Δ^3	S_b	♀ $S_b\ M_n$	$\Delta^3\ M_n$	♂ Non-M_n
B36	19	29	19	8	36
775	37	38	30	23	46
776	10	11	23	12	30
777	41	52	43	35	68
778	24	24	21	15	20
Total	131	154	136	93	200

margin. Furthermore, the stock itself looked like Delta^3; so that, either a mutation from Delta to Delta^3 occurred, or what is far more likely, a mistake was made in selecting flies from the stock room, where the Delta allelomorphs are kept close together.

The combinations of Delta^3 and the Minutes (tables 18, 19) show the same essential characteristics as those of Delta and the Minutes. The lethal threshold, however, is different; a more extreme Minute is needed to produce a lethal effect with Delta^3. Only the most extreme Minutes are lethal, or semi-lethal with Delta^3—that is to say, Minute-j and Minute-l. The others show, as before, intensification of the Delta and Minute characters. Again the variations are variations only in degree, with the less extreme Minutes (table 19) least affected.

TABLE 19

The effect of Delta^3 upon Minutes not lethal with Delta.

A. M_e. $\Delta^3/s_t S_b s_r CIIIRMo$ ♀ × $M_e/b\ p_r\ c$ ♂.

Culture	Δ^3	S_b	$S_b\ M_e$	$\Delta^3\ M_e$	Crossovers
B42	75	75	56	42	1
B43	65	65	73	75	4
B47	52	44	14	44	..
Total	192	184	143	161	5

B. M_g. $\Delta^3/s_t S_b s_r CIIIRMo$ ♀ × $s_t\ I\ e^s\ M_g/e^s\ r_o\ c_a$ ♂.

Culture	Δ^3	S_b	$s_t\ I\ S_b\ M_g$	$I\ \Delta^3\ M_g$	Crossovers
B37	107	85	72	72	3
B38	58	56	55	61	2
Total	165	141	127	133	5

C. MIV. $MIV/+$ ♀ × $\Delta^3/s_t S_b s_r CIIIRMo$ ♂.

Culture	Δ^3	S_b	$S_b\ MIV$	$\Delta^4\ MIV$
B39	12	21	8	9
B40	67	80	67	35
B41	75	83	57	42
Total	154	184	132	86

These experiments with Delta^3 provide unmistakable evidence of the heterogeneity in the group of Minutes lethal with Delta. There appears to be a continuous series from the most extreme to the least extreme Minute; and where in this series the lethal threshold falls is determined by which allelomorph of Delta we use as indicator. Thus with Delta^4, which is the least extreme Delta allelomorph, we should expect that even the most extreme Minutes would die at a late stage, or survive. This is found to be true (table 20). For example, Minute-j, as we have seen, formed no imago with Delta. But with Delta^4, the combination dies in the late pupal stage, and occasionally survives. The behavior of Minute-j with Delta^4 is like that of the less extreme Minute, Minute-w, with the more extreme allelomorph, Delta itself. But Minute-w with Delta^4 gives a combination of very good viability; a combination which shows only a very slight intensification effect. And another extreme Minute, Minute-l, combines with Delta^4 to produce an intensified double mutant form which very closely resembles the combination of, for example, Minute-w and Delta^3. Wide deltas were present at the wing margin (figure 4), a fact which is particularly noteworthy since Delta^4 itself produces no deltas.

TABLE 20

The effect of Delta^4 upon Minutes w, j and l.

1. M_w. $M_w/e\,CIII$ ♀ × $\Delta^4/S_b\,s_r\,CIIIRMo$ ♂.

Culture	Δ^4	S_b	$S_b\,M_w$	$\Delta^4\,M_w$
205	52	63	47	63
213	26	40	21	27
215	36	37	37	43
223	55	67	54	49
224	59	46	38	48
Total	228	253	197	230

2. M_l. $\Delta^4/S_b\,s_r\,CIIIRMo$ ♀ × $M_l/b_w\,s_p$ ♂.

Culture	Δ^4	S_b	$S_b\,M_l$	$\Delta^4\,M_l$
524	121	76	66	57
528	93	60	52	29
545	38	51	52	28
546	42	55	34	32
Total	294	242	204	146

3. Mj. $\Delta^4/S_b\,s_r\,CIIIRMo$ ♀ × $M_j/e^s\,r_o\,c_a$ ♂.

Culture	Δ^4	S_b	$S_b\,Mj$	$\Delta^4\,Mj$	Crossovers
539	107	72	48	..	..
682	87	86	78	7	4
812	71	68	58	1	..
813	79	101	89	2	..
Total	344	327	273	10	4

It is interesting in this connection to recall the description of Delta-b

(BRIDGES and MORGAN 1923). The character was in the third chromosome and showed extreme Delta features: "The wings were small, and were held out at a wide angle from the body. The veins were slightly branched and knotted, and were confluent at the margins. The dorsal hairs were more numerous than normal, and the rows were irregular. The bristles were strong, and there were supernumerary anterior post alars. The body color was dark, as in Delta, and the eyes were extreme Star. The third legs were shortened as in bent." This description is very similar to that of a Delta Minute, except for the bristles. The stock was lost because in the first generation, all but four of the individuals died in the pupal stage. The four which survived were sterile. If this was a more extreme allelomorph of Delta (it was known to be in the third chromosome) its close resemblance to the Delta Minute combination is what might be expected. For if the effects of the Delta allelomorphs with the Minutes are considered with particular reference to the manifestation of Delta, what happens in combinations with Minutes is that a weaker Delta allelomorph looks like a stronger one alone. Hence, a stronger allelomorph even than Delta, would look like the Delta Minute combination.

