SOME RECENT ASPECTS OF GENETICS

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The rise of genetics has been the most outstanding feature in the development of biology during the present century. The main credit for the rediscovery of the Mendelian laws of heredity in 1900 is due to deVries. It happened that at that time the study of chromosomes had reached a point where it was recognized almost immediately that their behaviour in the germ cells of plants and animals furnished the necessary mechanism for just this type of hereditary behaviour. The independent segregation of the members of each chromosome pair was soon recognized as determining the segregation of characters which is witnessed in the second generation from a hybrid cross. This greatly strengthened the view, which had long been tentatively held, that the chromosomes furnish the material basis of heredity, i.e., of genetic continuity from cell to cell and from generation to generation. Without this stable self-perpetuating mechanism in the nuclei of every cell, the phenomena of heredity in the infinite complexity of organic structure would be impossible.

Various lines of experimental evidence have since proved the essential part played by the chromosomes. One of the earliest of these consisted in showing that *Oenothera lata*, a mutation originally discovered by deVries among the offspring of *O. Lamarckiana*, always had 15 chromosomes, the duplication of one chromosome accounting for the peculiar features of leaf, flower and habit which are invariably present in this mutant. The same broad-leaved mutation has since been found arising from various other species, and the recognition of this fact in 1912 constituted the discovery of the principle of parallel mutations. This principle has become one of great

evolutionary importance, whose significance is not even yet fully recognized.

Before it was known that what are now called trisomic mutations (with an extra chromosome) existed, the process of non-disjunction, or failure of one pair to separate in meiosis, giving one daughter cell with 8 chromosomes and one with 6, had been discovered in *Oenothera rubrinervis* (Gates, 1908). Some years later the same process was observed in Drosophila. In Datura, which has 12 pairs of chromosomes, the corresponding twelve trisomic mutations have all been discovered by Blakeslee and his colleagues (1934) and investigated in full detail.

It has since been shown that the chromosomes of most *Oenothera* species are linked together into one or more rings in meiosis. Similar conditions (catenation) of the chromosomes have since been observed in various other genera of plants, including Pisum, Campanula and Gaura. This condition has arisen through interchange of ends between two different pairs of chromosomes, followed by crossing with the original form in which such interchange had not taken place.

Later investigations lead to the view that each of these chromosomes which are linked end-to-end is homologous with a different chromosome as regards each of its ends, while the middle portion (around the spindle fibre attachment) is differential as between the two members of a pair, i.e., two consecutive chromosomes in the ring, each chromosome having thus a fixed position in the ring (see Fig. 1). Since consecutive chromosomes normally go into separate nuclei in the reduction division of this zigzag ring of chromosomes, two types of pollen grain and egg cell are produced in equal numbers by this separation. Generally one type of pollen and the other type of egg (embryo sac) are non-viable, and so the species continues to breed true although it is in a hybrid or heterozygous condition.

The two ends of each chromosome are now denoted by numbers, so that a species with a ring of 14 may be written

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(1.2   3.4   5.6   7.8   9.10     11.12     13.14
   \  /  \  /  \  /  \  /   \   /    \   /    \
    2.3   4.5   6.7   8.9   10.11    12.13     14.1)
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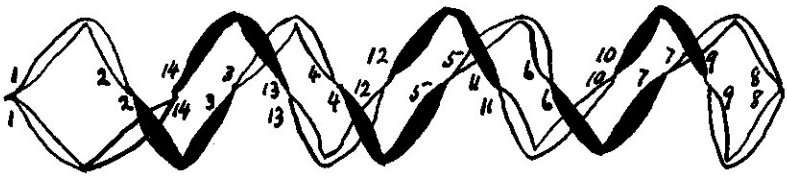
In simple non-disjunction any two consecutive chromosomes may go to the same pole. At the moment of separation they appear as in Fig. 1.



One of my staff (Catcheside, 1936) has shown that in *O. Lamarckiana*, which has a ring of 12 and one free pair of chromosomes, there are three cytological types of non-disjunction, each giving 12 different 8-chromosome gametes, making 36 different types of such gametes in all. These are functional only on the female side, but each can combine with either a *velans* or a *gaudens*,[1] pollen grain, giving 72 possible trisomic types. In addition, one other trisomic type can arise when both members of the free pair of chromosomes goes to the same pole. These 72 possible trisomics belong in six different cytological classes and five of these classes will breed true notwithstanding the presence of the extra chromosome. Many of these mutations have been observed and analyzed, although some are no doubt non-viable.

