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BASIC PATENTS IN NATURE[1]

By WILLIAM K. GREGORY

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At a time when the very word "adaptation" is anathema to many scientists it may seem reactionary to choose an even more anthropomorphic term such as "basic patents" to stand for the same idea. Nevertheless, as I shall try to show later, each one of us is able to carry on the business of life solely by means of our capital stock of Nature's patents, inherited from ancestors that have somehow gradually invented or come upon them in the long rise from fish to man. By basic patents I mean not only the things invented but the principles of construction and operation, of which Nature is the sole and rightful patentee; albeit many of her patents have been stolen from her by that Promethean rebel, *Homo sapiens,* who maintains to date a fairly successful revolt against her armies of other organisms that are perpetually waging war against him.

Here, however, we come at once into the midst of things. What are some of the reasons for this perpetual struggle and warfare which is the *vis à tergo* of evolution? The specific properties and reactions of water, carbonic acid, the atmosphere, and so forth, which collectively constitute the fitness of the environment for the support of life, appear to emerge from the interaction of still more elementary principles, such as the following: Nature is almost infinitely repetitious but variable. Her experiments are extended in time and her forces vary in intensity, duration and extent. From the recurrent clash of her cosmic forces the terrestrial environment experiences many cycles of day and night, of high tide and low tide, of summer and winter and the shifting of the poles, cycles of climate, cycles of mountain building and base leveling, of submergence and emergence. To all these the struggling populations of living organisms must adjust themselves or be crowded out.

These variable forces do not, however, wholly cancel each other; they leave cumulative results scat-

[1] Address of the president of the New York Academy of Sciences, given on December 18, 1933.

tered about for longer or shorter times. Hence it is no wonder that the organism which embodies a system of forces that are ultimately derived from the environment should develop and respond to the environment in a cyclical way, with corresponding accelerations and retardations of growth, with alternations of spending and storing up energy, *et cetera*.

In the Hall of the Natural History of Man, which we recently opened in the American Museum of Natural History, we have attempted to set forth some of the basic and subsequent patents of Nature by means of which the vertebrates have risen through grade after grade of structural advances.

In tracing the history of any of Nature's patents we ought logically to begin with the forces inside the hydrogen atom and work outward and upward through organic chemistry to man. But here the curator-in-charge had the excuse of lack of space. Since we had to begin somewhere we started with the sun as the source of terrestrial life and with man as a living solar engine, dependent upon the energy of the sun stored up in the green coloring matter of plants. Then it was easy to set forth, even if only in a very elementary way, the taking in of energy in the food, its digestion, its storage in the liver, its distribution by the blood stream, its utilization in the muscles and glands, its escape as heat, each adjustment involving a large number of Nature's inventions. In this exhibit human anatomy is visualized from its functional aspect and one's attention is thus directed to the mechanism of the "living bellows," including the diaphragm, to the "main pump" of the distributing system and to the "currency of the body," which is the blood corpuscles.

Relatively early stages in the evolution of these basic patents may be seen in such lowly vertebrates as the shark, where, as every young student in zoology soon learns, we meet remarkably primitive conditions of every system, so that, on the whole, the anatomy of the shark is practically an epitome of that of man.

One of the ways in which Nature builds up her new patents out of old ones may be illustrated in a brief comparison of the blood-vessels of the respiratory system in the shark with those of man. It is known to every beginner that in the shark the aortic arches that convey blood from the heart to the gills and from the gills to the body are five in number and that they are all much alike, and symmetrically arranged on either side of the midline; also that in mammals only one of these arches remains, that it is now of very large size and strongly asymmetrical, and that it serves a somewhat different function from that of the aortic arches of the shark. For the former condition, in which there is a series of several or many homologous parts all constructed and functioning alike, I have recently invented the name "polyisomerism," (from *poly*—many; *isos*—equal; *meros*—part); the latter condition, in which one or more of these parts become enlarged and asymmetrical, I have named "anisomerism." The development of polyisomeres in the individual normally takes place through processes that are analogous with budding, while anisomeres are usually lop-sided or uneven polyisomeres; although, as we shall see, anisomerism may often affect whole regions.

As another example, the dentition of a shark is highly polyisomerous. In the mouth of any ordinary shark you may see the crowding polyisomeres produced by the unchecked budding of the dental lamina; the dentition of man, on the other hand, is largely anisomerous, the teeth being few in number and much less like each other than they were in the earliest vertebrates. Thus one great triumph of Nature, by means of which she has been able to people the earth with myriads of organic forms, was the invention of adaptable polyisomeres and the subsequent modification of these into anisomeres.

