CHAPTER IV

CHROMOSOMES AND GENES

NOT only do the chromosomes pass through a series of manœuvres that go far toward supplying a mechanism for the theory of heredity, but from other sources evidence has accumulated supporting the view that the chromosomes are the bearers of the hereditary elements or genes, and this evidence has steadily grown stronger each year. The evidence comes from several sources. The earliest indication came from the discovery that the male transmits equally with the female. In animals, the male contributes, as a rule, only the head of the spermatozoön, which contains almost exclusively the nucleus composed of the condensed chromosomes. Although the egg contributes all the visible protoplasm of the future embryo, it has no preponderating influence on development, except so far as the beginning stages of development are determined by the egg protoplasm that has been under the influence of the maternal chromosomes. Despite this initial influence, which can be entirely ascribed to the previous influence of its own chromosomes, the later stages of development and the adult show no preponderance of maternal influence.

This evidence from the mutual influence of the two parents is not, however, in itself convincing, for, dealing with elements that are ultramicroscopical, it might be claimed that the sperm contributes something more than its chromosomes to the future embryo. In fact, in recent years it has been shown that visible protoplasm elements, the centrosomes, may possibly be brought into the egg by

the sperm. It has not been established, however, that the centrosomes have any specific effects on the developmental process.

From another quarter the significance of the chromosomes was shown. When two (or more) sperms enter the egg, the three sets of chromosomes that result may be distributed irregularly at the first division of the egg. Four instead of two cells, as in normal development, are formed. It has been shown by a detailed study of such eggs, combined with a study of the development of each of the isolated quarters, that normal development does not take place unless at least one full set of chromosomes is present. At least this is the most reasonable interpretation of the results. Since in these cases the chromosomes are not marked, the evidence does not do more than create a presumption that at least one full set of chromosomes must be present.

More recently still evidence in favor of such an interpretation has come from other sources. It has been shown, for example, that one set of chromosomes alone (haploid) is capable of producing an individual which, to a large extent, is a replica of the normal form, but this evidence also indicates that these haploid individuals are not as vigorous as the normal diploid type of the species. While this difference may depend on factors other than the chromosomes, the presumption remains that two sets of chromosomes are better than one, as things stand. On the other hand, in mosses, where there is a haploid stage in the life cycle, the artificial transformation of the haploid stage into a diploid stage does not appear to give an advantage. Furthermore, it remains to be shown that twice the number of chromosomes present in artificial tetraploids confers any advantage over the normal diploid set. It is evident, then, that we must be cautious as to the merits of one, two, three, or four sets of chromo-

somes, especially when suddenly an artificial situation is created by increasing or decreasing the normal complement of chromosomes to which the machinery of development is already adjusted.

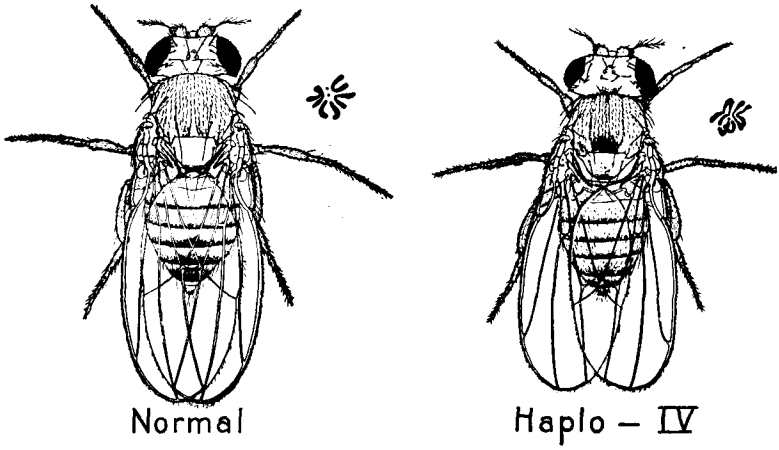

FIG. 29.