Another of my colleagues (Ford, 1936) showed that in an *Oenothera* with a ring of 14 chromosomes (and this is the condition in all the Canadian species so far as we know) 49 types of 8-chromosome gametes are possible. As these normally function only on the female side but can mate with both types of pollen, there are 98 possible 15-chromosome zygotes from such a species. They fall into seven classes, six of which are monomorphic or breed true, while the other is dimorphic, giving both the mutant and the parent type in their offspring. Probably many of these are non-viable; nevertheless a number of such mutants from wild Canadian species have been investigated in my cultures.

[1] These are the names of the two kinds of gametes which arise in *O. Lamarckiana* from segregation of the chromosomes as described in the last paragraph.

From time to time an interchange of ends has taken place between two chromosomes, as already mentioned. Thus 2.3 might interchange with 7.8, producing two new chromosomes 2.7 and 3.8 or 2.8 and 3.7. When a gamete in which this has occurred mates with a normal one new linkages of the chromosomes are produced. By elaborate series of crosses between forms whose chromosome ends are identified and forms in which they are unknown, the arrangement of the ends in a series of species, and hence their evolutionary origin and relationship, can ultimately be determined by the various rings and pairs they form in each hybrid. This slow and laborious work is now in progress (Catcheside, 1940) and will ultimately lead to a full genetic analysis of the many species of *Oenothera*.

Since 1932 I have been conducting a genetic survey of the genus *Oenothera* in Eastern Canada, including the Maritimes, Quebec and Ontario as well as some from the adjacent States and Western Canada. Hundreds of cultures have been grown from seeds collected by myself or sent to me by friends and correspondents. The results of three years' cultures have been published in a monograph (Gates, 1936) in which many new species and varieties were described. Since then many other new forms have been studied and a mass of material is awaiting publication, this work having been suspended owing to the war.

The resulting general evolutionary picture is that of a genus which has been rapidly evolving as the vegetation moved northwards on the American continent, following the retreat of the ice. The primitive condition in the south was that of a species with large flowers and seven free pairs of chromosomes. The small flowers of Canadian species have since developed, apparently by a series of dominant mutations. Linkage or catenation of the chromosomes appears to have resulted in nature from exchange of chromsome ends followed by crossing, thus producing larger and larger rings and finally a ring of 14. These ring arrangements became stabilised by the development of a balanced lethal condition in which only

certain gametic types are able to survive. In the meantime numerous other gene mutations affecting various parts of the plant have occurred. These, together with the occasional occurrence of hybrids, which breed true owing to the mechanism we have already briefly explained, will account for the great diversity of *Oenothera* forms now found scattered over most of the continent.

One other of the many genetic peculiarities of *Oenothera* may be mentioned, because it has a bearing on much of the cytological research which has been developed in my Laboratory in recent years. The most primitive species of *Oenothera*, *O. Hookeri*, and all other species examined (with one exception), although they only have 14 chromosomes, which is an ordinary diploid number, yet have two pairs of nucleoli (Badhuri, 1940). Formerly it was supposed that the number of nucleoli in the cells of an organism was of no significance. Now we know from much cytological work on many plant genera both in my Laboratory and in various others, that the nucleoli arise from particular chromosomes in the cell and that the number of pairs of nucleoli together with the number, size and shape of the chromosomes can be used in tracing the phylogeny from species to species in a genus and even in larger groups.

The evidence shows that one pair of nucleolar chromosomes is necessary in every active cell. The presence of two pairs in rice plants shows, together with several other lines of evidence (see Ramanujam, 1938), that the 12 pairs of chromosomes in cultivated rice have been derived from an ancestral condition in which there were five pairs. It may be that in *Oenothera* also the seven pairs of chromosomes are derived from a lower ancestral number, but there are other possibilities regarding the significance of the two pairs of nucleoli in *Oenothera*. For instance, this may represent a stabilized condition in which the functions of the two pairs of nucleoli are differentiated in the life of the cell (see Gates, 1942). In any case, it is clear that the two pairs have existed throughout the whole evolutionary history of this genus.

