

F, G, and K type spectra. This would be in agreement with the hypothesis of Eddington, already referred to, that the relation between velocity and spectral type might be a relation between velocity and distance, the stars nearest the sun, mainly the types F, G, and K, moving more rapidly than the distant stars. Eddington considered this hypothesis as disproved because an analysis of the A type stars indicated no increase of radial velocity with increasing proper motion. The fact that such an increase exists in the case of the later type stars, however, is shown clearly in Table I. Because of the slight range in proper motion a similar variation for the B and A stars is less certain, although indicated on the face of the results.

The principal feature of interest in this comparison of proper motion and radial velocity is the low average velocity found for the distant stars of types F to M. These stars are on the average stars of high absolute luminosity, and the possibility of a relationship between radial velocity and absolute luminosity has been considered in the communication by Kapteyn and Adams, to which reference has already been made. The observational material included here is much too limited to provide the basis for a discussion of this question. It may be noted, however, that the average radial velocity corrected for the solar motion of such absolutely faint stars as have been observed at Mount Wilson is exceptionally great. The average velocity of sixteen stars with absolute magnitudes below 8 on a scale for which the sun is 5.5 is 36 km. Eight have velocities exceeding 40 km. Since these stars are probably of small mass the evidence so far as it goes is in favor of Halm's hypothesis⁵ of the equipartition of energy among the stars, their motions being a function of their masses.

¹ *British Association Report*, 1911.

² These PROCEEDINGS, 1, 14 (1915).

³ *Lick Obs. Bull.*, No. 196.

⁴ *Stellar Movements and the Structure of the Universe*, p. 157.

⁵ *London, Mon. Not. R. Ast. Soc.*, 71, 634 (1911).

LOCALIZATION OF THE HEREDITARY MATERIAL IN THE GERM CELLS

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It has come to be recognized that it must be more than a coincidence that in each animal and plant there are two representatives of each hereditary character (one derived from the mother and one derived from

the father), and that there are two of each kind of chromosome (one derived from the mother and one derived from the father). Moreover, this relation becomes much more impressive when it is found that in the formation of the germ cells the representatives of the different characters separate from each other, and that the chromosomes separate also, so that each germ cell has but one set of factors and but one set of chromosomes. The comparison does not stop even here, and I propose to review briefly the further evidence that leads to the conclusion that the chromosomes are the bearers of the hereditary characters and that the known chromosomal behavior suffices as a mechanism to explain Mendel's law.

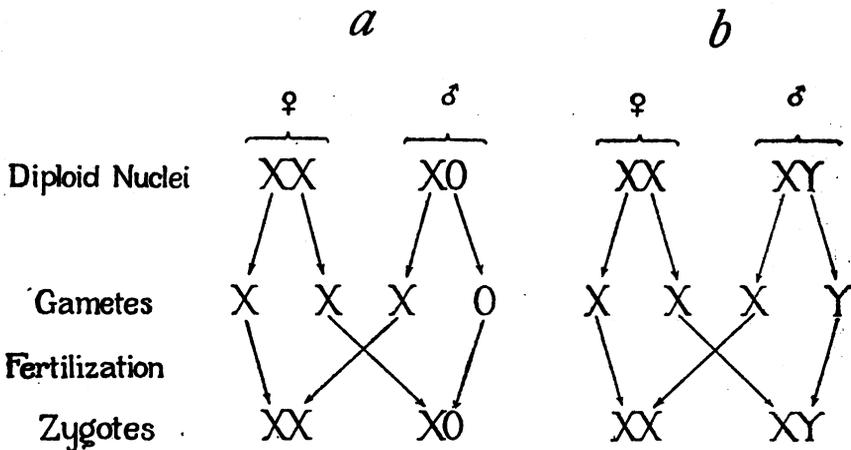


FIG. 1. DIAGRAMS OF SEX DETERMINATION; A, TYPE IN WHICH THE FEMALE IS XX AND THE MALE XO; B, TYPE IN WHICH THE FEMALE IS XX AND THE MALE XY.

