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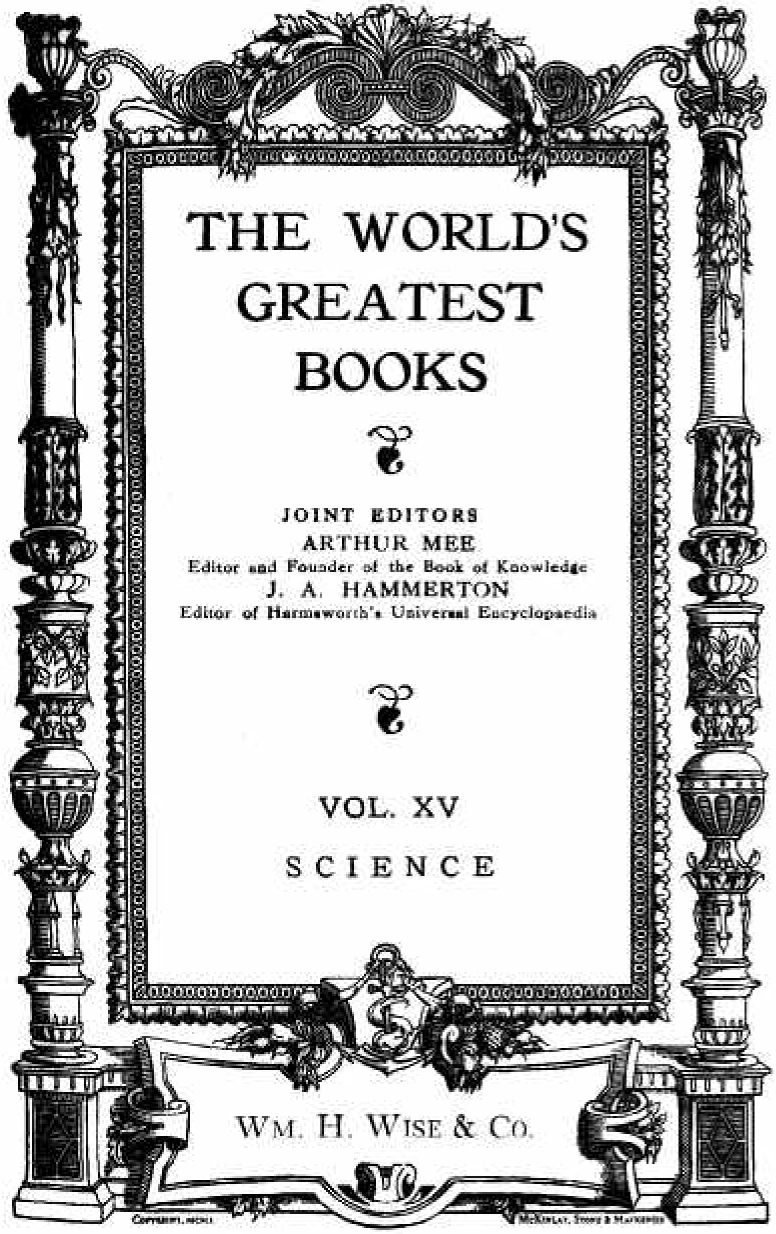

THE WORLD'S GREATEST BOOKS

JOINT EDITORS
ARTHUR MEE
Editor and Founder of the Book of Knowledge
J. A. HAMMERTON
Editor of Harmsworth's Universal Encyclopaedia

VOL. XV

SCIENCE

WM. H. WISE & CO.

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Acknowledgment

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Science

JOHN MILNE BRAMWELL

Hypnotism: Its History, Practice and Theory

John Milne Bramwell was born in Perth, Scotland, May 11, 1852. The son of a physician, he studied medicine in Edinburgh, and after obtaining his degree of M.B., in 1873, he settled at Goole, Yorkshire. Fired by the unfinished work of Braid, Bernheim and Liébeault, he began, in 1889, a series of hypnotic researches, which, together with a number of successful experiments he had privately conducted, created considerable stir in the medical world. Abandoning his general practice and settling in London in 1892, Dr. Bramwell became one of the foremost authorities in the country on hypnotism as a curative agent. His Works include many valuable treatises, the most important being "Hypnotism: its History, Practice and Theory," published in 1903, and here summarised for the WORLD'S GREATEST BOOKS by Dr. Bramwell himself.

I.—Pioneers of Hypnotism

JUST as chemistry arose from alchemy, astronomy from astrology, so hypnotism had its origin in mesmerism. Phenomena such as Mesmer described had undoubtedly been observed from early times, but to his work, which extended from 1756 to his death, in 1815, we owe the scientific interest which, after much error and self-deception, finally led to what we now term hypnotism.

John Elliotson (1791–1868), the foremost physician of his day, was the leader of the mesmeric movement in England. In 1837, after seeing Dupotet's work, he commenced to experiment at University College Hospital, and continued, with remarkable success, until ordered to desist by the council of the college. Elliotson felt the insult keenly, indignantly [Pg 2] resigned his appointments, and never afterwards entered the hospital he had done so much to establish. Despite the persistent and virulent attacks of the medical press, he continued his mesmeric researches up to the time of his death, sacrificing friends, income and reputation to his beliefs.

The fame of mesmerism spread to India, where, in 1845, James Esdaile (1808–1859), a surgeon in the East India Company, determined to investigate the subject. He was in charge of the Native Hospital at Hooghly, and successfully mesmerised a convict before a painful operation. Encouraged by this, he persevered, and, at the end of a year, reported 120 painless operations to the government. Investigations were instituted, and Esdaile was placed in charge of a hospital at Calcutta, for the express purpose of mesmeric practice; he continued to occupy similar posts until he left India in 1851. He recorded 261 painless capital operations and many thousand minor ones, and reduced the mortality for the removal of the enormous tumours of elephantiasis from 50 to 5 per cent.

According to Elliotson and Esdaile, the phenomena of mesmerism were entirely physical in origin. They were supposed to be due to the action of a vital curative fluid, or peculiar physical force, which, under certain circumstances, could be transmitted from one human being to another. This was usually termed the "od," or "odylic," force; various inanimate objects, such as metals, crystals and magnets, were supposed to possess it, and to be capable of inducing and terminating the mesmeric state, or of exciting or arresting its phenomena.

The name of James Braid (1795–1860) is familiar to all students of hypnotism. Braid was a Scottish surgeon, practising in Manchester, where he had already gained a high reputation as a skilful surgeon, when, in 1841, he first began to investigate mesmerism. He [Pg 3] successfully demonstrated that the phenomena were entirely subjective. He published "Neurypnology, or the Rationale of Nervous Sleep," in 1843, and invented the terminology we now use. This was followed by other more or less important works, of which I have been able to trace forty-one, but all have been long out of print.

During the eighteen years Braid devoted to the study of hypnotism, his views underwent many changes and modifications. In his first theory, he explained hypnosis from a physical standpoint; in the second, he considered it to be a condition of involuntary monoideism and concentration, while his third theory differed from both. He recognised that reason and volition were unimpaired, and that the attention could be simultaneously directed to more points than one. The condition, therefore, was not one of monoideism. He realised more and more that the state was a conscious one, and that the losses of memory which followed on waking could always be restored in subsequent hypnoses. Finally, he described as "double consciousness" the condition he had first termed "hypnotic," then "monoideistic."

Braid maintained an active interest in hypnotism up to his death, and, indeed, three days before it, sent his last MS. to Dr. Azam, of Bordeaux, "as a mark of esteem and regard." Sympathetic notices appeared in the press after his death, all of which bore warm testimony to his professional character. Although hypnotic work practically ceased in England at Braid's death, the torch he had lighted passed into France.

In 1860, Dr. A.A. Liébeault (1823–1900) began to study hypnotism seriously, and four years later gave up general practice, settled in Nancy, and practised hypnotism gratuitously among the poor. For twenty years his labours were unrecognised, then Bernheim (one of whose patients Liébeault had cured) came to see him, and soon became a zealous pupil. The fame of the Nancy school spread, Liébeault's name became known throughout the world, [Pg 4] and doctors flocked to study the new therapeutic method.

While Liébeault's work may justly be regarded as a continuation of Braid's, there exists little difference between the theories of Charcot and the Salpêtrière school and those of the later mesmerists.

II.—Theory of Hypnotism

The following is a summary of Braid's latest theories: (1) Hypnosis could not be induced by physical means alone. (2) Hypnotic and so-called mesmeric phenomena were subjective in origin, and both were excited by direct or by indirect suggestion. (3) Hypnosis was characterised by physical as well as by psychical changes. (4) The simultaneous appearance of several phenomena was recognised, and much importance was attached to the intelligent action of a secondary consciousness. (5) Volition was unimpaired, moral sense increased, and suggested crime impossible. (6) *Rapport* was a purely artificial condition created by suggestion. (7) The importance of direct verbal suggestion was fully recognised, as also the mental influence of physical methods. Suggestion was regarded as the device used for exciting the phenomena, and not considered as sufficient to explain them. (8) Important differences existed between hypnosis and normal sleep. (9) Hypnotic phenomena might be induced without the subject having passed through any condition resembling sleep. (10) The mentally healthy were the easiest, the hysterical the most difficult, to influence.

In England, during Braid's lifetime, his earlier views were largely adopted by certain well-known men of science, particularly by Professors W.B. Carpenter and J. Hughes Bennett, but they appear to have known little or nothing of his latest theories. Bennett's [Pg 5] description of the probable mental and physical conditions involved in the state Braid described as "monoideism" is specially worthy of note. Not only is it interesting in itself, but it serves also as a standard of comparison with which to measure the theories of later observers, who have attempted to explain hypnosis by cerebral inhibition, psychical automatism, or both these conditions combined.

(a) *Physiological.*—According to Bennett, hypnosis was characterised by alterations in the functional activity of the nerve tubes of the white matter of the cerebral lobes. He suggested that a certain proportion of these became paralysed through continued monotonous stimulation; while the action of others was consequently exalted. As these tubes connected the cerebral ganglion-cells, suspension of their functions was assumed to bring with it interruption of the connection between the ganglion-cells.

(b) *Psychical.*—From the psychical side, he explained the phenomena of hypnosis by the action of predominant and unchecked ideas. These were able to obtain prominence from the fact that other ideas, which, under ordinary circumstances, would have controlled their development, did not arise, because the portion of the brain with which the latter were associated had its action temporarily suspended—*i.e.*, the connection between the ganglion-cells was broken, owing to the interrupted connection between the "fibres of association." Thus, he said, the remembrance of a sensation could always be called up by the brain; but, under ordinary circumstances, from the exercise of judgment, comparison, and other mental faculties, we knew it was only a remembrance. When these faculties were exhausted, the suggested idea predominated, and the individual believed in its reality. Thus, he attributed to the faculties of the mind a certain power of correcting the fallacies which each of them was likely to fall into; just as the illusions of one sense were capable of being detected by the healthy use of the other senses. There were mental and sensorial illusions, the former caused by predominant ideas and corrected by proper reasoning, the latter caused by perversion of one sense and corrected by the right application of the others. [Pg 6]

In hypnosis, according to this theory, a suggested idea obtained prominence and caused mental and sensorial illusions, because the check action—the inhibitory power—of certain higher centres had been temporarily suspended. These theories were first published by Professor Bennett in 1851.

III.—Hypnotic Induction

The methods by which hypnosis is induced have been classed as follows: (1) physical; (2) psychical; (3) those of the magnetisers. The modern operator, whatever his theories may be, borrows his technique from Mesmer and Liébeault with equal impartiality, and thus renders classification impossible. The members of the Nancy school, while asserting that everything is due to suggestion, do not hesitate to use physical means, and, if these fail, Bernheim has recourse to narcotics.

The following is now my usual method: I rarely begin treatment the first time I see a patient, but confine myself to making his acquaintance, hearing his account of his case, and ascertaining his mental attitude with regard to suggestion. I usually find, from the failure of other methods of treatment, that he is more or less sceptical as to the chance of being benefited. I endeavour to remove all erroneous ideas, and refuse to begin treatment until the patient is satisfied of the safety and desirability of the experiment. I never say I am certain of being able to influence him, but explain how much depends on his mental attitude and power of carrying out my directions. I further explain to the patient that next time he comes [Pg 7] to see me I shall ask him to close his eyes, to concentrate his attention on some drowsy mental picture, and try to turn it away from me. I then make suggestions of two kinds: the first refer to the condition I wish to induce while he is actually in the armchair, thus, "Each time you see me, you will find it easier to concentrate your attention on something restful. I do not wish you to go to sleep, but if you can get into the drowsy condition preceding natural sleep, my suggestions are more likely to be responded to." I explain that I do not expect this to happen at once, although it does occur in rare instances, but it is the repetition of the suggestions made in this particular way which brings about the result. Thus, from the very first treatment, the patient is subjected to two distinct processes, the object of one being to induce the drowsy, suggestible condition, that of the other to cure or relieve disease.

I wish particularly to mention that although I speak of hypnotism and hypnosis—and it is almost impossible to avoid doing so—I rarely attempt to induce so-called hypnosis, and find that patients respond to treatment as readily, and much more quickly, now that I start curative suggestions and treatment simultaneously, than they did in the days when I waited until hypnosis was induced before making curative suggestions.

I have obtained good results in treating all forms of hysteria, including *grande hysterie*, neurasthenia, certain forms of insanity, dipsomania and chronic alcoholism, morphinomania and other drug habits, vicious and degenerate children, obsessions, stammering, chorea, seasickness, and all other forms of functional nervous disturbances.

It is impossible to discuss the different theories in detail here, but I will briefly summarise the more important points, (1) Hypnotism, as a science, rests on the recognition of the subjective nature of its phenomena. (2) The theories of Charcot and the Salpêtrière school [Pg 8] are practically a reproduction of mesmeric error. (3) Liébeault and his followers combated the views of the Salpêtrière school and successfully substituted their own, of which the following are the important points: (*a*) Hypnosis is a physiological condition, which can be induced in the healthy. (*b*) In everyone there is a tendency to respond to suggestion, but in hypnosis this condition is artificially increased. (*c*) Suggestion explains all. Despite the fact that the members of the Nancy school regard the condition as purely physiological and simply an exaggeration of the normal, they consider it, in its profound stages at all events, a form of automatism.

These and other views of the Nancy school have been questioned by several observers. As Myers justly pointed out, although suggestion is the artifice used to excite the phenomena, it does not create the condition on which they depend. The peculiar state which enables the phenomena to be evoked is the essential thing, not the signal which precedes their appearance.

Within recent times another theory has arisen, which, instead of explaining hypnotism by the arrested action of some of the brain centres which subserve normal life, attempts to do so by the arousing of certain powers over which we normally have little or no control. This theory appears under different names, "Double Consciousness," "Das Doppel-Ich," etc., and the principle on which it depends is largely admitted by science. William James, for example, says: "In certain persons, at least, the total possible consciousness may be split into parts which co-exist, but mutually ignore each other."

The clearest statement of this view was given by the late Frederic Myers; he suggested that the stream of consciousness in which we habitually lived was not our only one. Possibly our habitual consciousness might be a mere selection from a multitude of thoughts [Pg 9] and sensations—some, at least, equally conscious with those we empirically knew. No primacy was granted by this theory to the ordinary waking self, except that among potential selves it appeared the fittest to meet the needs of common life. As a rule, the waking life was remembered in hypnosis, and the hypnotic life forgotten in the waking state; this destroyed any claim of the primary memory to be the sole memory. The self below the threshold of ordinary consciousness Myers termed the "subliminal consciousness," and the empirical self of common experience the "supraliminal." He held that to the subliminal consciousness and memory a far wider range, both of physiological and psychical activity, was open than to the supraliminal. The latter was inevitably limited by the need of concentration upon recollections useful in the struggle for existence; while the former included much that was too rudimentary to be retained in the supraliminal memory of an organism so advanced as that of man. The recollection of processes now performed automatically and needing no supervision, passed out of the supraliminal memory, but might be retained by the subliminal. The subliminal, or hypnotic, self could exercise over the vaso-motor and circulatory systems a degree of control unparalleled in waking life.

Thus, according to the Nancy school, the deeply hypnotised subject responds automatically to suggestion before his intellectual centres have had time to bring their inhibitory action into play; but, on the other hand, in the subliminal consciousness theory, volition and consciousness are recognised to be unimpaired in hypnosis.

IV.—Curative Value of Hypnotism

The intelligent action of the secondary self may be illustrated by the execution of certain post-hypnotic acts. Thus, one of my patients who, at a later period, consented to become the [Pg 10] subject of experiment, developed an enormously increased power of time appreciation. If told, during hypnosis, for example, that she was to perform some specific act in the waking state at the expiration of a complicated number of minutes, as, for example, 40,825, she generally carried out the suggestion with absolute accuracy. In this and similar experiments, three points were noted. (1) The arithmetical problems were far beyond her normal powers; (2) she normally possessed no special faculty for appreciating time; (3) her waking consciousness retained no recollection of the experimental suggestions or of anything else that had occurred during hypnosis.

It is difficult to estimate the exact value of suggestion in connection with other forms of treatment. There are one or two broad facts which ought to be kept in mind.

1. Suggestion is a branch of medicine, which is sometimes combined by those who practise it with other forms of treatment. Thus it is often difficult to say what proportion of the curative results is due to hypnotism and what to other remedies.

2. On the other hand, many cases of functional nervous disorder have recovered under suggestive treatment after the continued failure of other methods. Further, the diseases which are frequently cured are often those in which drugs are of little or no avail. For example, what medicine would one prescribe for a man in good physical health who had suddenly become the prey of an obsession? Such patients are rarely insane; they recognise that the idea which torments them is morbid; but yet they are powerless to get rid of it.

3. In estimating the results of suggestive treatment, it must not be forgotten that the majority of cases are extremely unfavourable ones. As the value of suggestion and its freedom from danger become more fully recognised, it will doubtless be employed in earlier [Pg 11] stages of disease.

4. It should be clearly understood that the object of all suggestive treatment ought to be the development of the patient's will power and control of his own organism. Much disease would be prevented if we could develop and control moral states.