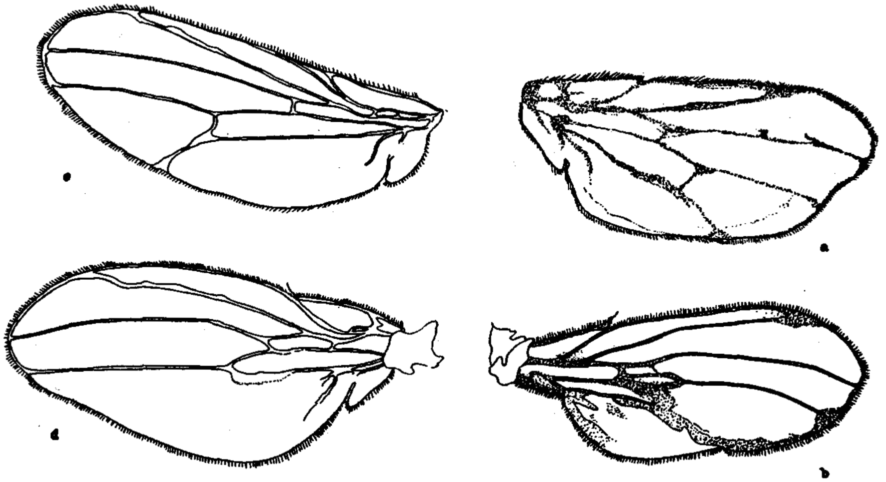

FIGURE 4.—a, Wing of Delta^4 Minute-l; b, Wing of Delta^3 Minute-w; c, Wing of Star Delta^3: d, Wing of Star Delta^3 Minute-w.

The effects of Hairless and of Star upon Delta Minutes

There is a method by which we may directly test whether the lethal effect in the combinations of Delta and the Minutes is a function of the intensification of the somatic effects of those mutants. As has been seen, Hairless very largely suppresses Delta; by combining Hairless with Delta Minute, we should find out more about the correlation between the lethal effect of Delta with Minutes, and the intensification effects which we have discussed.

In the case of Minute, Minute-h and Minute-w (table 21), Delta Hairless Minutes were seen. These were not nearly so extreme as the Delta Minutes. The legs were more nearly normal, the eyes were smoother, and the venation less disturbed. There seems also to be a slight improvement of the viability. This improvement is more marked in the case of Hairless^2, which is a more extreme allelomorph of Hairless (unpublished data of STURTEVANT, and PLUNKETT 1926). The Delta Hairless^2 Minute-w combination is more viable; but it is still not as good as Delta^3 Minute-w. The data are not extensive enough to admit detailed discussion; but that there is at least a partial correlation between the lethal effect and the manifestation of the Delta character seems to be clear.

Another modifier of Delta is the dominant mutant Star. This mutant suppresses only the wing effect of Delta; the eyes of the combinations are very rough, particularly so, since the major effect of Star itself is of this nature. Star is known to have an inhibiting effect on plexus, another venation character; so this inhibition of Delta is not completely unexpected. Combinations of Star, Delta^3, Hairless and Minute-w were seen (table 17C). The Star Delta^3 Hairless flies are Hairless with roughened eyes—Delta has quite vanished. The Star Delta^3 Minute-w combination is like the Delta Minute combination with Hairless, except for its roughened eyes. In figure 4, wings of Star Delta^3, Star Delta^3 Minute-w and Delta^3 Minute-w are shown. The inhibition of the Delta character in the wing is obvious. But from these data the relation of Star to the lethal effects in Delta Minute combinations cannot be determined.

The case of Haplo-IV

Haplo-IV presents an interesting problem in connection with the effects of Hairless. It is well known (BRIDGES 1921) that Haplo-IV intensifies Hairless. Nevertheless, Haplo-IV is generally lethal with Delta (table 22); but in the few survivors, the Delta character is suppressed. This is similar to the Delta Hairless Minute-w case, except that a different kind of suppression takes place. The combination of Delta and Minute-w with Hairless has a thin textured wing, while Haplo-IV with Delta has a small wing of heavy texture. This is strikingly seen with Delta^3, where more survivors are present.

TABLE 21

Combinations of Delta, Hairless and Minutes.

A. M_w and ΔH. 1. $\Delta H e^s c_d/CIII\,lIIIa$ ♀ × $e^s M_w/CIII\,lIIIa$ ♂.

Culture	ΔH	M_w	$\Delta H e^s M_w$
A372	103	68	..
A380	91	62	..
A440	46	20	..
Total	240	150	..

2. $\Delta H e^s cd/CIII\,lIIIa$ ♀ × $M_w/e\,CIII$ ♂.