Normal and haplo-IV flies of Drosophila melanogaster. Their respective chromosome groups are shown above and to the right of each.

Probably the most complete and convincing evidence concerning the significance of the chromosomes in heredity has come from the recent genetic results that have to do with the specific effects of changes in the number of the chromosomes where each one carries genetic factors that enable us to identify its presence.

Recent evidence of this kind comes from the loss or from the addition of one of the small fourth chromosomes of Drosophila (chromosome-IV). It has been shown both by genetic and cytological methods that chromosome-IV is sometimes lost from one of the germ-cells—egg or sperm. If an egg lacking this chromosome is fertilized by

a normal sperm, the fertilized egg contains only one of the fourth chromosomes. It develops into a fly ("haplo-IV") that shows in many parts of its body slight differences from the normal fly (Fig. 29).

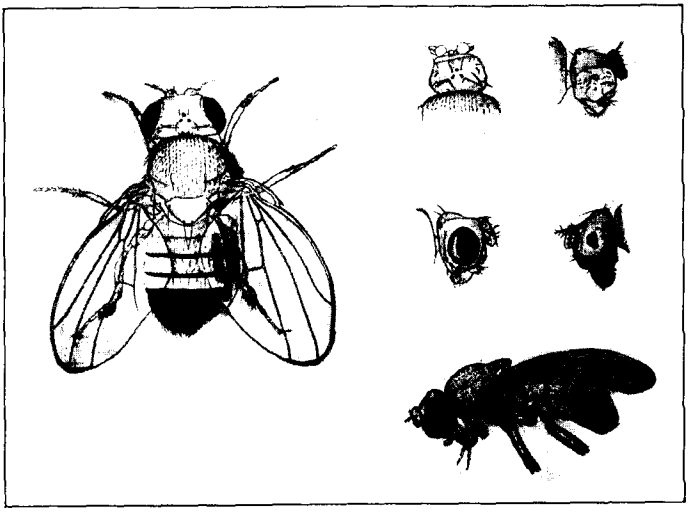

FIG. 30.

Characters in the fourth linkage group of D. melanogaster. To the left, bent wings; to the right (above), four heads showing "eyeless," one in dorsal, three in side view; below, and to the right, shaven.

The result shows that specific effects are produced when one of these chromosomes is absent, even in the presence of the other fourth chromosome.

There are three mutant elements or genes in this chromosome, namely, eyeless, bent, shaven (Fig. 30). All three are recessives. If a haplo-IV female is mated to a diploid eyeless male with two fourth chromosomes (each ripe sperm with one) some of the offspring that hatch are eyeless, and if the pupae that do not hatch are removed

from their pupa-cases and examined, more eyeless flies are detected. The eyeless fly has come from an egg that did not carry chromosome-IV and was fertilized by a sperm with chromosome-IV carrying the eyeless gene.

