On Conceptions of the Processes of Heredity.*

By Miss E. R. SAUNDERS, F.L.S.

I.

BY the term "inheritance" we are accustomed to signify the obvious fact of the resemblance displayed by all living organisms between offspring and parents, as the direct outcome of the contributions received from the two sides of the pedigree at fertilisation; to indicate, in fact, owing to lack of knowledge of the workings of the hereditary process, merely the *visible* consequence—the final result of a chain of events. Now, however, that we have made a beginning in our analysis of the stages which culminate in the appearance of any character, a certain looseness becomes apparent in our ordinary use of the word "heredity," covering as it does the two concomitant essentials, genetic potentiality and somatic expression—a looseness which may lead us into the paradoxical statement that inheritance is wanting in a case in which, nevertheless, the evidence shows that the genetic constitution of the children is precisely like that of the parents. When we say that a character is inherited no ambiguity is involved, because the appearance of the character entails the inheritance of the genetic potentiality. But when a character is stated not to be inherited it is not thereby indicated whether this result is due to environmental conditions, to genetic constitution, or to both causes combined. That we are now able in some measure to analyse the genetic potentialities of the individual is due to one of those far-reaching discoveries which change our whole outlook, and bring immediately in their train a rapidly increasing array of new facts, falling at once into line with our new conceptions, or by some orderly and constant discrepancy pointing a fresh direction for attack.

The earliest attempts to frame some general law which would co-ordinate and explain the observed facts of inheritance were those of Galton and Pearson. These schemes, however, take no account of the physiological nature of this as of all other processes in the living organism. They have, in consequence, failed to bring us nearer to our goal—a fuller comprehension of the workings of the hereditary mechanism. Progress in this direction has resulted from the method of inquiry which deals with the unit in place of the mass. The revelation came with the opening of the present century, for in 1900 was announced the re-discovery of Mendel's work, actually given to the world thirty-five years earlier, but at the time leaving no impress upon scientific thought. It chanced that in each pair of characters selected by Mendel for experiment the opposites are related to each other in the following simple manner: An individual which had received both allelomorphs, one from either parent, exhibited one of the two characteristics, hence called the dominant, to the exclusion of the other. Among the offspring of such an individual both characteristics appeared, the dominant in some, its opposite, the recessive, in others, in the proportion approximately of three to one. This is the result which might be expected from random pairing in fertilisation of two opposites, where the manifestation in the zygote of the one completely masks the presence of the other. As workers along Mendelian lines increased and the field of inquiry widened, it soon, however, became apparent that the dominant-recessive relationship is not of universal occurrence. It likewise became clear that the simple ratios which

obtained in Mendel's experiments are not characteristic of every case. Mendel's own results were all, as it happened, explicable on the supposition that the two alternative forms of each character were dependent on a *single* element or factor. We now know, however, that many characters are not controlled by one single factor, but by two or more. One of the most familiar instances of the two-factor character is the appearance of the colouring matter anthocyanin in the petals of plants such as the stock and sweet pea. Our proof that two factors (at least) are here involved is obtained when we find that two true breeding forms devoid of colour yield coloured offspring when mated together. In this case the two complementary factors are carried, one by each of the two crossed forms. When both factors meet in the one individual, colour is developed. We have in such cases the solution of the familiar, but previously unexplained, phenomenon of reversion. Confirmatory evidence is afforded when among the offspring of such cross-bred individuals we find the simple 3 to 1 ratio of the one-factor difference replaced by a ratio of 9 to 7. Similarly, we deduce from a ratio of 27 to 37 that three factors are concerned, from a ratio of 81 to 175 four factors, and so on. The occurrence of these higher ratios proves that the hereditary process follows the same course whatever the number of factors controlling the character in question.