BUFFON [Pg 12]

Natural History

Georges Louis Leclerc, created in 1773 Comte de Buffon, was born at Montbard, in France, on September 7, 1707. Evincing a marked bent for science he became, in 1739, director of the Jardin du Roi and the King's Museum in Paris. He had long contemplated the preparation of a complete History of Nature, and now proceeded to carry out the work. The first three volumes of the "Histoire Naturelle, Générale et Particulière" appeared in 1749, and other volumes followed at frequent intervals until his death at Paris on April 16, 1788. Buffon's immense enterprise was greeted with abounding praise by most of his contemporaries. On July 1, 1752, he was elected to the French Academy in succession to Languet de Gergy, Archbishop of Sens, and, at his reception on August 25 in the following year, pronounced the oration in which occurred the memorable aphorism, "Le style est l'homme même" (The style is the very man). Buffon also anticipated Thomas Carlyle's definition of genius ("which means the transcendent capacity of taking trouble, first of all") by his famous axiom, "Le génie n'est autre chose qu'une grande aptitude à la patience."

Scope of the Work

Buffon planned his "Natural History" on an encyclopaedic scale. His point of view was unique. Natural history in its widest sense, he tells us, embraces every object in the visible universe. The obvious divisions of the subject, therefore, are, first, the earth, the air, and the water; then the animals—quadrupeds, birds, fishes, and so on—inhabiting each of these "elements," to use the phrase of his day. Now, Buffon argued, if man were required to give some account of the animals by which he was surrounded, of course he would begin with those with which he was most familiar, as the horse, the dog, the cow. From these he would proceed to the creatures with which he was less familiar, and finally deal—through the [Pg 13] medium of travellers' tales and other sources of information—with the denizens of field, forest and flood in foreign lands. In similar fashion he would consider the plants, minerals, and other products of Nature, in addition to recounting the marvels revealed to him by astronomy.

Whatever its defects on the scientific side, Buffon's plan was simplicity itself, and was adopted largely, if not entirely, in consequence of his contempt—real or affected—for the systematic method of the illustrious Linnæus. Having charted his course, the rest was plain sailing. He starts with the physical globe, discussing the formation of the planets, the features of the earth—mountains, rivers, seas, lakes, tides, currents, winds, volcanoes, earthquakes, islands, and so forth—and the effects of the encroachment and retreat of the ocean.

Animate nature next concerns him. After comparing animals, plants and minerals, he proceeds to study man literally from the cradle to the grave, garnishing the narrative with those incursions into the domains of psychology, physiology and hygiene, which, his detractors insinuated, rendered his work specially attractive and popular.

I.—The Four-Footed Animals

Such questions occupied the first three volumes, and the ground was now cleared for the celebrated treatise on Quadrupeds, which filled no fewer than twelve volumes, published at various dates from 1753 (vol. iv.) to 1767 (vol. xv., containing the New World monkeys, indexes, and the like). Buffon's *modus operandi* saved him from capital blunders. Though inordinately vain—"I know but five great geniuses," he once said; "Newton, Bacon, Leibniz, Montesquieu, and myself"—he was quite conscious of his own limitations, and had the common-sense to entrust to Daubenton the description of the anatomy and other [Pg 14] technical matters as to which his own knowledge was comparatively defective. He reserved to himself what may be called the "literary" aspect of his theme, recording the place of each animal in history, and relating its habits with such gusto as his ornate and grandiose style permitted.

After a preliminary dissertation on the nature of animals, Buffon plunges into an account of those that have been domesticated or tamed. Preference of place is given to the horse, and his method of treatment is curiously anticipatory of modern lines. Beginning with some notice of the horse in history, he goes on to describe its appearance and habits and the varieties of the genus, ending (by the hand of Daubenton) with an account of its structure and physiology. As evidence of the pains he took to collect authority for his statements, it is of interest to mention that he illustrates the running powers of the English horse by citing the instance of Thornhill, the postmaster of Stilton, who, in 1745, wagered he would ride the distance from Stilton to London thrice in fifteen consecutive hours. Setting out from Stilton, and using eight different horses, he accomplished his task in 3 hours 51 minutes. In the return journey he used six horses, and took 3 hours 52 minutes. For the third race he confined his choice of horses to those he had already ridden, and, selecting seven, achieved the distance in 3 hours 49 minutes. He performed the undertaking in 11 hours and 32 minutes. "I doubt," comments Buffon, "whether in the Olympic Games there was ever witnessed such rapid racing as that displayed by Mr. Thornhill."

Justice having been done to it, the horse gives place to the ass, ox, sheep, goat, pig, dog, and cat, with which he closes the account of the domesticated animals, to which three volumes are allotted. It is noteworthy that Buffon frequently, if not always, gives the synonyms of the animals' names in other languages, and usually supports his textual statements by footnote references to his authorities. [Pg 15]

When he comes to the Carnivores—"les animaux nuisibles"—the defects of Buffon's higgledy-piggledy plan are almost ludicrously evident, for flesh-eaters, fruit-eaters, insect-eaters, and gnawers rub shoulders with colossal indifference. Doubtless, however, this is to us all the more conspicuous, because use and wont have made readers of the present day acquainted with the advantages of classification, which it is but fair to recognise has been elaborated and perfected since Buffon's time.

As his gigantic task progressed, Buffon's difficulties increased. At the beginning of vol. xii. (1764) he intimates that, with a view to break the monotony of a narrative in which uniformity is an unavoidable feature, he will in future, from time to time, interrupt the general description by discourses on Nature and its effects on a grand scale. This will, he naively adds, enable him to resume "with renewed courage" his account of details the investigation of which demands "the calmest patience, and affords no scope for genius."

II.—The Birds

Scarcely had he finished the twelve volumes of Quadrupeds when Buffon turned to the Birds. If this section were less exacting, yet it made enormous claims upon his attention, and nine volumes were occupied before the history of the class was concluded. Publication of "Des Oiseaux" was begun in 1770, and continued intermittently until 1783. But troubles dogged the great naturalist. The relations between him and Daubenton had grown acute, and the latter, unwilling any longer to put up with Buffon's love of vainglory, withdrew from the enterprise to which his co-operation had imparted so much value. Serious illness, also, and the death of Buffon's wife, caused a long suspension of his labours, which were, however, lightened by the assistance of Guéneau de Montbéliard. [Pg 16]

One stroke of luck he had, which no one will begrudge the weary Titan. James Bruce, of Kinnaird, on his return from Abyssinia in 1773, spent some time with Buffon at his château in Montbard, and placed at his disposal several of the remarkable discoveries he had made during his travels. Buffon was not slow to appreciate this godsend. Not only did he, quite properly, make the most of Bruce's disinterested help, but he also expressed the confident hope that the British Government would command the publication of Bruce's "precious" work. He went on to pay a compliment to the English, and so commit them to this enterprise. "That respectable nation," he asserts, "which excels all others in discovery, can but add to its glory in promptly communicating to the world the results of the excellent travellers' researches."

Still unfettered by any scheme of classification, either scientific or logical, Buffon begins his account of the birds with the eagles and owls. To indicate his course throughout the vast class, it will suffice to name a few of the principal birds in the order in which he takes them after the birds of prey. These, then, are the ostrich, bustard, game birds, pigeons, crows, singing birds, humming birds, parrots, cuckoos, swallows, woodpeckers, toucans, kingfishers, storks, cranes, secretary bird, herons, ibis, curlews, plovers, rails, diving birds, pelicans, cormorants, geese, gulls, and penguins. With the volume dealing with the picarian birds (woodpeckers) Buffon announces the withdrawal of Guéneau de Montbéliard, and his obligations for advice and help to the Abbé Bexon (1748–1784), Canon of Sainte Chapelle in Paris.

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III.—Supplement and Sequel

At the same time that the Birds volumes were passing through the press, Buffon also issued periodically seven volumes of a supplement (1774–1789), the last appearing posthumously under the editorship of Count Lacépède. This consisted of an olla podrida of all sorts of papers, such as would have won the heart of Charles Godfrey Leland. The nature of the hotchpotch will be understood from a recital of some of its contents, in their chronological order. It opened with an introduction to the history of minerals, partly theoretical (concerning light, heat, fire, air, water, earth, and the law of attraction), and partly experimental (body heat, heat in minerals, the nature of platinum, the ductility of iron). Then were discussed incandescence, fusion, ships' guns, the strength and resistance of wood, the preservation of forests and reafforestation, the cooling of the earth, the temperature of planets, additional observations on quadrupeds already described, accounts of animals not noticed before, such as the tapir, quagga, gnu, nylghau, many antelopes, the vicuña, Cape ant-eater, star-nosed mole, sea-lion, and others; the probabilities of life (a subject on which the author plumed himself), and his essay on the Epochs of Nature.

Nor did these concurrent series of books exhaust his boundless energy and ingenuity, for in the five years preceding his death (1783–1788), he produced his "Natural History of Minerals" in five volumes, the last of which was mainly occupied with electricity, magnetism, and the loadstone. It is true that the researches of modern chemists have wrought havoc with Buffon's work in this field; but this was his misfortune rather than his fault, and leaves untouched the quantity of his output.

Buffon invoked the aid of the artist almost from the first, and his "Natural History" is illustrated by hundreds of full-page copper-plate engravings, and embellished with [Pg 18] numerous elegant headpiece designs. The figures of the animals are mostly admirable examples of portraiture, though the classical backgrounds lend a touch of the grotesque to many of the compositions. Illustrations of anatomy, physiology, and other features of a technical character are to be numbered by the score, and are, of course, indispensable in such a work. The *editio princeps* is cherished by collectors because of the 1,008 coloured plates ("Planches Enluminées") in folio, the text itself being in quarto, by the younger Daubenton, whose work was spiritedly engraved by Martinet. Apparently anxious to illustrate one section exhaustively rather than several sections in a fragmentary manner, the artist devoted himself chiefly to the birds, which monopolise probably nine-tenths of the plates, and to which he may also have been attracted by their gorgeous plumages.

As soon as the labourer's task was over, his scientific friends thought the best monument which they could raise to his memory was to complete his "Natural History." This duty was discharged by two men, who, both well qualified, worked, however, on independent lines. Count Lacépède, adhering to the format of the original, added two volumes on the Reptiles (1788–1789), five on the Fishes (1798–1803), and one on the Cetaceans (1804). Sonnini de Manoncourt (1751–1812), feeling that this edition, though extremely handsome, was cumbersome, undertook an entirely new edition in octavo. This was begun in 1797, and finished in 1808. It occupied 127 volumes, and, Lacépède's treatises not being available, Sonnini himself dealt with the Fishes (thirteen volumes) and Whales (one volume), P.A. Latreille with the Crustaceans and Insects (fourteen volumes), Denys-Montfort with the Molluscs (six volumes), F.M. Dandin with the Reptiles (eight volumes), and C.F. Brisseau-Mirbel and N. Jolyclerc with the Plants (eighteen volumes). Sonnini's edition constituted the [Pg 19] cope-stone of Buffon's work, and remained the best edition, until the whole structure was thrown down by the views of later naturalists, who revolutionised zoology.

IV.—Place and Doctrine

Buffon may justly be acclaimed as the first populariser of natural history. He was, however, unscientific in his opposition to systems, which, in point of fact, essentially elucidated the important doctrine that a continuous succession of forms runs throughout the animal kingdom. His recognition of this principle was, indeed, one of his greatest services to the science.

Another of his wise generalisations was that Nature proceeds by unknown gradations, and consequently cannot adapt herself to formal analysis, since she passes from one species to another, and often from one genus to another, by shades of difference so delicate as to be wholly imperceptible.

In Buffon's eyes Nature is an infinitely diversified whole which it is impossible to break up and classify. "The animal combines all the powers of Nature; the forces animating it are peculiarly its own; it wishes, does, resolves, works, and communicates by its senses with the most distant objects. One's self is a centre where everything agrees, a point where all the universe is reflected, a world in miniature." In natural history, accordingly, each animal or plant ought to have its own biography and description.

Life, Buffon also held, abides in organic molecules. "Living beings are made up of these molecules, which exist in countless numbers, which may be separated but cannot be destroyed, which pierce into brute matter, and, working there, develop, it may be animals, it may be plants, according to the nature of the matter in which they are lodged. These indestructible molecules circulate throughout the universe, pass from one being to another, [Pg 20] minister to the continuance of life, provide for nutrition and the growth of the individual, and determine the reproduction of the species."

Buffon further taught that the quantity and quality of life pass from lower to higher stages —in Tennysonian phrase, men "rise on stepping-stones of their dead selves to higher things"—and showed the unity and structure of all beings, of whom man is the most perfect type.

It has been claimed that Buffon in a measure anticipated Lamarck and Darwin. He had already foreseen the mutability of species, but had not succeeded in proving it for varieties and races. If he asserted that the species of dog, jackal, wolf and fox were derived from a single one of these species, that the horse came from the zebra, and so on, this was far from being tantamount to a demonstration of the doctrine. In fact, he put forward the mutability of species rather as probable theory than as established truth, deeming it the corollary of his views on the succession and connection of beings in a continuous series.

Some case may be made out for regarding Buffon as the founder of zoogeography; at all events he was the earliest to determine the natural habitat of each species. He believed that species changed with climate, but that no kind was found throughout all the globe. Man alone has the privilege of being everywhere and always the same, because the human race is one. The white man (European or Caucasian), the black man (Ethiopian), the yellow man (Mongol), and the red man (American) are only varieties of the human species. As the Scots express it with wonted pith, "We're a' Jock Tamson's bairns."

As to his geological works, Buffon expounded two theories of the formation of the globe. In his "Théorie de la Terre" he supported the Neptunists, who attributed the phenomena of [Pg 21] the earth to the action of water. In his "Epoques de la Nature" he amplified the doctrines of Leibniz, and laid down the following propositions: (1) The earth is elevated at the equator and depressed at the poles in accordance with the laws of gravitation and centrifugal force; (2) it possesses an internal heat, apart from that received from the sun; (3) its own heat is insufficient to maintain life; (4) the substances of which the earth is composed are of the nature of glass, or can be converted into glass as the result of heat and fusion—that is, are verifiable; (5) everywhere on the surface, including mountains, exist enormous quantities of shells and other maritime remains.

To the theses just enumerated Buffon added what he called the "monuments," or what Hugh Miller, a century later, more aptly described as the Testimony of the Rocks. From a consideration of all these things, Buffon at length arrived at his succession of the Epochs, or Seven Ages of Nature, namely: (1) the Age of fluidity, or incandescence, when the earth and planets assumed their shape; (2) the Age of cooling, or consolidation, when the rocky interior of the earth and the great vitrescible masses at its surface were formed; (3) the Age when the waters covered the face of the earth; (4) the Age when the waters retreated and volcanoes became active; (5) the Age when the elephant, hippopotamus, rhinoceros, and other giants roamed through the northern hemisphere; (6) the Age of the division of the land into the vast areas now styled the Old and the New Worlds; and (7) the Age when Man appeared.

ROBERT CHAMBERS [Pg 22]

Vestiges of Creation

Robert Chambers was born in Peebles, Scotland, July 10, 1802, and died at St. Andrews on March 17, 1871. He was partner with his brother in the publishing firm of

W. & R. Chambers, was editor of "Chambers's Journal," and was author of several works when he published anonymously, in October 1844, the work by which his name will always be remembered, "Vestiges of the Natural History of Creation." His previous works, some thirty in number, did not deal with science, and his labour in preparing his masterpiece was commensurate with the courage which such an undertaking involved. When the book was published, such interest and curiosity as to its authorship were aroused that we have to go back to the publication of "Waverley" for a parallel. Little else was talked about in scientific circles. The work was violently attacked by many hostile critics, F.W. Newman, author of an early review, being a conspicuous exception. In the historical introduction to the "Origin of Species," Darwin speaks of the "brilliant and powerful style" of the "Vestiges," and says that "it did excellent service in this country in calling attention to the subject, in removing prejudice, and in thus preparing the ground for the reception of analogous views." Darwin's idea of selection as the key to the history of species does not occur in the "Vestiges," which belongs to the Lamarckian school of unexamined belief in the hereditary transmission of the effects of use and disuse.

I.—The Reign of Universal Law

THE stars are suns, and we can trace amongst them the working of the laws which govern our sun and his family. In these universal laws we must perceive intelligence; something of which the laws are but as the expressions of the will and power. The laws of Nature cannot be regarded as primary or independent causes of the phenomena of the physical world. We come, in short, to a Being beyond Nature—its author, its God; infinite, inconceivable, it may be, and yet one whom these very laws present to us with attributes showing that our [Pg 23] nature is in some way a faint and far-cast shadow of His, while all the gentlest and the most beautiful of our emotions lead us to believe that we are as children in His care and as vessels in His hand. Let it then be understood—and this for the reader's special attention—that when natural law is spoken of here, reference is made only to the mode in which the Divine Power is exercised. It is but another phrase for the action of the ever-present and sustaining God.

Viewing Nature in this light, the pursuit of science is but the seeking of a deeper acquaintance with the Infinite. The endeavour to explain any events in her history, however grand or mysterious these may be, is only to sit like a child at a mother's knee, and fondly ask of the things which passed before we were born; and in modesty and reverence we may even inquire if there be any trace of the origin of that marvellous arrangement of the universe which is presented to our notice. In this inquiry we first perceive the universe to consist of a boundless multitude of bodies with vast empty spaces between. We know of certain motions among these bodies; of other and grander translations we are beginning to get some knowledge. Besides this idea of locality and movement, we have the equally certain one of a former soft and more diffused state of the materials of these bodies; also a tolerably clear one as to gravitation having been the determining cause of both locality and movement. From these ideas the general one naturally suggested to us is—a former stage in the frame of material things, perhaps only a point in progress from some other, or a return from one like the present—universal space occupied with gasiform matter. This, however, was of irregular constitution, so that gravitation caused it to break up and gather into patches, producing at once the relative localities of astral and solar systems, and the movements which they have since observed, in themselves and with regard to each other— [Pg 24] from the daily spinning of single bodies on their own axes, to the mazy dances of vast families of orbs, which come to periods only in millions of years.

How grand, yet how simple the whole of this process—for a God only to conceive and do, and yet for man, after all, to trace out and ponder upon. Truly must we be in some way immediate to the august Father, who can think all this, and so come into His presence and council, albeit only to fall prostrate and mutely adore.