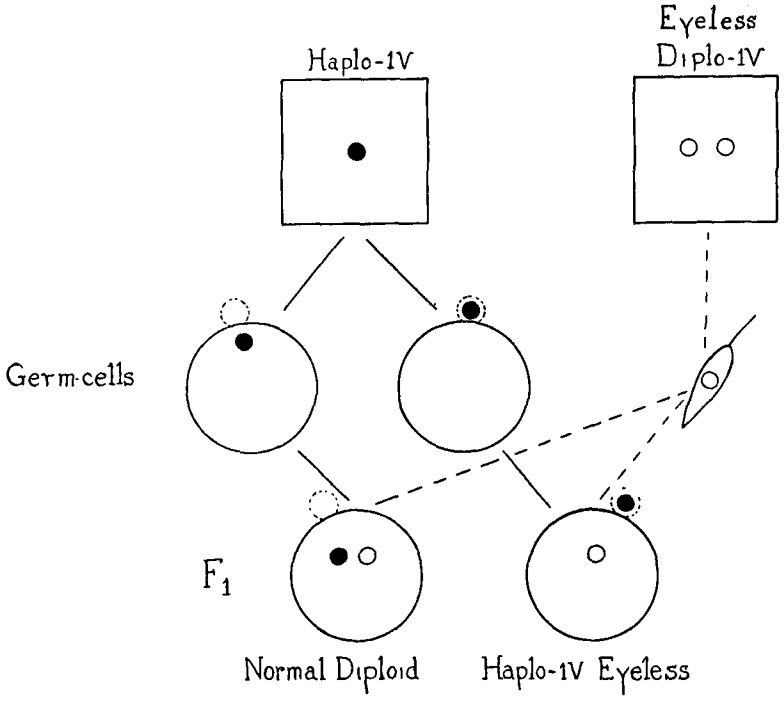

FIG. 31.

Diagram of a cross between a normal-eyed, haplo-IV fly, and an eyeless fly with two fourth chromosomes, each carrying a gene for eyeless. The fourth chromosome carrying the eyeless gene is here represented by an open circle, that for normal eyes by a black dot.

As shown in the diagram (Fig. 31), half of the flies should be eyeless, but most of these do not pass beyond the pupal stage, which means that the eyeless gene itself has a weakening effect on the individual, and that when to this is added the effects due to the absence of one of the fourth

chromosomes only a few such flies survive. The occurrence, however, of such recessive eyeless flies in the first generation corroborates the interpretation that the eyeless gene is carried by chromosome-IV.

The same results are obtained when the two other mutant genes, bent and shaven, are used in a similar

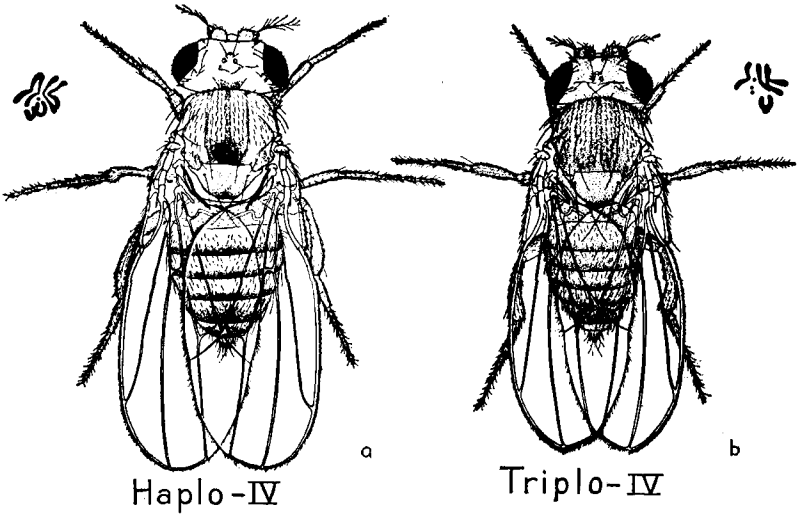

FIG. 32.

Haplo-IV and triplo-IV of D. melanogaster. The chromosome groups are represented, respectively, above to the left, and to the right of the figures.

experiment, but the proportion of recessive flies that hatch in F_1 is still smaller, indicating that these genes have an even greater weakening effect than the eyeless gene.

Occasionally flies arise in which three chromosome-IV's are present. These are triplo-IV's (Fig. 32). They also differ from the wild type in several, or many, perhaps in all their characters. The eyes are smaller, the body color is darker, and the wings are narrower. If a

triplo-IV is bred to an eyeless fly two kinds of offspring result (Fig. 33). Half are triplo-IV's, and half have the normal number of chromosomes, as shown in the diagram.