Sex Linked Inheritance and the Sex Chromosomes. There is one exception to the rule of the dual nature of the chromosomes and at the same time an exception to the rule of the dual nature of the hereditary factors. In many species of animals it has been shown that while there are two sex chromosomes in the female, there is only one in the male (fig. 1 a). It is true in other animals often closely related to these, that the male may have one sex chromosome like the two in the female, and in addition a smaller Y chromosome, and in a few cases the Y may be as large as the X (fig. 1 b). In *Drosophila* there is an XY pair in the male, but the Y chromosome has been shown not to carry any factors that affect the characters due to factors carried by the X chromosomes. The influence of the Y is therefore nil, and the results are the same as though no Y were present.

The unequal distribution of the X chromosomes in the two sexes has furnished an opportunity to examine the theory that the chromosomes are the bearers of the hereditary factors, because it can be shown that the inheritance of a certain class of characters follows the known distribution of the sex chromosomes. For example, color blindness in man is inherited in the following way (figs. 2 and 3). A color blind man married to a normal woman (fig. 2) produces normal sons and daughters. If two individuals that have had this origin should marry each other, the daughters will all be normal, half of the sons will be normal but half will be color blind. In other words the color blind grandfather has transmitted his defect to none of his granddaughters, but to half of his grandsons. If we assume that color blindness is due to factors carried by the X chromosomes—in this case by the single X chromosome of the grandfather—the inheritance of the chromosome (to the right) and of the defect (to the left) is the same, as shown by the scheme (fig. 2).

Conversely if a color blind female is married to a normal male (fig. 3), all of the sons will be color blind, but all of the daughters will be normal. If such a color blind male (or any color blind male in fact) is mated with a female having this origin, half of the daughters will be color blind, half normal; half of the sons will be color blind, half will be normal. In other words the color blind grandmother transmits her defect to all of her sons, and to half of her granddaughters and to half of her grandsons. The inheritance of the chromosomes and of the defect is strictly parallel in this case also, as seen in the diagram (fig. 3). In the fruit-fly *Drosophila ampelophila*) there have been found over 40 sex-linked characters all of which are inherited according to the scheme given above. Moreover all possible combinations and tests that have been made—and there are many ways of testing such a conclusion—have given results that are entirely consistent with this scheme.

Linkage. If the hereditary characters are carried by the chromosomes we should expect that there would be great groups of characters that go together in inheritance, because while the number of the chromosomes is limited the number of the hereditary characters must be very great.

In *Drosophila* the number of pairs of chromosomes is only four, while over one hundred mutant characters have been studied. These characters fall into four great groups. The names of some of these characters that involve nearly all parts of the body, are given in the following list:

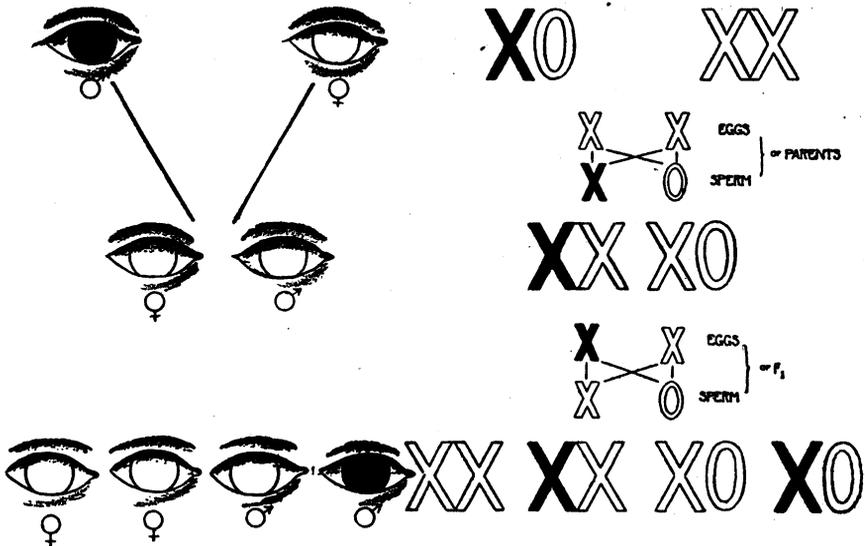


FIG. 2. DIAGRAM OF INHERITANCE OF COLOR BLINDNESS IN MAN. THE COLOR BLIND EYE AND THE X CHROMOSOME THAT CARRIES THE FACTOR FOR COLOR BLINDNESS ARE REPRESENTED IN SOLID BLACK. IN THIS DIAGRAM THE CHARACTER ENTERS THROUGH MALE.