Culture	$\Delta H e^s$	+	M_w	$\Delta H M_w$
B64	63	74	43	10
B65	83	86	47	1
B66	53	56	56	..
Total	199	216	146	11

3. $e^s M_w/e^s$ ♀ × $\Delta H e^s cd/CIII\,lIIIa$ ♂.

Culture	$\Delta H e^s$	+	M_w	$\Delta H e^s M_w$
A379	65	80	15	1

4. $M_w/e\,CIII$ ♀ × $\Delta H e^s c_d/c_d$ ♂.

Culture	$\Delta H e^s$	+	M_w	$\Delta H M_w$
B67	24	20	38	2

B. M_w and ΔH^2. $\Delta H^2/S_b s_r CIIIRMo$ ♀ × $M_w/S_b s_r CIIIRMo$ ♂.

Culture	$\Delta H^2 S_b$	$S_b M_w$	$\Delta H^2 M_w$	Crossovers
837	82	88	17	1

C. $M_h H$ and Δ. $\Delta/CIII\,lIIIa$ ♀ × $s_e M_h H/l\,CL\,CR$ ♂.

Culture	Δ	+	$M_h H$	$M_h \Delta H$
B70	34	22	28	1

D. $H M$ and Δ. $\Delta/S_b s_r CIIIRMo$ ♀ × $H M/+$ ♂.

Culture	Δ	S_b	$S_b H M$	$\Delta H M$	Crossovers
390	50	58	57	6	2

But Minute-IV, which is simply the Minute portion of the fourth chromosome, as we have seen, behaves with Delta as does any Minute of its general characteristics. That is to say, although it is not lethal with Delta, the combination is an intensified Delta. One may then assume with justice that the peculiarity exhibited by Haplo-IV in combination with Delta is not due to the Minute portion of the chromosome, but to some other portion.

TABLE 22

Haplo-IV in combination with Delta, Delta^3, Hairless^2 and Delta Hairless^2.

A. Δ and Haplo-IV. $\Delta/S_b\, s_r\, CIIIRMo$ ♀ × Haplo-IV. ♂

Culture	Δ	S_b	S_b Haplo-IV	Δ Haplo-IV	Crossovers
B21	16	14	18	2	1
399	50	63	33	1	7
400	63	63	50	1	..
401	24	30	23	2	..
Total	153	170	124	6	8

B. Δ^3 and Haplo-IV. $\Delta^3/s_t\, S_b\, s_r\, CIIIRMo$ ♀ × Haplo-IV ♂.

Culture	Δ^3	S_b	S_b Haplo-IV	Δ^3 Haplo-IV	Crossovers
656	73	72	83	48	..
844	50	74	19	4	4
Total	123	146	102	52	4

C. H^2 and Haplo-IV. $H^2/S_b\, s_r\, CIIIRMo$ ♀ × Haplo-IV ♂.

Culture	H^2	S_b	S_b Haplo-IV	H^2 Haplo-IV	Crossovers
994	58	58	92	48	1
995	82	73	91	64	..
Total	140	131	183	112	1

D. ΔH^2 and Haplo-IV. $\Delta H^2/S_b\, s_r\, CIIIRMo$ ♀ × Haplo-IV ♂.

Culture	ΔH^2	S_b	S_b Haplo-IV	ΔH^2 Haplo-IV
843	75	81	59	16
848	81	92	51	11
849	87	102	74	27
895	79	77	49	24
896	53	47	62	17
898	51	58	27	23
Total	426	457	322	118

That this other locus is concerned with the Delta Hairless reaction seems probable. There is further evidence of this. Hairless^2 is even more strongly intensified by Haplo-IV than is Hairless: the combination lacks most of the head and thoracic bristles, as well as the small hairs on the thorax. Delta Hairless^2 Haplo-IV was much closer to wild type—that is to say, Delta inhibited the intensification usually caused by Hairless; and at the same time, the combination was much more viable than that of Delta and Haplo-IV. The problem is resolved into the study of an antagonism between Delta, Hairless and Haplo-IV.

We may use Triplo-IV to analyze this further. If a deficiency for a locus in the fourth chromosome suppresses Delta, a duplication of that locus might under certain circumstances have an intensifying effect. The balanced stock of Triplo-IV was used in one experiment with Delta (table 23B), in which half of the Delta offspring should be Triplo-IV. No differences were noted among the Delta flies other than the slight ones usually associated with Triplo-IV. The latter are very difficult to classify; no separation was made in the cultures reported.

A similar experiment, in which the five to one ratio of normal to eyeless provided a criterion for distinguishing the presence of three fourth chromosomes (MORGAN, BRIDGES and STURTEVANT 1925), was performed with Delta^3. Here again no intensification of Delta was observed (table 23A).