If, now, one of these triplo-IV flies is back-crossed to

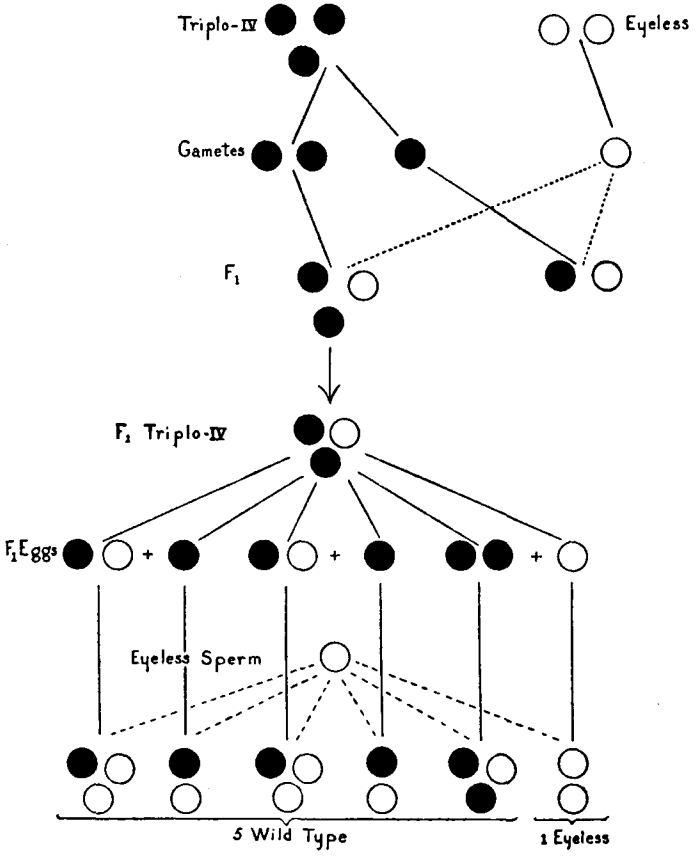

FIG. 33.

Diagram of a cross between a triplo-IV fly with normal eyes and a normal diploid fly, pure for eyeless. In the lower half of the diagram an F_1 triplo-IV fly (whose gametes are represented in "F_1 eggs") is crossed to a diploid eyeless fly (whose "eyeless sperm" is represented by the open circle), giving five kinds of flies in the ratio of five wild type eyes to one eyeless.

an eyeless fly (from stock) the expectation is that there will be five wild-type flies to one eyeless (Fig. 33, lower half) instead of equality as in the ordinary case when a heterozygous individual is back-crossed to its recessive. The diagram (Fig. 33) shows the recombinations of germ-cells that are expected to give rise to the 5 to 1 ratio. The actual number of eyeless obtained approximates expectation.

These and other experiments of the same kind show that the genetic results check up at every point with the known history of chromosome-IV. No one familiar with the evidence can doubt for a moment that there is something in this chromosome that is responsible for the observed results.

There is also evidence that the sex-chromosomes are the bearers of certain genes. In Drosophila there are as many as 200 characters whose inheritance is said to be sex-linked. This term means only that they are carried by the sex-chromosomes. It does not mean that the characters are confined to one or the other sex. Owing to the differential pair of sex-chromosomes in the male, the X and the Y, the inheritance of characters whose gene lies in the X-chromosomes is somewhat different from that of any of the other characters. There is evidence that the Y-chromosome does not contain in Drosophila any genes that conceal the recessives in the X. It may, therefore, be ignored except in so far as it acts as the mate of the X in the male at the reduction division of the sperm-cells. The mode of inheritance of linked characters of Drosophila has already been given in Chapter I (Figs. 11, 12, 13, 14). The mode of transmission of the sex-chromosome is given in Fig. 38. An examination of the latter shows that these characters follow the known distribution of the chromosome.