And here I may pause to dwell for a moment upon a point of which it is well that we should remind ourselves from time to time, since, though tacitly recognised, it finds no explicit expression in our ordinary representation of genetic relations. The method of factorial analysis based on the results of inter-breeding enables us to ascertain the least possible number of genetic factors concerned in controlling a particular somatic character, but what the total of such factors actually is we cannot tell, since our only criterion is the number by which the forms we employ are found to differ. How many may be common to these forms remains unknown. In illustration I may take the case of surface character in the genera *Lychnis* and *Matthiola*. In *Lychnis viscaria* the type form is hairy; in the variety *glabra*, recessive to the type, hairs are entirely lacking. Here all glabrous individuals have so far proved to be similar in constitution, and when bred with the type give a 3 to 1 ratio in F_2 (Report to the Evolution Committee, Royal Society, i., 1902). We speak of hairiness in this case, therefore, as being a one-factor character. In the case of *Matthiola incana* v. *glabra*, of which many strains are in cultivation, it so happened that the commercial material originally employed in these investigations contained all except one of the factors since identified as present in the type and essential to the manifestation of hairiness. Hence it appeared at first that here also hairiness must be controlled, as in *Lychnis*, by a single factor. But further experiment revealed the fact that though the total number of factors contained in these glabrous forms was the same, the respective factorial combinations were not identical. By inter-breeding these and other strains obtained later, hairy F_1 cross-breds were produced giving ratios in F_2 which proved that at least four distinct factors are concerned (Proc. Roy. Soc., B, vol. lxxxv., 1912). Whereas, then, the glabrous appearance in *Lychnis* always indicates the loss (if for convenience we may so represent the nature of the recessive condition) of

* From the opening address of the President of Section K (Botany) delivered at the Cardiff meeting of the British Association on August 24.

one and the same factor, analysis in the stock shows that the glabrous condition results if *any factor out of a group of four* is represented by its recessive allelomorph. Hence we describe hairiness in the latter case as a four-factor character.

It will be apparent from the cases cited that we cannot infer from the genetic analysis of one type that the factorial relations involved are the same for the corresponding character in another. That this should be so in wholly unrelated plants is not, perhaps, surprising, but we find it to be true also where the nature of the characteristic and the relationship of the types might have led us to expect uniformity. This is well seen in the case of a morphological feature distinctive of the N.O. Gramineæ. The leaf is normally ligulate, but individuals are occasionally met with in which the ligule is wanting. In these plants, as a consequence, the leaf-blade stands nearly erect instead of spreading out horizontally. Nilsson-Ehle ("Kreuzungsuntersuchungen an Hafer und Weizen," Lund, 1909) discovered that in oats there are at least four, and possibly five, distinct factors determining ligule formation, all with equal potentialities in this direction. Hence, only when the complete series is lacking is the ligule wanting. In mixed families the proportion of ligulate to non-ligulate individuals depends upon the number of these ligule-producing factors contained in the dominant parent. Emerson (Annual Report of the Agricultural Experiment Station of the University of Nebraska, 1912) found, on the other hand, that in maize mixed families showed constantly a 3 to 1 ratio, indicating the existence of only one controlling factor.

From time to time the objection has been raised that the Mendelian type of inheritance is not exhibited in the case of specific characters. That no such sharp line of distinction can be drawn between the behaviour of varietal and specific features has been repeatedly demonstrated. As a case in point, and one of the earliest in which clear proof of Mendelian segregation was obtained, we may instance *Datura*. The two forms, *D. stramonium* and *D. tatula*, are ranked by all systematists as distinct species. Among other specific differences is the flower colour. The one form has purple flowers, the other pure white. In the case of both species a variety *inermis* is known in which the prickles characteristic of the fruit in the type are wanting. It has been found that in whatever way the two pairs of opposite characters are combined in a cross between the species, the F_2 generation is mixed, comprising the four possible combinations in the proportions which we should expect in the case of two independently inherited pairs of characters, when each pair of opposites shows the dominant-recessive relation. Segregation is as sharp and clean in the specific character flower colour as in the varietal character of the fruit.

Among the latest additions to the list of specific hybrids showing Mendelian inheritance, those occurring in the genus *Salix* are of special interest, since heretofore the data available had been interpreted as conflicting with the Mendelian conception. The recent observations of Heribert-Nilsson ("Experimentelle Studien über Variabilität, Spaltung, Artbildung und Evolution in der Gattung *Salix*," 1918) show that those characters which are regarded by systematists as constituting the most distinctive marks of the species are referable to an extremely simple factorial system, and that the factors mendelise in the ordinary way. Furthermore, these specific-character factors control not only the large constant *morphological features*, but