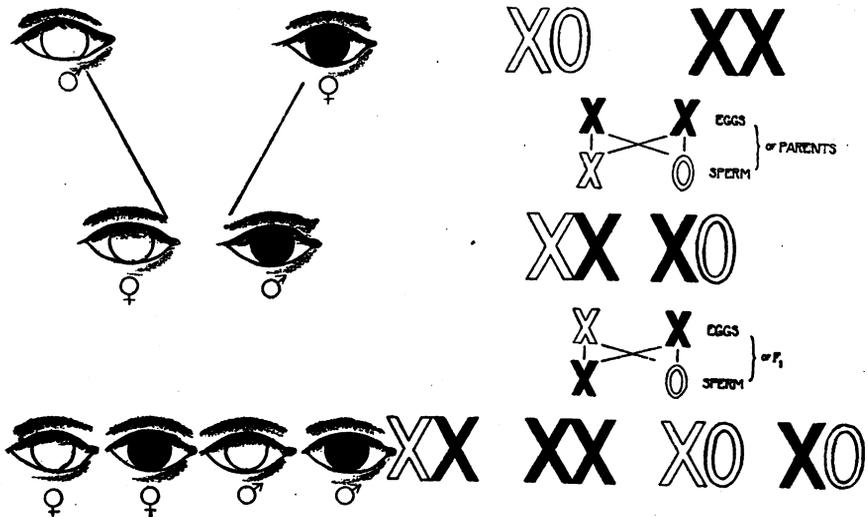


FIG. 3. AS IN FIG. 2, BUT HERE THE COLOR BLINDNESS ENTERS THROUGH THE FEMALE.

<i>Group I</i>	<i>Group II</i>	<i>Group III</i>	<i>Group IV</i>
Abnormal	Antlered	Band	Bent
Bar	Apterous	Beaded	Eyeless
Bifid	Arc	Cream III	
Bow	Balloon	Deformed	
Cherry	Black	Dwarf	
Chrome	Blistered	Ebony	
Cleft	Comma	Giant	
Club	Confluent	Kidney	
Depressed	Cream II	Low crossing over	
Dotted	Curved	Maroon	
Eosin	Dachs	Peach	
Facet	Extra vein.	Pink	
Forked	Fringed	Rough	
Furrowed	Jaunty	Safranin	
Fused	Limited	Sepia	
Green	Little crossover	Sooty	
Jaunty	Morula	Spineless	
Lemon	Olive	Spread	
Lethal's, 13	Plexus	Trident	
Miniature	Purple	Truncate intensifier	
Notch	Speck	Whitehead	
Reduplicated	Strap	White ocelli	
Ruby	Streak		
Rudimentary	Trefoil		
Sable	Truncate		
Shifted	Vestigial		
Short			
Skee			
Spoon			
Spot			
Tan			
Truncate intensifier			
Vermilion			
White			
Yellow			

A group consists of those characters that are inherited together, or rather *tend* to be inherited together. The chromosome groups of the male and of the female of *Drosophila ampelophila* are shown in figure 4. There is a pair of sex chromosomes, two pairs of large chromosomes, and a very small pair—four pairs in all. The coincidence between the number of hereditary groups and of the chromosomes is sufficiently evident to render comment unnecessary.

Crossing over. I have said that the characters that belong to the first group tend to be inherited together. Thus, if a fly with white eyes and yellow wings be crossed to the wild type, having red eyes and gray wings, the second generation of flies will be white yellow and gray red gray, *except* that once in a hundred times a fly will be found that is white

gray or else red yellow. In other words an exchange of characters has in some way taken place, but not oftener than once in a hundred times. We can see the exchange taking place in the reverse way if we cross a white eyed, gray winged fly to a red eyed, yellow winged fly. In the second generation the flies will now be white gray and red yellow, except that once in a hundred times a fly will appear that is white yellow or red gray.