Finally, when Hairless^2 was used as a "sensitizer" to a possible effect on the relationship, no difference was observed in the Delta classes, in a

TABLE 23

Crosses of Triplo-IV to Delta, to Delta^3, and to Delta Hairless.^{2}

A. $\Delta^3/s_t S_b s_r CIIIRMo\ e_y^2/e_y^2$ ♀ × $e_y^2/s_h/+$ ♂.

Culture	Δ^3	$\Delta^3 e_y^2$	S_b	$S_b e_y^2$
125	66	17	66	10
126	125	37	148	17
138	62	7	64	14
139	59	14	77	16
Total	312	75	355	57

B. $MIV/s_h/s_h$ ♀ × $\Delta/S_b s_r CIIIRMo$ ♂.

Culture	Δ	S_b	ΔMIV	$S_b MIV$
489	68	64	28	18
496	110	98	21	31
502	66	84	15	32
Total	244	246	64	81

C. $\Delta H^2/S_b s_r CIIIRMo$ ♀ × $MIV/s_h/s_h$ ♂.

Culture	ΔH^2	S_b	$\Delta H^2 MIV$	$S_b MIV$
930	114	99	28	33

cross to the balanced stock of Triplo-IV (table 23C). Clearly, the duplication of this locus in the fourth chromosome has no effect upon Delta. This is parallel to the general slight effects of Triplo-IV on the appearance of Drosophila; so that this negative result does not disturb the point at issue, that the anomalous behavior of Haplo-IV with Delta is due to another portion of the fourth chromosome than that producing the Minute.

The secondary nature of the reaction between Delta and the Minutes

The assumption has been made throughout the discussion, that Delta does not affect the primary reactions that cause the different Minutes. This has been assumed because of the fact, established above, that the primary reactions of the Minutes are known to be different from each other; but their effects with Delta are similar. We may test this directly, however, by the use of the Pale-III duplication for Minute-l.

If it is the primary reaction of the Minutes which is affected by Delta, then this duplication should suppress Delta. For it is the opposite in genic balance to a Minute which is lethal with Delta; and if it is a primary reaction due to the absence of a dose of these genes which causes the lethal effect, the presence of an extra allelomorph should have the opposite result.

A cross was made between Delta Hairless^2 and the same balanced stock of the duplication used in the Minute-l crosses (table 24). The not-Curly not-Stubble individuals should be Delta Hairless^2 Minute-l Pale-III; and among the Curly classes is the critical class Delta Hairless^2 Pale-III. By comparing the Curly Delta Hairless^2 Stubble class with that containing Pale-III instead of Stubble, we may see whether the duplication has

TABLE 24

The combination of Pale-III and Delta Hairless^2.

$\Delta^3 H^2/S_b\, s_r\, CIIIRMo$ ♀ × $w^e\, Ml/C_y \quad PIII/S_b\, s_r\, CIIIRMo$ ♂.

Culture	$C_y S_b$	$C_y S_b\ \Delta H^2$	$C_y\ \Delta H^2\ \ PIII$	$\Delta H^2\ PIII$	$S_b\ PIII$
984	51	66	47	45	58
985	36	33	36	43	38
986	52	62	43	52	59
987	21	22	15	11	13
988	40	43	32	36	29
989	16	11	18	14	19
Total	216	237	191	201	216

any effect on Delta. And the suppressed Minute classes serve as a control for the effect of the rest of the duplication besides that concerned with the Minute.

No significant differences were observed between the three classes, outside the usual variability. Since, then, a duplication for a Minute locus produces no effect upon Delta, we are justified in our assumption that the interaction between Delta and the Minutes is a secondary one as regards the Minutes. For it seems admissible to generalize from the case of Minute-l to that of other Minutes.

But we may attack this problem from another angle, by observing whether Minutes are also similar in their behavior with other modifiers than Delta.

Jammed, and other modifiers of Minutes

The most extensively analyzed case, excepting that of Delta, is the interraction of Minutes with Jammed, a second chromosomal dominant. Jammed narrows the wings to thin strings, whose venation is partially obliterated. Tests were made with two stocks, the Star Jammed/Curly, and Jammed/Star Curly. Since the same result is obtained with both stocks, the effect may be attributed to the combination of Jammed with the Minutes.

Of ten Minutes tested, four were found to be lethal in combination with Jammed. These were all among the more extreme Minutes which are lethal with Delta—approximately the same seriation holds here also (table 25). The combinations probably die as pupae.

TABLE 25

The effect of Jammed upon Minutes.

A. Effect upon Minutes which are lethal with Delta.

1. Haplo-IV. $S\,J/C_y$ ♀ × Haplo-IV ♂.

Culture	$S\,J$	C_y	C_y Haplo-IV	$S\,J$ Haplo-IV
167	15	15	14	..
168	42	54	28	..
176	41	36	32	..
Total	98	105	74	..

$J/S\,C_y$ ♀ × Haplo-IV ♂.

Culture	J	$S\,C_y$	$S\,C_y$ Haplo-IV	J Haplo-IV
169	62	70	58	2
170	34	46	41	..
Total	96	116	99	2

TABLE 25—*Continued*

2. M_z. $M_z\,p_r/d_p\,b\,p_r\,c\,p_x\,s_p$ ♀ × $S\,J/C_y$ ♂.

Culture	$S\,J$	C_y	$C_y\,M_z$	$S\,J\,M_z$
A462	45	91	34	4

$M_z\,p_r/C_y$ ♀ × $S\,J/C_y$ ♂.