Occasionally the sex-chromosomes "go wrong," and

this slip furnishes an opportunity to study the changes that take place in sex-linked inheritance. The most common disturbance is due to the failure of the two X's in the female to disjoin at one of the maturation divisions. The process is called non-disjunction. If an egg that has

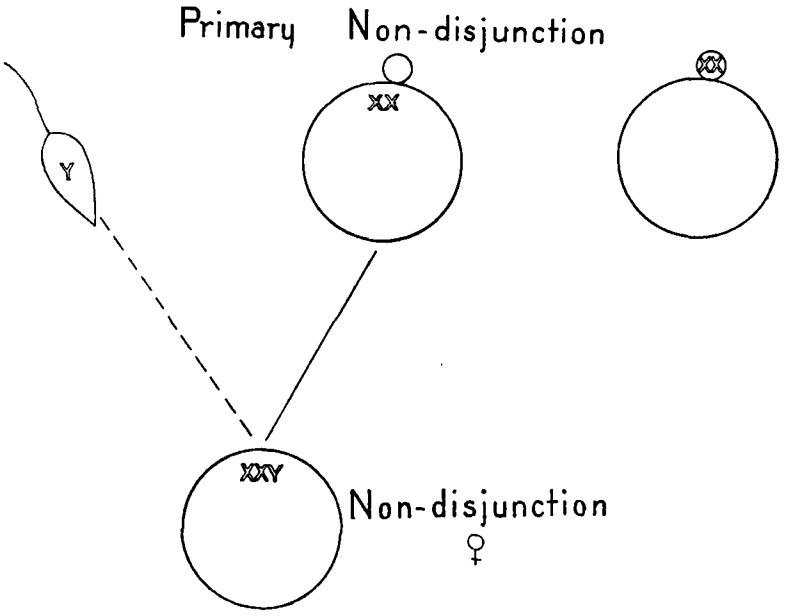

FIG. 34.

Diagram to show the fertilization of an XX-egg by a Y-sperm, producing a non-disjunctional XXY female.

retained its two X-chromosomes (and one of each of the other chromosomes, Fig. 34) is fertilized by a Y-sperm, an individual is produced—a female—that has two X's and a Y. When the eggs of the XXY female mature, that is, when the reduction of the chromosomes takes place, some irregularity is introduced in the distribution of the

