Darwinian Evolution of Mutations.*

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During the second half of the nineteenth century the Darwinian theory of the gradual evolution of all living forms by the agency of Natural Selection, slowly won its way to acceptance, first by men of science, especially breeders and geologists, and finally by the whole body of educated opinion. It is not here the place to survey the full extent of this revolution in human thought; it is enough that to thoughtful minds it dominated the outlook upon the history and destiny of the human race, and gave birth at the hands of Francis Galton to the Science, or rather the philosophy of Eugenics. But, during the present century Darwin's views have been exposed to criticism in detail and in gross, from the two classes of students, the breeders and the Palaeontologists by whom it was first most readily received. It is the purpose of the present note to examine very briefly the causes of this change of attitude, and to clear away certain misunderstandings, which spring chiefly from changes in the use of words, which have taken place during the past half century.

In the first place the discovery of Mendelism had made us familiar with the fact that obvious and easily distinguished differences in animals and plants are sometimes due to a single heritable factor, and some Mendelians have in consequence taken offence at the gradual and cumulative character which Darwin assigned to evolution. On the other hand certain palaeontologists to whom the gradual and progressive character of the evolution of fossil remains is becoming more and more evident, feel that we have here something which the geneticist cannot explain, and consequently fall back upon Lamarck's suggestion of the inheritance of acquired characters, or upon the mystic word ''orthogenesis.'' Others again, impressed by the genetic constancy observed in pure line breeding, have somewhat rashly insisted that genuine mutations never occur. These different views, though proper to put forward for discussion among men of science, exert a bewildering effect upon the general public, who tend to lose their belief that science has anything to teach them about the history and the destiny of their race.

Of the facts unknown to Darwin and his contemporaries we have to take two into consideration. In the first place Mendelism shows not only that obvious and easily distinguished differences may be due to single factors, but that the ordinary differences between parents and offspring, or between children of the same parentage, may be, and probably are for the most part, due to the segregation of Mendelian genes, and not, as Darwin seems to have thought, largely to new and arbitrary mutations of a heritable nature. What the older evolutionists took to be for the most part new heritable differences, the Mendelian interprets as, for the most part, old heritable differences, newly arranged accord

* For of, read by.

ing to the Mendelian system. In the second place pure line experiments have shown that in genetically pure strains, the appearance of entirely new genes is of relatively rare occurrence. It is not usually understood that these two new facts are logically connected : for, once the Mendelian view is accepted that genes do not blend, but segregate intact, it is clear that if in every generation new genes are introduced, the variability of the species will increase without limit. If the genes of the parents were to blend in the offspring, continual new mutations would be necessary to maintain the variability; but as under the Mendelian system of segregation there is no tendency for the variability to diminish, except in so far as by the gradual action of selection certain genes tend to disappear, we must not assume that in a state of nature, where the variability is approximately constant, new Mendelian alterations are introduced into the currency of the stock, more rapidly than this gradual elimination takes place.

The fundamental facts upon which Darwin grounded his theory are more firmly established than ever: the universal tendency of animals and plants to breed up to the limits of subsistence has never been seriously questioned; the existence in wild and domesticated races of heritable differences has been consistently verified; the incidence of natural selection and the actual modification of types has been proved by many careful investigations. Nevertheless owing to the changes which have taken place in the use of words, many would feel almost as though they were out of date if they styled themselves Darwinians. This change in terminology is principally due to the far reaching effects of the factorial system on our ideas of the constitution of living things. There is no need here to discuss the proper use of modern terms; for the purposes of the present note, it will be sufficient to say that we shall speak of a species as differing in any Mendelian factor, when two or more allelomorphs of that factor are to be found in individuals of the species; that every individual of the species must belong, in respect of this factor, to one or other of the homozygous and heterozygous types formed by combining like or unlike allelomorphs, that the word *gene* will be used for the material basis of any allelomorph, and the word *locus* for the material basis of a factor : so that we may speak of one gene supplanting another in the same locus as one allelomorph replaces another of the same factor. On the factorial system, then, an individual is specified, if, for every factor concerned, we assign it to one or other of the homozygous and heterozygous types: in the simplest case, when the factor is dimorphic, there being only two homozygous and one heterozygous types. Any organ or trait of the individual will usually be influenced by many factors, so that the selection of any one trait will influence the proportions of the allelomorphs of all the factors which effect that trait. Since in nature many traits are, or more correctly the whole complex of traits is, subject to selection, natural selection within any species will necessarily be gradually increasing the proportions of some allelomorphs, and diminishing those of their alternatives, so that a gradual progress of the whole specific group must take place on the whole in the direction of improved adaptation to those needs which dominate selection.