also *fundamental reactions* such as those determining the condition of physiological equilibrium and vitality in general. In so far as any distinction can be drawn between the behaviour of factors determining the varietal as opposed to the specific characters of the systematist, Heribert-Nilsson concludes that the former are more localised in their action, while the latter produce more diffuse results, which may affect almost all the organs and functions of the individual, and thus bring about striking alterations in the general appearance. *S. caprea*, for example, is regarded as the reaction product of two distinct factors which together control the leaf-breadth character, and also affect, each separately and in a different way, leaf form, leaf colour, height, and the periodicity of certain phases. We cannot, however, draw a hard-and-fast line between the two categories. The factor controlling a varietal characteristic often produces effects in different parts of the plant. For example, the factors which lead to the production of a coloured flower no doubt also in certain cases cause the tinging seen in the vegetative organs, and affect the colour of the seed. Heribert-Nilsson suggests that fertility between species is a matter of close similarity in genotypic (factorial) constitution rather than of outward morphological resemblance. Forms sundered by the systematist on the ground of gross differences in certain anatomical features may prove to be more akin, more compatible in constitution, than others held to be more nearly related because the differentiating factors happen to control less conspicuous features.

Turning to the consideration of the more complex types of inheritance already referred to, we find numerous instances where a somatic character shows a certain degree of coupling or linkage with another perhaps wholly unrelated character. This phenomenon becomes still further complicated when, as is now known to occur fairly frequently, somatic characters are linked also with the sex character. The results of such linkages appear in the altered proportions in which the various combinations of the several characters appear on cross-breeding. Linkage of somatic characters can be readily demonstrated in the garden stock. Some strains have flowers with deeply coloured sap, e.g. full red or purple; others are of a pale shade, such as a light purple or flesh colour. In most commercial strains the "eye" of the flower is white owing to absence of colour in the plastids, but in some the plastids are cream-coloured, causing the sap colour to appear of a much richer hue and giving a cream "eye." Cream plastid colour is recessive to white, and the deep sap colours are recessive to the pale. When a cream-eyed strain lacking the pale factor is bred with a white-eyed plant of some pale shade, the four possible combinations appear in F_2 , but not, as we should expect in the case of two independently inherited one-factor characters, in the proportions 9:3:3:1, with the double recessive as the least abundant of the four forms. We find instead that the double dominant and the double recessive are both in excess of expectation, the latter being more abundant than either of the combinations of one dominant character with one recessive. The two forms which preponderate are those which exhibit the combinations seen in the parents, the two smaller categories are those representing the new combinations of one paternal with one maternal characteristic. In the sweet pea several characters are linked in this manner, viz. flower colour with pollen shape, flower colour with form of standard, pollen shape with form of standard, colour of leaf axil with functioning capacity of the anthers. If in these cases the cross happens to be made in such a way that the two dominant characters are

brought in one from each side of the pedigree instead of both being contributed by one parent, we get again a result in which the two parental combinations occur more frequently, the two recombinations or "cross-overs" less often than we should expect. In the first case the two characters appear to hang together in descent to a certain extent, but not completely; in the latter, similarly to repel each other.

This type of relationship has been found to be of very general occurrence. The linked characters do not otherwise appear to be connected in any way that we can trace, and we therefore conclude that the explanation must be sought in the mechanism of distribution. Two main theories having this fundamental principle as their basis, but otherwise distinct, have been put forward, and are usually referred to as the *reduplication* and the *chromosome* view respectively. The reduplication view, proposed by Bateson and Punnett (Proc. Roy. Soc., 1911), rests on the idea that segregation of factors need not necessarily occur simultaneously at a particular cell-division. The number of divisions following the segregation of some factors being assumed to be greater than those occurring in the case of others, there would naturally result a larger number of gametes carrying some factorial combinations and fewer carrying others. If this differential process is conceived as occurring in an orderly manner it would enable us to account for the facts observed. It has, however, to be said that we cannot say *why* segregation should be successive, nor at what moments, on this view, it must be presumed to occur. On the other hand, the conceptions embodied in the chromosome hypothesis as formulated by Morgan and his fellow-workers ("The Mechanism of Mendelian Heredity" (Morgan, Sturtevant, Muller, and Bridges), 1915) are, in these respects, quite precise. They are built around one cardinal event in the life-cycle of animals and plants (some of the lowest forms excepted), viz. the peculiar type of cell-division at which the number of chromosomes is reduced to half that to be found during the period of the life-cycle extending backwards from this moment to the previous act of fertilisation. In the large number of cases already investigated the chromosome number has been found, as a rule, to be the same at each division of the somatic cells. We can, in fact, take it as established that it is ordinarily constant for the species.