Before leaving the subject of plant genetics I ought to say that some years before the war we developed in Regent's Park, London, a Laboratory for the genetical investigation of plants. Research was carried out here on many tropical and temperate economic plants such as rice, cotton, wheat, tora, as well as others, such as *Oenothera*, of purely scientific interest.

To avoid wearying you by further details of plant genetics and cytology, let us pass to a brief consideration of some features in the genetics of man himself. This is a subject with which I have long been concerned. It leads one into the fields of anthropology, racial crossing, population, eugenics, blood groups, mental inheritance, and medicine, especially in their genetical aspects. "Heredity in Man" (1929) summarized our knowledge of human genetics up to a decade ago. The Bureau of Human Heredity was founded in London about 1935 to continue the accumulation, filing and abstracting of all papers, books and other data on human inheritance as fast as they appeared. This work is being continued on a reduced scale during the war.

It was formerly said, sometimes even by geneticists, that the laws of Mendelian inheritance do not apply strictly to mankind, although we know that he has the same chromosome mechanism as other organisms. Such views are, however, no longer tenable, and I believe that all who know the facts and complications of modern genetics are now agreed that the same principles apply universally to man as to other organisms. All human races, so far as known, have 48 chromosomes, including an XY pair of sex chromosomes. Such features as colour blindness and haemophilia are sex-linked in inheritance because they have arisen as mutations in the X-chromosome. It has recently been shown that these conditions are, as would be expected, linked with each other. Thus the sons of a woman who is normal but is a transmitter of both colour-blindness and haemophilia, because they are present as recessive mutations in one of her X-chromosomes will usually have both conditions or be free from both. But occasionally, owing to a cross-over between the two X-chromo-

somes, these conditions will be separated. Then some sons will have one condition and some the other.

The Y-chromosome is the smallest of all, and in most organisms it contains few or no genes. It is transmitted directly from father to son, because its presence determines a male individual. The genes it contains will then be inherited in the same way, but this male-to-male type of inheritance is rare because the Y contains so few genes. Webbed toes appear to be inherited in this way, however, in certain pedigrees. In most animals this type of inheritance is also rare, but in certain fishes Winge (1927) has shown that a series of genes determining colour patterns are in the Y-chromosome and they occasionally cross over with the X. Another rare form of inheritance is directly from mother to daughter only. This type of inheritance of colour-blindness was found in a Belgian family over a century ago. The same female-to-female inheritance was discovered in a strain of the fruit fly, *Drosophila melanogaster*, and was shown (see L. V. Morgan, 1938) to be due to a linking together end-to-end of the two X-chromosomes in the female. Such cases as these give an indication of the irregularities in chromosome behaviour which may be found in man with future investigation.

The 24 pairs of chromosomes in man is a relatively high number, although certain monkeys have more. In *Drosophila melanogaster*, which has only four pairs of chromosomes, all the genetic differences or mutations, of which some 500 are known, have to fit into four linkage groups, because all genes in the same chromosome will be linked with each other. Similarly, among plants, the sweet pea, with seven pairs of chromosomes, has been shown to have seven linkage groups, and maize, with ten pairs, ten linkage groups. In man, on the other hand, there will be 24 linkage groups. The known genes may be scattered in all these pairs, with the result that very few are likely to be found in the same chromosome pair until the linkage relations of a large number of genetic characters have been investigated. We have already

seen that sex-linked characters, being in the same chromosome, are linked with each other.

Proved cases of linkage of genes in other chromosomes are still rare. The evidence on this head has been mostly negative up to now. For instance, it has been found that the blood group, eye colour, recessive polydactyly and telangiectasis are all due to genes located in separate chromosome pairs. Similarly, using recently developed statistical methods, it has been shown that brachydactyly, blood group, Friedrich's ataxia and taste blindness to phenyl-thio-carbamide are probably in separate chromosomes. Again it has been shown that the ABO blood groups, the MN blood types, eye colour and allergy are independently transmitted. On the other hand, by what is known as the paired sib method, linkage has been found between (1) eye colour and myopia, (2) hair colour and absence of certain teeth. There is also a well-known pedigree in which the individuals with black hair have a crooked little finger and those with blond hair a straight little finger. This could only be accounted for by the genes for these two unrelated conditions residing in the same chromosome.