Culture	$S\,J\,C_y$	$C_y\,M_z$	$S\,J\,M_z$
D7	18	21	..
D8	9	12	..
D9	25	20	..
Total	52	53	..

$M_z\,b/C_y$ ♀ × J/C_y ♂.

Culture	$J\,C_y$	$C_y\,M_z$	$J\,M_z$
D45	90	71	3

3. M_j. $J/S\,C_y$ ♀ × $M_j/e^s\,r_o\,c_a$ ♂.

Culture	J	$S\,C_y$	$S\,C_y\,M_j$	$J\,M_j$
530	81	111	31	..
695	51	45	12	..
770	76	79	29	..
771	80	83	20	..
772	69	97	7	..
Total	357	415	99	..

4. M_l. $S\,J/C_y$ ♀ × $M_l/b_w\,s_p$ ♂.

Culture	$S\,J$	C_y	$C_y\,M_l$	$S\,J\,M_l$
D43	36	26	13	..
540	74	74	4	..
Total	110	100	17	..

$J/S\,C_y$ ♀ × $M_l/b_w\,s_p$ ♂.

Culture	J	$S\,C_y$	$S\,C_y\,M_l$	$J\,M_l$
537	86	72	5	..
549	82	81	3	..
Total	168	153	8	..

5. M. $J/S\,C_y$ ♀ × $S_b\,M/l\,C\textsc{l}\,C\textsc{r}$ ♂.

Culture	$S\,C_y$	J	$S\,C_y\,S_b\,H$	$J\,S_b\,M$
179	52	70	69	48
180	62	50	74	55
Total	114	120	143	103

TABLE 25—*Continued*

6. M_h. $J/S\,C_y$ ♀ × $s_e\,M_h\,H/l\,CL\,CR$ ♂.

Culture	$S\,C_y$	J	$S\,C_y\,M_h\,H$	$J\,M_h\,H$
150	81	68	49	38
151	88	88	52	77
Total	169	156	101	115

$S\,J/C_y$ ♀ × $s_e\,M_h\,H/l\,CL\,CR$ ♂.

Culture	C_y	$S\,J$	$C_y\,M_h\,H$	$S\,J\,M_h\,H$
148	27	36	11	10

$S\,J/CIIL\,CIIR$ ♀ × $M_h\,s_t\,e^s/e^s$ ♂.

Culture	+	$S\,J$	M_h	$S\,J\,M_h$
939	49	44	44	5
940	46	31	25	5
941	34	30	29	11
Total	129	105	98	21

7. M_v. $S\,J/C_y$ ♀ × $h\,M_v\,s_t/l\,CL$ ♂.

Culture	C_y	$S\,J$	$C_y\,M_v$	$S\,J\,M_v$
162	89	97	74	35

$J/S\,C_y$ ♀ × $h\,M_v\,s_t/l\,CL$ ♂.

Culture	$S\,C_y$	J	$S\,C_y\,M_v$	$J\,M_v$
696	56	75	67	7
705	77	61	53	33
Total	133	136	120	40

8. M_w. $J/S\,C_y$ ♀ × $M_w/e\,CIII$ ♂.

Culture	$S\,C_y$	J	$S\,C_y\,M_w$	$J\,M_w$
163	44	58	49	23
164	46	63	43	18
Total	90	121	92	41

$S\,J/C_y$ ♀ × $M_w/e\,CIII$ ♂.

Culture	C_y	$S\,J$	$C_y\,M_w$	$S\,J\,M_w$
165	60	79	45	13
166	20	20	17	..
Total	80	99	62	13

TABLE 25—*Continued*

B. The effect on Minutes which are not lethal with Delta.

1. $M_p. J/S\,C_y$ ♀ × M_p/C_y ♂.

Culture	$J\ C_y$	$S\ C_y\ M_p$	$J\ M_p$	$S\ C_y/C_y$
177	78	71	14	4
178	100	106	39	4
Total	178	177	53	8

2. $M_l'. J/S\,C_y$ ♀ × M_l'/C_y ♂.

Culture	$J\ C_y$	$S\ C_y\ M_l'$	$J\ M_l'$	$S\ C_y/C_y$
171	65	34	25	2
172	101	61	56	..
Total	166	95	81	2

$S\,J/C_y$ ♀ × M_l'/C_y ♂.

Culture	SJC_y	$C_y\ M_l'$	$S\ J\ M_l'$	C_y/C_y
173	120	72	33	5
174	88	90	41	4
Total	308	162	74	9

The Jammed effect is obviously not so extreme as the Delta effect. But even where the combination is not lethal, in this case as in that of Delta, the characteristics of the mutant are intensified, and the viability of the combination is lowered. Ordinarily, as a culture grows older, genetically Jammed flies often appear normal; the specific environmental factor concerned is not known. But all Jammed Minutes were extreme Jammed to the end of the count; and those which came through in the early days displayed a marked intensification: the groove between scutellum and thorax was often absent, and the scutellum itself was short and lacked bristles.

It is clear, then, that the differences between the Minutes as regards their reaction to Jammed are again only differences of degree. This again justifies the assumption that the secondary reactions causing Minutes are similar in all Minutes.