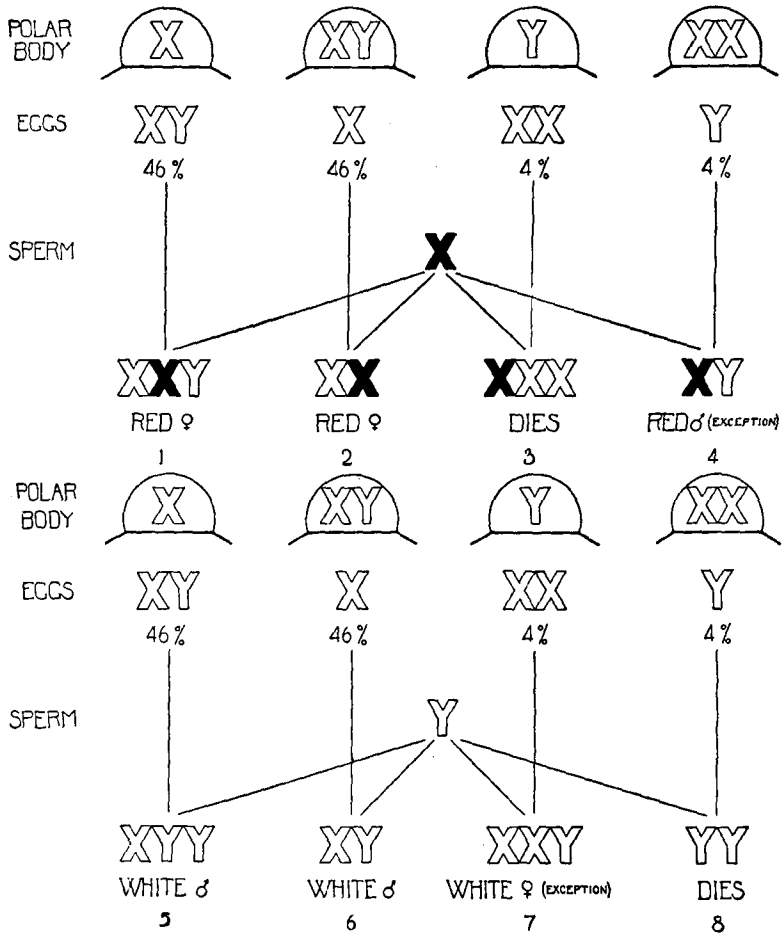

Fig. 35.

Diagram illustrating the fertilization of an XXY-egg, whose X-chromosomes carry each the gene for white eyes, by a red-eyed male. In the upper half of the diagram the fertilization of the four possible kinds of eggs by the red-eyed producing X-chromosome of the male is shown. In the lower part of the diagram the fertilization of the same four kinds of eggs by the Y-chromosome of a male is shown.

two X's and the Y, because the X's may conjugate, leaving the Y free to move to either pole, or one X and the Y may mate, leaving a free X. Possibly all three may come together, and then separate so that two go to one pole of the maturation spindle and one to the opposite pole. The results are practically the same in either case. Four kinds of eggs are expected, as shown in the diagram (Fig. 35).

In order to follow the genetic changes it is necessary that the X-chromosomes of the female or of the male carry one or more recessive genes. For instance, if the two X's in the female carry each the gene for white eyes, and the X in the male carries the allelomorphic gene for red eyes, and if the former are indicated by open (white) X's and the latter by a black X (Fig. 35), the combinations that result are those indicated in the diagram (Fig. 35). Eight kinds of individuals are expected, one of which (YY), not containing even one X-chromosome, is expected to die. In fact, this individual does not appear. Two of these individuals, *viz.*, No. 4 and No. 7, never appear when an ordinary white-eyed (XX) female is fertilized by a red-eyed male. Their presence here, however, is in accord with the expectation from an XXY white-eyed female. They have been tested by genetic evidence and found to correspond to the formula here given them. Furthermore, the white-eyed XXY female has been also shown, by cytological examination, to have two X's and a Y in her cells.

There is one additional kind of female expected that has three X-chromosomes. The diagram indicates that she dies, and this happens in the great majority of cases; but rarely one comes through. She has certain peculiarities by which she can be easily identified. She is sluggish, her wings are short and often irregular (Fig. 36) and she is sterile. A microscopic examination of her cells has shown that she contains three X-chromosomes.

This evidence points to the correctness of the theory

that the sex-linked genes are carried by the X-chromosomes.

There is another aberrant condition in the X-chromosomes that also supports this conclusion. A type of female arose whose genetic behavior could be explained

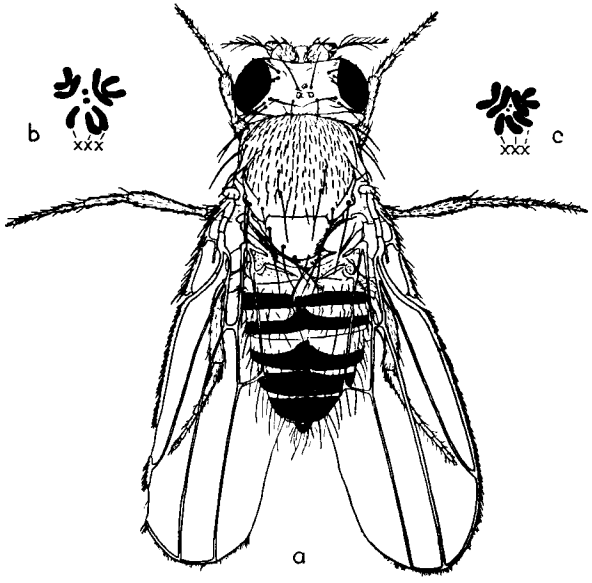

FIG. 36.