The elements of the locomotor apparatus are likewise polyisomerous to a high degree. It is estimated that there are several billions of muscle fibrillae in the human body; these are integrated into a few million muscle fibers and these in turn into several hundred muscles. In the fish the red muscle fibers, stretched between septa, are arranged in W-shaped myomeres along either side of the backbone. These again are typical polyisomeres. It is by contraction of these elements, one after another, first on one side and then on the other, that a series of waves is set up, each wave passing down the backbone toward the tail and pushing the body forward. It is well known that traces of this primitive arrangement are found in the developing human embryo, in which, as shown in the Carnegie Monographs on human embryology, the embryonic somites containing the tissue that gives rise to the axial muscles and to the backbone itself are seen as a series of small blocks in the position of the primitive myomeres of the fish. It is from these polyisomeres in the embryo that are developed the markedly anisomerous muscles of the human adult.

The evolution of the skeleton of vertebrates from fish to man tells a similar story of the transformation of primitive polyisomeres into specialized anisomeres. The vertebral column of the earliest fishes consisted chiefly of a continuous notochordal rod, highly polyisomerous in its microscopic make-up, surrounded by incomplete rings and surmounted by many similar slender rods.

Even up to the time of the early amphibians the axial skeleton shows only a gradual differentiation, or regional anisomerism, as we pass from the neck backward to the tail. But as the first reptiles invaded the dry land and began to run about or to dig holes, the stresses on different parts of the column became more highly differentiated and strong local anisomerism resulted. For example, the sacral ribs, which were at first but little different from ordinary ribs, became greatly enlarged and anisomerous as they took on the function of transmitting the thrusts of the hind limbs to the column.

At the upper end of the series, in man, this tendency toward anisomerism, or differentiation of the regions of the backbone, becomes very marked, partly as a result of the new and difficult position in which the backbone finds itself, at right angles to its primitive horizontal position.

The concept of polyisomerism and anisomerism is well illustrated also in the story of the first appearance and rise of the paired limbs corresponding to our arms and legs. Among the earliest known fish-like vertebrates, the anaspid ostracoderms of Silurian times, the future paired fins were apparently represented merely by two rows of small projecting scutes on the ventral surface of the fish, which converged gradually toward the median ventral fins. These projecting scutes were evidently primitive and polyisomerous to a high degree.

In a higher stage, preserved in certain genera of acanthodian sharks of the Lower Devonian period, there were still present several pairs of accessory or intermediate paired fins lying between the pectoral and pelvic pairs. In other words, the paired fins of these later acanthodians were merely the anisomerous survivors reduced to two pairs of a former series of polyisomeres.

The same principle may be illustrated in the later history of the paired fins. In the fossil cladoselachian sharks the paired fins were exactly like the median or unpaired fins in that they were supported by polyisomerous series of cartilaginous rods, to which were attached the polyisomerous muscles of the body wall. In the course of time, however, anisomerism grew out of polyisomerism in the usual way by the enlargement of some of the series, the reduction and disappearance of others, and the coalescence of some of those that remained. In this way the base of the fin shortened and a mobile, wrist-like paddle which could turn on its own base was gradually evolved.

But at this point it is necessary to describe another basic process which has entered into the further evolution of paired paddles, as it has into many other patents of Nature. It is a very curious but abundantly attested fact that anisomeres may often begin to bud and thus give rise to polyisomeres of the second degree. Such, it seems, was the case in the paired fins, as evident in the leaf-shaped paddles of the earliest known lobe-finned and dipnoan fishes, which, according to weighty paleontological evidence, were closely related to the stem of the amphibians.

In the lobe-finned or crossopterygian ganoids the leaf-like paired fins had a central axis composed of budded anisomeres plus a diminishing row of marginal rods, perhaps remnants of the more primitive rods of earlier ages. Now until two weeks ago I had never been able to visualize in detail the probable steps by which the paddle of the lobe-finned fish became transformed into the five-toed hand of the primitive amphibian. One reason for my persistent inability to solve the problem was that in all earlier restorations of the lobe-finned fish the names applied to the upper and lower borders of the paddle were reversed. But as soon as this error was corrected by Professor Romer, of the University of Chicago, I set to work again on this classic problem and am now able to offer a new but apparently promising, if tentative, solution, as follows.