A point of interest in this connection concerns the interaction of Delta with Jammed. The combination of these two mutants is a simple superposition of one character upon the other. It follows, then, that the secondary reaction which seems to be common to the Minutes is a very sensitive one, and one which concerns a number of otherwise unrelated developmental reactions. The extraordinarily large number of modifiers is another point in favor if this conception. For example, according to BRIDGES vestigial in heterozygous form weakens the viability of Minutes; and plexus, usually only slightly dominant, is intensified in the presence of a Minute (unpublished data).

In crosses of Haplo-IV, Minute-j and Minute-z to the yellow attached-X Star Curly Dichaete stock, STERN (unpublished) has noted a lethal effect of these Minutes with Dichaete. This is probably dependent upon a specific modifier of the Dichaete Minute interaction, since in crosses with other stocks of Dichaete the combination survives. In these cases also, however, Dichaete and Minute act as mutual modifiers. There are fewer bristles than in Dichaete, those present are smaller than usual Minute bristles, and the shape of the head is abnormal (see PLUNKETT 1926).

It is possible that such specific modifiers as those noted above are responsible for the bimodal distribution of mortality among Haplo-IV cultures, noted by BRIDGES as being dependent upon changes in the pupal stage (MORGAN, BRIDGES and STURTEVANT 1925).

Intensification effects have been noted of Minutes in combination with Notch-19 and Plexate (STERN, unpublished), and with Pointed-wing. These are wing characters, and their effect with Minutes is similar to that of Delta^3. A lethal effect has been found of Minute-w with the third-chromosome dominant Deformed; and occasional lethal effects are seen with Curly (see table 25B, cross 4).

This brief resumé of cases incidentally noted will serve to give an idea of how sensitive Minutes are to modifiers. It is obvious that they must affect a reaction which is of cardinal importance in development.

We may return now to a consideration of the differences between the Minutes. In the cases which we have studied closely, these resolve themselves into differences of degree. How are these differences in the various instances correlated? In table 26 a comparison of the Minutes is given, on the basis of the various experiments detailed above. The viability of a given Minute has been expressed as the mean of the percentage ratios of Minute to non-Minute in the crosses presented in table 2. According to these ratios, the Minutes have been arranged in a series, with the most extreme at the top, the least extreme at the bottom. Following this, the effect with Delta has been represented as the percentage ratio of Delta Minute to Minute; and the Delta allelomorphs and Jammed have been treated in the same way. It is obvious, that the series of Minutes obtained by a consideration of the viability differences of one set of experiments, agrees in a rough way with the results from Delta, Delta^3, Delta^4 and Jammed. The agreement is extraordinarily good, if one considers the heterogeneity of the material. In all cases Minute-j is the most extreme, and the gradation, except in a few cases, is the same in the different experiments.

TABLE 26

Quantitative differences among the Minutes.

MINUTE	VIABILITY	Δ M/M	$\Delta^3 M/M$	$\Delta^4 M/M$	J M/M
M_j	.64	.00	.01	.04	.00
M_l	.68	.00	.26	.72	.00
M_t	.78	.04	...	..	.04
M	.82	.02	.88	..	.84
Haplo-IV	..	.05	.52	..	.02
M_h	.84	.06	.69	..	.25
M_w	.85	.00	.65	1.17	.35
M_y	.86	.00	..	..	..
M_{28}	..	.00	..	..	..
M_n	..	.08	.69	..	..
M_o	..	.13	.88	..	..
MIV	..	.38	.71	..	..
M_g	.88	.90	1.10	..	..
M_e	.90	.53	1.20	..	..
M_p	.98	.91	..	..	..
M_l'	1.05	.44	..	..	..

Moreover, if we measure the length of Minute bristles, we find that the same seriation is shown, even when we neglect volume differences. In table 27 measurements of bristles of twenty-five males of three different Minutes are presented. The wild-type measurements are from unpublished data of DR. TH. DOBZHANSKY, which he has kindly furnished. The differences between the Minutes are clearly significant, and

TABLE 27

The length of Minute, and of normal bristles.

MINUTE		POSTERIOR DORSOCENTRAL	POSTERIOR SCUTELLAR	FEMUR
Mean length (micra)	M_j	233.0±2.0	269.0±2.8	492.0±2.8
	M_l'	244.5±1.4	301.0±0.6	528.0±3.8
	M_g	243.5±2.8	303.5±2.8	532.5±1.4
	+	364.5±2.1	460.5±1.8	
Differences	$M_l' - M_j$	11.5±2.4	32.0±2.9	36.0±4.7
	$M_g - M_j$	10.5±3.2	34.5±4.0	40.5±3.1
	$+ - M_j$	131.5±2.9	191.5±3.4	

are in the right direction; Minute-j, the more extreme Minute, has smaller bristles than Minute-l.

Moreover, it has been shown earlier (table 4) that Minute-l develops more slowly than the less extreme Minute-h. This has not been investigated accurately as yet for other Minutes, but it is generally true that the more extreme the Minute, the more slowly it develops.