Not only are the orbs of space inextricably connected in the manner which has been described, but the constitution of the whole is uniform, for all consist of the same chemical elements. And now, in our version of the romance of Nature, we descend from the consideration of orb-filled space and the character of the universal elements, to trace the history of our own globe. And we find that this falls significantly into connection with the primary order of things suggested by Laplace's theory of the origin of the solar system in a vast nebula or fire-mist, which for ages past has been condensing under the influence of gravitation and the radiation of its heat.

II.—History of the Earth's Crust

When we study the earth's crust we find that it consists of layers or strata, laid down in succession, the earlier under the influence of heat, the later under the influence of water. These strata in their order might be described as a record of the state of life upon our planet from an early to a comparatively recent period. It is truly such a record, but not one perfectly complete.

Nevertheless, we find a noteworthy and significant sequence. We learn that there was dry land long before the occurrence of the first fossils of land plants and animals. In different geographical formations we find various species, though sometimes the same species is [Pg 25]
found in different formations, having survived the great earth changes which the record of the rocks indicates. There is an unbroken succession of animal life from the beginning to the present epoch. Low down, where the records of life begin, we find an era of backboneless animals only, and the animal forms there found, though various, are all humble in their respective lines of gradation.

The early fishes were low, both with respect to their class as fishes, and the order to which they belong—that of the cartilaginous or gristly fishes. In all the orders of ancient animals there is an ascending gradation of character from first to last. Further, there is a succession from low to high types in fossil plants, from the earliest strata in which they are found to the highest. Several of the most important living species have left no record of themselves in any formation beyond what are, comparatively speaking, modern. Such are the sheep and the goat, and such, above all, is our own species. Compared with many humbler animals, man is a being, as it were, of yesterday.

Thus concludes the wondrous section of the earth's history which is told by geology. It takes up our globe at an early stage in the formation of its crust—conducts it through what we have every reason to believe were vast spaces of time, in the course of which many superficial changes took place, and vegetable and animal life was gradually evolved—and drops it just at the point when man was apparently about to enter on the scene. The compilation of such a history, from materials of so extraordinary a character, and the powerful nature of the evidence which these materials afford, are calculated to excite our admiration, and the result must be allowed to exalt the dignity of science as a product of man's industry and his reason.

It is now to be remarked that there is nothing in the whole series of operations displayed [Pg 26] in inorganic geology which may not be accounted for by the agency of the ordinary forces of Nature. Those movements of subterranean force which thrust up mountain ranges and upheaved continents stand in inextricable connection, on the one hand, with the volcanoes which are yet belching forth lavas and shaking large tracts of ground, as, on the other, with the primitive incandescent state of the earth. Those forces which disintegrated the early rocks, of which detritus formed new beds at the bottom of the sea, are still seen at work to the same effect.

To bring these truths the more nearly before us, it is possible to make a substance resembling basalt in a furnace; limestone and sandstone have both been formed from suitable materials in appropriate receptacles; the phenomena of cleavage have, with the aid of electricity, been simulated on a small scale, and by the same agent crystals are formed. In short, the remark which was made regarding the indifference of the cosmical laws to the scale on which they operated is to be repeated regarding the geological.

A common furnace will sometimes exemplify the operation of forces which have produced the Giant's Causeway; and in a sloping ploughed field after rain we may often observe, at the lower end of a furrow, a handful of washed and neatly deposited mud or sand, capable of serving as an illustration of the way in which Nature has produced the deltas of the Nile and Ganges. In the ripple-marks on sandy beaches of the present day we see Nature's exact repetition of the operations by which she impressed similar features on the sandstones of the carboniferous era. Even such marks as wind-slanted rain would in our day produce on tide-deserted sands have been read upon tablets of the ancient strata.

It is the same Nature—that is to say, God through or in the manner of Nature—working everywhere and in all time, causing the wind to blow, and the rain to fall, and the tide to ebb [Pg 27] and flow, inconceivable ages before the birth of our race, as now. So also we learn from the conifers of those old ages that there were winter and summer upon earth, before any of us lived to liken the one to all that is genial in our own nature, or to say that the other breathed no airs so unkind as man's ingratitude. Let no one suppose there is any necessary disrespect for the Creator in thus tracing His laws in their minute and familiar operations. There is really no true great and small, grand and familiar, in Nature. Such only appear when we thrust ourselves in as a point from which to start in judging. Let us pass, if possible, beyond immediate impressions, and see all in relation to Cause, and we shall chastenedly admit that the whole is alike worshipful.

The Creator, then, is seen to have formed our earth, and effected upon it a long and complicated series of changes, in the same manner in which we find that he conducts the affairs of Nature before our living eyes; that is, in the manner of natural law. This is no rash or unauthorised affirmation. It is what we deduce from the calculation of a Newton and a Laplace on the one hand, and from the industrious observation of facts by a Murchison and a Lyell on the other. It is a point of stupendous importance in human knowledge; here at once is the whole region of the inorganic taken out of the dominion of marvel, and placed under an idea of Divine regulation.

III.—The History of the Earth's Life

Mixed up, however, with the geological changes, and apparently as final object connected with the formation of the globe itself, there is another set of phenomena presented in the course of our history—the coming into existence, namely, of a long suite of living things, vegetable and animal, terminating in the families which we still see occupying the surface. [Pg 28] The question arises: In what manner has this set of phenomena originated? Can we touch at and rest for a moment on the possibility of plants and animals having likewise been produced in a natural way, thus assigning immediate causes of but one character for everything revealed to our sensual observation; or are we at once to reject this idea, and remain content, either to suppose that creative power here acted in a different way, or to believe unexaminingly that the inquiry is one beyond our powers? Taking the last question first, I would reply that I am extremely loth to imagine that there is anything in Nature which we should, for any reason, refrain from examining. If we can infer aught from the past history of science, it is that the whole of Nature is a legitimate field for the exercise of our intellectual faculties; that there is a connection between this knowledge and our well-being; and that, if we may judge from things once despaired of by our inquiring reason, but now made clear and simple, there is none of Nature's mysteries which we may not hopefully attempt to penetrate. To remain idly content to presume a various class of immediate causes for organic Nature seems to me, on this ground, equally objectionable.

With respect to the other question the idea has several times arisen that some natural course was observed in the production of organic things, and this even before we were permitted to attain clear conclusions regarding inorganic nature. It was always set quickly aside as unworthy of serious consideration. The case is different now, when we have admitted law in the whole domain of the inorganic.

Otherwise, the absurdities into which we should be led must strike every reflecting mind. The Eternal Sovereign arranges a solar or an astral system, by dispositions imparted primordially to matter; he causes, by the same means, vast oceans to join and continents to [Pg 29] rise, and all the grand meteoric agencies to proceed in ceaseless alternation, so as to fit the earth for a residence of organic beings. But when, in the course of these operations, fuci and corals are to be, for the first time, placed in these oceans, a change in his plan of administration is required. It is not easy to say what is presumed to be the mode of his operations. The ignorant believe the very hand of Deity to be at work. Amongst the learned, we hear of "creative fiats," "interferences," "interpositions of the creative energy," all of them very obscure phrases, apparently not susceptible of a scientific explanation, but all tending simply to this: that the work was done in a marvellous way, and not in the way of Nature.

But we need not assume two totally distinct modes of the exercise of the divine power—one in the course of inorganic nature and the other in intimately connected course of organic nature.

Indeed, when all the evidence is surveyed, it seems difficult to resist the impression that vestiges, at least, are seen of the manner and method of the Creator in this part of His work. It appears to be a case in which rigid proof is hardly to be looked for. But such evidences as exist are remarkably consistent and harmonious. The theory pointed to consorts with everything else which we have learned accurately regarding the history of the universe. Science has not one positive affirmation on the other side. Indeed, the view opposed to it is not one in which science is concerned; it appears as merely one of the prejudices formed in the non-age of our race.

For the history, then, of organic nature, I embrace, not as a proved fact, but as a rational interpretation of things as far as science has revealed them, the idea of progressive development. We contemplate the simplest and most primitive types of being as giving birth to a type superior to it; this again producing the next higher, and so on to the highest. We [Pg 30] contemplate, in short, a universal gestation of Nature, like that of the individual being, and attended as little by circumstances of a miraculous kind as the silent advance of an ordinary mother from one week to another of her pregnancy.

Thus simple—after ages of marvelling—appears organic creation, while yet the whole phenomena are, in another point of view, wonders of the highest kind, being the undoubted results of ordinances arguing the highest attributes of foresight, skill and goodness on the part of their Divine Author.

If, finally, we study the mind of man, we find that its Almighty Author has destined it, like everything else, to be developed from inherent qualities.

Thus the whole appears complete on one principle. The masses of space are formed by law; law makes them in due time theatres of existence for plants and animals; sensation, disposition, intellect, are all in like manner sustained in action by law.

It is most interesting to observe into how small a field the whole of the mysteries of Nature thus ultimately resolve themselves. The inorganic has been thought to have one final comprehensive law—gravitation. The organic, the other great department of mundane things, rests in like manner on one law, and that is—development. Nor may even these be after all twain, but only branches of one still more comprehensive law, the expression of a unity flowing immediately from the One who is first and last.

IV.—The Future and its Meaning

The question whether the human race will ever advance far beyond its present position in intellect and morals is one which has engaged much attention. Judging from the past, we [Pg 31] cannot reasonably doubt that great advances are yet to be made; but, if the principle of development be admitted, these are certain, whatever may be the space of time required for their realisation. A progression resembling development may be traced in human nature, both in the individual and in large groups of men. Not only so, but by the work of our thoughtful brains and busy hands we modify external nature in a way never known before. The physical improvements wrought by man upon the earth's surface I conceive as at once preparations for, and causes of, the possible development of higher types of humanity, beings less strong in the impulsive parts of our nature, more strong in the reasoning and moral, more fitted for the delights of social life, because society will then present less to dread and more to love.

The history and constitution of the world have now been hypothetically explained, according to the best lights which a humble individual has found within the reach of his perceptive and reasoning faculties.

We have seen a system in which all is regularity and order, and all flows from, and is obedient to, a divine code of laws of unbending operation. We are to understand from what has been laid before us that man, with his varied mental powers and impulses, is a natural problem of which the elements can be taken cognisance of by science, and that all the secular destinies of our race, from generation to generation, are but evolutions of a law statuted and sustained in action by an all-wise Deity.

There may be a faith derived from this view of Nature sufficient to sustain us under all sense of the imperfect happiness, the calamities, the woes and pains of this sphere of being. For let us but fully and truly consider what a system is here laid open to view and we cannot well doubt that we are in the hands of One who is both able and willing to do us the most entire justice. Surely, in such a faith we may well rest at ease, even though life should have [Pg 32] been to us but a protracted malady. Thinking of all the contingencies of this world as to be in time melted into or lost in some greater system, to which the present is only subsidiary, let us wait the end with patience and be of good cheer.

GEORGES CUVIER [Pg 33]

The Surface of the Globe

Georges Cuvier was born Aug. 24, 1769, at Montbéliard, France. He had a brilliant academic career at Stuttgart Academy, and in 1795, at the age of twenty-six, he was appointed assistant professor of comparative anatomy at the Museum d'Histoire Naturelle in Paris, and was elected a member of the National Institute. From this date onwards to his death in 1832, his scientific industry was remarkable. Both as zoologist and palæontologist he must be regarded as one of the greatest pioneers of science. He filled many important scientific posts, including the chair of Natural History in the Collège de France, and a professorship at the Jardin des Plantes. In 1808 he was made member of the Council of the Imperial University; and in 1814, President of the Council of Public Instruction. In 1826 he was made grand officer of the Legion of Honour, and five years later was made a peer of France. The "Discours sur les Révolutions de la Surface du Globe," published in 1825, is essentially a preliminary discourse to the author's celebrated work, "Recherches sur les Ossemens fossiles de Quadrupèdes." It is an endeavour to trace the relationship between the changes which have taken place on the surface of the globe and the changes which have taken place in its animal inhabitants, with especial reference to the evidence afforded by fossil remains of quadrupeds. "It is apparent," Cuvier writes, "that the bones of quadrupeds conduct us, by various reasonings, to more precise results than any other relics of organised bodies." The two books together may be considered the first really scientific palæontology.

I.—Effects of Geological Change

My first object will be to show how the fossil remains of the terrestrial animals are connected with the theory of the earth. I shall afterwards explain the principles by which fossil bones may be identified. I shall give a rapid sketch of new species discovered by the application of these principles. I shall then show how far these varieties may extend, owing [Pg 34] to the influence of the climate and domestication. I shall then conceive myself justified in concluding that the more considerable differences which I have discovered are the results of very important catastrophes. Afterwards I shall explain the peculiar influence which my researches should exercise on the received opinions concerning the revolutions of the globe.

Finally, I shall examine how far the civil and religious history of nations accords with the results of observation on the physical history of the earth.

When we traverse those fertile plains, where tranquil waters cherish, as they flow, an abundant vegetation, and where the soil, trod by a numerous people, adorned with flourishing villages, rich cities, and superb monuments, is never disturbed save by the ravages of war, or the oppression of power, we can hardly believe that Nature has also had her internal commotions. But our opinions change when we dig into this apparently peaceful soil, or ascend its neighboring hills. The lowest and most level soils are composed of horizontal strata, and all contain marine productions to an innumerable extent. The hills to a very considerable height are composed of similar strata and similar productions. The shells are sometimes so numerous as to form the entire mass of the soil, and all quarters of the globe exhibit the same phenomenon.

The time is past when ignorance could maintain that these remains of organised bodies resulted from the caprice of Nature, and were productions formed in the bosom of the earth by its generative powers; for a scrupulous comparison of the remains shows not the slightest difference between the fossil shells and those that are now found in the ocean. It is clear, then, that they inhabited the sea, and that they were deposited by the sea in the places where they are now found; and it follows, too, that the sea rested in these places long enough to [Pg 35] form regular, dense, vast deposits of aquatic animals.

The bed of the sea, accordingly, must have undergone some change either in extent or situation.

Further, we find under the horizontal strata, *inclined* strata. Thus the sea, previously to the formation of the horizontal strata, must have formed others, which have been broken, inclined, and overturned by some unknown causes.

More than this, we find that the fossils vary with the depth of the strata, and that the fossils of the deeper and more ancient strata exhibit a formation proper to themselves; and we find in some of the strata, too, remains of terrestrial life.

The evidence is thus plain that the animal life in the sea has varied, and that parts of the earth's surface have been alternately dry land and ocean. The very soil, which terrestrial animals at present inhabit has a history of previous animal life, and then submersion under the sea.

The reiterated irruptions and retreats of the sea have not all been gradual, but, on the contrary, they have been produced by sudden catastrophes. The last catastrophe, which inundated and again left dry our present continents, left in the northern countries the carcasses of large quadrupeds, which were frozen, and which are preserved even to the present day, with their skin, hair and flesh. Had they not been frozen the moment they were killed, they must have putrefied; and, on the other hand, the intense frost could not have been the ordinary climatic condition, for they could not have existed at such low temperatures. In the same instant, then, in which these animals perished the climate which they inhabited must have undergone a complete revolution.

The ruptures, the inclinations, the overturnings of the more ancient strata, likewise point to sudden and violent changes.

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Animal life, then, has been frequently disturbed on this earth by terrific catastrophes. Living beings innumerable have perished. The inhabitants of the dry land have been engulfed by deluges; and the tenants of the water, deserted by their element, have been left to perish from drought.

Even ancient rocks formed or deposited before the appearance of life on the earth show signs of terrific violence.

It has been maintained by some that the causes now at work altering the face of the world are sufficient to account for all the changes through which it has passed: but that is not so. None of the agents Nature now employs—rain, thaw, rivers, seas, volcanoes—would have been adequate to produce her ancient works.

To explain the external crust of the world, we require causes other than those present in operation, and a thousand extraordinary theories have been advanced. Thus, according to one philosopher, the earth has received in the beginning a uniform light crust which caused the abysses of the ocean, and was broken to produce the Deluge. Another supposed the Deluge to be caused by the momentary suspension of the cohesion of minerals.

Even accomplished scientists and philosophers have advanced impossible and contradictory theories.

All attempts at explanation have been stultified by an ignorance of the facts to be explained, or by a partial survey of them, and especially by a neglect of the evidence afforded by fossils. How was it possible not to perceive that the theory of the earth owes its origin to fossils alone? They alone, in truth, inform us with any certainty that the earth has not always had the same covering, since they certainly must have lived upon its surface before they were buried in its depths. If there were only strata without fossils, one might maintain that the strata had all been formed together. Hitherto, in fact, philosophers have been at variance on every point save one, and that is that the sea has changed its bed; and [Pg 37] how could this have been known except for fossils?

From this consideration I was led to study fossils; and since the field was immense I was obliged to specialise in one department of fossils, and selected for study the fossil bones of quadrupeds. I made this selection because only from a study of fossil quadrupeds can one hope to ascertain the number and periods and contents of irruptions of the sea; and because, since the number of quadrupeds is limited, and most quadrupeds known, we have better means of assuring ourselves if the fossil remains are remains of extinct or extant animals. Animals such as the griffin, the cartazonon, the unicorn, never lived, and there are probably very few quadrupeds now living which have not been found by man.

But though the study of fossil quadruped be enlightening, it has its own special difficulties. One great difficulty arises from the fact that it is very rare to find a fossil skeleton approaching to a complete state.

Fortunately, however, there is a principle in comparative anatomy which lessens this difficulty. Every organised being constitutes a complete and compact system with all its parts in mutual correspondence. None of its parts can be changed without changing other parts, and consequently each part, taken separately, indicates the others.

Thus, if the intestines of an animal are made to digest raw flesh, its jaws must be likewise constructed to devour prey, its claws to seize and tear it, its teeth to rend it, its limbs to overtake it, its organs of sense to discern it afar. Again, in order to enable the jaw to seize with facility, a certain form of condyle is necessary, and the zygomatic arch must be well developed to give attachment to the masseter muscle. Again, the muscles of the neck must be powerful, whence results a special form in the vertebræ and the occiput, where the [Pg 38] muscles are attached. Yet again, in order that the claws may be effective, the toe-bones must have a certain form, and must have muscles and tendons distributed in a certain way. In a word, the form of the tooth necessitates the form of the condyle, of the shoulder-blade, and of the claws, of the femur, and of all the other bones, and all the other bones taken separately will give the tooth. In this manner anyone who is scientifically acquainted with the laws of organic economy may from a fragment reconstruct the whole animal. The mark of a cloven hoof is sufficient to tell the form of the teeth and jaws and vertebræ and leg-bones and thigh-bones and pelvis of the animal. The least fragment of bone, the smallest apophysis, has a determinative character in relation to the class, the order, the genus, and species to which it may belong. This is so true that, if we have only a single extremity of bone well preserved, we may, with application and a skilful use of analogy and exact comparison, determine all those points with as much certainty as if we were in possession of the entire animal. By the application of these principles we have identified and classified the fossil remains of more than one hundred and fifty mammalia.