Now if at the time when the chromosomes conjugate the two like chromosomes should exchange pieces, a consistent explanation of the results described above can be given. As a matter of fact there are several stages before, during and after conjugation of the chromosomes when interchange of pieces might take place. One of the phases is il-



FIG. 4. DIAGRAMS OF THE CHROMOSOMES OF *DROSOPHILA AMPELOPHILA*: TO THE LEFT, NORMAL FEMALE; IN THE MIDDLE, NORMAL MALE; TO THE RIGHT, NON-DISJUNCTIONAL FEMALE.

lustrated in the following diagram (fig. 5). Two homologous chromosomes are represented as each made up of a single line of beads. During conjugation, like chromosomes come together, and as they unite they can be seen often to twist around each other in consequence of which the parts come to line up on opposite sides of each other, as shown in the figure. When the chromosomes move apart the beads on one side are represented as passing to one pole, and those on the opposite side to the other pole; this means that during conjugation the pairs of factors, here represented by the beads, segregate independently of each other, and that the forces that draw the beads apart are often stronger than those that hold consecutive beads in their original line or series.

It may then, I think, be fairly claimed that the facts of crossing-over which must be due to interchange between homologous chromosomes, if chromosomes be admitted as the bearers of the hereditary factors, can be accounted for without departing from the known behavior of the chromosomes at the time of conjugation. On the other hand it should be clearly understood that the conclusion as to the way in which the

interchange takes place is not as yet on the same footing as are the other relations previously described.

Non-disjunction. In some experiments carried out by Mr. C. B. Bridges a race of flies was found that gave in 5% of cases exceptional results. There were $2\frac{1}{2}\%$ of males that were like their father (patroclinous) when the expectation was that all of the males should be like their mother, in the sex-linked character in question; and there were $2\frac{1}{2}\%$ of females that were like their mother (matroclinous) when the expectation was that they should all be like their father. From certain evidence that I can not now consider, Bridges was led to suspect that an additional sex chromosome was present in the mother that gave these

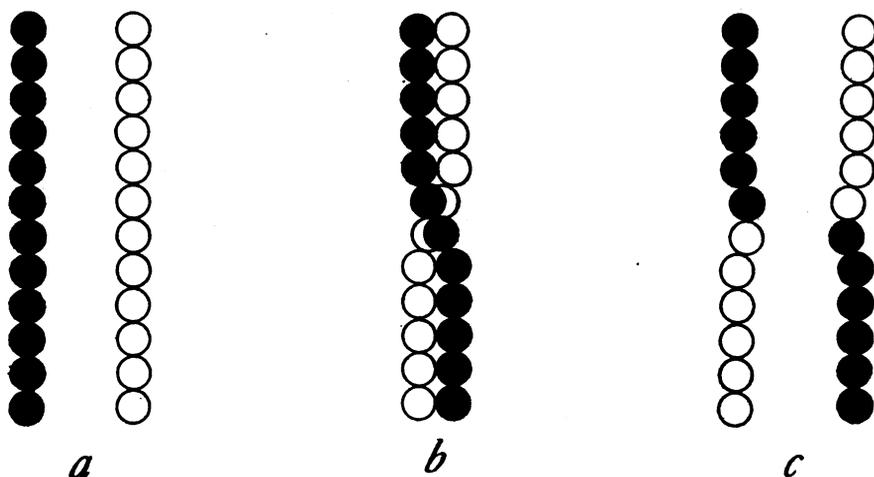


FIG. 5. DIAGRAM ILLUSTRATING CROSSING OVER OF THE MEMBERS OF A PAIR OF HOMOLOGOUS CHROMOSOMES REPRESENTED BY A SERIES OF BLACK AND A SERIES OF WHITE CIRCLES.

results; and from certain genetic evidence it was predicted that this chromosome could be none other than the Y chromosome. A cytological study of these females has demonstrated that the inference was correct.

