General Article

DARWIN'S THEORY OF EVOLUTION
BACKGROUND ACHIEVEMENT AND CONSEQUENCES

[Part II-A] Achievement

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Darwin's major contribution in the evolutionary biology, as per our present appraisal, is two-fold: (1) He for the first time explained evolution as a stochastic process, that is, as a class of random phenomena where a regularity and order may be clearly discerned in the large scale and in the long run; (2) And he explained origin of species as a historically diverging process, that is, accumulation of gradual changes in the form of variation among the progenies within a species successfully leading to origination of new species.

Let us explain one by one.

Statistical Regularity: Pre-Darwin literature on evolution sought to explain modification of organism and species at the individual level. In the catastrophic paradigm of Buffon and Cuvier, individuals lived in one situation and died en masse with a catastrophic change of the earth. Then a whole new set of organisms came into being. The emphasis was on break and extinction, as well as on separate creations. They conceived of no gradual modification. In the gradualist paradigm like Lamarck's, on the other hand, individuals trying to achieve something in order to adapt to a given or changing situation by modifying their bodily organs modified themselves. If they could live up to adulthood, they would transmit the modified characters to their progeny. As a result, a section of the organism began to change, first by small degrees and then rapidly. The members of that group of animal adapted better with the given conditions of life. When they procreated, the offspring acquired the new characters and still better match the conditions. Gradually the modified variety would prevail over the original species and itself become a new species. This continuous scheme of change allowed only modifications and additions of species to species, thereby projecting a "ladder of life" imagery; there was hardly any room for extinction of species.

For example, take the case of the giraffe. How did it acquire its long neck? Lamarck thought that proto-giraffes were short-necked and strained their necks upward to browse the leaves and branches of the tall trees to survive. So some of them got slightly longer necks. A fraction of them lived up to the age to give birth to offspring, which possessed longer necks. The process continued for several generations acquiring increasingly longer necks. At some point of time the modern giraffe came with the present form.

Note that Lamarck's theory tacitly assumed three things: (i) modification at the individual level; (ii) inheritance of acquired character; and, (iii) innate capacity of an organism to achieve a directed and preplanned variation.

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While wrongly accepting the second assumption Darwin rightly understood that the third assumption, with an implicit teleology (despite Lamarck's best contrary wishes), was a necessary sequel to the first; once he accepted the first he could not escape the third. And teleology cannot dispense with divine involvement. Having already freed himself from the theological viewpoint of all sorts, he went in search of a way out, and quite sooner found it. It perhaps bothered him why – if the Lamarckian scheme were true – only giraffe would modify its neck for tree-top browsing; why also not horse or zebra, or other large herbivores. He found his way out of the problem of teleology and 'innate urge' only by going beyond the individuals, to a population of organisms.

Moreover, Darwin found out, no organism could change alone, without at the same time causing to change some others. For example, in an ecology where giraffes had appeared dwarf plants got a larger survival value than previously. That would have a multiplier effect on certain groups of insects. Increase in those insect populations would lead to a higher rate of cross-pollination for some plant groups. So on and so forth. He therefore focussed his attention to the varieties from which some modified organism emerged.

Having assumed variation as the first step towards modification, he intuitively adopted a statistical approach to the problem, no matter whether he was conscious of it or not. This was the beginning of population biology. As his immense collection of data suggested, the offspring of every adult organism – plant as well as animal – were subject to a process of random variation in terms of structures of some organs, or their functional capacities, or both. Why random? For, they were not predisposed to serve any predefined purpose in the life of an organism, which they might or might not serve. Each was a chance variation with a certain probability of occurrence. For example, given a large number of offspring of some adult cats, some proportion of the kittens would inevitably show a certain definite feature. On the other hand, this randomness was not lawlessness to him. For, he clearly saw that there was a finite range of variation, howsoever wide, for each kind of organism, at each generation.

Alright, there are variations! But why do some survive up to adulthood while others do not? This is the point where both Darwin and Wallace stumbled and fumbled for some time. And interestingly, both found a solution in an utmost reactionary social theory expounded by the bourgeois classical political economist, Thomas Robert Malthus. A thoroughly misanthropist and anti-liberal intellectual that he was, Malthus applied the cut-throat free competition perspective of the capitalist economy of the time to the overall functioning of human society. He argued that increase in resources always lags behind the faster growing size of population; so the unfit and unqualified among them, unless supported by any welfare scheme, would normally perish under pressures of life.