II.—What the Fossils Teach

An examination of the fossils on the lines I have indicated shows that out of one hundred and fifty mammiferous and oviparous quadrupeds, ninety are unknown to present naturalists, and that in the older layers such oviparous quadrupeds as the ichthyosauri and plesiosauri abound. The fossil elephant, the rhinoceros, the hippopotamus, and the mastodons are not found in the more ancient layers. In fact, the species which appear the same as ours are found only in superficial deposits.

Now, it cannot be held that the present races of animals differ from the ancient races [Pg 39] merely by modifications produced by local circumstances and change of climate—for if species gradually changed, we must find traces of these gradual modifications, and between the palæotheria and the present species we should have discovered some intermediate formation; but to the present time none of these have appeared.

Why have not the bowels of the earth preserved the monuments of so remarkable a genealogy unless it be that the species of former ages were as constant as our own, or at least because the catastrophe that destroyed them had not left them time to give evidence of the changes?

Further, an examination of animals shows that though their superficial characteristics, such as colour and size, are changeable, yet their more radical characteristics do not change. Even the artificial breeding of domestic animals can produce only a limited degree of variation. The maximum variation known at the present time in the animal kingdom is seen in dogs, but in all the varieties the relations of the bones remain the same and the shape of the teeth undergoes no palpable change.

I know that some naturalists rely much on the thousands of ages which they can accumulate with a stroke of the pen; but there is nothing which proves that time will effect any more than climate and a state of domestication. I have endeavoured to collect the most ancient documents of the forms of animals. I have examined the engravings of animals including birds on the numerous columns brought from Egypt to Rome. M. Saint Hilaire collected all the mummies of animals he could obtain in Egypt—cats, ibises, birds of prey, dogs, monkeys, crocodiles, etc.—and we cannot find any more difference between them and those of the present day than between human mummies of that date and skeletons of the present day.

There is nothing, then, in known facts which can support the opinion that the new genera discovered among fossils—the palæotheria, anoplotheria, megalonyces, mastodontes, pterodactyli, ichthyosauri, etc.—could have been the sources of any animals now existing, which would differ only by the influence of time or climate. [Pg 40]

As yet no human bones have been discovered in the regular layers of the surface of the earth, so that man probably did not exist in the countries where fossil bones are found at the epoch of the revolutions which buried these bones, for there cannot be assigned any reason why mankind should have escaped such overwhelming catastrophes, or why human remains should not be discovered. Man *may* have inhabited some confined tract of country which escaped the catastrophe, but his establishment in the countries where the fossil remains of land animals are found—that is to say, in the greatest part of Europe, Asia, and America—is necessarily posterior not only to the revolutions which covered these bones, but even to those which have laid open the strata which envelop them; whence it is clear that we can draw neither from the bones themselves nor from the rocks which cover them any argument in favour of the antiquity of the human species in these different countries. On the contrary, in closely examining what has taken place on the surface of the globe, since it was left dry for the last time, we clearly see that the last revolution, and consequently the establishment of present society, cannot be very ancient. An examination of the amount of alluvial matter deposited by rivers, of the progress of downs, and of other changes on the surface of the earth, informs us clearly that the present state of things did not commence at a very remote period.

The history of nations confirms the testimony of the fossils and of the rocks. The chronology of none of the nations of the West can be traced unbroken farther back than 3,000 years. The Pentateuch, the most ancient document the world possesses, and all subsequent writings allude to a universal deluge, and the Pentateuch and Vedas and Chou-king date this catastrophe as not more than 5,400 years before our time. [Pg 41] Is it possible that mere chance gave a result so striking as to make the traditional origin of the Assyrian, Indian, and Chinese monarchies agree in being as remote as 4,000 or 5,000 years back? Would the ideas of nations with so little inter-communication, whose language, religion, and laws have nothing in common, agree on this point if they were not founded on truth? Even the American Indians have their Noah or Deucalion, like the Indians, Babylonians, and Greeks.

It may be said that the long existence of ancient nations is attested by their progress in astronomy. But this progress has been much exaggerated. But what would this astronomy prove even if it were more perfect? Have we calculated the progress which a science would make in the bosom of nations which had no other? If among the multitude of persons solely occupied with astronomy, even then, all that these people knew might have been discovered in a few centuries, when only 300 years intervened between Copernicus and Laplace.

Again, it has been pretended that the zodiacal figures on ancient temples give proof of a remote antiquity; but the question is very complicated, and there are as many opinions as writers, and certainly no conclusions against the newness of continents and nations can be based on such evidence. The zodiac itself has been considered a proof of antiquity, but the arguments brought forward are undoubtedly unsound.

Even if these various astronomical proofs were as certain as they are unconvincing, what conclusion could we draw against the great catastrophe so indisputably demonstrated? We should only have the right to conclude that astronomy was among the sciences preserved by those persons whom the catastrophe spared.

In conclusion, if there be anything determined in geology, it is that the surface of our globe has been subjected to a revolution within 5,000 years, and that this revolution buried the countries formerly inhabited by man and modern animals, and left the bottom of the former sea dry as a habitation for the few individuals it spared. Consequently, our present human societies have arisen since this catastrophe. [Pg 42]

But the countries now inhabited had been inhabited before, as fossils show, by animals, if not by mankind, and had been overwhelmed by a previous deluge; and, indeed, judging by the different orders of animal fossils we find, they had perhaps undergone two or three irruptions of the sea.

CHARLES DARWIN [Pg 43]

The Origin of Species

Charles Robert Darwin was born at Shrewsbury, England, Feb. 12, 1809, of a family distinguished on both sides. Abandoning medicine for natural history, he joined H.M.S. Beagle in 1831 on the five years' voyage, which he described in "The Voyage of the Beagle," and to which he refers in the introduction to his masterpiece. The "Origin of Species" containing, in the idea of natural selection, the distinctive contribution of Darwin to the theory of organic evolution, was published in November, 1859. In only one brief sentence did he there allude to man, but twelve years later he published the "Descent of Man," in which the principles of the earlier volume found their logical outcome. In other works Darwin added vastly to our knowledge of coral reefs, organic variation, earthworms, and the comparative expression of the emotions in man and animals. Darwin died in ignorance of the work upon variation done by his great contemporary, Gregor Mendel, whose work was rediscovered in 1900. "Mendelism" necessitates much modification of Darwin's work, which, however, remains the maker of the greatest epoch in the study of life and the most important contribution to that study ever made. Its immortal author died on April 19, 1882, and was buried in Westminster Abbey.

I.—Creation or Evolution?

WHEN on board H.M.S. Beagle as naturalist, I was much struck with certain facts in the distribution of the organic beings inhabiting South America, and in the geographical relations of the present to the past inhabitants of that continent. These facts, as will be seen in the latter chapters of this volume, seemed to throw some light on the origin of species—that mystery of mysteries, as it has been called by one of our greatest philosophers. On my return home, in 1837, it occurred to me that something might perhaps be made out on this question by patiently accumulating and reflecting on all sorts of facts which could possibly [Pg 44] have any bearing on it. After five years' work, I allowed myself to speculate on the subject, and drew up some short notes; these I enlarged in 1844 into a sketch of the conclusions which then seemed to me probable. From that period to the present day I have steadily pursued the same object. I hope that I may be excused for entering on these personal details, as I give them to show that I have not been hasty in coming to a decision.

In considering the origin of species, it is quite conceivable that a naturalist, reflecting on the mutual affinities of organic beings, on their embryological relations, their geographical distribution, geological succession, and other such facts, might come to the conclusion that species had not been independently created, but had descended, like varieties, from other species. Nevertheless, such a conclusion, even if well founded, would be unsatisfactory, until it could be shown how the innumerable species inhabiting this world have been modified so as to acquire that perfection of structure and co-adaptation which justly excites our admiration.

Naturalists continually refer to external conditions, such as climate, food, etc., as the only possible cause of variation. In one limited sense, as we shall hereafter see, this may be true; but it is preposterous to attribute to mere external conditions the structure, for instance, of the woodpecker, with its feet, tail, beak, and tongue, so admirably adapted to catch insects under the bark of trees. In the case of the mistletoe, which draws its nourishment from certain trees, which has seeds that must be transported by certain birds, and which has flowers with separate sexes absolutely requiring the agency of certain insects to bring pollen from one flower to the other, it is equally preposterous to account for the structure of the parasite, with its relations to several distinct organic beings, by the effects of external conditions, or of habit, or of the volition of the plant itself. [Pg 45]

It is, therefore, of the highest importance to gain a clear insight into the means of modification and co-adaptation. At the beginning of my observations it seemed to me probable that a careful study of domesticated animals and of cultivated plants would offer the best chance of making out this obscure problem. Nor have I been disappointed; in this and in all other perplexing cases I have invariably found that our knowledge, imperfect though it be, of variation under domestication, afforded the best and safest clue. I may venture to express my conviction of the high value of such studies, although they have been very commonly neglected by naturalists.

Although much remains obscure, and will long remain obscure, I can entertain no doubt, after the most deliberate study and dispassionate judgment of which I am capable, that the view which most naturalists until recently entertained, and which I formerly entertained—namely, that each species has been independently created—is erroneous. I am fully convinced that species are not immutable, but that those 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. Furthermore, I am also convinced that Natural Selection has been the most important, but not the exclusive, means of modification.

II.—Variation and Selection

All living beings vary more or less from one another, and though variations which are not inherited are unimportant for us, the number and diversity of inheritable deviations of structure, both those of slight and those of considerable physiological importance, are endless.

No breeder doubts how strong is the tendency to inheritance; that like produces like is his fundamental belief. Doubts have been thrown on this principle only by theoretical writers. [Pg 46] When any deviation of structure often appears, and we see it in the father and child, we cannot tell whether it may not be due to the same cause having acted on both; but when amongst individuals, apparently exposed to the same conditions, any very rare deviation, due to some extraordinary combination of circumstances, appears in the parent—say, once amongst several million individuals—and it re-appears in the child, the mere doctrine of chances almost compels us to attribute its reappearance to inheritance.

Everyone must have heard of cases of albinism, prickly skin, hairy bodies, etc., appearing in members of the same family. If strange and rare deviations of structure are really inherited, less strange and commoner deviations may be freely admitted to be inheritable. Perhaps the correct way of viewing the whole subject would be to look at the inheritance of every character whatever as the rule, and non-inheritance as the anomaly.

The laws governing inheritance are for the most part unknown. No one can say why the same peculiarity in different individuals of the same species, or in different species, is sometimes inherited and sometimes not so; why the child often reverts in certain characters to its grandfather or grandmother, or more remote ancestor; why a peculiarity is often transmitted from one sex to both sexes, or to one sex alone, more commonly but not exclusively to the like sex.

The fact of heredity being given, we have evidence derived from human practice as to the influence of selection. There are large numbers of domesticated races of animals and plants admirably suited in various ways to man's use or fancy—adapted to the environment of which his need and inclination are the most essential constituents. We cannot suppose that all the breeds were suddenly produced as perfect and as useful as we now see them; indeed, in many cases, we know that this has not been their history. The key is man's power of [Pg 47] accumulative selection. Nature gives successive variations; man adds them up in certain directions useful to him. In this sense he may be said to have made for himself useful breeds.

The great power of this principle of selection is not hypothetical. It is certain that several of our eminent breeders have, even within a single lifetime, modified to a large extent their breeds of cattle and sheep. What English breeders have actually effected is proved by the enormous prices given for animals with a good pedigree; and these have been exported to almost every quarter of the world. The same principles are followed by horticulturists, and we see an astonishing improvement in many florists' flowers, when the flowers of the present day are compared with drawings made only twenty or thirty years ago.

The practice of selection is far from being a modern discovery. The principle of selection I find distinctly given in an ancient Chinese encyclopædia. Explicit rules are laid down by some of the Roman classical writers. It is clear that the breeding of domestic animals was carefully attended to in ancient times, and is now attended to by the lowest savages. It would, indeed, have been a strange fact had attention not been paid to breeding, for the inheritance of good and bad qualities is so obvious.

Study of the origin of our domestic races of animals and plants leads to the following conclusions. Changed conditions of life are of the highest possible importance in causing variability, both by acting directly on the organisation, and indirectly by affecting the reproductive system. Spontaneous variation of unknown origin plays its part. Some, perhaps a great, effect may be attributed to the increased use or disuse of parts.

The final result is thus rendered infinitely complex. In some cases the intercrossing of aboriginally distinct species appears to have played an important part in the origin of our [Pg 48] breeds. When several breeds have once been formed in any country, their occasional intercrossing, with the aid of selection, has, no doubt, largely aided in the formation of new sub-breeds; but the importance of crossing has been much exaggerated, both in regard to animals and to those plants which are propagated by seed. Over all these causes of change, the accumulative action of selection, whether applied methodically and quickly, or unconsciously and slowly, but more efficiently, seems to have been the predominant power.

III.—Variation Under Nature

Before applying these principles to organic beings in a state of nature, we must ascertain whether these latter are subject to any variation. We find variation everywhere. Individual differences, though of small interest to the systematist, are of the highest importance for us, for they are often inherited; and they thus afford materials for natural selection to act and accumulate, in the same manner as man accumulates in any given direction individual differences in his domesticated productions. Further, what we call varieties cannot really be distinguished from species in the long run, a fact which we can clearly understand if species once existed as varieties, and thus originated. But the facts are utterly inexplicable if species are independent creations.

How have all the exquisite adaptations of one part of the body to another part, and to the conditions of life, and of one organic being to another being, been perfected? For everywhere we find these beautiful adaptations.

The answer is to be found in the struggle for life. Owing to this struggle, variations, however slight, and from whatever cause proceeding, if they be in any degree profitable to [Pg 49] the individuals of a species in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals, and will generally be inherited by the offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection, in order to mark its relation to man's power of selection. But the expression, often used by Mr. Herbert Spencer, of the Survival of the Fittest, is more accurate.

We have seen that man, by selection, can certainly produce great results, and can adapt organic beings to his own uses, through the accumulation of slight but useful variations given to him by the hand of Nature. Natural Selection is a power incessantly ready for action, and is as immeasurably superior to man's feeble efforts as the works of Nature are to those of Art.

All organic beings are exposed to severe competition. Nothing is easier than to admit in words the truth of the universal struggle for life, or more difficult—at least, I have found it so—than constantly to bear this conclusion in mind. Yet, unless it be thoroughly engrained in the mind, the whole economy of Nature, with every fact of distribution, rarity, abundance, extinction, and variation, will be dimly seen or quite misunderstood. We behold the face of Nature bright with gladness; we often see superabundance of food. We do not see, or we forget, that the birds which are idly singing round us mostly live on insects or seeds, and are thus constantly destroying life; or we forget how largely these songsters, or their eggs, or their nestlings, are destroyed by birds or beasts of prey. We do not always bear in mind that, though food may be superabundant, it is not so at all seasons of each recurring year.

A struggle for existence, the term being used in a large, general, and metaphorical sense, inevitably follows from the high rate at which all organic beings tend to increase. [Pg 50]

Every being, which during its natural lifetime produces several eggs or seeds, must suffer destruction during some period of its life, and during some season or occasional year; otherwise, on the principle of geometrical increase, its numbers would quickly become so inordinately great that no country could support the product. Hence, as more individuals are produced than can possibly survive, there must in every case be a struggle for existence, either one individual with another of the same species, or with the individuals of distinct species, or with the physical conditions of life. It is the doctrine of Malthus applied with manifold force to the whole animal and vegetable kingdoms; for in this case there can be no artificial increase of food, and no prudential restraint from marriage. Although some species may be now increasing, more or less rapidly, in numbers, all cannot do so, for the world would not hold them.

There is no exception to the rule that every organic being naturally increases at so high a rate that, if not destroyed, the earth would soon be covered by the progeny of a single pair. Even slow-breeding man has doubled in twenty-five years, and at this rate, in less than a thousand years, there would literally not be standing-room for his progeny. Linnæus has calculated that if an annual plant produced only two seeds—and there is no plant so unproductive as this—and their seedlings next year produced two, and so on, then in twenty years there would be a million plants. The elephant is reckoned the slowest breeder of all known animals, and I have taken some pains to estimate its probable minimum rate of natural increase. It will be safest to assume that it begins breeding when thirty years old, and goes on breeding until ninety years old, bringing forth six young in the interval, and [Pg 51] surviving till one hundred years old. If this be so, after a period of from 740 to 750 years there would be nearly nineteen million elephants alive, descended from the first pair.

The causes which check the natural tendency of each species to increase are most obscure. Eggs or very young animals seem generally to suffer most, but this is not invariably the case. With plants there is a vast destruction of seeds. The amount of food for each species of course gives the extreme limit to which each can increase; but very frequently it is not the obtaining food, but the serving as prey to other animals, which determines the average number of a species. Climate is important, and periodical seasons of extreme cold or drought seem to be the most effective of all checks.

The relations of all animals and plants to each other in the struggle for existence are most complex, and often unexpected. Battle within battle must be continually recurring with varying success; and yet in the long run the forces are so nicely balanced that the face of Nature remains for long periods of time uniform, though assuredly the merest trifle would give the victory to one organic being over another. Nevertheless, so profound is our ignorance, and so high our presumption, that we marvel when we hear of the extinction of an organic being; and as we do not see the cause, we invoke cataclysms to desolate the world, or invent laws on the duration of the forms of life!

The struggle for life is most severe between individuals and varieties of the same species. The competition is most severe between allied forms which fill nearly the same place in the economy of Nature. But great is our ignorance on the mutual relations of all organic beings. All that we can do is to keep steadily in mind that each organic being is striving to increase in a geometrical ratio; that each at some period of its life, during some season of the year, [Pg 52] during each generation or at intervals, has to struggle for life and to suffer great destruction. When we reflect on this struggle, we may console ourselves with the full belief that the war of Nature is not incessant, that no fear is felt, that death is generally prompt, and that the vigorous, the healthy, and the happy survive and multiply.