The action of selection upon such a species will be exactly what the

Darwinian would anticipate, with the theoretical reservation that in the absence of any mutations, progress must sooner or later cease; for the number of possible types formed by combining all the possible allelomorphs of all the factors present, though inconceivably great, is still finite. Of these types one is presumably the best adapted to the selecting environment, and when that type is attained improvement ceases. Of course the best possible combination of factors may not, when selection commences, exist in a population of many millions; thousands of generations of severe selection may be needed to bring it into existence, and establish it as the dominant type; it is true also that in the absence of new genes, the average value of any trait, such as human stature, might be changed to a value far outside the existing range of variation, merely by selection. Still it must be admitted that in the absence of mutation the variability of the selected species would be progressively diminished, and will finally vanish, so bringing evolutionary progress to an end.

But modern work, especially that of American workers on *Drosophila* shows conclusively that mutations, though infrequent, do in fact occur; and it is worth while to observe exactly what bearing this fact has upon the Darwinian theory of evolution.

If we suppose then that a mutation has occurred, and an entirely new gene is present in a single individual of population consisting of some thousands of millions, the history of its survival may be broadly divided into two periods. In the first period its survival or extinction is due mainly to chance; in the second period mainly to the general advantage or disadvantage in the struggle for existence which the new allelomorph confers, on the average and in combination with the existing currency of genetic types, as compared with the alternative allelomorph which it displaces.

In consideration of the first stage we may suppose that the chance of any gene of one individual appearing in 0, 1, 2, 3, ——— individuals in the second generation, to be $p_0, p_1, p_2, p_3, \ldots$ etc., such that $p_0 + p_1 + p_2 + \ldots = 1$. These fractions will depend on the stage in the life history of the individual which we pick out for consideration: for the adult reproductive stage of many plants and animals, the series will be very similar to the Poisson series.

If we construct a function $f(x) = p_0 + p_1 x + p_2 x^2 + \ldots$ then the chance of any one gene being represented in the second filial generation by 0, 1, 2, 3, —— individuals will be found by substituting $f(f(x))$ for $f(x)$.

This method enables us to compute the chance that the gene will not have become extinct in any number of generations; assuming the Poisson series the chance of survival for n generations is nearly $2/n$; while *if it do survive* the average number of individuals affected will be $\frac{1}{2}n$. Thus roughly one mutation in 50 will survive 100 generations, and if so, it will on the average be represented in 50 individuals. These results are worked out for a population stationary in number.

Very disadvantageous genes, such as dominant lethals, will of course be cut off at once, but for those which are only of moderate advantage or disadvantage, the above may be taken to represent the first stage in survival, which is principally governed by chance. The second stage commences with the new gene established in a fairly large group of individuals, of varying genetic constitution, so that a fair number of new genetic combinations are being tested simultaneously. If those individuals which contain the new gene are found on the average of the chances of life, and on the average of the genetic natures with which it is combined, to be at a disadvantage in the struggle for existence, then the number of the mutant form will gradually diminish, with large fluctuations due to chance; in this way the disadvantageous gene will always be kept sufficiently rare to be in danger of extinction, and though the number bearing it may repeatedly be reduced very low without actual extinction, yet sooner or later fortune will fail it, and it will disappear from the race. On the other hand the gene which is found to confer a slight average benefit on the individuals bearing it, will tend to increase in numbers somewhat more rapidly than its less favourable allelomorph. Even if the average advantage be only of the order of 1% in a generation, it will gradually spread through the population

At first the fluctuations from year to year will be large; so that when 100 individuals are affected the average increase will be one in a generation with a standard deviation of 10. But when the number of affected individuals is larger the increase takes place with greater and greater regularity; when the number of the new type has reached 1,000,000, each generation will bring an increase of 10,000 with a standard deviation of 1,000. At this point the spread of the favoured gene takes place with calculable regularity. Finally when nearly the whole population is affected, its less favourable allelomorph becomes sufficiently rare for its survival or extinction to be at the caprice of fortune.

If we have rightly described the manner in which a new mutation is incorporated into the general stock of the hereditary qualities of a species, and the manner in which the variability of the species is maintained in spite of the occasional extinction of genes by selection, we are in a position to see how great an advantage it is to a species to have adopted methods of sexual reproduction with inheritance on the Mendelian system. For mutation is necessarily a leap in the dark: the chances of failure are far greater than those of success, especially when the effect of the mutation is large. Hence there is a great deal to be gained if it be possible to maintain the variability of the species, with a minimum of mutations;—that is to say with the greatest stability of the reproductive processes. Now in a population differing in a great many Mendelian factors, as all sexual populations are found in nature to do, a single mutation may enable thousands of new genetic combinatious to be tested, and if any of these should happen to be very advantageous, it will by selection become the predominant type. It cannot be denied that many groups of animals and plants appear to carry on successfully by asexual methods of reproduction, but the advantage of the Mendelian inheritance of sexually reproductive organisms, especially when complex adaptations have to be made to a slowly changing environment, is sufficiently manifest.

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