The two naturalists got a clue to solve their problem by removing the normative shell of the argument for human society and turning it into a functional correlative for the wild life forms. Had the natural resources for any species been infinite, and if there were no feeder-food relation among the various plants and animals, all of them could live and survive and produce offspring as many as they liked. The actual situation is different; vastly more individuals are born to a species than the existing available resources can sustain. So there is a competition among the living beings for gathering food as well as for self-defence. Besides, there are hazards regarding natural conditions, climatic changes,

* 1. Darwin (and Wallace too) adopted no more than this clue from Malthus irrespective of the veracity or otherwise of his social theory in general. In Darwin's writings, at least, there is no indication that he approved of Malthusianism for human society. There are on the contrary some hints of oblique disapproval, as we shall have occasion to see later. Writers, who glorify Malthus with the name and prestige of Darwin, or who criticize Darwin for his uncritical acceptance of Malthusianism, both err from oversight.

2. More or less at the same time as Darwin was groping for a proper theory of population biology and found none better than the Malthusian one, in 1838, a French scholar P. F. Verlhurst proposed in an essay a much better and more accurate theory for population dynamics. Published in an innocuous journal, however, it failed to attract any attention of the abler experts. So the wrong theory of Malthus remained unassailed before the academics.

[See for details*: Ashoke Mukhopadhyay – "Malthus' Population Theory: An Irony in the Annals of Science";* Breakthrough*, Vol. 10, No. 2 (November 2003)]*

geological changes, geographical isolation, so on and so forth.

All these factors together bring in what is called the struggle for existence It goes on at two levels – within the members of the same species on the one hand (intra-specific struggle), and across the members of different species on the other (inter-specific struggle). Those which survive can do so in virtue of some qualifications which others do not have – qualifications which help them to get more food, defend better from enemy, withstand natural hazards, safely procreate and safeguard progenies, etc. In other words, some varieties are better suited than others to survive, attain adulthood and leave offspring with those qualities. They adapt to the given conditions of existence better than others. The number of members of this variety therefore goes on increasing; the number of the other varieties including those which more resembled the parents goes on decreasing over time.

Obviously, certain members of a species with a peculiar variation in the structure and/or function of some or all of their organs, which finds this adaptive advantage, soon preponderate over the others, and the variety seems to become This phenomenon is termed by Darwin natural selection. At a certain stage of development when the variety becomes sufficiently distinct from the parent theory of origin of species through natural selection. Thus, in his scheme of change through variation-selection-modification-speciation, Darwin embraced both gradualism and breach in the course of evolution. Up to a certain level of gradation in the similarities of characters members of an organism form varieties; and other members, which go beyond a threshold level of gradation but remain stable as a separately interbreeding group, form a new species.

The kernel of this theory is that individual organisms are not made to fit with the living conditions nor do they change themselves on purpose to do so; but that from amongst a host of individual varieties of organism, some are better able to cope with the given environment; they survive and proliferate; they are as if selected by nature. Taking the case of giraffe, one may say, in certain tropical woods full of large trees, there were ancestors of the present giraffes with perhaps not too long necks to start with. Among them those which had longer necks were better able to browse higher and thereby get more adequate nutrition. These varieties survived longer, produced larger number of offspring, and thus passed on the characteristics of long neck. The process continued over a long period through generations, when ultimately the present giraffe appeared on the scene.

Amongst many varieties of its ancestors, the long-necked ones were selected by (or, more appropriately, in) nature.

Divergence by Descent: The second most important contribution of his was to point out that the process of emergence of ever newer species was actually a long term historical process of descent in various lines spread over the different geo-climatic conditions of the earth. That is why he defined species in an interesting way, attaching this historical sense: "… the only distinction between species and well-marked varieties is that the latter are known, or are believed, to be connected by intermediate gradations, whereas species were formerly thus connected."[1] In other words, what are known as separate species today belonging to a common genus, were earlier varieties of the same parent species. Similarly, some of those which are today varieties of a species may become new species in future. He further felt: "I look at varieties which are in any degree more distinct and permanent, as steps leading to more strongly marked and more permanent varieties; and at these latter, as leading to sub-species, and to species. … Hence I believe a well-marked variety may be called an incipient species; …"[2] He could not say anything more definite about species at that time. Still it helps us to understand the concept in an historical perspective.