IV.—The Survival of the Fittest

How will the struggle for existence act in regard to variation? Can the principle of selection, which we have seen is so potent in the hands of man, apply under Nature? I think we shall see that it can act most efficiently. Let the endless number of slight variations and individual differences occurring in our domestic productions, and, in a lesser degree, in those under Nature, be borne in mind, as well as the strength of the hereditary tendency. Under domestication, it may be truly said that the whole organisation becomes in some degree plastic.

But the variability, which we almost universally meet with in our domestic productions, is not directly produced by man; he can neither originate variations nor prevent their occurrence; he can only preserve and accumulate such as do occur. Unintentionally he exposes organic beings to new and changing conditions of life, and variability ensues; but similar changes of condition might and do occur under Nature.

Let it also be borne in mind how infinitely complex and close-fitting are the mutual relations of all organic beings to each other and to their physical conditions of life, and consequently what infinitely varied diversities of structure might be of use to each being under changing conditions of life. Can it, then, be thought improbable, seeing what variations useful to man have undoubtedly occurred, that other variations, useful in some way to each being in the great complex battle of life, should occur in the course of many [Pg 53] successive generations? If such do occur, can we doubt, remembering that many more individuals are born than can possibly survive, that individuals having any advantage over others, would have the best chance of surviving and of procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favourable individual differences and variations, and the destruction of those which are injurious, I have called Natural Selection, or the Survival of the Fittest.

The term is too frequently misapprehended. Variations neither useful nor injurious would not be affected by natural selection. It is not asserted that natural selection induces variability. It implies only the preservation of such varieties as arise and are beneficial to the being under its conditions of life. Again, it has been said that I speak of natural selection as an active Power or Deity; but who objects to an author speaking of the attraction of gravity as ruling the movements of the planets? It is difficult to avoid personifying the word Nature;

but I mean by Nature only the aggregate action and product of many natural laws, and by laws the sequence of events as ascertained by us.

As man can produce, and certainly has produced, a great result by his methodical and unconscious means of selection, what may not natural selection effect? Man can act only on external and visible characters; Nature, if I may be allowed to personify the natural preservation or survival of the fittest, cares nothing for appearances, except in so far as they are useful to any being. She can act on every internal organ, on every shade of constitutional difference, on the whole machinery of life. Man selects only for his own good; Nature only for that of the being which she tends. Every selected character is fully exercised by her, as is implied by the fact of their selection. Man keeps the natives of many climates in the same [Pg 54] country; he seldom exercises each selected character in some peculiar and fitting manner; he feeds a long and a short-beaked pigeon on the same food; he does not exercise a long-backed or long-legged quadruped in any peculiar manner; he exposes sheep with long and short wool to the same climate.

Man does not allow the most vigorous males to struggle for the females. He does not rigidly destroy all inferior animals, but protects during each varying season, as far as lies in his power, all his productions. He often begins his selection by some half-monstrous form; or at least by some modification prominent enough to catch the eye or to be plainly useful to him.

But under Nature, the slightest differences of structure or constitution may well turn the nicely-balanced scale in the struggle for life, and so be preserved. How fleeting are the wishes and efforts of man! How short his time! And, consequently, how poor will be his results compared with those accumulated by Nature during whole geological periods! Can we wonder that Nature's productions should be far "truer" in character than man's productions; that they should be infinitely better adapted to the most complex conditions of life, and should plainly bear the stamp of far higher workmanship?

It may metaphorically be said that natural selection is daily and hourly scrutinising, throughout the world, the slightest variations; rejecting those that are bad, preserving and adding up all that are good; silently and insensibly working, whenever and wherever opportunity offers, at the improvement of each organic being in relation to its organic and inorganic conditions of life. We see nothing of these slow changes in progress until the hand of time has marked the lapse of ages, and then so imperfect is our view into long-past geological ages that we see only that the forms of life are now different from what they formerly were.

Although natural selection can act only through and for the good of each being, yet [Pg 55] characters and structures, which we are apt to consider as of very trifling importance, may thus be acted on.

Natural selection will modify the structure of the young in relation to the parent, and of the parent in relation to the young. In social animals it will adapt the structure of each individual for the benefit of the whole community, if the community profits by the selected change. What natural selection cannot do is to modify the structure of one species, without giving it any advantage, for the good of another species; and though statements to this effect may be found in works of natural history, I cannot find one case which will bear investigation.

A structure used only once in an animal's life, if of high importance to it, might be modified to any extent by natural selection; for instance, the great jaws possessed by certain insects, used exclusively for opening the cocoon, or the hard tip to the beak of unhatched birds, used for breaking the egg. It has been asserted that of the best short-beaked tumbler pigeons a greater number perish in the egg than are able to get out of it; so that fanciers assist in the act of hatching. Now, if Nature had to make the beak of a full-grown pigeon very short for the bird's own advantage, the process of modification would be very slow, and there would be simultaneously the most rigorous selection of all the young birds within the egg, for all with weak beaks would inevitably perish; or more easily broken shells might be selected, the thickness of the shell being known to vary like every other structure.

With all beings there must be much fortuitous destruction, which can have little or no influence on the course of natural selection. For instance, a vast number of eggs or seeds are annually devoured, and these could be modified through natural selection only if they varied [Pg 56] in some manner which protected them from their enemies. Yet many of these eggs or seeds would perhaps, if not destroyed, have yielded individuals better adapted to their conditions of life than any of those which happened to survive. So, again, a vast number of mature animals and plants, whether or not they be the best adapted to their conditions, must be annually destroyed by accidental causes, which would not be in the least degree mitigated by certain changes of structure or constitution which would in other ways be beneficial to the species.

But let the destruction of the adults be ever so heavy, if the number which can exist in any district be not wholly kept down by such causes—or, again, let the destruction of eggs or seeds be so great that only a hundredth or a thousandth part are developed—yet of those which do survive, the best adapted individuals, supposing there is any variability in a favourable direction, will tend to propagate their kind in larger numbers than the less well adapted.

On our theory the continued existence of lowly organisms offers no difficulty; for natural selection does not necessarily include progressive development; it only takes advantage of such variations as arise and are beneficial to each creature under its complex relations of life.

The mere lapse of time by itself does nothing, either for or against natural selection. I state this because it has been erroneously asserted that the element of time has been assumed by me to play an all-important part in modifying species, as if all the forms of life were necessarily undergoing change through some innate law.

V.—Sexual Selection

This form of selection depends, not on a struggle for existence in relation to other organic beings or to external conditions, but on a struggle between the individuals of one sex, [Pg 57] generally the males, for the possession of the other sex. The result is not death to the unsuccessful competitor, but few or no offspring. Sexual selection is, therefore, less rigorous than natural selection. Generally, the most vigorous males, those which are best fitted for their places in Nature, will leave most progeny. But, in many cases, victory depends not so much on general vigour as on having special weapons, confined to the male sex. A hornless stag or spurless cock would have a poor chance of leaving numerous offspring. Sexual selection, by always allowing the victor to breed, might surely give indomitable courage, length to the spur, and strength to the wing to strike in the spurred leg, in nearly the same manner as does the brutal cock-fighter by the careful selection of his best cocks.

How low in the scale of Nature the law of battle descends I know not. Male alligators have been described as fighting, bellowing, and whirling round, like Indians in a war-dance, for the possession of the females; male salmons have been observed fighting all day long; male stag-beetles sometimes bear wounds from the mandibles of other males; the males of certain other insects have been frequently seen fighting for a particular female who sits by, an apparently unconcerned beholder of the struggle, and then retires with the conqueror. The war is, perhaps, severest between the males of the polygamous animals, and these seem oftenest provided with special weapons. The males of carnivorous animals are already well armed, though to them special means of defence may be given through means of sexual selection, as the mane of the lion and the hooked jaw of the salmon. The shield may be as important for victory as the sword or spear.

Amongst birds, the contest is often of a more peaceful character. All those who have attended to the subject believe that there is the severest rivalry between the males of many species to attract, by singing, the females. The rock-thrush of Guiana, birds of paradise, and [Pg 58] some others, congregate; and successive males display with the most elaborate care, and show off in the best manner, their gorgeous plumage; they likewise perform strange antics before the females, which, standing by as spectators, at last choose the most attractive partner.

If man can in a short time give beauty and an elegant carriage to his bantams, according to his standard of beauty, I can see no good reason to doubt that female birds, by selecting, during thousands of generations, the most melodious or beautiful males, according to their standard of beauty, might produce a marked effect.

VI.—The Struggle for Existence

Under domestication we see much variability, caused, or at least excited, by changed conditions of life; but often in so obscure a manner that we are tempted to consider the variations as spontaneous. Variability is governed by many complex laws—by correlated growth, compensation, the increased use and disuse of parts, and the definite action of the surrounding conditions. There is much difficulty in ascertaining how largely our domestic productions have been modified; but we may safely infer that the amount has been large, and that modifications can be inherited for long periods. As long as the conditions of life remain the same, we have reason to believe that a modification, which has already been inherited for many generations, may continue to be inherited for an almost infinite number of generations. On the other hand, we have evidence that variability, when it has once come into play, does not cease under domestication for a very long period; nor do we know that it ever ceases, for new varieties are still occasionally produced by our oldest domesticated productions.

Variability is not actually caused by man; he only unintentionally exposes organic beings [Pg 59] to new conditions of life, and then Nature acts on the organisation and causes it to vary. But man can and does select the variations given to him by Nature, and thus accumulates them in any desired manner. He thus adapts animals and plants for his own benefit or pleasure.

He may do this methodically, or he may do it unconsciously by preserving the individuals most useful or pleasing to him without an intention of altering the breed.

It is certain that he can influence the character of a breed by selecting, in each successive generation, individual differences so slight as to be inappreciable except by an educated eye. This unconscious process of selection has been the agency in the formation of the most distinct and useful domestic breeds. That many breeds produced by man have to a large extent the character of natural species is shown by the inextricable doubts whether many of them are varieties or aboriginally distinct species.

There is no reason why the principles which have acted so efficiently under domestication should not have acted under Nature. In the survival of favoured individuals and races, during the constantly recurrent struggle for existence, we see a powerful and ever-acting form of selection. The struggle for existence inevitably follows from the high geometrical ratio of increase which is common to all organic beings. This high rate of increase is proved by calculation; by the rapid increase of many animals and plants during a succession of peculiar seasons and when naturalised in new countries. More individuals are born than can possibly survive. A grain in the balance may determine which individuals shall live and which shall die; which variety or species shall increase in number, and which shall decrease, or finally become extinct.

As the individuals of the same species come in all respects into the closest competition with each other, the struggle will generally be most severe between them; it will be almost [Pg 60] equally severe between the varieties of the same species, and next in severity between the species of the same genus. On the other hand, the struggle will often be severe between beings remote in the scale of Nature. The slightest advantage in certain individuals, at any age or during any season, over those with which they come into competition, or better adaptation, in however slight a degree, to the surrounding physical conditions, will, in the long run, turn the balance.

With animals having separated sexes, there will be in most cases a struggle between the males for the possession of the females. The most vigorous males, or those which have most successfully struggled with their conditions of life, will generally leave most progeny. But success will often depend on the males having special weapons, or means of defence, or charms; and a slight advantage will lead to victory.

As geology plainly proclaims that each land has undergone great physical changes, we might have expected to find that organic beings have varied under Nature in the same way as they have varied under domestication. And if there has been any variability under Nature, it would be an unaccountable fact if natural selection had not come into play. It has often been asserted, but the assertion is incapable of proof, that the amount of variation under Nature is a strictly limited quantity. Man, though acting on external characters alone, and often capriciously, can produce within a short period a great result by adding up mere individual differences in his domestic productions; and everyone admits that species present individual differences. But, besides such differences, all naturalists admit that natural varieties exist, which are considered sufficiently distinct to be worthy of record in systematic works.

No one has drawn any clear distinction between individual differences and slight [Pg 61] varieties, or between more plainly marked varieties and sub-species and species. On separate continents, and on different parts of the same continent when divided by barriers of any kind, what a multitude of forms exist which some experienced naturalists rank as varieties, others as geographical races or sub-species, and others as distinct, though closely allied species!

If, then, animals and plants do vary, let it be ever so slightly or slowly, why should not variations or individuals, differences which are in any way beneficial, be preserved and accumulated through natural selection, or the survival of the fittest? If man can, by patience, select variations useful to him, why, under changing and complex conditions of life, should not variations useful to Nature's living products often arise, and be preserved, or selected? What limit can be put to this power, acting during long ages and rigidly scrutinising the whole constitution, structure, and habits of each creature—favouring the good and rejecting the bad? I can see no limit to this power, in slowly and beautifully adapting each form to the most complex relations of life.

In the future I see open fields for far more important researches. Psychology will be based on the foundation already well laid by Mr. Herbert Spencer—that of the necessary acquirement of each mental power and capacity by gradation. Much light will be thrown on the origin of man and his history.

Authors of the highest eminence seem to be fully satisfied with the view that each species has been independently created. To my mind it accords better with what we know of the laws impressed on matter by the Creator that the production and extinction of the past and present inhabitants of the world should have been due to secondary causes, like those determining the birth and death of the individual. When I view all beings not as special creations, but as the lineal descendants of some few beings which lived long before the first [Pg 62] bed of the Cambrian system was deposited, they seem to me to become ennobled. Judging from the past, we may safely infer that not one living species will transmit its unaltered likeness to a distant futurity.

Of the species now living very few will transmit progeny of any kind to a far distant futurity; for the manner in which all organic beings are grouped shows that the greater number of species in each genus, and all the species in many genera, have left no descendants, but have become utterly extinct. We can so far take a prophetic glance into futurity as to foretell that it will be the common and widely-spread species, belonging to the larger and dominant groups within each class, which will ultimately prevail and procreate new and dominant species. As all the living forms of life are the lineal descendants of those which lived long before the Cambrian epoch, we may feel certain that the ordinary succession by generation has never once been broken, and that no cataclysm has desolated the whole world. We may look with some confidence to a secure future of great length. As natural selection works solely by and for the good of each being, all corporeal and mental endowments will tend to progress towards perfection.

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance, which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse; a ratio of increase so high as to lead to a struggle for life, and, as a consequence, to Natural Selection, entailing Divergence of Character and the Extinction of less improved forms. Thus, from the war of Nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms, or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved. [Pg 63]

SIR HUMPHRY DAVY [Pg 64]

Elements of Chemical Philosophy

Humphry Davy, the celebrated natural philosopher, was born Dec. 17, 1778, at Penzance, England. At the age of seventeen he became an apothecary's apprentice, and at the age of nineteen assistant at Dr. Beddoes's pneumatic institution at Bristol. During researches at the pneumatic institution he discovered the physiological effects of "laughing gas," and made so considerable a reputation as a chemist that at the age of twenty-two he was appointed lecturer, and a year later professor, at the Royal Institution. For ten years, from 1803, he was engaged in agricultural researches, and in 1813 published his "Elements of Agricultural Chemistry." During the same decade he conducted important investigations into the nature of chemical combination, and succeeded in isolating the elements potassium, sodium, strontium, magnesium, and chlorine. In 1812 he was knighted, and married Mrs. Apreece, *née* Jane Kerr. In 1815 he investigated the nature of fire-damp and invented the Davy safety lamp. In 1818 he received a baronetcy, and two years later was elected President of the Royal Society. On May 29, 1829, he died at Geneva. Davy's "Elements of Chemical Philosophy," of which a summary is given here, was published in one volume in 1812, being the substance of lectures delivered before the Board of Agriculture.

I.—Forms and Changes of Matter

THE forms and appearances of the beings and substances of the external world are almost infinitely various, and they are in a state of continued alteration. In general, matter is found in four forms, as (1) solids, (2) fluids, (3) gases, (4) ethereal substances.

1. *Solids.* Solids retain whatever mechanical form is given to them; their parts are separated with difficulty, and cannot readily be made to unite after separation. They may be either elastic or non-elastic, and differ in hardness, in colour, in opacity, in density, in weight, and, if crystalline, in crystalline form.

2. *Fluids.* Fluids, when in small masses, assume the spherical form; their parts possess freedom of motion; they differ in density and tenacity, in colour, and in opacity. They are usually regarded as incompressible; at least, a very great mechanical force is required to compress them. [Pg 65]

3. *Gases.* Gases exist free in the atmosphere, but may be confined. Their parts are highly movable; they are compressible and expansible, and their volumes are inversely as the weight compressing them. All known gases are transparent, and present only two or three varieties of colour; they differ materially in density.

4. *Ethereal Substances.* Ethereal substances are known to us only in their states of motion when acting upon our organs of sense, or upon other matter, and are not susceptible of being confined. It cannot be doubted that there is such matter in motion in space. Ethereal matter differs either in its nature, or in its affections by motion, for it produces different effects; for instance, radiant heat, and different kinds of light.

All these forms of matter are under the influence of active forces, such as gravitation, cohesion, heat, chemical and electrical attraction, and these we must now consider.

1. *Gravitation.* When a stone is thrown into the atmosphere, it rapidly descends towards the earth. This is owing to gravitation. All the great bodies in the universe are urged towards each other by a similar force. Bodies mutually gravitate towards each other, but the smaller body proportionately more than the larger one; hence the power of gravity is said to vary directly as the mass. Gravitation also varies with distance, and acts inversely as the square of the distance.

2. *Cohesion.* Cohesion is the force which preserves the forms of solids, and gives globularity to fluids. It is usually said to act only at the surface of bodies or by their immediate contact; but this does not seem to be the case. It certainly acts with much greater [Pg 66] energy at small distances, but the spherical form of minute portions of fluid matter can be produced only by the attractions of all the parts of which they are composed, for each other; and most of these attractions must be exerted at sensible distances, so that gravitation and cohesion may be mere modifications of the same general power of attraction.

3. *Heat.* When a body which occasions the sensation of heat on our organs is brought into contact with another body which has no such effect, the hot body contracts and loses to a certain extent its power of communicating heat; and the other body expands. Different solids and fluids expand very differently when heated, and the expansive power of liquids, in general, is greater than that of solids.