We may consider then, that we have established the basic similarity of the secondary reactions of the Minutes, and their quantitative differences from each other. We shall consider this further.

THE MINUTE REACTION

As a result of the various experiments detailed above, it is evident that at least two things are involved in the production of the Minute character: a primary reaction, concerned with whether or not the Minute reaction is effected; and a secondary, which we may call the Minute reaction proper.

The necessity for assuming such a separation arises from the failure of the Minutes to reinforce each other in normal diploids and under conditions of suppression involving triploidy. This indicates, as we have shown, a primary difference among the Minutes.

It remains, however, an interesting puzzle that several Minutes are deficiencies; it is possible that all of them are (see MORGAN, BRIDGES and STURTEVANT 1925). Moreover, in two cases in which the same Minute has occurred more than once, the more extreme Minute is known to be a deficiency for a longer section of chromosome (unpublished data of BRIDGES and of the writer). This correlation between the number of genes affected and the extent of the effect is, of course, not unexpected. Moreover, this relationship indicates that the complex of characters associated in a Minute are not manifold effects of a single gene (see DOBZHANSKY 1927). For example, the high sterility associated with Minute-l, deficient for arc and plexus, is not found in its allelomorph, which is presumably deficient for a shorter section to the right of these mutants. And the case of Minute-IV and of Haplo-IV, dealt with above, may be called to mind.

To say that all Minutes are deficiencies is, however, a gratuitous assumption. There are, in the first place, recessive short bristled mutants (for example MOHR 1925), which may affect the same reaction. Furthermore, as has been pointed out by WRIGHT (1925), any variation affecting a given reaction is likely to affect it quantitatively. So if we suppose, as seems likely, (GOLDSCHMIDT 1927 and many others) that genes produce catalysts affecting the velocities of developmental reactions, either the production of a less effective catalyst or the loss of a catalyst due to a deficiency, may have the same result.

We are faced by another difficulty, even where the usual proof for the existence of the deficiency is provided. The mosaic patches in Minutes produced, according to BRIDGES (1925) and STERN (1927), by the elimination of the Minute-bearing portion of the chromosome, are not Minute, but normal bristled. Such mosaics have been found with Minute-l, the deficiency for arc and plexus, and with a sex-linked Minute, Minute-30, deficient for crossveinless (unpublished data of the writer). This means that very much longer deficiency produced by chromosome elimination approaches normal more nearly than does the short one responsible for the Minute. A formal answer to this difficulty, the same one encountered in the problem of the XO male, is possible in terms of "unit segments" of chromosome, identical in genic balance with the system as a whole. But this merely states a problem.

Whether or not the Minutes are all deficiencies, their secondary similarities present a striking special case of a more general situation: namely, that organisms may give the same reaction to a variety of stimuli. In this instance, we have attempted an explanation on the assumption that a reaction exists in development, in which a great many genes are involved; and that changes in any of these contributors may set off a secondary reaction which we have called the Minute reaction.

It is the Minute reaction which is concerned with Delta, Jammed and the numerous other modifiers of Minutes. It is this reaction which does not take place in triploids with only a single dose of Minute present. It is the Minute reaction which is common to Minutes.

The differences among the Minutes, as we have seen, are largely quantitative. It is very unlikely, however, that these differences depend upon a difference in quantity of the same gene, a point effectively established in the first part of this paper. The danger of assuming quantitative differences in the genes themselves, from such differences in their effects, is emphasized by the present situation, where the end results are quantitatively different, while their causes apparently differ qualitatively.

The Minute reaction is probably, in its essentials, concerned with the growth of the fly. That cell division is affected is indicated by the chromosome elimination caused by Minutes. Given this fact, it is not hard to conceive a system of reactions which will present both the primary differences and the secondary similarities of the Minutes. In the many reactions concerned with growth (perhaps even of the growth of the chromosomes themselves) we may imagine that the normal allelomorphs of the Minutes are involved. Any Minute represents a decrease in the rate of one of these processes, which then becomes a limiting reaction in growth. When two Minutes are combined, the slowest should control the process of growth; and the lethal effects of Minutes when homozygous fit in quite nicely with this view, for, on this assumption a necessary process does not here take place at all. Experimental verification of such an hypothesis should not be difficult, and the fact that so simple a one is available is encouraging.

The Minutes form by no means an isolated case in which different loci produce the same somatic effect. Many eye color mutants of Drosophila, for example, are nearly identical in appearance and have no cumulative effect upon each other; and the same is true of other systems. Whether or not a similar mechanism is at work here one need not say; but the facts are suggestive.

SUMMARY

1. The interrelationships of the group of similar mutants in *Drosophila melanogaster* known as the Minutes have been studied with a view to the analysis of the developmental process involved.
2. The technique employed is purely genetic; that is, a study is made of the effects of different combinations of the genes under investigation.
3. Combinations of two Minutes with each other produce no cumulative effect as regards the appearance of the Minute character, the viability of the combination, the rate of development, or the partial female-sterility characteristic of Minutes.
4. Three Minutes in combination with each other show no cumulative effect.
5. These facts indicate that the primary reactions causing the Minute characters are different in the different Minutes.
6. Triplo-IV and Pale-III, suppressors respectively of Minute-IV and Minute-l, do not suppress other Minutes.
7. All the Minutes tested were found to be recessive to two normal allelomorphs in triploid Drosophilas.
8. Two doses of a single Minute in a triploid have a lethal effect.
9. The combination of two different Minutes in a triploid appears wild type; the two Minutes do not reinforce each other.
10. These experiments rule out the hypothesis that the differences in the primary reactions are merely quantitative differences, in a system involving an all-or-none reaction.
11. By a study of the behavior of Minutes with respect to genetic

modifiers, the nature of the secondary reactions of Minutes may be investigated.