With this historical approach he brought forward a new understanding of the taxonomical classification of the plants and animals. We already know that with the extensive travels of the explorers to far away lands and discovery of ever increasing number of flora and fauna as well as ever newer fossils, naturalists were facing the problem of classification of their finds. In 1735, Carl von Linnaeus achieved the most successful classification of the living world in species, genus, order, family, class, phylum respectively. It was no doubt a very important milestone in the development of biological sciences. In spite of many changes of and additions into details, modern taxonomy still follows the Linnaean methodology.

However, we must remember, neither Linnaeus nor anybody else could grasp the real import of this classification. They viewed it as nothing more than a convenience, required for museum purpose, to arrange their specimen collection in accordance with the points of similarity and dissimilarity. It was Darwin who for the first time sensed something more. Once "fully convinced that species are not immutable" he felt that the classification indicated lines of descent. It was kind of a still picture of what happened in the history of living beings. For, "those [species] belonging to what are called the same genera, are lineal descendants of some other and generally extinct species, in the same manner as the acknowledged varieties of any one species are the descendants of that species."[3] And he wanted to extend the argument through all the various stages of groups of plants and animals: "As descent has been universally used in classing together the individuals of the same species, though the males and females and larvae are sometimes extremely different; and as it has been used in classing varieties which have undergone a certain and sometimes considerable amount of modification, may not this same element of descent have been unconsciously used in grouping species under genera, and genera under higher groups, though in these cases the modification has been greater in degrees, and has taken a longer to complete?"[4]

On the basis of these arguments he claimed: "Finally, we have seen that natural selection, which results from the struggle for existence, and which inevitably induces extinction and divergence of characters in the many descendants from one dominant parent-species, explains that great and universal feature in the affinities of all organic beings, namely, their subordination in group under group. We use the element of descent in classing the individuals of both sexes and of all ages, although having few characters in common, under one species; we use descent in classing acknowledged varieties, however different they may be from their parent; and I believe this element of descent is the hidden bond of connection which naturalists have sought under the term of the Natural System. On this idea of the natural system being, in so far as it has been perfected, genealogical in its arrangement, with the grades of difference between the descendants from a common parent, expressed by the terms genera, families, orders, etc., we can understand the rules which we are compelled to follow in our classification."[5]

It should be mentioned here that Darwin was inspired to view in the taxonomical classification an evidence of genealogy, among others, from the emerging science of linguistics: "It may be worth while to illustrate this view of classification by taking the case of languages. … The various degrees of difference in the languages from the same stock would have to be expressed by groups subordinate to groups; but the proper or even only possible arrangement would still be genealogical; and this would be strictly natural, as it would connect together all languages, extinct and modern, by the closest affinities, and would give the filiation and origin of each tongue."[6] In the nineteenth century scholars in Europe discovered family ties between languages of distant countries and sought to explain genealogy of the broad language families in terms of historical dispersion of large human groups from an original ancestral home to distant territories. Darwin, on the other hand, drew on the argument of genealogy to explain the increasing diversification of organisms in time in groups under groups. On the basis of this idea he tried to project a visual image about the "tree of life" as it flourished over time (see Fig. 1, adopted from The Origin, the only figure in his celebrated opus), which presented quite a different perspective on evolution from the Lamarckian "ladder of life".