It is evident that the density of bodies must be diminished by expansion; and in the case of fluids and gases, the parts of which are mobile, many important phenomena depend upon this circumstance. For instance, if heat be applied to fluids and gases, the heated parts change their places and rise, and the currents in the ocean and atmosphere are due principally to this movement. There are very few exceptions to the law of the expansion of bodies at the time they become capable of communicating the sensation of heat, and these exceptions seem to depend upon some chemical change in the constitution of bodies, or on their crystalline arrangements.

The power which bodies possess of communicating or receiving heat is known as *temperature*, and the temparature of a body is said to be high or low with respect to another in proportion as it occasions an expansion or contraction of its parts.

When equal volumes of different bodies of different temperatures are suffered to remain in contact till they acquire the same temperature, it is found that this temperature is not a mean one, as it would be in the case of equal volumes of the same body. Thus if a pint of [Pg 67] quicksilver at 100° be mixed with a pint of water at 50°, the resulting temperature is not 75°, but 70°; the mercury has lost thirty degrees, whereas the water has only gained twenty degrees. This difference is said to depend on the different *capacities* of bodies for heat.

Not only do different bodies vary in their capacity for heat, but they likewise acquire heat with very different degrees of celerity. This last difference depends on the different power of bodies for *conducting* heat, and it will be found that as a rule the densest bodies, with the least capacity for heat, are the best conductors.

Heat, or the power of repulsion, may be considered as the *antagonist* power to the attraction of cohesion. Thus solids by a certain increase of temperature become fluids, and fluids gases; and, *vice versâ*, by a diminution of temperature, gases become fluids, and fluids solids.

Proofs of the conversion of solids, fluids, or gases into ethereal substances are not distinct. Heated bodies become luminous and give off radiant heat, which affects the bodies at a distance, and it may therefore be held that particles are thrown off from heated bodies with great velocity, which, by acting on our organs, produce the sensations of heat or light, and that their motion, communicated to the particles of other bodies, has the power of expanding them. It may, however, be said that the radiant matters emitted by bodies in ignition are specific substances, and that common matter is not susceptible of assuming this form; or it may be contended that the phenomena of radiation do in fact, depend upon motions communicated to subtile matter everywhere existing in space.

The temperatures at which bodies change their states from fluids to solids, though in general definite, are influenced by a few circumstances such as motion and pressure.

When solids are converted into fluids, or fluids into gases, there is always a loss of heat [Pg 68] of temperature; and, *vice versâ*, when gases are converted into fluids, or fluids into solids, there is an increase of heat of temperature, and in this case it is said that *latent* heat is absorbed or given out.

The expansion due to heat has been accounted for by supposing a subtile fluid, or *caloric*, capable of combining with bodies and of separating their parts from each other, and the absorption and liberation of latent heat can be explained on this principle. But many other facts are incompatible with the theory. For instance, metal may be kept hot for any length of time by friction, so that if *caloric* be pressed out it must exist in an inexhaustible quantity. Delicate experiments have shown that bodies, when heated, do not increase in weight.

It seems possible to account for all the phenomena of heat, if it be supposed that in solids the particles are in a constant state of vibratory motion, the particles of the hottest bodies moving with the greatest velocity and through the greatest space; that in fluids and gases the particles have not only vibratory motion, but also a motion round their own axes with different velocities, and that in ethereal substances the particles move round their own axes and separate from each other, penetrating in right lines through space. Temperature may be conceived to depend upon the velocity of the vibrations, increase of capacity on the motion being performed in greater space; and the diminution of temperature during the conversion of solids into fluids or gases may be explained on the idea of the loss of vibratory motion in consequence of the revolution of particles round their axes at the moment when the body becomes fluid or aeriform, or from the loss of rapidity of vibration in consequence of the motion of particles through greater space.

4. *Chemical Attraction.* Oil and water will not *combine*; they are said to have no chemical *attraction* or *affinity* for each other. But if oil and solution of potassa in water be mixed, the [Pg 69] oil and the solution blend and form a soap; and they are said to attract each other chemically or to have a *chemical affinity* for each other. It is a general character of chemical combination that it changes the qualities of the bodies. Thus, corrosive and pungent

substances may become mild and tasteless; solids may become fluids, and solids and fluids gases.

No body will act chemically upon another body at any sensible distance; apparent contact is necessary for chemical action. A freedom of motion in the parts of the bodies or a want of cohesion greatly assists action, and it was formerly believed that bodies cannot act chemically upon each other unless one of them be fluid or gaseous.

Different bodies unite with different degrees of force, and hence one body is capable of separating others from certain of their combinations, and in consequence mutual decompositions of different compounds take place. This has been called *double affinity*, or *complex chemical affinity*.

As in all well-known compounds the proportions of the elements are in certain definite ratios to each other, it is evident that these ratios may be expressed by numbers; and if one number be employed to denote the smallest quantity in which a body combines, all other quantities of the same body will be multiples of this number, and the smallest proportions into which the undecomposed bodies enter into union being known, the constitution of the compounds they form may be learnt, and the element which unites chemically in the smallest quantity being expressed by unity, all the other elements may be represented by the relations of their quantities to unity.

5. *Electrical Attraction.* A piece of dry silk briskly rubbed against a warm plate of polished flint glass acquires the property of adhering to the glass, and both the silk and the glass, if apart from each other, attract light substances. The bodies are said to be *electrically* [Pg 70] *excited*. Probably, all bodies which differ from each other become electrically excited when rubbed and pressed together. The electrical excitement seems of two kinds. A pith-ball touched by glass excited by silk repels a pith-ball touched by silk excited by metals. Electrical excitement of the same nature as that in glass excited by silk is known as *vitreous* or *positive*, and electrical excitement of the opposite nature is known as *resinous* or *negative*.

A rod of glass touched by an electrified body is electrified only round the point of contact. A rod of metal, on the contrary, suspended on a rod of glass and brought into contact with an electrical surface, instantly becomes electrical throughout. The glass is said to be a *non-conductor*, or *insulating substance*; the metal a *conductor*.

When a non-conductor or imperfect conductor, provided it be a thin plate of matter placed upon a conductor, is brought in contact with an excited electrical body, the surface opposite to that of contact gains the opposite electricity from that of the excited body, and if the plate be removed it is found to possess two surfaces in opposite states. If a conductor be brought into the neighbourhood of an excited body—the air, which is a non-conductor, being between them—that extremity of the conductor which is opposite to the excited body gains the opposite electricity; and the other extremity, if opposite to a body connected with the ground, gains the same electricity, and the middle point is not electrical at all. This is known as *induced* electricity.

The common exhibition of electrical effects is in attractions and repulsions; but electricity also produces chemical phenomena. If a piece of zinc and copper in contact with each other at one point be placed in contact at other points with the same portion of water, the zinc will corrode, and attract oxygen from the water much more rapidly than if it had not been in contact with the copper; and if sulphuric acid be added, globules of inflammable air are given off from the copper, though it is not dissolved or acted upon. [Pg 71]

Chemical phenomena in connection with electrical effects can be shown even better by combinations in which the electrical effects are increased by alterations of different metals and fluids—the so-called *voltaic batteries*. Such are the decomposing powers of such batteries that not even insoluble compounds are capable of resisting their energy, for even glass, sulphate of baryta, fluorspar, etc., are slowly acted upon, and the alkaline, earthy, or acid matter carried to the poles in the common order.

The most powerful voltaic combinations are formed by substances that act chemically with most energy upon each other, and such substances as undergo no chemical changes in the combination exhibit no electrical powers. Hence it was supposed that the electrical powers of metals were entirely due to chemical changes; but this is not the case, for contact produces electricity even when no chemical change can be observed.

II.—Radiant or Ethereal Matter

When similar thermometers are placed in different parts of the solar beam, it is found that different effects are produced in the differently coloured rays. The greatest heat is exhibited in the red rays, the least in the violet rays; and in a space beyond the red rays, where there is no visible light, the increase of temperature is greatest of all.

From these facts it is evident that matter set in motion by the sun has the power of producing heat without light, and that its rays are less refrangible than the visible rays. The invisible rays that produce heat are capable of reflection as well as refraction in the same manner as the visible rays.

Rays capable of producing heat with and without light proceed not only from the sun, but also from bodies at the surface of the globe under peculiar agencies or changes. If, for instance, a thermometer be held near an ignited body, it receives an impression connected with an elevation of temperature; this is partly produced by the conducting powers of the air, and partly by an impulse which is instantaneously communicated, even to a considerable distance. This effect is called the radiation of terrestrial heat. [Pg 72]

The manner in which the temperatures of bodies are affected by rays producing heat is different for different substances, and is very much connected with their colours. The bodies that absorb most light, and reflect least, are most heated when exposed either to solar or terrestrial rays. Black bodies are, in general, more heated than red; red more than green; green more than yellow; and yellow more than white. Metals are less heated than earthy or stony bodies, or than animal or vegetable matters. Polished surfaces are less heated than rough surfaces.

The bodies that have their temperatures most easily raised by heat rays are likewise those that are most easily cooled by their own radiation, or that at the same temperature emit most heat-making rays. Metals radiate less heat than glass, glass less than vegetable substances, and charcoal has the highest radiating powers of any body as yet made the subject of experiment.

Radiant matter has the power of producing chemical changes partly through its heating power, and partly through some other specific and peculiar influence. Thus chlorine and hydrogen detonate when a mixture of them is exposed to the solar beams, even though the heat is inadequate to produce detonation.

If moistened silver be exposed to the different rays of the solar spectrum, it will be found that no effect is produced upon it by the least refrangible rays which occasion heat without light; that a slight discoloration only will be produced by the red rays; that the effect of [Pg 73] blackening will be greater towards the violet end of the spectrum; and that in a space beyond the violet, where there is no sensible heat or light, the chemical effect will be very distinct. There seem to be rays, therefore, more refrangible than the rays producing light and heat.

The general facts of the refraction and effects of the solar beam offer an analogy to the agencies of electricity.

In general, in Nature the effects of the solar rays are very compounded. Healthy vegetation depends upon the presence of the solar beams or of light, and while the heat gives fluidity and mobility to the vegetable juices, chemical effects are likewise occasioned, oxygen is separated from them, and inflammable compounds are formed. Plants deprived of light become white and contain an excess of saccharine and aqueous particles; and flowers owe the variety of their hues to the influence of the solar beams. Even animals require the presence of the rays of the sun, and their colours seem to depend upon the chemical influence of these rays.

Two hypotheses have been invented to account for the principal operations of radiant matter. In the first it is supposed that the universe contains a highly rare elastic substance, which, when put into a state of undulation, produces those effects on our organs of sight which constitute the sensations of vision and other phenomena caused by solar and terrestrial rays. In the second it is conceived that particles are emitted from luminous or heat-making bodies with great velocity, and that they produce their effects by communicating their motions to substances, or by entering into them and changing their composition.

Newton has attempted to explain the different refrangibility of the rays of light by supposing them composed of particles differing in size. The same great man has put the query whether light and common matter are not convertible into each other; and, adopting the idea that the phenomena of sensible heat depend upon vibrations of the particles of [Pg 74] bodies, supposes that a certain intensity of vibrations may send off particles into free space, and that particles in rapid motion in right lines, in losing their own motion, may communicate a vibratory motion to the particles of terrestrial bodies.

MICHAEL FARADAY [Pg 75]

Experimental Researches in Electricity

Michael Faraday was the son of a Yorkshire blacksmith, and was born in London on September 22, 1791. At the age of twenty he became assistant to Sir Humphry Davy, whose lectures he had attended at the Royal Institution. Here he worked for the rest of his laborious life, which closed on August 25, 1867. The fame of Faraday, among those whose studies qualify them for a verdict, has risen steadily since his death, great though it then was. His researches were of truly epoch-making character, and he was the undisputed founder of the modern science of electricity, which is rapidly coming to dominate chemistry itself. Faraday excelled as a lecturer, and could stand even the supreme test of lecturing to children. Faraday's "Experimental Researches in Electricity" is a record of some of the most brilliant experiments in the history of science. In the course of his investigations he made discoveries which have had momentous consequences. His discovery of the mutual relation of magnets and of wires conducting electric currents was the beginning of the modern dynamo and all that it involves; while his discoveries of electric induction and of electrolysis were of equal significance. Most of the researches are too technical for epitomisation; but those given are representative of his manner and methods.

I.—Atmospheric Magnetism

It is to me an impossible thing to perceive that two-ninths of the atmosphere by weight is a highly magnetic body, subject to great changes in its magnetic character, by variations in its temperature and condensation or rarefaction, without being persuaded that it has much to do with the variable disposition of the magnetic forces upon the surface of the earth.

The earth is a spheroidal body consisting of paramagnetic and diamagnetic substances irregularly disposed and intermingled; but for the present the whole may be considered a [Pg 76] mighty compound magnet. The magnetic force of this great magnet is known to us only on the surface of the earth and water of our planet, and the variations in the magnetic lines of force which pass in or across this surface can be measured by their action on small standard magnets; but these variations are limited in their information, and do not tell us whether the cause is in the air above or the earth beneath.

The lines of force issue from the earth in the northern and southern parts and coalesce with each other over the equatorial, as would be the case in a globe having one or two short magnets adjusted in relation to its axis, and it is probable that the lines of force in their circuitous course may extend through space to tens of thousands of miles. The lines proceed through space with a certain degree of facility, but there may be variations in space, *e.g.*, variations in its temperature which affect its power of transmitting the magnetic influence.

Between the earth and space, however, is interposed the atmosphere, and at the bottom of the atmosphere we live. The atmosphere consists of four volumes of nitrogen and one of oxygen uniformly mixed and acting magnetically as a single medium. The *nitrogen* of the air is, as regards the magnetic force, neither paramagnetic nor diamagnetic, whether dense or rare, or at high or low temperatures.

The *oxygen* of the air, on the other hand, is highly paramagnetic, being, bulk for bulk, equivalent to a solution of protosulphate of iron, containing of the crystallised salt seventeen times the weight of the oxygen. It becomes less paramagnetic, volume for volume, as it is rarefied, and apparently in the simple proportion of its rarefaction, the temperature remaining the same. When its temperature is raised—the expansion consequent thereon being permitted—it loses very greatly its paramagnetic force, and there is sufficient reason to conclude that when its temperature is lowered its paramagnetic condition is exalted. [Pg 77] These characters oxygen preserves even when mingled with the nitrogen in the air.

Hence the atmosphere is a highly magnetic medium, and this medium is changed in its magnetic relations by every change in its density and temperature, and must affect both the intensity and direction of the magnetic force emanating from the earth, and may account for the variations which we find in terrestrial magnetic power.

We may expect as the sun leaves us on the west some magnetic effect correspondent to that of the approach of a body of cold air from the east. Again, the innumerable circumstances that break up more or less any average arrangement of the air temperatures may be expected to give not merely differences in the regularity, direction, and degree of magnetic variation, but, because of vicinity, differences so large as to be many times greater than the mean difference for a given short period, and they may also cause irregularities in the times of their occurrence. Yet again, the atmosphere diminishes in density upwards, and this diminution will affect the transmission of the electric force.

The result of the *annual variation* that may be expected from the magnetic constitution and condition of the atmosphere seems to me to be of the following kind.

Since the axis of the earth's rotation is inclined 23° 28' to the plane of the ecliptic, the two hemispheres will become alternately warmer and cooler than each other. The air of the cooled hemisphere will conduct magnetic influence more freely than if in the mean state, and the lines of force passing through it will increase in amount, whilst in the other hemisphere the warmed air will conduct with less readiness than before, and the intensity will diminish. In addition to this effect of temperature, there ought to be another due to the increase of the ponderable portion of the air in the cooled hemisphere, consequent on its contraction and the coincident expansion of the air in the warmer half, both of which circumstances tend to increase the variation in power of the two hemispheres from the [Pg 78] normal state. Then, as the earth rolls on its annual journey, that which was at one time the cooler becomes the warmer hemisphere, and in its turn sinks as far below the average magnetic intensity as it before had stood above it, while the other hemisphere changes its magnetic condition from less to more intense.

II.—Electro-Chemical Action

The theory of definite electrolytical or electro-chemical action appears to me to touch immediately upon the absolute quantity of electricity belonging to different bodies. As soon as we perceive that chemical powers are definite for each body, and that the electricity which we can loosen from each body has definite chemical action which can be measured, we seem to have found the link which connects the proportion of that we have evolved to the proportion belonging to the particles in their natural state.

Now, it is wonderful to observe how small a quantity of a compound body is decomposed by a certain quantity of electricity. One grain of water, for instance, acidulated to facilitate conduction, will require an electric current to be continued for three minutes and three-quarters to effect its decomposition, and the current must be powerful enough to keep a platina wire $^{1}/_{104}$ inch in thickness red hot in the air during the whole time, and to produce a very brilliant and constant star of light if interrupted anywhere by charcoal points. It will not be too much to say that this necessary quantity of electricity is equal to a very powerful flash of lightning; and yet when it has performed its full work of electrolysis, it has separated the elements of only a single grain of water.

On the other hand, the relation between the conduction of the electricity and the [Pg 79] decomposition of the water is so close that one cannot take place without the other. If the water be altered only in that degree which consists in its having the solid instead of the fluid state, the conduction is stopped and the decomposition is stopped with it. Whether the conduction be considered as depending upon the decomposition or not, still the relation of the two functions is equally intimate.

Considering this close and twofold relation—namely, that without decomposition transmission of electricity does not occur, and that for a given definite quantity of electricity passed an equally definite and constant quantity of water or other matter is decomposed; considering also that the agent, which is electricity, is simply employed in overcoming electrical powers in the body subjected to its action, it seems a probable and almost a natural consequence that the quantity which passes is the equivalent of that of the particles separated; *i.e.*, that if the electrical power which holds the elements of a grain of water in combination, or which makes a grain of oxygen and hydrogen in the right proportions unite into water when they are made to combine, could be thrown into a current, it would exactly equal the current required for the separation of that grain of water into its elements again; in other words, that the electricity which decomposes and that which is evolved by the decomposition of a certain quantity of matter are alike.

This view of the subject gives an almost overwhelming idea of the extraordinary quantity or degree of electric power which naturally belongs to the particles of matter, and the idea may be illustrated by reference to the voltaic pile.