12. The allelomorphs at the Delta locus are found to be modifiers of the Minutes, producing either a lethal effect, or an extreme Delta Minute.

13. The differences between the behavior of the different Minutes with Delta and its allelomorphs are differences of degree, similar to those between the action of the various allelomorphs of Delta upon a given Minute.

14. Modifiers which suppress Delta are found to improve the viability of the Delta Minute combination.

15. Haplo-IV is found to suppress the wing character of Delta, even though the combination is usually lethal. Evidence is presented for assuming another locus in the fourth chromosome, distinct from that which produces the Minute character, to be responsible for this suppression, and for the intensification of Hairless.

16. The relation between Delta and the Minutes is shown to concern a secondary Minute reaction. The evidence for this is the absence of an effect upon Delta, of Pale-III, a duplication for a Minute locus.

17. The Minutes behave alike in their reactions to other modifiers than Delta, notable Jammed. Here again the differences seem to be merely quantitative.

18. The concept of a secondary reaction, the Minute reaction, which is alike in all the Minutes, is discussed. The same kind of secondary reaction is judged to result from many different primary reactions, which accounts for both the differences and the similarities of the Minutes.

19. A discussion is presented, in which the Minutes are considered as deficiencies, a possible hypothesis accounting for the Minute reaction as a growth reaction is discussed, and it is shown that in the present case, quantitative variation of somatic characters is not associated with quantitative variation in the gene.

LITERATURE CITED

BRIDGES, C. B., 1921a Proof of non-disjunction for the fourth chromosome of *Drosophila melanogaster*. Science **53**: 308.

1921b Triploid intersexes in *Drosophila melanogaster*. Science **54**: 252–254.

1922 The origin of variations in sexual and sex-limited characters. Am. Nat. **56**: 51–63.

1925 Elimination of chromosomes due to a mutant (Minute-n) in *Drosophila melanogaster*. Proc. Nat. Acad. Sci. **11**: 703–710.

BRIDGES, C. B., and MORGAN, T. H., 1923 The third chromosome group of mutant characters of *Drosophila melanogaster*. Carnegie Inst. Wash., publ. **327**: 251 pp.

DOBZHANSKY, TH., 1927 Studies on the manifold effect of certain genes in *Drosophila melanogaster*., Zeitschr. indukt. Abstamm. u. Vererb. **43**: 330–388.

GOLDSCHMIDT, R., 1927 Physiologische Theorie der Vererbung. Berlin: Julius Springer. 247 pp.

LI, JU CHI, 1927 The effect of chromosomal aberrations on development in *Drosophila melanogaster*. Genetics **12**: 1–58.

MOHR, O. L., 1925 A minute-like III-chromosome recessive in *Drosophila melanogaster*. British Journ. Exp. Zool. **2**: 189–198.

MORGAN, T. H., BRIDGES, C. B., and STURTEVANT, A. H., 1925 The genetics of *Drosophila*. 'S-Gravenhage, Martinus Nijhoff. 262 pp.

MORGAN, T. H., STURTEVANT, A. H., and BRIDGES, C. B., 1926 The constitution of the germ plasm in relation to heredity. Carnegie Inst. Year Book No. **25**: 308–312.

1927 The constitution of the germ plasm in relation to heredity. Carnegie Inst. Wash. Year Book No. **26**: 284–288.

MULLER, H. J., 1918 Genetic variability, twin hybrids and constant hybrids, in a case of balanced lethal factors. Genetics **3**: 422–499.

1928 The measurement of gene mutation rate in *Drosophila*, its high variability, and its dependence on temperature. Genetics **13**: 280–357.

PLUNKETT, C. R., 1926 The interaction of genetic and environmental factors in development. Jour Exp. Zool. **46**: 181–244.

STERN, CURT, 1927 Über Chromosomenelimination bei der Taufliege. Naturwissenschaften **15**: 740–746.

STURTEVANT, A. H., 1918 An analysis of the effects of selection. Carnegie Inst. Wash. Publ. **264**: 68 pp.

1926 A crossover reducer in *Drosophila melanogaster* due to inversion of a section of the third chromosome. Biol. Zentralbl. **46**: 697–702.

WARD, L., 1923 The genetics of Curly wing in *Drosophila*, another case of balanced lethal factors. Genetics **8**: 276–300.

WRIGHT, S., 1925 The factors of the albino series of guinea pigs and their effects on black and yellow pigmentation. Genetics **10**: 223–260.

1927 The effects in combination of the major color-factors of the guinea pig. Genetics **12**: 530–659.