A three-X female, a, having three X-chromosomes and two of each of the other kinds (autosomes), as shown in b and c.

only on the assumption that her two X-chromosomes had become attached to each other. During the maturation division of her eggs both X's go together, *i.e.*, they both stay in the egg, or both go out together (Fig. 37). A microscopic examination shows in fact that the two X's of these females are stuck together end to end, and it shows also that these females contain a Y-chromosome that acts, presumably, as a mate of the two attached

chromosomes. The diagram gives the expected results when such a female is fertilized. By good fortune the X-chromosomes that became attached carried each the recessive gene for yellow wings. The presence of the two

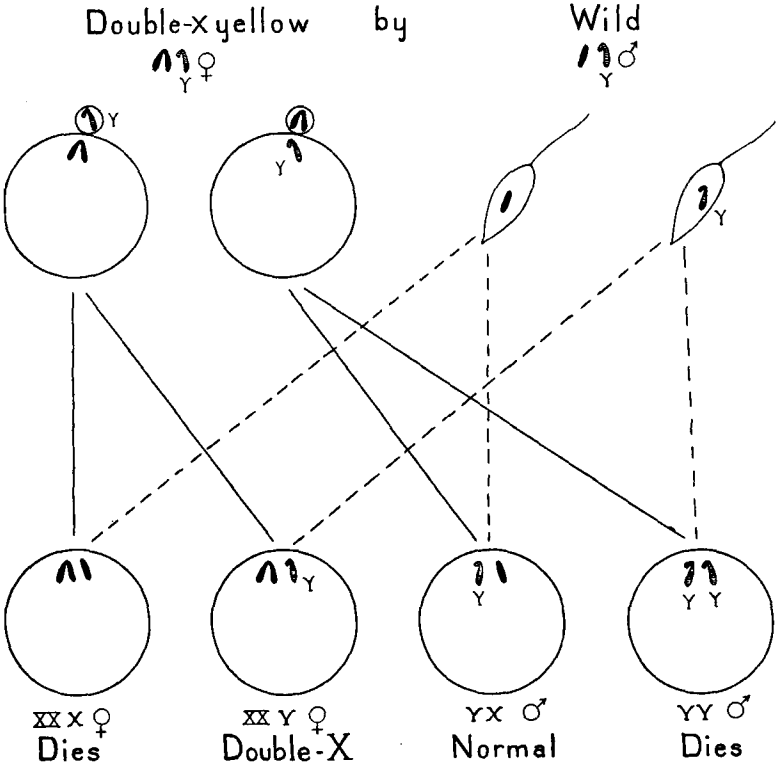

FIG. 37.

Diagram illustrating the fertilization of the two kinds of eggs of an attached, XX, yellow female (whose double X-chromosome is represented here in solid black) by wild type male. There is a Y-chromosome in the double-X female. It is represented here by cross-hatching. The Y-chromosome in the male is indicated in the same way. After reduction two kinds of eggs are present (see above to left). These fertilized by the two kinds of spermatozoa of the normal (wild type) male (see above to right) give the four classes at the bottom of the diagram.

genes for yellow enables us to follow the genetic history of the attached X's when such a female is bred to a normal wild type male with gray wings. For example: the diagram (Fig. 37) shows that two kinds of eggs are expected after the maturation division: one egg retains the double yellow X, the other egg retains the Y-chromosome. If these eggs are fertilized by any kind of male, preferably by one whose X-chromosome contains recessive genes, four kinds of offspring should be produced, two of which die. The two that survive are a double XXY female that is yellow, like her mother, and an XY male that is like his father with respect to his sex-linked characters because he gets his X from his father.

This result is exactly the reverse of what happens when a normal female with recessive genes is fertilized by a different kind of male, and the apparent contradiction is understandable, at once, on the assumption of attached X-chromosomes. A cytological examination of these double X females never fails to show two X's attached to each other.