The source of the electricity in the voltaic instrument is due almost entirely to chemical action. Substances interposed between its metals are all electrolytes, and the current cannot be transmitted without their decomposition. If, now, a voltaic trough have its extremities [Pg 80] connected by a body capable of being decomposed, such as water, we shall have a continuous current through the apparatus, and we may regard the part where the acid is acting on the plates and the part where the current is acting upon the water as the reciprocals of each other. In both parts we have the two conditions, *inseparable in such bodies as these*: the passing of a current, and decomposition. In the one case we have decomposition associated with a current; in the other, a current followed by decomposition.

Let us apply this in support of my surmise respecting the enormous electric power of each particle or atom of matter.

Two wires, one of platina, and one of zinc, each one-eighteenth of an inch in diameter, placed five-sixteenths of an inch apart, and immersed to the depth of five-eighths of an inch in acid, consisting of one drop of oil of vitriol and four ounces of distilled water at a temperature of about 60° Fahrenheit, and connected at the other ends by a copper wire eighteen feet long, and one-eighteenth of an inch in thickness, yielded as much electricity in little more than three seconds of time as a Leyden battery charged by thirty turns of a very large and powerful plate electric machine in full action. This quantity, although sufficient if passed at once through the head of a rat or cat to have killed it, as by a flash of lightning, was evolved by the mutual action of so small a portion of the zinc wire and water in contact with it that the loss of weight by either would be inappreciable; and as to the water which could be decomposed by that current, it must have been insensible in quantity, for no trace of hydrogen appeared upon the surface of the platina during these three seconds. It would appear that 800,000 such charges of the Leyden battery would be necessary to decompose a single grain of water; or, if I am right, to equal the quantity of electricity which is naturally associated with the elements of that grain of water, endowing them with their mutual [Pg 81] chemical affinity.

This theory of the definite evolution and the equivalent definite action of electricity beautifully harmonises the associated theories of definite proportions and electro-chemical affinity.

According to it, the equivalent weights of bodies are simply those quantities of them which contain equal quantities of electricity, or have naturally equal electric powers, it being the electricity which *determines* the equivalent number, *because* it determines the combining force. Or, if we adopt the atomic theory or phraseology, then the atoms of bodies which are equivalent to each other in their ordinary chemical action have equal quantities of electricity naturally associated with them. I cannot refrain from recalling here the beautiful idea put forth, I believe, by Berzelius in his development of his views of the electro-chemical theory of affinity, that the heat and light evolved during cases of powerful combination are the consequence of the electric discharge which is at the moment taking place. The idea is in perfect accordance with the view I have taken of the quantity of electricity associated with the particles of matter.

The definite production of electricity in association with its definite action proves, I think, that the current of electricity in the voltaic pile is sustained by chemical decomposition, or, rather, by chemical action, and not by contact only. But here, as elsewhere, I beg to reserve my opinion as to the real action of contact.

Admitting, however, that chemical action is the source of electricity, what an infinitely small fraction of that which is active do we obtain and employ in our voltaic batteries! Zinc and platina wires one-eighteenth of an inch in diameter and about half an inch long, dipped into dilute sulphuric acid, so weak that it is not sensibly sour to the tongue, or scarcely sensitive to our most delicate test papers, will evolve more electricity in one-twentieth of a minute than any man would willingly allow to pass through his body at once. [Pg 82]

The chemical energy represented by the satisfaction of the chemical affinities of a grain of water and four grains of zinc can evolve electricity equal in quantity to that of a powerful thunderstorm. Nor is it merely true that the quantity is active; it can be directed—made to perform its full equivalent duty. Is there not, then, great reason to believe that, by a closer investigation of the development and action of this subtile agent, we shall be able to increase the power of our batteries, or to invent new instruments which shall a thousandfold surpass in energy those we at present possess?

III.—The Gymnotus, or Electric Eel

Wonderful as are the laws and phenomena of electricity when made evident to us in inorganic or dead matter, their interest can bear scarcely any comparison with that which attaches to the same force when connected with the nervous system and with life.

The existence of animals able to give the same concussion to the living system as the electrical machine, the voltaic battery, and the thunderstorm being made known to us by various naturalists, it became important to identify their electricity with the electricity produced by man from dead matter. In the case of the *Torpedo* [a fish belonging to the family of Electric Rings] this identity has been fully proved, but in the case of the *Gymnotus* the proof has not been quite complete, and I thought it well to obtain a specimen of the latter fish.

A gymnotus being obtained, I conducted a series of experiments. Besides the hands two kinds of collectors of electricity were used—one with a copper disc for contact with the fish, and the other with a plate of copper bent into saddle shape, so that it might enclose a certain extent of the back and sides of the fish. These conductors, being put over the fish, collected power sufficient to produce many electric effects. [Pg 83]

Shock. The shock was very powerful when the hands were placed one near the head and the other near the tail, and the nearer the hands were together, within certain limits, the less powerful was the shock. The disc conductors conveyed the shock very well when the hands were wetted.

Galvanometer. A galvanometer was readily affected by using the saddle conductors, applied to the anterior and posterior parts of the gymnotus. A powerful discharge of the fish caused a deflection of thirty or forty degrees. The deflection was constantly in a given direction, the electric current being always from the anterior part of the animal through the galvanometer wire to the posterior parts. The former were, therefore, for the time externally positive and the latter negative.

Making a Magnet. When a little helix containing twenty-two feet of silked wire wound on a quill was put into a circuit, and an annealed steel needle placed in the helix, the needle became a magnet; and the direction of its polarity in every cast indicated a current from the anterior to the posterior parts of the gymnotus.

Chemical Decomposition. Polar decomposition of a solution of iodide of potassium was easily obtained.

Evolution of Heat. Using a Harris' thermo-electrometer, we thought we were able, in one instance, to observe a feeble elevation of temperature.

Spark. By suitable apparatus a spark was obtained four times.

Such were the general electric phenomena obtained from the gymnotus, and on several occasions many of the phenomena were obtained together. Thus, a magnet was made, a galvanometer deflected, and, perhaps, a wire heated by one single discharge of the electric force of the animal. When the shock is strong, it is like that of a large Leyden battery charged to a low degree, or that of a good voltaic battery of, perhaps, one hundred or more pairs of plates, of which the circuit is completed for a moment only. [Pg 84]

I endeavoured by experiment to form some idea of the quantity of electricity, and came to the conclusion that a single medium discharge of the fish is at least equal to the electricity of a Leyden battery of fifteen jars, containing 3,500 square inches of glass coated on both sides, charged to its highest degree. This conclusion is in perfect accordance with the degree of deflection which the discharge can produce in a galvanometer needle, and also with the amount of chemical decomposition produced in the electrolysing experiments.

The gymnotus frequently gives a double and even a triple shock, with scarcely a sensible interval between each discharge.

As at the moment of shock the anterior parts are positive and the posterior negative, it may be concluded that there is a current from the former to the latter through every part of the water which surrounds the animal, to a considerable distance from its body. The shock which is felt, therefore, when the hands are in the most favourable position is the effect of a very small portion only of the electricity which the animal discharges at the moment, by far the largest portion passing through the surrounding water.

This enormous external current must be accompanied by some effect within the fish *equivalent* to a current, the direction of which is from the tail towards the head, and equal to the sum of *all these external* forces. Whether the process of evolving or exciting the electricity within the fish includes the production of the internal current, which is not necessarily so quick and momentary as the external one, we cannot at present say; but at the time of the shock the animal does not apparently feel the electric sensation which he causes [Pg 85] in those around him.

The gymnotus can stun and kill fish which are in very various relations to its own body. The extent of surface which the fish that is about to be struck offers to the water conducting the electricity increases the effect of the shock, and the larger the fish, accordingly, the greater must be the shock to which it will be subjected.

The Chemical History of a Candle

"The Chemical History of a Candle" was the most famous course in the long and remarkable series of Christmas lectures, "adapted to a juvenile auditory," at the Royal Institution, and remains a rarely-approached model of what such lectures should be. They were illustrated by experiments and specimens, but did not depend upon these for coherence and interest. They were delivered in 1860–61, and have just been translated, though all but half-a-century old, into German.

I.—Candles and their Flames

There is not a law under which any part of this universe is governed that does not come into play in the phenomena of the chemical history of a candle. There is no better door by which you can enter into the study of natural philosophy than by considering the physical phenomena of a candle.

And now, my boys and girls, I must first tell you of what candles are made. Some are great curiosities. I have here some bits of timber, branches of trees particularly famous for their burning. And here you see a piece of that very curious substance taken out of some of the bogs in Ireland, called *candle-wood*—a hard, strong, excellent wood, evidently fitted for good work as a resister of force, and yet withal burning so well that, where it is found, they make splinters of it, and torches, since it burns like a candle, and gives a very good light [Pg 86] indeed. And in this wood we have one of the most beautiful illustrations of the general nature of a candle that I can possibly give. The fuel provided, the means of bringing that fuel to the place of chemical action, the regular and gradual supply of air to that place of action—heat and light all produced by a little piece of wood of this kind, forming, in fact, a natural candle.

But we must speak of candles as they are in commerce. Here are a couple of candles commonly called dips. They are made of lengths of cotton cut off, hung up by a loop, dipped into melted tallow, taken out again and cooled; then re-dipped until there is an accumulation of tallow round the cotton. However, a candle, you know, is not now a greasy thing like an ordinary tallow candle, but a clean thing; and you may almost scrape off and pulverise the drops which fall from it without soiling anything.

The candle I have in my hand is a stearine candle, made of stearine from tallow. Then here is a sperm candle, which comes from the purified oil of the spermaceti whale. Here, also, are yellow beeswax and refined beeswax from which candles are made. Here, too, is that curious substance called paraffin, and some paraffin candles made of paraffin obtained from the bogs of Ireland. I have here also a substance brought from Japan, a sort of wax which a kind friend has sent me, and which forms a new material for the manufacture of candles.

Now, as to the light of the candle. We will light one or two, and set them at work in the performance of their proper function. You observe a candle is a very different thing from a lamp. With a lamp you take a little oil, fill your vessel, put in a little moss, or some cotton prepared by artificial means, and then light the top of the wick. When the flame runs down the cotton to the oil, it gets stopped, but it goes on burning in the part above. Now, I have no [Pg 87] doubt you will ask, how is it that the oil, which will not burn of itself, gets up to the top of the cotton, where it will burn? We shall presently examine that; but there is a much more wonderful thing about the burning of a candle than this. You have here a solid substance with no vessel to contain it; and how is it that this solid substance can get up to the place where the flame is? Or, when it is made a fluid, then how is it that it keeps together? This is a wonderful thing about a candle.

You see, then, in the first instance, that a beautiful cup is formed. As the air comes to the candle, it moves upwards by the force of the current which the heat of the candle produces, and it so cools all the sides of the wax, tallow, or fuel as to keep the edge much cooler than the part within; the part within melts by the flame that runs down the wick as far as it can go before it is stopped, but the part on the outside does not melt. If I made a current in one direction, my cup would be lopsided, and the fluid would consequently run over—for the same force of gravity which holds worlds together, holds this fluid in a horizontal position. You see, therefore, that the cup is formed by this beautifully regular ascending current of air playing upon all sides, which keeps the exterior of the candle cool. No fuel would serve for a candle which has not the property of giving this cup, except such fuel as the Irish bogwood, where the material itself is like a sponge, and holds its own fuel.

You see now why you have such a bad result if you burn those beautiful fluted candles, which are irregular, intermittent in their shape, and cannot therefore have that nicely-formed edge to the cup which is the great beauty in a candle. I hope you will now see that the perfection of a process—that is, its utility—is the better point of beauty about it. It is not the best-looking thing, but the best-acting thing which is the most advantageous to us. This good-looking candle is a bad burning one. There will be a guttering round about it because [Pg 88] of the irregularity of the stream of air and the badness of the cup which is formed thereby.

You may see some pretty examples of the action of the ascending current when you have a little gutter run down the side of a candle, making it thicker there than it is elsewhere. As the candle goes on burning, that keeps its place and forms a little pillar sticking up by the side, because, as it rises higher above the rest of the wax or fuel, the air gets better round it, and it is more cooled and better able to resist the action of the heat at a little distance. Now, the greatest mistakes and faults with regard to candles, as in many other things, often bring with them instruction which we should not receive if they had not occurred. You will always remember that whenever a result happens, especially if it be new, you should say:

"What is the cause? Why does it occur?" And you will in the course of time find out the reason.

Then there is another point about these candles which will answer a question—that is, as to the way in which this fluid gets out of the cup, up to the wick, and into the place of combustion. You know that the flames on these burning wicks in candles made of beeswax, stearine, or spermaceti, do not run down to the wax or other matter, and melt it all away, but keep to their own right place. They are fenced off from the fluid below, and do not encroach on the cup at the sides.

I cannot imagine a more beautiful example than the condition of adjustment under which a candle makes one part subserve to the other to the very end of its action. A combustible thing like that, burning away gradually, never being intruded upon by the flame, is a very beautiful sight; especially when you come to learn what a vigorous thing flame is, what power it has of destroying the wax itself when it gets hold of it, and of disturbing its proper form if it come only too near.

But how does the flame get hold of the fuel? There is a beautiful point about that. It is by [Pg 89] what is called capillary attraction that the fuel is conveyed to the part where combustion goes on, and is deposited there, not in a careless way, but very beautifully in the very midst of the centre of action which takes place around it.

II.—The Brightness of the Candle

Air is absolutely necessary for combustion; and, what is more, I must have you understand that *fresh* air is necessary, or else we should be imperfect in our reasoning and our experiments. Here is a jar of air. I place it over a candle, and it burns very nicely in it at first, showing that what I have said about it is true; but there will soon be a change. See how the flame is drawing upwards, presently fading, and at last going out. And going out, why? Not because it wants air merely, for the jar is as full now as it was before, but it wants pure, fresh air. The jar is full of air, partly changed, partly not changed; but it does not contain sufficient of the fresh air for combustion.

Suppose I take a candle, and examine that part of it which appears brightest to our eyes. Why, there I get these black particles, which are just the smoke of the candle; and this brings to mind that old employment which Dean Swift recommended to servants for their amusement, namely, writing on the ceiling of a room with a candle. But what is that black substance? Why, it is the same carbon which exists in the candle. It evidently existed in the candle, or else we should not have had it here. You would hardly think that all those substances which fly about London in the form of soots and blacks are the very beauty and life of the flame. Here is a piece of wire gauze which will not let the flame go through it, and I think you will see, almost immediately, that, when I bring it low enough to touch that part of the flame which is otherwise so bright, it quells and quenches it at once, and allows a [Pg 90] volume of smoke to rise up.

Whenever a substance burns without assuming the vaporous state—whether it becomes liquid or remains solid—it becomes exceedingly luminous. What I say is applicable to all substances—whether they burn or whether they do not burn—that they are exceedingly bright if they retain their solid state when heated, and that it is to this presence of solid particles in the candle-flame that it owes its brilliancy.

I have here a piece of carbon, or charcoal, which will burn and give us light exactly in the same manner as if it were burnt as part of a candle. The heat that is in the flame of a candle decomposes the vapour of the wax, and sets free the carbon particles—they rise up heated and glowing as this now glows, and then enter into the air. But the particles when burnt never pass off from a candle in the form of carbon. They go off into the air as a perfectly invisible substance, about which we shall know hereafter.

Is it not beautiful to think that such a process is going on, and that such a dirty thing as charcoal can become so incandescent? You see, it comes to this—that all bright flames contain these solid particles; all things that burn and produce solid particles, either during the time they are burning, as in the candle, or immediately after being burnt, as in the case of the gunpowder and iron-filings—all these things give us this glorious and beautiful light.

III.—The Products of Combustion

We observe that there are certain products as the result of the combustion of a candle, and that of these products one portion may be considered as charcoal, or soot; that charcoal, when afterwards burnt, produces some other product—carbonic acid, as we shall see; and it concerns us very much now to ascertain what yet a third product is. [Pg 91]

Suppose I take a candle and place it under a jar. You see that the sides of the jar become cloudy, and the light begins to burn feebly. It is the products, you see, which make the light so dim, and this is the same thing which makes the sides of the jar so opaque. If you go home and take a spoon that has been in the cold air, and hold it over a candle—not so as to soot it—you will find that it becomes dim, just as that jar is dim. If you can get a silver dish, or something of that kind, you will make the experiment still better. It is *water* which causes the dimness, and we can make it, without difficulty, assume the form of a liquid.

And so we can go on with almost all combustible substances, and we find that if they burn with a flame, as a candle, they produce water. You may make these experiments yourselves. The head of a poker is a very good thing to try with, and if it remains cold long enough over the candle, you may get water condensed in drops on it; or a spoon, or a ladle, or anything else may be used, provided it be clean, and can carry off the heat, and so condense the water.

And now—to go into the history of this wonderful production of water from combustibles, and by combustion—I must first of all tell you that this water may exist in different conditions; and although you may now be acquainted with all its forms, they still require us to give a little attention to them for the present, so that we may perceive how the water, whilst it goes through its protean changes, is entirely and absolutely the same thing, whether it is produced from a candle, by combustion, or from the rivers or ocean.

First of all, water, when at the coldest, is ice. Now, we speak of water as water; whether it be in its solid, or liquid, or gaseous state, we speak of it chemically as water. [Pg 92]

We shall not in future be deceived, therefore, by any changes that are produced in water. Water is the same everywhere, whether produced from the ocean or from the flame of the candle. Where, then, is this water which we get from a candle? It evidently comes, as to part of it, from the candle; but is it within the candle beforehand? No! It is not in the candle; and it is not in the air round about the candle, which is necessary for its combustion. It is neither in one nor the other, but it comes from their conjoint action, a part from the candle, a part from the air. And this we have now to trace.

If we decompose water we can obtain from it a gas. This is hydrogen—a body classed amongst those things in chemistry which we call elements, because we can get nothing else out of them. A candle is not an elementary body, because we can get carbon out of it; we can get this hydrogen out of it, or at least out of the water which it supplies. And this gas has been so named hydrogen because it is that element which, in association with another, generates water.

Hydrogen gives rise to no substance that can become solid, either during combustion or afterwards, as a product of its combustion. But when it burns it produces water only; and if we take a cold glass and put it over the flame, it becomes damp, and you have water produced immediately in appreciable quantity, and nothing is produced by its combustion but the same water which you have seen the flame of a candle produce. This hydrogen is the only thing in Nature that furnishes water as the sole product of combustion.