Moreover, generalizing upon this theory of descent of the later groups from earlier forms, he concluded that the earliest plants and animals were quite fewer in number, and that the broad division of life forms into plants and animals implied this differentiation of organisms from a primordial common stock: "I believe that animals have descended from at most four or five progenitors, and plants from an equal or lesser number. Analogy would lead me one step further, namely, to the belief that all animals and plants have descended from someone prototype. But analogy may be deceitful guide. Nevertheless all living things have much in common – in their chemical composition, their cellular structure, their laws of growth, and their liability to injurious influences. … If we look even to the two main divisions – namely, to the animal and vegetable kingdoms – certain low forms are so far intermediate in character that naturalists

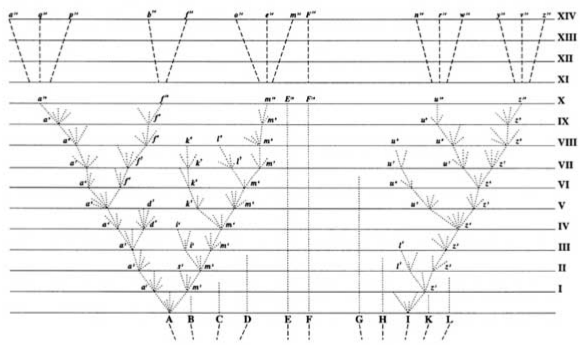

Fig. 1

have disputed to which kingdom they should be referred, …. Therefore, on the principle of natural selection with

divergence of character, it does not seem incredible that, from such low and intermediate form, both animals and plants may have been developed; and if we admit this, we must admit that all the organic beings which ever lived on this earth may have descended from someone primordial form."[7]
Within ten years of The Origin, the discovery of a large assortment of fossils pointing to the long route of evolution of horse by Othniel Charles Marsh, a US palaeontologist, in 1868, provided a strong support to Darwin's theory of descent (see Fig. 2). It showed the stage by stage modification of a grazing mammal barely 12 inches high existing in the Eocene epoch about 55 million years ago to the present five feet high browsing horse. In later years many more fossils related to horse had come to light, which further confirmed the theory (see Fig. 3).

Some difficulties: In spite of his success in explicating quite a large classes of data and problems in biology of his time, Darwin's theory failed to answer two very obvious questions: (1) How does variation occur in organism and how is it transmitted to its offspring? (2) Did evolution have the time necessary to create all the diversity found in the earth?

The first problem accrued from the facts that Darwin did not correctly know the mechanism of heredity, as also that he, like Lamarck and others of his time, believed in the inheritance of acquired characters. Moreover, going against his own rigorous adherence to objectivity, he hypothesized the existence of some miniature carriers of the characters in all parts of the body of an organism, named them gemmules and called the entire process of transmission as pangenesis.[8] These gemmules are passed through the reproductive organs to the progeny. For a newly acquired character the body forms a new batch of gemmules, which are then duly transmitted to the next generations.

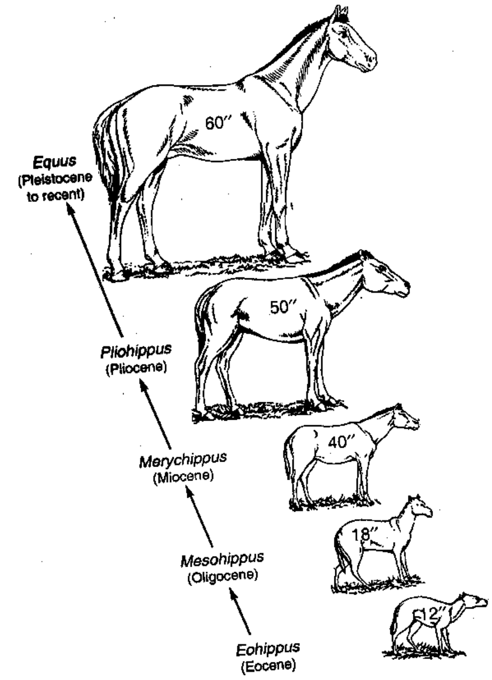

Fig. 2

Gregor Johann Mendel, a devoted monk by profession, who had conducted systematic experiments on heredity out of his personal curiosity and reported them in the Transactions of the Natural History Society, Brunn, in two parts (February and March 1865) in German[9], did not try to communicate with Darwin. His archives document that he had meticulously read the third German edition of Darwin's book and marked with a pencil the passages that dealt with the questions of transmission of characters to progeny and hybridization. Had he communicated with Darwin forthwith, it would immensely help the latter to come to terms with a host of problems in the field; it would also save him from the oblivion that he was consigned to for almost four decades. Probably the clergy in him forbade his scientific soul to get related to a man who had launched a theory to turn the divine into profane. And the other scientific personages he cared to send his paper to, did not pay any attention to it, for, they took the experiments of an abbot too casually, as amateur science.