These observations lend strong support to the view that the chromosomes are persistent structures—that is to say, that the chromatin tangle of the resting nucleus, whether actually composed of one continuous thread or not, becomes resolved into separate chromosomes at corresponding loci at each successive mitosis. The reduction from the diploid to the haploid number, according to the more generally accepted interpretation of the appearances during the meiotic phase, is due to the adhering together in pairs of homologous chromosomes, each member of the set originally received from one parent lying alongside and in close contact with its mate received from the other. Later, these bivalent chromosomes are resolved into their components so that the two groups destined one for either pole consist of whole dissimilar chromosomes, which then proceed to divide again longitudinally to furnish equivalent half chromosomes to each of the daughter nuclei.

The obvious close parallel between the behaviour of the chromosomes—their pairing and separation—and that of Mendelian allelomorphs which similarly show pairing and segregation, first led to the suggestion that the factors controlling somatic characters are located in these structures. The ingenious extension of this view which has been elaborated by Morgan

and his co-workers presumes the arrangement of the factors in linear series after the manner of the visible chromomeres—the beadlike elements which can be seen in many organisms to compose the chromatin structure—each factor and its opposite occupying corresponding loci in homologous chromosomes. From this conception follows the important corollary of the segregation of the factors during the process of formation and subsequent resolution of the bivalent chromosomes formed at the reduction division. We should suppose, according to Morgan, in the case of characters showing *independent* inheritance and giving identical Mendelian ratios whichever way the mating is made and however the factorial combination is brought about, that the factors controlling the several characters are located in *different* chromosomes. Thus in the case of *Datura* already mentioned the two factors affecting sap-colour and prickliness respectively would be presumed to be located so far apart in the resting chromatin thread that when separation into chromosomes takes place they become distributed to different members. Where unrelated characters show a *linked* inheritance the factors concerned are held, on the other hand, to lie so near together that they are always located in one and the same chromosome. Furthermore—and here we come to the most debatable of the assumptions in Morgan's theory—when the bivalent chromosome composed of a maternal and a paternal component gives rise at the reduction division to two single dissimilar chromosomes, these new chromosomes do not always represent the original intact maternal and paternal components. It has been observed in many forms that the bivalent structure has the appearance of a twisted double thread.

Already in 1909 cytological study of the salamander had led Janssen (*La Cellule*, xxv.) to conclude that fusion might take place at the crossing points, so that when the twin members ultimately draw apart each is composed of alternate portions of the original pair. Morgan explains the breeding results obtained with *Drosophila* by a somewhat similar hypothesis. He also conceives that in the process of separation of the twin lengths of chromatin cleavage between the two is not always clean, portions of the one becoming interchanged with corresponding segments of the other, so that both daughter chromosomes are made up of complementary sections of the maternal and paternal members of the duplex chromosome. On the main issue, however, both schemes are in accord. A physical basis for the phenomenon of linkage is found in the presumed nature and behaviour of the chromosomes, viz. their colloidal consistency, their adhesion after pairing at the points of contact when in the twisted condition, and their consequent failure to separate cleanly before undergoing the succeeding division.

According to Morgan, the frequency of separation of linked characters is a measure of the distance apart in the chromosome of the loci for the factors concerned, and it becomes possible to map their position in the chromosome relatively to one another. In this attempt to find in cytological happenings a basis for the observed facts of inheritance, our conception of the material unit in the sorting-out process has been pushed beyond the germ-cell, and even the entire chromosome, to the component sections and particles of the latter structure.

To substantiate the "chromosome" view the primary requisite was to obtain proof that a particular character is associated with a particular chromosome. With this object in view it was sought to discover a type in which individual chromosomes could be identified. Several observers working on different animals found that a particular chromosome differing

in form from the rest could be traced at the maturation division, and that this chromosome was always associated with the sex-character in the following manner. The female possessed an even number of chromosomes so that each egg received an identical number, including this particular sex-chromosome. The male contained an uneven number, having one fewer than the female, with the result that half the sperms received the same number as the egg including the sex-chromosome, and half were deficient in this particular chromosome. Eggs fertilised with sperms containing the full number of chromosomes developed into females, while those fertilised with sperms lacking this distinctive chromosome produced males. Morgan made the further discovery in the fruit-fly, *Drosophila ampelophila*, that certain factors controlling various somatic characters were located in the sex-chromosome. The inheritance of these characters

and of sex evidently went together. The sperms of *Drosophila* are therefore conceived as of two kinds, one containing the same sex-chromosome as the eggs, the so-called X chromosome, and the other a mate of a different nature, the Y chromosome, which appears to be inert and unable to carry the dominant allelomorphs.