These XXY females contain three elements that might be expected to come together during conjugation. The following situation then arises: X and X may conjugate and later pass to opposite poles (one going into the polar body), and Y would then be left to go to either pole. Two classes of eggs would result namely XY and X eggs. On the other hand X and Y might conjugate and pass to opposite poles (one going into the polar body) and the other X would then be left to go to either pole. The two classes of eggs that would result are XX

and XY. There would be expected then, in all, four classes of eggs from an XXY female. These might be fertilized by the female producing sperm of a male with the results shown in (1), (2), (3), (4) of figure 6; or by a male producing sperm with the results shown in the lower line of the same figure (5), (6), (7), (8). If the XXY female were a white eyed female (her two white bearing X's are represented by

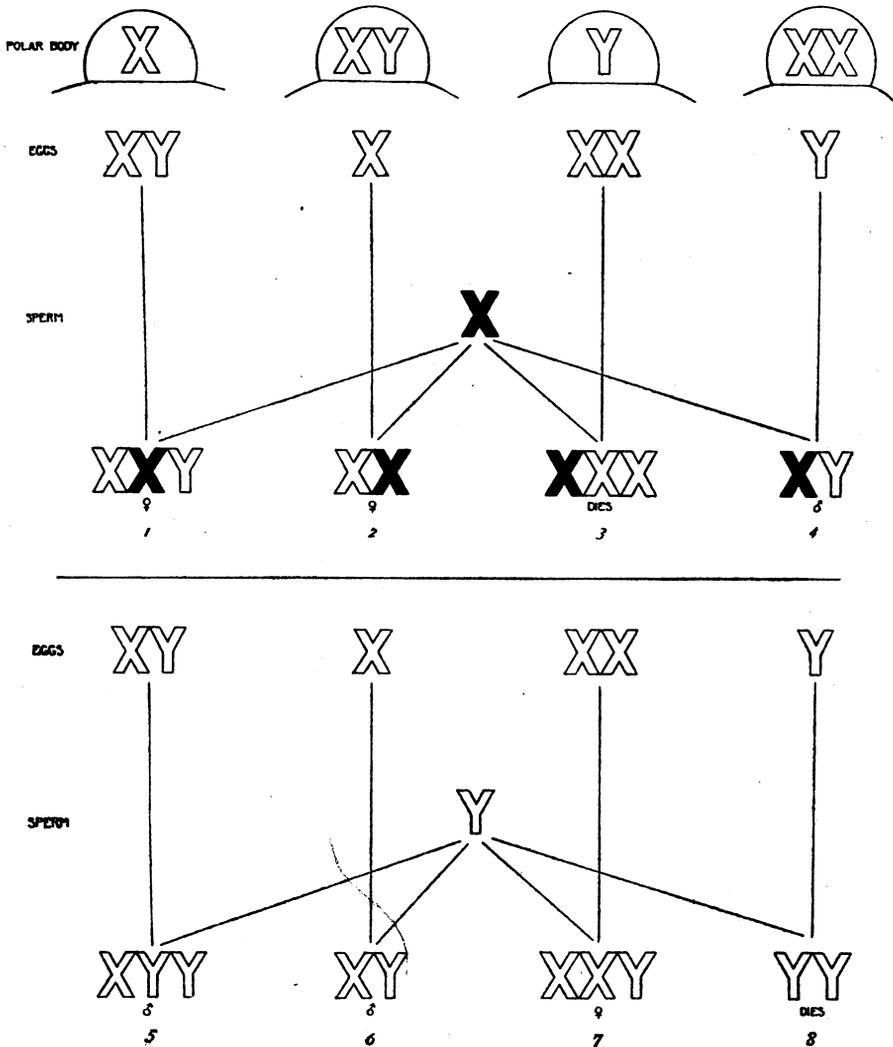


FIG. 6. DIAGRAM TO ILLUSTRATE THE PRODUCTION OF FOUR CLASSES OF EGGS OF A WHITE EYED FEMALE THROUGH NON-DISJUNCTION, AND THEIR FERTILIZATION BY AN X-BEARING SPERM, GIVING ZYGOTES 1, 2, 3, 4; AND BY Y-BEARING SPERM, GIVING ZYGOTES 5, 6, 7, 8.

the two open X's in the diagram) and if she were fertilized by a red eyed male (whose single X is represented by the black X in the diagram) the offspring will be expected to fall into the eight classes shown in the same diagram. The exceptional sons (4) arise when a Y bearing egg is fertilized by a female producing sperm (which here carries the factor for red). Thus a female producing sperm gives rise to a male, because maleness results from one X and not from anything else in the nature of the sperm that made him. The exceptional daughters (7) are the white eyed XXY females which arise when an XX egg is fertilized by a male producing sperm. Here again we see that femaleness is due to the occurrence of two X chromosomes, and it makes no difference whence these two X's have come.