In point of fact, let us note here, the experimental technique Mendel adopted for his study was too far ahead of the time and too much refined for the then biologists to understand. And they disliked his statistical applications as uncalled for in biology. The only person who could probably appreciate their worth – Charles Darwin – remained unaware.

As a result, an engineer by profession, Fleeming Jenkins, in an extended review[10] of The Origin in 1867 (also ignorant of Mendel's work) raised an interesting objection to Darwin's theory out of common sense: Favourable variations acquired by an organism and transmitted to its offspring, would be blended with other existing forms of the character and lose its advantages, if any, over the generations. In ten or so generations the newly acquired variation would be completely eliminated. There would be very few prominent varieties for natural selection to work upon. The idea of inheritance of acquired characters, if true, seemed to demolish both increasing diversification as well as natural selection. Jenkins, it may seem funny today to read, was so sure of his point as to solemnly declare: "Darwin's theory is an ingenious and plausible speculation, to which future physiologists will look back with the kind of admiration we bestow on the atoms of Lucretius, or the crystal spheres of Eudoxus, containing some faint half-truths, marking at once the ignorance of the age and the ability of the philosopher. Surely the time is past when a theory unsupported by evidence is received as probable, because in our ignorance we know not why it should be false, though we cannot show it to be true."[11] We feel amazed today to see how true this observation was! In his total ignorance (like Darwin's) of Mendel's work and of the mechanism of heredity as such, he could not know why his argument was abjectly wrong!

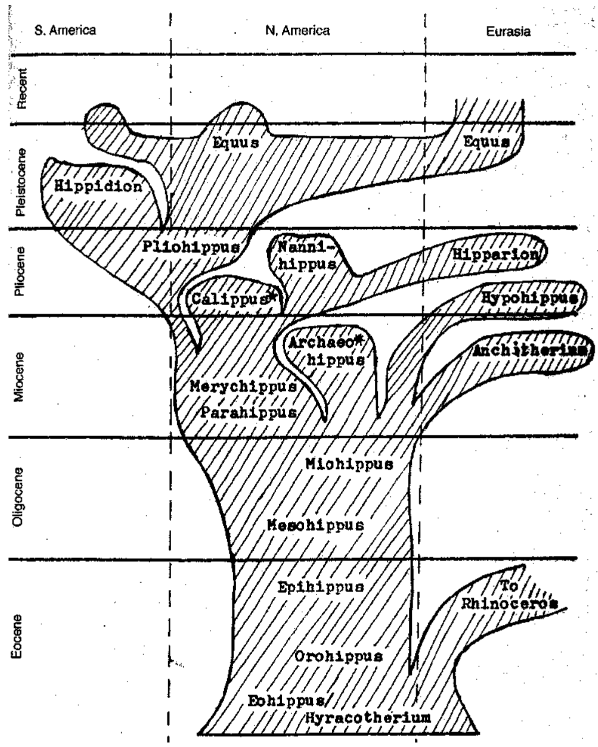

Fig. 3

The second objection came from the renowned physicist, Sir William Thomson (later knighted to Lord Kelvin), in some of his speeches from 1861 onwards in the British Association for the Advancement of Science, Royal Society of Edinburgh and Geological Society of Glasgow[12]. From the thermodynamic studies of the earth's cooling he concluded that the age of the sun could not be greater than five hundred million years, and the earth was at most 24 million years old; hence life could not exist on the earth for more than a few million years. This gave natural selection too short a spell to work out the vast diversity of life forms from a simple primordial organism. ”The limitation of geological periods, imposed by physical science, cannot, of course, disprove the hypothesis of transmutations species; but it does seem sufficient to disprove the doctrine that transmutation has taken place through ‘descent with modification by natural selection’.”[13]

To these objections Darwin had no answers to offer. He could not disprove blending as long as he accepted inheritance of acquired characters. Also he did not know how to tackle the objection raised by the celebrated physicist. He admitted in the fifth and sixth editions of his book that these objections were among the “gravest ones”, and that he did not know how to reconcile his theory with them. But he preferred to wait and allow the posterity to decide for him when more knowledge was gathered.