When the pectoral paddle began to be used as a fore limb, it was twisted on its axis and then turned downward in such a way that what is now the back of the hand was derived from that side of the paddle which then faced the surface of the body. In other words, when the whole fin was directed backward, the surface that would eventually give rise to our palms originally faced outward. The process of bending the paddle downward, then twisting it so that the outer surface gave rise to the palm, while the dorsally placed preaxial border became the thumb and the radius, is shown in a series of diagrams drawn under my direction by Mrs. Helen Ziska.

The origin of the carpal elements proved to be an almost insoluble puzzle, until I noticed that on the under side of the well-preserved skeleton of the Permian amphibian *Eryops megacephalus* Cope the small bones of the carpus were arranged in three obliquely curved series. Of these the first included the radiale, centrale 1 and probably the prepollex. The second series included four of the middle bones of the carpus, the third consisted of carpalia 1, 2, 3, 4, 5. Lines were then drawn delimiting these series. In the first series the amphibian carpus seems plainly to be represented in the lobe-finned fish by the small bones that lie on the dorsal or preaxial border and constitute the many-jointed secondary axis. The second or ulnar series not less plainly appears to be derived from the postaxial rods. The third series, or carpalia, had not yet appeared as such in the fish and was possibly represented by the epiphyses on the proximal ends of the fan-like rods that supported the distal portion of the fin and were to become the digits.

To derive the carpus of *Eryops,* then, from that of the lobe-finned fish, all that is necessary, in addition to the twisting and down-turning of the fin, is the downward extension of the radius so that it becomes nearly equal in length to the ulna, and the consequent crowding and slight displacement of the postaxial rods, which would thus be shortened up into the numerous small bones of the middle of the carpus. The diagrams show how this would easily come about as a result of the predominant growth of the digital rays and the downgrowth of the radius.

In this way was evolved one of the most important basic patents ever worked out by Nature, namely, the five-rayed hand and foot, which is the basis of the decimal system. It only remained for man to invent the anisomerous dollar. I need not remind you that the pentadactylate hand and foot have been transmitted intact by the long line of vertebrate forms that culminated in man and we can safely eliminate from the probable line of ascent to man all the thousands of known vertebrates that show any loss of the five digits on each hand and foot or any undue specialization in the remaining digits.

Thus the concept of polyisomerism and anisomerism has led in many directions to a testing and confirmation of the general validity of the series of skeletons presented in the exhibit as illustrating the general progress from fish to man. Of course it is nowhere claimed that this series illustrates an absolutely continuous line of ascent. All that is maintained is that this series is the small residue after the elimination of thousands of other species of vertebrates which have become specialized further away from the direct line of ascent than the forms shown in this series.

To return to the paired limbs, the series as a whole illustrates a gradually increasing anisomerism, or differentiation, between the pectoral and pelvic limbs, both of which originated as locomotor organs. Here it is commonly recognized that the anisomeric development of the fore limb in man has somehow been associated with, or perhaps was the cause of, a change of function.

The change of primitive polyisomeres into anisomeres and the multiplication of anisomeres to form secondary or pseudo-polyisomeres is nowhere better illustrated than in the evolutionary history of the nervous system. In some of the oldest chordates, from the Silurian and Devonian of Norway and Spitzbergen, the mud that filtered into the brain-chamber and into the tunnels of the nerves and blood-vessels became petrified, leaving a permanent record of these parts. In this beautiful specimen figured by Stensiö, for example, we can see at once that regional anisomerism is already under way, so that the capsules of the olfactory, optic and otic organs are well differentiated. Nevertheless, the cranial nerves and blood-vessels retained to a hitherto unknown degree a condition of primary polyisomerism. In plainer terms, they are all much alike in their branchings in contrast to the highly differentiated condition in modern forms.

But I forbear to enter upon the details of the story of the evolution of the human brain, which has been so much illuminated by the contemporary researches of Kappers, Elliot Smith, Tilney and many others. I choose rather to stress the inquiry into the general way in which Nature works out her basic patents and some of the reasons why she has done so. I will even dare to put the question, Why have the nervous systems in general proved to be such successful inventions of Nature? It even seems possible to discern reasons why, from a zoological view-point, the human mind has come into existence.

This is the aspect of Nature's patents which is stressed in the labels of the closing sections of our new exhibits of the Natural History of Man.