Instances of sex-linked inheritance are now known in many animals, some of which are strictly comparable with *Drosophila*; others follow the same general principle, but have the relations of the sexes reversed, as exemplified by the moth *Abraxas*, which has been worked out by Doncaster (Rep. Evolution Committee, iv., 1908), whose sudden death we have had so recently to deplore. Here the female is the heterozygous sex, and contains the dummy mate of the sex-chromosome.

(To be continued.)

The Department of Scientific and Industrial Research.

By J. W. WILLIAMSON.

THE Report of the Committee of the Privy Council for Scientific and Industrial Research for the year 1919-20¹ is of great interest to all those who are watching with sympathetic anxiety the attempt, embodied in the Department of Scientific and Industrial Research, to secure greater and better organised State aid for scientific research without subjecting the research worker to such Governmental control as would stifle his spirit and energies. The present report is the Committee's fifth annual report, and the Report of the Advisory Council which is subjoined, before proceeding to record the past year's work, takes the occasion to give a brief survey of its labours during the past five years.

The Government has entrusted to the Department during the past year new responsibilities. The Geological Survey and Museum of Practical Geology were transferred to the Department on November 1 last, and a Geological Survey Board has been appointed under the chairmanship of Sir Francis Ogilvie. At the beginning of this year the Cabinet decided that means should be adopted so to organise the scientific work that was needed for the fighting Services as to avoid unnecessary overlapping, to secure the utmost economy of *personnel* and equipment, to facilitate the interchange of scientific knowledge and experience between all the Departments concerned, and to provide a single direction and financial control for all work of a fundamental nature of civilian as well as military interest. It directed that the Department should establish a series of co-ordinating Boards, and that these Boards should include technical representatives of each of the fighting Services and of such civilian Departments as might be materially interested in their work, as well as independent men of science. Three Boards, one for chemistry, one for physics, and one for engineering, have been established, and these, with the existing Radio Research Board, form the nucleus of the scheme. These new arrangements are, obviously, an attempt to apply the principles of the co-operative conduct of research to Government Departments, and as the Advisory Council points out: "If firms competing with each other for existence can combine, as they have done, for their common benefit, it ought not to be more difficult for the members of a national service to do so merely because they are attached to different Departments of the Government."

The review of the past five years' work of the Department is a satisfying and promising record. The programme, it is explained, falls under four main heads: (1) The encouragement of the individual research worker, particularly in pure science; (2) the organisation of national industries into co-operative research associations; (3) the direction and co-ordination of research for national purposes; and (4) the aiding of suitable researches undertaken by scientific and professional societies and organisations.

Since the establishment of the Department, 136 maintenance grants have been made to students and 89 to independent workers, while 48 grants have been made to provide professors with research assistants of scientific standing. During the four academic years in which grants could be made, approximately 50,000*l.* was distributed in grants of the various kinds referred to, and it is anticipated that during the next academic year the distribution will amount to about 45,000*l.* The great majority of the grants have been made for work in the fundamental sciences. The Advisory Council goes on to say: "And here a word of explanation is needed in view of ill-informed criticism of our policy. No conditions are attached to the grants made to workers whose sole aim is the extension of knowledge, either as to the line of their work or as to the use to be made of the results. If they propose to make commercial use of their discoveries we require them to consult us, because at this point they are leaving the field of pure investigation. But, subject to this single condition, their tenure is as free as, and in some respects more free than, that of a scholarship, fellowship, or professorship."

With respect to the organisation of industries into research associations, the present position is that eighteen research associations have been established, and that five others have been approved by the Department and will shortly receive their licences from the Board of Trade. Of the 1,000,000*l.* fund it is estimated that the Department is committed at the present time to a total expenditure of nearly 450,000*l.* on account of the established research associations, and to a further expenditure of at least 120,000*l.* on account of those approved but not yet licensed. The total commitments out of the 1,000,000*l.* fund are expected shortly to reach 800,000*l.*, and the report observes: "It is clear that the sum placed at our disposal is not likely to be more than sufficient to aid the associations either formed or likely to be

¹ Report of the Committee of the Privy Council for Scientific and Industrial Research for the Year 1919-20. (Cmd. 905.) Pp. 120. (London: H.M. Stationery Office.) Price 2s. net.