The types of characters whose inheritance we have thus far considered have been mainly of interest and importance from a medical and a eugenic point of view. Racial characters are also of course inherited, and this is a matter for the anthropologist. The characters we have been considering are simple unit differences and each has probably arisen as a single mutation. Racial differences, on the other hand—and this is found to be true both in man and in the higher animals—are generally represented by multiple factors. Stature, a racial characteristic, is analyzable into a whole series of length factors with genic determination. Blue and brown eyes can be treated as a simple factor-pair with brown dominant to blue. But although the matter still awaits full analysis, a series of minor factors undoubtedly determine intermediate degrees and patterns of iris pigmentation. The cephalic index or length-breadth index of the head has been

regarded by anthropologists as a most characteristic racial feature. Thousands of heads and skulls have been measured all over the world. Yet we know very little of the genetics of head-shape and no race is uniform in its cephalic index. But from what is known of the inheritance of shape in such fruits as pumpkins, squashes, and gourds, where a few genetic factors determine the shape, it is clear that the human head is a much more complex problem and that much has to be done before the inheritance of human headshape can be understood.

Skin colour is one of the most characteristic racial differences. Crosses between whites and blacks and Indians indicate that in addition to two main factors which are additive in their effects, there is at least a third which produces a small amount of pigment in excess of the brunet. In my view, the white race has arisen from a dark-skinned race through several mutations in loss of pigmentation from skin, eyes and hair. The Nordic race, with fair hair, blue eyes and a fair complexion, represents the last stage (except the albino) in this process of depigmentation. The African negro, with intensely dark skin, hair and eyes, represents the other extreme, of adaptation to tropical conditions. In the temperate zone there is no advantage in relation to climate in having blue or brown eyes, blond or brunet complexion, but in the tropics it appears that Nordic coloration is a definite disadvantage. The glands of the negro skin and his relative hairlessness are also probably adaptations to tropical climate. The broad, flaring nostrils have been regarded as an adaptation to breathing warm, moist air, as the narrow nasal passages of the Eskimo are adaptive to cold arctic conditions.

It appears, however, that hair shape and most other racial differences have no adaptive value. It is significant that kinky hair has appeared as a dominant parallel mutation and been inherited through several generations in a Norwegian family and also in a family in Holland of pure European descent. They showed no negroid characters. Probably the kinky hair of the negro arose in the same way, and later spread to

become a racial character. In crosses, the kinky hair of the negro is dominant, as are the broad nose, prognathous jaw and other features, but genetic segregation of all these and other differences occurs in later generations. Even the recessive white skin colour segregates, and every year both in South Africa and the United States thousands of these segregates are near enough to the white type to "pass for white". The most striking case of this kind I have seen was in a descendant from a cross between a Nordic Dane and an Eskimo woman in Alaska. One of the daughters married another Nordic. I photographed the mother and two of her daughters on Great Slave Lake (see Gates, 1929, p. 337). One of these daughters was intermediate in coloration like her mother. The other, while having some Eskimo features, had a white skin, blue eyes and fair hair. From such cases there can be little doubt that racial differences segregate in crosses in the strictly Mendelian fashion.

Having long been interested in the genetics of the Canadian Indian tribes, and having made studies of various British Columbia Coastal tribes (Gates and Darby, 1934), of Ojibway mixed-breeds in Northern Ontario (Gates, 1928) and of Micmac mixtures in Nova Scotia (1938), I might refer for a moment to a few of the genetic conclusions gleaned from those studies: (1) The "black" Indian eye has a dominant intensifying factor which is not present in Europeans. Even Indian babies show the intense black eye colour. (2) In Indians of mixed European descent the degree of pigmentation in skin, hair and eye colour generally corresponds within rather narrow limits. (3) Some genetic factors for eye colour are however, independent (partially linked) of some factors for skin colour. (4) While the kinky hair of the negro is strongly dominant to the straight hair of the Indian, it is not clear that any dominance is involved as between the straight hair and the wavy or curly hair of Europeans. The genetics of these hair characters can only be cleared up by fuller detailed observations. In Indian-white mixtures straight hair is much less frequent than black hair and eyes or dark skin.

