THE PRODUCTION OF NON-DISJUNCTION BY γ-RADIATION FROM RADIUM

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THE occurrence of non-disjunction like that of gynandromorphism, of intersexes, and of sex-linked mosaics, is closely related to mutations due to chromosome change. It is probable that agents which effect non-disjunction will also give rise to mutations. For instance, in the case of X-rays, Mavor (1924) has shown that these radiations produce non-disjunction and Muller (1927) that the occurrence of mutations is greatly increased in *Drosophila* by subjecting the flies to the same radiations.

In view of the importance which some workers consider these results to bear to the problems of cancer growth (Strong, 1929), it was decided to investigate whether radium influences the occurrence of non-disjunction, since radium and X-rays are equally potent to produce cancer.

Two strains of the Fruit Fly, *Drosophila*, were kindly supplied by Dr Crew from Edinburgh; wild-type red-eyed flies and white-eyed flies. Both these strains were inbred through many generations and found to breed true in a normal manner. Radiation of the flies was carried out in flattened glass tubes which were placed between two radium applicators of 110 mg. radium bromide, area 2 × 2 cm., screening 3 mm. of lead, 0·12 mm. of silver and a layer of zinc-oxide plaster. The flies thus received γ-radiation apart from secondary β-radiation set up in the glass tubes which contained them.

Virgin red-eyed females were radiated immediately after hatching and then crossed with white-eyed males. Red-eyed sisters and white-eyed brothers of these flies were also crossed and served as controls.

The pairs of flies were placed in tubes containing cornflower-agar-malt-extract media on which the eggs were laid and on which the grubs fed. The pairs were transferred to fresh tubes at frequent intervals until the female died. The flies which hatched out were counted daily, their sex and eye colour being noted. The results obtained are given in Table I, Experimental series, and Table II, Control series.

Under these conditions non-disjunction is manifested by the occurrence of exceptional white-eyed sons, the normal result of mating red-eyed females to white-eyed males being red-eyed sons and daughters.

In the tables each horizontal column shows the progeny of a single pair of flies and gives the number of males hatching each day after the pairing of the

