GENETICS

The Theory of The Gene

"A Classic of Science"

Dr. Morgan's theory explains the mechanism by which inherited traits, following the laws of Mendel, are handed on, in various combinations, from generation to generation.

THE THEORY OF THE GENE, by Thomas Hunt Morgan. New Haven, MDCCCCXXVI (1926).

MENDEL'S paper was recovered in 1900. Four years later Bateson and Punnett reported observations that did not give the numerical results expected for two independent pairs of characters. For instance, when a sweet pea having purple flower-color and long pollen grains is crossed to one with red flowers and round pollen grains, the two types that go in together come out together more frequently than expected for independent assortment of purple-red and long-round. They spoke of these results as due to repulsion between the combinations purple and long and red and round, that went from opposite parents. Today these relations are called linkage. By linkage we mean that when certain characters enter a cross together, they tend to remain together in later generations, or, stated in a negative way, certain pairs of characters do not assort at random.

It would seem, then, so far as linkage holds, that there are limits to the subdivision of the germinal material. For example in the vinegar fly, *Drosophila melanogaster,* there are known about 400 new mutant types that fall into only four linkage groups.

One of these groups of characters of Drosophila is said to be sex-linked, because in inheritance the characters show certain relations to sex. There are about 150 of these sex-linked mutant characters. Several of them are modifications of the color of the eye, others relate to its shape or its size, or to the regularity of the distribution of its facets. Other characters involve the body color; others the shape of the wings, or the distribution of its veins; others the spines and hairs that cover the body.

A second group of about 120 linked characters includes changes in all parts of the body. None of the effects are identical with those of the first group.

A third group of about 130 characters also involves all parts of the body. None of these characters are the same as those of the other two groups.

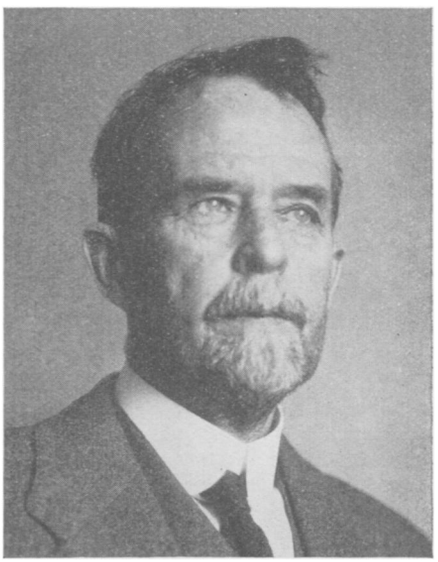
There is a small fourth group of only three characters: one involves the size of the eyes, leading in extreme cases to their total absence; one involves the mode of carriage of the wings; and the third relates to the reduction in size of the hairs.

The method of inheritance of linked characters is given in the following example. A male Drosophila with four linked characters (belonging to the second group), black body color, purple eyes, vestigial wings, and a speck at the base of the wings, is crossed to a wild type female with the corresponding normal characters, that may be called gray body color, red eyes, long wings, and absence of speck. The offspring are wild type. If one of the sons is now crossed to a stock female having the four recessive characters (black, purple, vestigial, speck), the offspring are of two kinds only, half are like one grandparent with the four recessive characters, and the other half are wild type like the other grandparent.

Two sets of contrasted (or allelomorphic) linked genes went into this cross. When the germ-cells in the male hybrid matured, one of these sets of linked genes went into half of the sperm-cells and the corresponding allelomorphic set into the wild type half of the sperm-cells. This was revealed, as described above, by crossing the hybrid (F_1) male to a female pure for the four recessive genes. All of her mature eggs contain one set of four recessive genes. Any egg fertilized by a sperm with one set of the dominant wild type genes should give a wild type fly. Any egg fertilized by a sperm with the four recessive genes (which are the same as those in the female here used) should give a black, purple, vestigial, speck fly. These are two kinds of individuals obtained.

Crossing-Over

The members of a linked group may not always be completely linked as in the case just given. In fact, in the F_1 female from the same cross, some of the recessive characters of one series



DR. THOMAS HUNT MORGAN
Formulator of the theory of the genes as bearers of heredity.

may be interchanged for wild type characters from the other series, but even then, since they remain united more often than they interchange, they are still said to be linked together. This interchange is called crossing-over, which means that, between two corresponding linked series, there may take place an orderly interchange involving great numbers of genes . . .

Linear Order of the Genes

It is self-evident that if two pairs of genes should be near together, the chance that crossing-over occurs between them is smaller than if they are further apart. If two other genes are still further apart the chance of crossing-over is correspondingly increased. We may utilize these relations to obtain information as to the "distance" at which any two pairs of elements lie with respect to each other. With this information we can construct charts of the series of elements in each of the linkage groups. This has been done for all the linkage groups of Drosophila . .

In the preceding illustrations of linkage and crossing over, that have been given, the genes are represented as lying in a line—like beads on a string. The numerical data from crossing-over

show, in fact, that this arrangement is the only one that is consistent with the results obtained, as the following example will serve to illustrate.