A modern writer depicted his attitude very accurately in the situation: “Always he shows himself to be honest and truth-seeking. Never is he more eager to sell his own product than to discover – let the chips fall where they may – what actually is the case. … He does not ignore or hush up any apparently falsifying facts. These are all recognized and recorded among the difficulties and objections. But they are not mistaken as constituting decisive reasons to abandon what is by far the most promising theory available. Instead, he continues to develop, to defend, and to use that theory, but always in a suitably provisional, tentative and undogmatic way.”[14]

Today we know the answers to both. The theory of organic evolution met both the challenges and came out victorious. With the refinement in the dating techniques, the age of the earth (together with the sun) is calculated nowadays to be around 4.6 billion years, which is much longer than required by evolution to create life and diversify it to the present magnitude. Darwin’s theory of natural selection rests comfortably settled there. As regards the first problem, it needs a bit detailed and separate treatment. For, new advances in the field of heredity brought to light an array of facts not only supporting natural selection but granting it a far deeper and wider significance.

Genetics, Heredity and Evolution: Mendel showed that contrary to popular belief no acquired character is inherited; and that the hereditary characters are not blended. If we can identify a specific character of a member of a species (like, say, colour of the eye of a cat, length of the pea-pod, thickness of beak of a bird, etc.), the character is transmitted in its entirety. It may be expressed or not; even when it is not expressed in a particular generation, it is fully extant in the body of the organisms, and may be expressed in the following generation. Mendel derived two laws of inheritance from his extensive studies, known as the law of particulate segregation and the law of independent assortment.

These laws were rediscovered more or less independently by three scientists at around the same time in 1900. Today it seems a strange coincidence that the Editorial Board of the Berichts der deutschen botanischen Gesellschaft (Bulletin of the German Botanical Society) received within three months in that year three separate articles reporting Mendel’s pioneering work sent by three scientists – Hugo de Vries from the Netherlands, Carl F. J. E. Correns from Germany and Erich von Tschermak from Austria in connection with their own studies on hybridization and the mechanism of heredity. Soon they were joined by Bateson in England, Cuénot in France, and many others who repeated Mendel’s experiments on other plants, then on animals, and thereafter on heredity of multiple characters. All of them reported that the results matched the Mendelian laws with the required statistical fit.

By the end of the nineteenth century the study of cell structure had advanced to a remarkable degree; nucleus was discovered; chromosomes were observed within the nucleus and found to replicate and segregate from the parent cell to the daughter cells; etc. The number of chromosomes in the cells of a particular species was found to be fixed. And it differed among organisms of different species. The mechanism of sexual reproduction was understood as the union of a male component (called male gamete) with a female component (called female gamete), each coming from the reproductive cells of each parent. It was found that mitosis, or the process of somatic cell division, where each chromosome of the parent cell is longitudinally split in to two threads and distributed among the emerging daughter cells, was different from meiosis, or the process of reproductive cell division, where the total chromosomes were partitioned in two groups and passed on to the daughter cells one in each. The science of embryology came to show the development of an adult organism from a single cell (called zygote) formed by the union of the male and female gametes (described as fertilization of the female egg cell by the male gamete). An attentive reader may well see how nicely Mendel's laws fitted with this panorama of advancing knowledge. All these information began to gradually tell us, on the one hand, "why I am more or less like my dad"; and, on the other, why I differ, even if slightly, from my dad.

The particulate and unit carriers of heredity were by now called genes and were understood to reside in the chromatins, the thread-like structures of the chromosomes. The genes passed on from generation to generation from parent cells to daughter cells usually unchanged. They are either expressed (dominant) or not (recessive). They are not fractionable. On the basis of this level of developments in heredity and genetics up to 1930s, R. A. Fisher gave birth to what is now known as the synthetic theory of evolution. Thereafter, the chromatin fibres were found to consist of a long and large molecular chain of deoxyribonucleic acid or DNA, and genes were seen as definite segments of this long chain punctuated from one another by other definite and suitable segments. Certain cells also contain another kind of long molecular chain called ribonucleic acid, or RNA

Two other things came to the notice of the scientific community. First, a specific character of an organism may be carried by one gene as well as by a group of genes, collectively called alleles. Secondly, the alleles (where they exist) for a character coming from the two parents may or may not be identical. As a result, at every cross breeding, the alleles for a specific character received by the offspring may belong to a wide (although finite) range of varieties. This is true for every other character. That is why no two individual members of a species are identical. At the lower levels of organisms, this variation may not be visible to the untrained eye. It becomes clearer at the higher levels. The total range of alleles for all characters of the members of a species is called the gene-pool of that species.