Table I. *Experimental Series.*

	Radiation in hours	Days of hatching																									Total males	Females
		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34		
1 *a*	2	.	.	.	.	3	5	4	3	1	2	2	0	6	2	1	1	.	.	.	.	.	.	.	.	.	.	30	35
2 *a*	2	.	.	.	2	7	5	5	3	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	27	18
2 *b*	2	.	.	1	3	0	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	7
2 *c*	2	.	.	1	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	4
3 *a*	2·5	.	.	3	2	5*	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	13
3 *b*	2·5	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4
3 *c*	2·5	.	.	.	.	.	.	1	0	0	0	5	1	3	2	4	2	.	.	.	.	.	.	.	.	.	.	18	25
3 *d*	2·5	.	.	4	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	12
4 *a*	2·75	.	5	3	5	6	10	11	6	7	12	3	6	4	3	0	1	4	.	.	.	.	.	.	.	.	.	86	87
4 *b*	2·75	.	.	5	9	4	4	2	2	2	8	1	1	0	0	0	1	.	.	.	.	.	.	.	.	.	.	39	38
4 *c*	2·75	.	.	8	0	2	1	1	5	4	5	5*	3	0	3	1	0	1	1	0	0	1	.	.	.	.	.	41	45
4 *d*	2·75	.	6	6	5	3	2	2	7	2	6	6	9	2	0	0	1	0	8*	0	1	2	2	.	.	.	.	70	71
4 *e*	2·75	.	1	5	2	1	12	4	7	3	10	5	3	4	1	3	1	.	.	.	.	.	.	.	.	.	.	62	58
5 *a*	3	.	.	5	0	6	6	4	1	1	0	5†	3	1	2	1	0	0	1	.	.	.	.	.	.	.	.	36	43
5 *b*	3	.	1	6	3	4	5	4	7	5	6	8	4	2	2	.	.	.	.	.	.	.	.	.	.	.	.	57	49
6 *a*	3·5	.	.	.	.	.	2	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	0
6 *b*	3·5	.	.	1	2	5	6	1	1	1	1	1	0	1	1	.	.	.	.	.	.	.	.	.	.	.	.	21	22
7 *a*	5	.	.	.	.	.	10	5	1	4	2	0	0	0	2	5	1	0	0	1	2	3	0	1	.	.	.	37	24
7 *b*	5	.	.	.	.	.	.	.	1	0	2	1	1	0	5	0	1	.	.	.	.	.	.	.	.	.	.	.	11	12
7 *c*	5	.	.	.	.	.	1	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	6
8 *a*	16	.	.	.	1	0	0	1	5	3	1	0	1	1	1	0	1*	.	.	.	.	.	.	.	.	.	.	15	23
8 *b*	16	.	.	.	.	3	2	2	2	1	1	1	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	15	7
8 *c*	16	.	1	2	3	2	0	5	1	3*	1	5*	1*	2	4	3	1	5	3	3	0	0	0	0	0	0	1	47	43
8 *d*	16	.	.	.	.	.	2	3†	0	3	0	2	0	0	0	0	3	1	1	1	.	.	.	.	.	.	.	16	20
9 *a*	24	.	.	1	2	0	1	1	1	4	2	0	0	0	1	1	0	0	2	1	9	0	2	0	2	3	.	33	23
9 *b*	24	.	.	1	2*	0	0	0	0	0	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	4
10 *a*	8	.	.	.	1	0	1	1	0	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	8
11 *a*	5	.	1	2	3	1	0	0	6	6	4	10	7	5	4	3	2	3	.	.	.	.	.	.	.	.	.	57	54
11 *b*	5	.	.	.	.	.	.	.	.	.	.	5	2	10	4	5	5	2	5	0	2	1	1	.	.	.	.	42	41
11 *c*	5	.	.	3	4	1	1	1	6	7	11	7	1	8	6	1	4	3	.	.	.	.	.	.	.	.	.	64	50
11 *d*	5	.	.	3	5	1	0	0	4*	4	2	2	9	16	9	1	1	0	1	•	.	.	.	.	.	.	.	58	59
11 *e*	5	.	.	.	1	0	2	0	4	1	1	0	2	0	0	1	.	.	.	.	.	.	.	.	.	.	.	12	18
11 *f*	5	.	.	.	.	.	.	.	1	3	2	0	1	3	3	3	5	4	1	0	2	1	3	1	0	1	.	34	44
12 *a*	4	.	.	2	1	2	3	3	1	2	3	5*	4	1	3	2	4	3	1	3	4	5	9	2	4	2	.	69	67
12 *b*	4	.	.	.	.	1	0	1	3	1	1	4	4	1	3	0	2	2	.	.	.	.	.	.	.	.	.	23	23
	Totals	.	15	62	63	59	89	65	79	74	85	83	65	71	61	35	37	28	24	9	20	13	17	4	6	6	1	1072	1057

Table II. *Controls.*

	Days of hatching																									Total males	Females
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
1 *a*	.	.	1	3	0	1	4	6	0	4	3	2	1	0	2	.	.	.	.	.	.	.	.	.	.	.	27	21
2 *a*	.	.	.	1	0	0	0	2	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	3
2 *b*	.	.	.	9	4	5	7	3	3	1	1	1	1	6	1	2	3	5	0	2	2	1	0	1	1	.	59	66
3 *a*	.	3	4	1	11	2	2	6	10	0	1	0	3	.	.	.	.	.	.	.	.	.	.	.	.	.	43	64
3 *b*	.	9	1	1	2	3	1	4	4	2	5	3	0	1	2	.	.	.	.	.	.	.	.	.	.	.	38	39
3 *c*	.	.	.	5	6	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	11
4 *a*	.	3	9	5	7	12	13	6	5	6	22	4	5	4	7	2	0	1	0	0	1	.	.	.	.	.	112	125
4 *b*	.	.	1	7	0	3	8	3	4	2	3	3	2	1	1	0	2	.	.	.	.	.	.	.	.	.	40	36
4 *c*	.	.	2	7	1	0	2	7	1	0	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	23	23
5 *a*	.	3	4	4	3	3	2	2	4	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	29	33
5 *b*	.	.	.	.	5	4	6	1	5	2	5	4	0	0	1	0	1	1	.	.	.	.	.	.	.	.	35	43
6 *a*	.	1	1	7	2	6	4	4	2	4	4	1	1	3	.	.	.	.	.	.	.	.	.	.	.	.	40	36
6 *b*	.	1	2	0	6	0	0	2	1	0	3	1	2	0	1	1	.	.	.	.	.	.	.	.	.	.	20	19
7 *a*	.	.	3	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	4
8 *a*	.	1	4	3	0	1	1	2	2	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	17	19
8 *b*	.	1	3	3	4	0	4	1	2	7	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	26	31
8 *c*	.	.	1	3	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	10
9 *a*	.	1	5	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	8
9 *b*	.	4	3	1	9	10	8	4	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	42	43
9 *c*	.	5	4	3	4	2	7	13	4	2	3*	6	4	1	4	1	.	.	.	.	.	.	.	.	.	.	63	55
10 *a*	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	10
10 *b*	.	1	1	4	5	1	2	0	2	0	1	1	0	0	1	.	.	.	.	.	.	.	.	.	.	.	19	22
11 *a*	.	.	3	2	1	1	2	3	3	4	0	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	22	15
11 *b*	.	.	.	2	0	2	1	3	3	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	12	19
11 *c*	.	.	.	.	.	.	.	.	1	0	4	5	3	1	1	3	4	1*	5	3	4	5	4	2	.	.	46	48
11 *d*	.	2	1	1	2	1	4	5	7	5	11	6	3	2	4	4	4	5*	0	1	.	.	.	.	.	.	69	49
11 *e*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	4	1	0	1	0	1	.	.	.	.	11	9
12 *a*	1	2	3	3	5	2	0	5	1	0	3	3	3	1	1	1	.	.	.	.	.	.	.	.	.	.	34	34
Totals	1	38	57	82	80	63	78	82	66	47	75	43	29	21	28	16	18	14	5	7	7	7	4	3	1	.	871	897