Suppose that crossing-over between yellow wings and white eyes occurs in 1.2 per cent of cases. If we then test white with a third member of the same series, such as bifid wings, we find 3.5 per cent of crossing-over. If bifid is in line and on one side of white it is expected to give with yellow 4.7 per cent crossing-over, if on the other side of white it is expected to give 2.3 per cent of crossing-over with yellow. In fact, it gives one of these values, namely, 4.7. We place it, therefore, below white in the diagram. This sort of result is obtained whenever a new character is compared with two other members of the same linkage group. The crossing-over of a new character is found to give, in relation to two other known factors, either the sum or the difference of their respective cross-over values. This is the known relation of points on a line, and is the proof of the linear order of the genes; for no other spatial relation has yet been found that fulfills these conditions.

Theory of the Gene

We are now in a position to formulate the theory of the gene. The theory states that the characters of the individual are referable to paired elements (genes) in the germinal material that are held together in a definite number of linkage groups; it states that the members of each pair of genes separate when the germ-cell matures in accordance with Mendel's first law, and in consequence each germ-cell comes to contain one set only; it states that the members belonging to different linkage groups assort independently in accordance with Mendel's second law; it states that an orderly interchange—crossing-over—also takes place, at times, between the elements in corresponding linkage groups; and it states that the frequency of crossing-over furnishes evidence of the linear order of the elements in each linkage group and of the relative position of the elements with respect to each other.

These principles, which taken together, I have ventured to call the theory of the gene, enable us to handle problems of genetics on a strictly numerical basis, and allow us to predict, with a great deal of precision, what will occur in any given situation. In these respects the theory fulfills the requirements of a scientific theory in the fullest sense. . . .

To What is the Mutation Process Due?

There remains . . . a problem of some interest, namely, whether some or many of the changes in the genes that lead to the occurrence of mutant characters (whether recessive, intermediate, or dominant makes little difference) may not be due to a breaking up of a gene, or to its reconstitution into another element producing somewhat different effects. There is, however, no reason for assuming that such change, if it occurs, is a downhill one rather than the development of a more complex gene, unless it appears more probable, *a priori,* that a highly complex stable compound is more likely to break down than to build up. Until we know more concerning the chemical constitution of the genes, and how they grow and divide, it is quite futile to argue the merits of the two sides of the argument. For the genetic theory it is only necessary to assume that any kind of a change may suffice as a basis for what is observed to take place.

It is equally futile to discuss, at present, whether new genes arise independently of the old ones, and worse than futile to discuss how the genes arose in the first instance. The evidence that we have furnished no grounds whatsoever for the view that new genes independently arise, but it would be extremely difficult, if not impossible, to show that they do not arise. . . .

Are Genes of the Order of Organic Molecules?

The only practical interest that a discussion of the question as to whether genes are organic molecules might have would relate to the nature of their stability. By stability we might mean only that the gene tends to vary about a definite mode, or we might mean that the gene is stable in the sense that an organic molecule is stable. The genetic problem would be simplified if we could establish the latter interpretation. If, on the other hand, the gene is regarded as merely a quantity of so much material, we can give no satisfactory answer as to why it remains so constant through all the vicissitudes of outcrossing, unless we appeal to mysterious powers of organization outside the genes that keep them constant. There is little hope at present of settling the question. A few years ago I attempted to make a calculation as to the size of the gene in the hope that it might throw a little light on the problem, but at present we lack sufficiently exact measurements to make such a calculation more than a speculation. It seemed to show that the order of magnitude of the gene is near that of the larger-sized organic molecules. If any weight can be attached to the result it indicates, perhaps, that the gene is not too large for it to be considered as a chemical molecule, but further than this we are not justified in going. The gene might even then not be a molecule but only a collection of organic matter not held together in chemical combination.

When all this is given due weight it nevertheless is difficult to resist the fascinating assumption that the gene is constant because it represents an organic chemical entity. This is the simplest assumption that one can make at present, and since this view is consistent with all that is known about the stability of the gene it seems, at least, a good working hypothesis.

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ORNITHOLOGY

Pigeon Vaccine Prevents Fowl Pox

CHICKENS can now be protected from fowl pox, a highly infectious disease that often plays havoc with flocks, by a new vaccine made from pigeons. The vaccine was developed by Capt. T. M. Doyle of the Veterinary Laboratory, Ministry of Agriculture for Great Britain.

Fowls treated with it acquire immunity against fowl pox both under laboratory conditions and also in ordinary commercial practice. The immunity is fully established about the fourteenth day after the chickens are inoculated.

The vaccine does not give rise to any loss of condition or constitutional disturbance, nor does it seem to interfere with egg production. During the past six months, 50,000 doses of the vaccine have been given to infected fowls. The results were all excellent except in one case, and in that case it is just possible that the fowl was suffering from some disease other than fowl pox.

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