A word may be permitted regarding the racial significance of the human blood groups. My interest in them arose from the fact that they are sharply marked unit differences, A and B both being inherited as simple dominants to O. While their genetics is therefore known, the reason for the wide differences in the frequencies of A, B, AB and O in different races have been much discussed, and hundreds of thousands of tests have been made of races in all parts of the world, without unanimity being reached as to the cause of these diversities. A general survey of the subject was made (Gates, 1936a) and numerous reports have been published as Secretary of a British Association Committee for the blood grouping of primitive peoples (see Brit. Assoc. Annual Reports). Results have been obtained, not only from the Canadian Indian tribes already mentioned and from Eskimos, but also from various other parts of the world. Several people were set to work among the many primitive tribes of India, but most of this work came to an end when the war began.

The racial significance of blood groups is too lengthy a subject to discuss here. My own views on this subject have developed gradually during the last decade. It appears to be clear that natural selection has played no part in the distribution of the A and B. I take the view that O was the primitive condition, from which A and afterwards B developed as dominant mutations. Since about 40% of A and little or no B is present in such primitive peoples as the Australian aborigines, the South African Bushmen, the Basques of Western Europe and the arctic Lapps, the A must have been derived from our anthropoid ancestors, all four genera of which have it. It is true that such a condition can accumulate simply through repeated mutation in the absence of any selective effect. But the time required would be excessive unless we assumed considerably higher mutation rates than are known to exist in other cases.

As regards the origin of the B blood group, it has been shown to differ from the B of the gorilla and cannot reasonably be derived from an anthropoid ancestor. It has then probably

arisen independently in the human line of ancestry as a parallel mutation. It seems to have been more recent than A in its development and is highest in Eastern Asia and India where it reaches about 35% in Mongolia and in the Hindu population. The native jungle tribes of India are often very different in their blood group percentages. It would seem, then, that the spread of the blood groups could be accounted for by their manner of inheritance, accompanied by racial migrations, racial crossing which has frequently taken place in the past, and a low mutation rate.

The problem of the American Indian blood groups is one by itself. Until a few years ago the evidence indicated that the American Indians were originally O. This raised a difficulty, because anthropologists are agreed that the Indians came across from Asia either towards or after the end of the Ice Age, and the Mongoloids, from whom they are believed to be derived, now have a high percentage of both A and B. A tentative solution of this dilemma was suggested (Gates and Darby, 1934) in our study of the Kwakiutls, Haidas and other British Columbia coastal tribes. Since then it has been found (Matson and Schrader, 1933) that the Blackfeet and Blood Indians of Montana and Alberta have a very high percentage of A individuals. This may even reach 80%. Have they derived this A from their Asiatic ancestors, or has it accumulated through a high mutation rate (O to A), or is it simply a chance result through the isolation of a few ancestors who had the A and produced the present population? Before these questions can be answered it will be necessary to blood group more tribes in the Canadian Northwest and in Alaska, as well as in Siberia. But it will be seen that the blood groups can throw a clear light on the origin and history of a race. When combined with the study of other anthropological characters they can be of much value in determining relationships and racial history.

Finally, while we have been discussing purely scientific questions of racial history and origin and human genetics, it seems desirable to point out that the facts of human genetics

all have a practical bearing on our own lives. The study of eugenics was founded by Galton as a means of improving the human race by taking thought of ancestry and recognizing the importance of heredity. Genetic evidence makes it clear that not only physical but mental differences are inherited, although there has not been time to discuss this aspect. An aim of society should be so to regulate social conditions that those of superior ability in every walk of life should have a better opportunity to perpetuate their kind. Feeblemindedness and other forms of mental defect are generally inherited. They represent unfortunate mutations which have occurred in the germplasm, sometimes many generations previously, as feeblemindedness is recessive in its inheritance. Improvement of the conditions of living is of course a desirable aim, but it should not be forgotten that improvement or even maintenance of the stock cannot take place in this way. Hardship may purge a race of its weaker elements, but soft living is more likely to lead to racial decay.

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