As long as variation of the members of a species remains confined within its gene-pool, the pressure of selection is too weak to work (except in some extraordinary situation). On the other hand, every organism, in course of its life may get modified in its body or habit to cope with the available conditions. Cats and dogs, normally carnivorous, may get used to vegetable diet. Rats reared in dark rooms of the physiological laboratories may lose much of their vision. A plant reared in a dark corner of a room with an open window at the far end will tend to bend its branches towards the window (called phototropism). These are called ontogenetic or phenotypic variation on the basis of acquired characters. These are not inherited by the progeny of an organism. If the next generations of cats and dogs go on living on vegetable diet, or the rats in the laboratory are repeatedly born with weak vision, that is not due to inheritance; each of these cases is a result of separate and independent interaction of each of the organism with its living conditions. The new saplings born of the above mentioned plant and reared in an open field will not have their branches bent. For these changes do not affect the reproductive cells of the organism, and therefore, cannot be passed on to the next generations. The species-character is quite stable within certain limits of living conditions.

But sometimes, owing to certain physical chemical or metabolic factors the molecular structure of the DNA segment referring to a gene within any cell of an organism may undergo changes, giving birth to new characters. If the cell belongs to the body, it will not be able to pass on this new arrangement to the next generation. But if such a change occurs in the reproductive cells, there is a possibility of its transmission to the progeny. If the changed cells undergoing meiosis participate in fertilization, form new kind of zygotes, and the zygotes mature successfully into adulthood, they will belong to a new gene-pool. This is called mutation.

Mutation is a rare event in normal conditions, there being so many “ifs” involved. Then, most of the mutations are not advantageous for the organism in its struggle for life. So mutations are usually abortive and are soon deleted. Hence species remain stable for a fairly long period.

But, on the other hand, considered over a long span of time for a large population of a species (that is, again statistically speaking), some successful mutations are almost certain to occur. That is why we see occasional variations among the members of a stable species, which have better survival chances, and which, therefore, tend to proliferate over the existing variety. This is called a genotypic or phyllogenetic variation. Differences in the gene-pool of this new variety from that of the existing form set up a breeding barrier between them; so they begin to rapidly diverge from each other. A new species is born.

Mutation may also occur in some disparate segments of the same species population, separated by territorial distance or geographical isolation. The successful mutant progeny will rapidly diverge from the parent species, and may outbid it in the long run. In this way also a new species may be born.[15] However, whatever be the case, every speciation is a culmination of some successful mutation within a segment of an existing species-population. If the routes of adaptation of the parent and mutant species clash (e. g., if they feed on the same diet), the former will gradually perish in course of the struggle for existence. If they do not, the two species will branch out in different adaptive pathways.

Darwin, for obvious reasons, could not differentiate between the two levels of variations. Now we are not only able to demarcate them but can also trace the variation to a much deeper level, to the genetic level. It is clear that in the ultimate analysis the pressure of selection acts on variations at the gene-pool level. Here also the theory of Darwinian selection is fully valid in the sense that all mutations are random, undirected and chance occurrences, without any predefined or predetermined aim. Those which survive do so not because they were bestowed with some appropriate genetic materials, but because the genetic endowment made them fit for the prevailing conditions of life. Others, and these are the majority, perish.

With the knowledge of genetics and heredity we can now answer Jenkins: the characters are not blended at any stage; they are either expressed or not. So there is no question of evening out of the differences or variations. Secondly, new variations which are meaningful for evolution do not undergo interbreeding with the old forms; so there is no question of mixing up. It seems amusing today that Jenkins tried to prove Darwin wrong by touching on his sore points. Darwin's strong points, his major contributions in evolutionary biology – theory of natural selection, and introduction of the population approach – remain permanently secure.

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15. For more detailed discussion on genetics and heredity, see the articles in Breakthrough. □