Some years ago[2] I elaborated the following ideas: That all vital reactions are essentially anticipatory—the food must be secured and eaten before it can be digested and assimilated; the tooth grows under the gum before it erupts ready for use, the egg is fertilized and subdivided in anticipation, so to speak, of the adult that will grow out of the egg. Such reactions to future events are possible because the same environmental situations and the same internal needs and urges occur again and again. Now if a disagreeable pattern, A B C D, is unfolding, it would surely be an advantage if the organism could get out of the way quickly before the full consequences developed; if, on the other hand, E F G H I J K, etc., were a favorable sequence, it would normally be advantageous if the organism could appropriate it as soon as possible. Thus it would conceivably be advisable in the first instance for the organism to begin to move out of the way as soon as it received the first part of the signal, A, B, C, D, and in the second instance if it could move toward the object without waiting for the full signal. But it would be a still greater advantage if it had some arrangement whereby the bitter or sweet memories of past responses to such situations could further hasten the anticipatory reaction in the right direction in the well-known manner of the conditioned response.

Thus we see at once that the nervous system, even in the lowest organisms, not only shortens the time of reaction to present stimuli and to future results, but also makes possible the invention of memory and the utilization of experience. In other words, the habit of gambling in futures is by no means confined to

[2] "On Design in Nature," *The Yale Review*, January, 1924.

Wall Street but is a fundamental reaction of all organisms.

Now among the vertebrates there are two general types of central nervous systems and accompanying reactions: one, a very low type illustrated by the brain of the shark, the other, a very advanced type represented by the brain of man. And just as in other anatomical systems, the anatomy of the shark is practically an epitome of that of man, so in the case of the nervous system the shark's brain is, broadly speaking, the foundation upon which the human brain has been built. If we offer a shark a piece of salt pork on a hook he will probably snatch it without hesitation if he is hungry. This is paleokinesis, the more immediate response to sensory stimuli. If you offer a man a pork chop, however, he may refuse it because he is dieting, or for other reasons. This is neokinesis, which is, in plain terms, action controlled by ideas.

So too among other mammals with a neopallium the central nervous system has become above all else the great organ of anticipation. It is not enough to get out of the way when one is kicked. A neopallium enables one to jump aside just before the blow lands, or even to open hostilities with aggressive defense reactions of various objectionable sorts.

When beavers fell trees, build dams, lay in a stock of food and prepare excellent winter houses where they can live comfortably and defy the wintry blasts and sheeted ice, they represent a relatively high type of anticipatory reaction. Perhaps some of the wiser heads remember the chill of the previous winter; under the stirring memory of formerly empty bellies they start cutting down trees to encourage the others to begin in time. But to scientists, who dislike such anthropomorphic images, it seems nearer to the evidence to assume only that the relatively simple association systems of the beaver's neopallium supply the beavers with pleasant sensations whenever they work their jaws, push trees about, heap up the mud, and so forth, in the patterns that have proved most profitable to the race in the past. In other words, we must assume that the mechanism of heredity is so delicately geared that after millions of years it produces beavers that will react in those complex ways when they get the right stimuli, say from each other's presence, or from the nest-building instinct, or from the instinct to push logs against the stream and so forth.

Some thinkers may prefer to emulate the mystic philosopher of the bluebird and to postulate a grandfather beaver spirit, which presides over the society of the beavers and has successfully directed their endeavors since early times. If that be true, the grandfather beaver spirit must be the descendant of the *n*th great-grandfather spirit of *Eutypomys,* who was the physical ancestor of the beavers in Oligocene times. Thus we must reconstruct a family tree of beaver spirits paralleling that of their physical counterparts. Such dualism for beavers ought to appeal to all those who insist upon dualism in man.

In conclusion, to return now to the subject of basic and subsequent patents in Nature, it may be profitable first to list some of the features in which Nature's patents resemble human patents and then to examine the differences between them.

Both human and natural inventions are put together in such a way that they transform potential energy into mechanical work, work that is normally useful either to the maintenance of the individual or to the perpetuation of the race. Or they may act as a stimulus to the nervous system of organisms, causing them to react in ways profitable to the owners of the patents.

Since the mechanical and chemical conditions of the environment are much the same for both natural and human inventions, these two classes frequently adopt similar mechanical devices, such as the simple and compound lever, the cord, the lubricated groove and fulcrum, the arrangement of many similar motors, either in series or parallel, and so forth. The two kinds of invention are equally the product of evolution, that is, each stage grows out of earlier stages and both evolve through the principle of interest and compound interest in which the advantageous increments become cumulative with time. Both human and natural inventions are often constructed of a number of similar pieces, together with parts that are highly differentiated.