There are many ways in which the hypothesis that non-disjunction is due to the presence of a Y chromosome, in the females that give these unique results, can be tested. For instance, the exceptional white

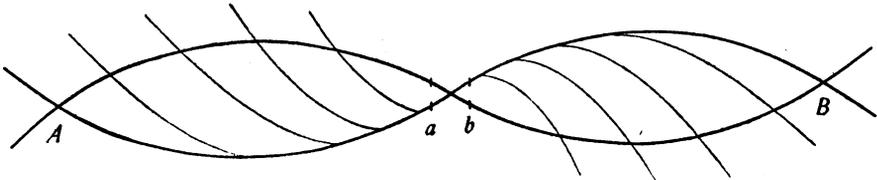


FIG. 7. DIAGRAM TO ILLUSTRATE INTERFERENCE: THE DISTANCE BETWEEN THE POINTS WHERE THE HEAVY LINES CROSS REPRESENTS THE AVERAGE DISTANCE BETWEEN TWO POINTS OF CROSSING OVER; THE LIGHTER LINES INDICATE THE LESS FREQUENT POINTS OF CROSSING OVER IN THE PROTECTED REGION.

females should repeat the non-disjunctional process. In fact, all such white females give non-disjunction. On the other hand the exceptional red males should neither give, nor transmit, non-disjunction, and this has been found to be true. The red females should be of two kinds; half (2) are expected to behave like normal females, and half (1) should show non-disjunction. These two kinds of females are found, and in equal numbers. There are two kinds of white males, XYY (5), and XY (6). The former should produce some XY spermatozoa. Such sperm would produce daughters, that would be XXY in composition, and from them non-disjunctional offspring are to be expected. This also has been tested and it has been found that half of the white males transmit through their daughters the peculiarity of non-disjunction. A diagram of a chromosome group of an XXY female is shown in figure 4.

Interference. If there is an average length of loop between crossing-over points, it would seem to follow that the region of the chromosomes on each side of the point where crossing over occurs would be pro-

tected, as it were, from another crossing over. This relation is illustrated in the diagram (fig. 7). If crossing over occurs at some point between two pairs of factors a and b indicated on the diagram, the next crossing over point of the chromosome would, if it occurred at all, lie at some distance away, rather than near by. This possibility can be tested in a case where several known points are present in a pair of chromosomes. If in such a case we determine how often crossing over occurs between A and a in general and then determine how often it occurs between A and a in those cases where it is known to have taken place between a and b , we find an enormous decrease in the number of times it occurs between A and a when at the same time it has occurred between a and b . In general one may say that crossing over at any level interferes with crossing over in the region of each side of that level.

Conclusions. The chromosomes not only furnish a mechanistic explanation of Mendelian heredity, but in the case of Non-disjunction and in the case of the point by point correspondence between the Linkage Groups and the chromosomes, furnish a *verifiable* explanation of the results. In the case of Crossing-over and of Interference the chromosomes give us the only objective explanation of the results that has been as yet offered.

RESEARCHES ON THE CHEMICAL AND MINERALOGICAL COMPOSITION OF METEORITES

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The primary motive of these investigations was to test the authenticity of numerous reported occurrences of certain minor constituents, such as antimony, arsenic, gold, lead, tin, tungsten, uranium, zinc, etc., and incidentally to formulate the analyses in such a way that the results might be made comparable with those of terrestrial rocks. Upwards of twenty meteorites were subjected to searching chemical analyses, with the particular end in view stated above. The results were in part confirmatory and in part contradictory. In none of the samples tested, either metallic or stony, could any traces be discovered of antimony, arsenic, gold, lead, tin, tungsten, uranium, or zinc. The presence in traces of platinum, palladium, iridium, ruthenium, and vanadium was, however, proved beyond apparent question, ruthenium being noted for the first time, and vanadium having previously been reported but once.