mother. The exceptional males are denoted by an asterisk. It is seen that there were two exceptional males in the control series and 12 in the experimental series. All these exceptional males were crossed with white-eyed females to test their fertility, for the reason that they should be sterile. Among the experimental series two (denoted by a dagger) were found to be fertile; their progeny were carried through two generations and found to breed quite normally. They must therefore be excluded from the series and looked upon as technical faults, due possibly to an escaped normal white-eyed male having penetrated the cotton plug of the breeding tube, or to the white-eyed female with which they were crossed not being a virgin. The history of the exceptional males is given in Table III.

Table III. *Exceptional Males.*

Experimentals.

Pairs from which derived	Time of hatching after pairing of parents in days	Age at death in days	Description of fly	Breeding	Progeny
3 *a*	13	10	Normal	No	—
4 *c*	19	1	Wings unexpanded	No	—
4 *d*	26	11	Normal	No	—
5 *a*	19	35	Normal	Yes	38 ♂, 47 ♀
8 *a*	24	29	Normal	No	—
8 *c* 1	17	32	Normal	No	—
8 *c* 2	19	36	Short legs left side	No	—
8 *c* 3	20	25	Normal	No	—
8 *d*	15	21	Normal	Yes	115 ♂, 107 ♀
9 *b*	12	33	Normal	No	—
11 *d*	16	13	Normal	No	—
12 *a*	19	11	Normal	No	—

Controls.

9 *c*	19	D. in bottle	Short wings, legs and sex combes	Not paired	—
11 *d*	26	15	Normal	No	—

It is seen that the exceptional males in the experimental series did not emerge at any definite period. Mavor, in his experiments on non-disjunction produced by X-rays, concluded that there were two periods when their emergence chiefly occurred. These results do not confirm this, but the series is small to decide this point.

On comparing the radiated and control flies with regard to time of emergence of their progeny, the figures show a slight decrease in numbers of the early hatchings in the experimentals as if the radium had either destroyed the early eggs or delayed their development. The figures, however, show that the sex ratio was not disturbed by the radiation. In the radiated series 10 exceptional males occurred among 1072 male flies, or 1 in 107, whereas in the control series there were 2 in 871, or 1 in 435. The difference is sufficiently large not to require any mathematical

analysis. The normal percentage occurrence of non-disjunction is given by Safir (1920) as 0·07 per cent. In this series of controls it was 0·2 per cent. In another research dealing with the same strains of flies in the control series 1302 males were counted with no exceptional male. The results therefore confirm Mavor's findings with X-rays, as was to be expected, since γ-radiation differs from X-radiation only in being of shorter wave-length. The results obtained are of importance with regard to the cancer problem in that (confirming the findings of Mavor (1924)) they suggest the possibility that cancer may be due to the mutation of a somatic cell; so it is that both X-rays and radium give rise to cancer.

Conclusion. The occurrence of non-disjunction in *Drosophila* is greatly increased by subjecting newly hatched females to the γ-rays from radium.

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