Both are not only anticipatory in action, but normally embody the results of a long line of trial and error. They are equally subject to the guiding force of selection operating in certain directions. They depend for their future success upon the regular recurrence or continuation of conditions that have been successfully met by similar arrangements in the past. In other words, they project past experience into the future. Human inventions, however, are products of the central nervous system, which has become the chief organ of anticipation. They project memory and experience, which have been perpetuated by tradition or written records, the human counterpart of heredity.

Perhaps the greatest difference between human and natural designs is that, whereas natural designs can change only by the slow modification of a single type, human designs commonly evolve also by a principle of cross-breeding or the conjunction of hitherto separate lines of development in one new complex organization. Thus the first steam locomotive was a hybrid between a wagon and a steam-engine. These combinations are, however, paralleled to a certain extent in nature by the symbiosis of certain fungi and algae into lichens, or by the complex interactions of hosts and parasites.

Finally, it is not generally recognized that the human mind is, on the whole, such a successful device of Nature because it embodies to a high degree the anticipatory qualities which are essential to all life.

However, the resemblances between natural and human inventions are probably deceptive if they lead us to impute anthropomorphic qualities to Nature.

THE SEPARATION AND PROPERTIES OF THE ISOTOPES OF HYDROGEN[1]

By Professor HAROLD C. UREY

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As all chemists know, the atoms of the elements are not all precisely identical. Most of the elements consist of mixtures of two or more varieties of atoms having similar chemical properties but different atomic weights. In most cases, the chemical and physical properties of these isotopes, as they are called, are so nearly identical that it is very difficult indeed to detect any differences except those which depend upon mass directly. In the case of the hydrogen isotopes, however, the mass ratio is one to two, and this large difference gives rise to very appreciable differences in the physical and chemical properties. Because of these outstanding differences it has seemed desirable to name each of the isotopes, and we have proposed the name protium for the isotope of hydrogen having an atomic weight of one, and deuterium for that of atomic weight two. The exact atomic weights are 1.00778 and 2.01356, based upon a standard of O^{16} having an exact atomic weight of sixteen.

Since the heavier isotope of hydrogen was discovered about two years ago, some seventy-five papers and notes have been published dealing with its properties. It would be difficult to give an adequate review of the subject in the time available for this talk, and therefore I shall confine myself to a few topics which have interested us at Columbia, giving them in detail and referring only briefly to other interesting and valuable work. I shall discuss methods of separation and the properties of the hydrogens. The method of discovery is history now and need not be reviewed.

THE SEPARATION OF THE ISOTOPES OF HYDROGEN

Because of the large mass ratio of the two isotopes of hydrogen, all methods for separating isotopes should be more effective when applied to these isotopes than when applied to any others. In the past, isotopes have been separated slightly by fractional evaporation and fractional diffusion through porous solids. Mass spectrographs have separated very minute amounts of the isotopes of many elements, but the complete separation of two isotopes in any quantity has only recently been accomplished in the cases of neon and hydrogen. In the case of neon, the separation was secured by Hertz, using a diffusion method. The separation and properties of the hydrogen isotopes is the subject of the present discussion.

The first appreciable increase in concentration of the hydrogen isotopes was secured by the distillation of liquid hydrogen near its triple point. Calculations by Dr. Murphy and myself, based on the third law of thermodynamics and the Debye theory of the solid state, showed that such a distillation should be effective. The ratio of vapor pressures of H^1_2 and H^1H^2 over their pure solids at 13.95° A should be 2.37. How closely this was the case is not known, for the hydrogen used was electrolytic hydrogen and the isotopic composition unknown, but the effect was appreciable but probably smaller than expected from theory. In this way, samples containing the heavy isotope to the extent of about 1 part in 1,000 were prepared by Dr. F. G. Brickwedde, of the U. S. Bureau of Standards. At that time distillation of hydrogen seemed to be a logical method for concentrating the isotope, but due to the low surface tension of liquid hydrogen, it is difficult to prevent its escape as mist in a fractionating column. Such methods have not been successful.

Last year Dr. D. MacGillavry and I attempted the separation of the hydrogen isotopes by diffusing hydrogen gas across a flowing stream of mercury vapor. This gave a fractionation factor of 2.5. This is rather high, but the speed of the process is too low to make this method effective as compared with other methods.

The progress which has been possible during this year on the hydrogen isotopes is due to the discovery by Washburn and myself of the electrolytic method of separation. Dr. Washburn suggested the possibility

[1] Address before the New York Section of the American Chemical Society, December 8, 1933.