Water can be decomposed by electricity, and then we find that its other constituent is the gas oxygen in which, as can easily be shown, a candle or a lamp burns much more brilliantly than it does in air, but produces the same products as when it burns in air. We thus find that oxygen is a constituent of the air, and by burning something in the air we can [Pg 93] remove the oxygen therefrom, leaving behind for our study the nitrogen, which constitutes about four-fifths of the air, the oxygen accounting for nearly all the rest.

The other great product of the burning of a candle is carbonic acid—a gas formed by the union of the carbon of the candle and the oxygen of the air. Whenever carbon burns, whether in a candle or in a living creature, it produces carbonic acid.

IV.—Combustion and Respiration

Now I must take you to a very interesting part of our subject—to the relation between the combustion of a candle and that living kind of combustion which goes on within us. In every one of us there is a living process of combustion going on very similar to that of a candle. For it is not merely true in a poetical sense—the relation of the life of man to a taper. A candle will burn some four, five, six, or seven hours. What, then, must be the daily amount of carbon going up into the air in the way of carbonic acid? What a quantity of carbon must go from each of us in respiration! A man in twenty-four hours converts as much as seven ounces of carbon into carbonic acid; a milch cow will convert seventy ounces, and a horse seventy-nine ounces, solely by the act of respiration. That is, the horse in twenty-four hours burns seventy-nine ounces of charcoal, or carbon, in his organs of respiration to supply his natural warmth in that time.

All the warm-blooded animals get their warmth in this way, by the conversion of carbon; not in a free state, but in a state of combination. And what an extraordinary notion this gives us of the alterations going out in our atmosphere! As much as 5,000,000 pounds of carbonic acid is formed by respiration in London alone in twenty-four hours. And where does all this [Pg 94] go? Up into the air. If the carbon had been like lead or iron, which, in burning, produces a solid substance, what would happen? Combustion would not go on. As charcoal burns, it becomes a vapour and passes off into the atmosphere, which is the great vehicle, the great carrier, for conveying it away to other places. Then, what becomes of it?

Wonderful is it to find that the change produced by respiration, which seems so injurious to us, for we cannot breathe air twice over, is the very life and support of plants and vegetables that grow upon the surface of the earth. It is the same also under the surface in the great bodies of water, for fishes and other animals respire upon the same principle, though not exactly by contact with the open air. They respire by the oxygen which is dissolved from the air by the water, and form carbonic acid; and they all move about to produce the one great work of making the animal and vegetable kingdoms subservient to each other.

All the plants growing upon the surface of the earth absorb carbon. These leaves are taking up their carbon from the atmosphere, to which we have given it in the form of carbonic acid, and they are prospering. Give them a pure air like ours, and they could not live in it; give them carbon with other matters, and they live and rejoice. So are we made dependent not merely upon our fellow-creatures, but upon our fellow-existers, all Nature being tied by the laws that make one part conduce to the good of the other.

AUGUSTE FOREL [Pg 95]

The Senses of Insects

Auguste Forel, who in 1909 retired from the Chair of Morbid Psychology in the University of Zürich, was born on September 1, 1848, and is one of the greatest students of the minds and senses of the lower animals and mankind. Among his most famous works are his "Hygiene of Nerves and Mind," his great treatise on the whole problem of sex in human life, of which a cheap edition entitled "Sexual Ethics" is published, his work on hypnotism, and his numerous contributions to the psychology of insects. The chief studies of this remarkable and illustrious student and thinker for many decades past have been those of the senses and mental faculties of insects. He has recorded the fact that his study of the beehive led him to his present views as to the right constitution of the state—views which may be described as socialism with a difference. His work on insects has served the study of human psychology, and is in itself the most important contribution to insect psychology ever made by a single student. Only within the last two years has the work of Forel, long famous on the European Continent, begun to be known abroad.

I.—Insect Activity and Instinct

This subject is one of great interest, as much from the standpoint of biology as from that of comparative psychology. The very peculiar mechanism of instincts always has its starting-point in sensations. To comprehend this mechanism it is essential to understand thoroughly the organs of sense and their special functions.

It is further necessary to study the co-ordination which exists between the action of the different senses, and leads to their intimate connection with the functions of the nerve-centres, that is to say, with the specially instinctive intelligence of insects. The whole question is, therefore, a chapter of comparative psychology, a chapter in which it is necessary to take careful note of every factor, to place oneself, so to speak, on a level with [Pg 96] the mind of an insect, and, above all, to avoid the anthropomorphic errors with which works upon the subject are filled.

At the same time the other extreme must equally be avoided—"anthropophobia," which at all costs desires to see in every living organism a "machine," forgetting that a "machine" which lives, that is to say, which grows, takes in nutriment, and strikes a balance between income and expenditure, which, in a word, continually reconstructs itself, is not a "machine," but something entirely different. In other words, it is necessary to steer clear of two dangers. We must avoid (1) identifying the mind of an insect with our own, but, above all, (2) imagining that we, with what knowledge we possess, can reconstruct the mind by our chemical and physical laws.

On the other hand, we have to recognise the fact that this mind, and the sensory functions which put it on its guard, are derived, just as with our human selves, from the primitive protoplasmic life. This life, so far as it is specialised in the nervous system by nerve irritability and its connections with the muscular system, is manifested under two aspects. These may be likened to two branches of one trunk.

(*a*) *Automatic* or *instinctive* activity. This, though perfected by repetition, is definitely inherited. It is uncontrollable and constant in effect, adapted to the circumstances of the special life of the race in question. It is this curious instinctive adaptation—which is so intelligent when it carries out its proper task, so stupid and incapable when diverted to some other purpose—that has deceived so many scientists and philosophers by its insidious analogy with humanly constructed machines.

But, automatic as it may appear, instinct is not invariable. In the first place, it presents a racial evolution which of itself alone already demonstrates a certain degree of plasticity [Pg 97] from generation to generation. It presents, further, individual variations which are more distinct as it is less deeply fixed by heredity. Thus the divergent instincts of two varieties, *e.g.*, of insects, present more individual variability and adaptability than do those instincts common to all species of a genus. In short, if we carefully study the behaviour of each individual of a species of insects with a developed brain (as has been done by P. Huber, Lubbock, Wasmann, and myself, among others, for bees, wasps, and ants), we are not long in finding noteworthy differences, especially when we put the instinct under abnormal conditions. We then force the nervous activity of these insects to present a second and plastic aspect, which to a large extent has been hidden from us under their enormously developed instinct.

(*b*) The *plastic* or *adaptive* activity is by no means, as has been so often suggested, a derivative of instinct. It is primitive. It is even the fundamental condition of the evolution of life. The living being is distinguished by its power of adaptation; even the amoeba is plastic. But in order that one individual may adapt itself to a host of conditions and possibilities, as is the case with the higher mammals and especially with man, the brain requires an enormous quantity of nerve elements. But this is not the case with the fixed and specialised adaptation of instinct.

In secondary automatism, or habit, which we observe in ourselves, it is easy to study how this activity, derived from plastic activity, and ever becoming more prompt, complex, and sure (technical habits), necessitates less and less expenditure of nerve effort. It is very difficult to understand how inherited instinct, hereditary automatism, could have originated from the plastic activities of our ancestors. It seems as if a very slow selection, among individuals best adapted in consequence of fortunate parentage, might perhaps account for it.

To sum up, every animal possesses two kinds of activity in varying degrees, sometimes one, sometimes the other predominating. In the lowest beings they are both rudimentary. In insects, special automatic activity reaches the summit of development and predominance; in man, on the contrary, with his great brain development, plastic activity is elevated to an extraordinary height, above all by language, and before all by written language, which substitutes graphic fixation for secondary automatism, and allows the accumulation outside the brain of the knowledge of past generations, thus serving his plastic activity, at once the adapter and combiner of what the past has bequeathed to it. [Pg 98]

According to the families, *genera*, and species of insects, the development of different senses varies extremely. We meet with most striking contrasts, and contrasts which have not been sufficiently noticed. Certain insects, dragon-flies, for instance, live almost entirely by means of sight. Others are blind, or almost blind, and subsist exclusively by smell and taste (insects inhabiting caves, most working ants). Hearing is well developed in certain forms (crickets, locusts), but most insects appear not to hear, or to hear with difficulty. Despite their thick, chitinous skeleton, almost all insects have extremely sensitive touch, especially in the antennæ, but not confined thereto.

It is absolutely necessary to bear in mind the mental faculties of insects in order to judge with a fair degree of accuracy how they use their senses. We shall return to that point when summing up.

II.—The Vision of Insects

In vision we are dealing with a certain definite stimulus—light, with its two modifications, colour and motion. Insects have two sets of organs for vision, the faceted eye and the so-called simple eye, or ocellus. These have been historically derived from one and the same organ. In order to exercise the function of sight the facets need a greater pencil of light rays by night than by day. To obtain the same result we dilate the pupil. But nocturnal insects are dazzled by the light of day, and diurnal insects cannot see by night, for neither possess the faculty of accommodation. Insects are specially able to perceive motion, but there are only very few insects that can see distinctly. [Pg 99]

For example, I watched one day a wasp chasing a fly on the wall of a veranda, as is the habit of this insect at the end of summer and in the autumn. She dashed violently in flight at the flies sitting on the wall, which mostly escaped. She continued her pursuit with remarkable pertinacity, and succeeded on several occasions in catching a fly, which she killed, mutilated, and bore away to her nest. Each time she quickly returned to continue the hunt.

In one spot of the wall was stuck a black nail, which was just the size of a fly, and I saw the wasp very frequently deceived by this nail, upon which she sprang, leaving it as soon as she perceived her error on touching it. Nevertheless, she made the same mistake with the nail shortly after. I have often made similar observations. We may certainly conclude that the wasp saw something of the size of a fly, but without distinguishing the details; therefore she saw it indistinctly. Evidently a wasp does not only perceive motion; she also distinguishes the size of objects. When I put dead flies on a table to be carried off by another wasp, she took them, one after another, as well as spiders and other insects of but little different size placed by their side. On the other hand, she took no notice of insects much larger or much smaller put among the flies.

Most entomologists have observed with what ingenuity and sureness dragon-flies distinguish, follow, and catch the smallest insects on the wing. Of all insects, they have the [Pg 100] best sight. Their enormous convex eyes have the greatest number of facets. Their number has been estimated at 12,000, and even at 17,000. Their aerial chases resemble those of the swallows. By trying to catch them at the edge of a large pond, one can easily convince oneself that the dragon-flies amuse themselves by making sport of the hunter; they will always allow one to approach just near enough to miss catching them. It can be seen to what degree they are able to measure the distance and reach of their enemy.

It is an absolute fact that dragon-flies, unless it is cold or in the evening, always manage to fly at just that distance at which the student cannot touch them; and they see perfectly well whether one is armed with a net or has nothing but his hands; one might even say that they measure the length of the handle of the net, for the possession of a long handle is no advantage. They fly just out of reach of one's instrument, whatever trouble one may give oneself by hiding it from them and suddenly lunging as they fly off. Whoever watches butterflies and flies will soon see that these insects also can measure the distance of such objects as are not far from them. The males and females of bees and ants distinguish one another on the wing. It is rare for an individual to lose sight of the swarm or to miss what it pursues flying. It has been proved that the sense of smell has nothing to do with this matter. Thus insects, though without any power of accommodation for light or distance, are able to perceive objects at different distances.

It is known that many insects will blindly fly and dash against a lamp at night, until they burn themselves. It has often been wrongly thought that they are fascinated. We ought first to remember that natural lights, concentrated at one point like our artificial lights, are extremely rare in Nature. The light of day, which is the light of wild animals, is not concentrated at one point. Insects, when they are in darkness—underground, beneath bark [Pg 101] or leaves—are accustomed to reach the open air, where the light is everywhere diffused, by directing themselves towards the luminous point. At night, when they fly towards a lamp, they are evidently deceived, and their small brains cannot comprehend the novelty of this light concentrated at one spot. Consequently, their fruitless efforts are again and again renewed against the flame, and the poor innocents end by burning themselves. Several domestic insects, which have become little by little adapted to artificial light in the course of generations, no longer allow themselves to be deceived thereby. This is the case with house-flies.

Bees distinguish all colours, and seldom confound any but blue and green; while wasps scarcely react to differences of colour, but note better the shape of an object, and note, for instance, where the place of honey is; so that a change of colour on the disc whereon the honey is placed hardly upsets them. Further, wasps have a better sense of smell than bees.

The chief discovery regarding the vision of insects made in the last thirty years is that of Lubbock, who proved that ants perceive the ultra-violet rays of the spectrum, which we are unable, or almost unable, to perceive.

It has lately been proved also that many insects appreciate light by the skin.

They do not see as clearly as we do; but when they possess well-developed compound eyes they appreciate size, and more or less distinctly the contours of objects.

Ants have a great faculty for recognition, which probably testifies to their vision and visual memory. Lubbock observed ants which actually recognised each other after more than a year of separation.

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III.—Smell, Taste, Hearing, Pain

Smell is very important in insects. It is difficult for us to judge of, since man is of all the vertebrates except the whales, perhaps, the one in which this sense is most rudimentary. We can evidently, therefore, form only a feeble idea of the world of knowledge imparted by a smell to a dog, a mole, a hedgehog, or an insect. The instruments of smell are the antennæ. A poor ant without antennæ is as lost as a blind man who is also deaf and dumb. This appears from its complete social inactivity, its isolation, its incapacity to guide itself and to find its food. It can, therefore, be boldly supposed that the antennæ and their power of smell, as much on contact as at a distance, constitute the social sense of ants, the sense which allows them to recognise one another, to tend to their larvæ, and mutually help one another, and also the sense which awakens their greedy appetites, their violent hatred for every being foreign to the colony, the sense which principally guides them—a little helped by vision, especially in certain species—in the long and patient travels which they have to undertake, which makes them find their way back, find their plant-lice, and all their other means of subsistence.

As the philosopher Herbert Spencer has well pointed out, the visceral sensations of man, and those internal senses which, like smell, can only make an impression of one kind as regards space—two simultaneous odours can only be appreciated by us as a mixture—are precisely those by which we can gain little or no information relative to space. Our vision, on the contrary, which localises the rays from various distant points of space on various distinct points of our retina at the same time, is our most relational sense, that which gives us the most vast ideas of space.

But the antennæ of insects are an olfactory organ turned inside out, prominent in space, [Pg 103] and, further, very mobile. This allows us to suppose that the sense of smell may be much more relational than ours, that the sensations thence derived give them ideas of space and of direction which may be qualitatively different from ours.

Taste exists in insects, and has been very widely written on, but somewhat inconclusively. The organs of taste probably are to be found in the jaws and at the base of the tongue. This sense can be observed in ants, bees, and wasps; and everyone has seen how caterpillars especially recognise by taste the plants which suit them.

Much has been written on the hearing of insects; but, in my judgment, only crickets and several other insects of that class appear to perceive sounds. Erroneous views have been due to confusing hearing with mechanical vibrations.

We must not forget that the specialisation of the organ of hearing has reached in man a delicacy of detail which is evidently not found again in lower vertebrates.

Pain is much less developed in insects than in warm-blooded vertebrates. Otherwise, one could not see either an ant, with its abdomen or antennæ cut off, gorge itself with honey; or a humble-bee, in which the antennæ and all the front of the head had been removed, go to find and pillage flowers; or a spider, the foot of which had been broken, feed immediately on this, its own foot, as I myself have seen; or, finally, a caterpillar, wounded at the "tail" end, devour itself, beginning behind, as I have observed more than once.

IV.—Insect Reason and Passions

Insects reason, and the most intelligent among them, the social hymenoptera, especially the wasps and ants, even reason much more than one is tempted to believe when one observes the regularly recurring mechanism of their instincts. To observe and understand [Pg 104] these reasonings well, it is necessary to mislead their instinct. Further, one may remark little bursts of plastic judgment, of combinations—extremely limited, it is true—which, in forcing them an instant from the beaten track of their automatism, help them to overcome difficulties, and to decide between two dangers. From the point of view of instinct and intelligence, or rather of reason, there are not, therefore, absolute contrasts between the insect, the mammal, and the man.

Finally, insects have passions which are more or less bound up with their instincts. And these passions vary enormously, according to the species. I have noted the following passions or traits of character among ants: choler, hatred, devotion, activity, perseverance, and gluttony. I have added thereto the discouragement which is sometimes shown in a striking manner at the time of a defeat, and which can become real despair; the fear which is shown among ants when they are alone, while it disappears when they are numerous. I can add further the momentary temerity whereby certain ants, knowing the enemy to be weakened and discouraged, hurl themselves alone in the midst of the black masses of enemies larger than themselves, hustling them without taking the least further precaution.

When we study the manners of an insect, it is necessary for us to take account of its mental faculties as well as of its sense organs. Intelligent insects make better use of their senses, especially by combining them in various ways. It is possible to study such insects in their homes in a more varied and more complete manner, allowing greater accuracy of observations.

GALILEO

[Pg 105]

Dialogues on the System of the World

Galileo Galilei, famous as an astronomer and as an experimental physicist, was born at Pisa, in Italy, Feb. 18, 1564. His talents were most multifarious and remarkable; but his mathematical and mechanical genius was dominant from the first. As a child he constructed mechanical toys, and as a young man he made one of his most important discoveries, which was that of the pendulum as an agent in the measurement of time, and invented the hydrostatic balance, by which the specific gravity of solid bodies might be ascertained. At the age of 24 a learned treatise on the centre of gravity of solids led to a lectureship at Pisa University. Driven from Pisa by the enmity of Aristotelians, he went to Padua University, where he invented a kind of thermometer, a proportional compass, a microscope, and a telescope. The last invention bore fruit in astronomical discoveries, and in 1610 he discovered four of the moons of Jupiter. His promulgation of the Copernican doctrine led to renewed attacks by the Aristotelians, and to censure by the Inquisition. (See Religion, vol. xiii.) Notwithstanding this censure, he published in 1632 his "Dialogues on the System of the World." The interlocutors in the "Dialogues," with the exception of Salviatus, who expounds the views of the author himself, represent two of Galileo's early friends. For the "Dialogues" he was sentenced by the Inquisition to incarceration at its pleasure, and enjoined to recite penitential psalms once a week for three years. His life thereafter was full of sorrow, and in 1637 blindness added to his woes; but the fire of his genius still burnt on till his death on January 8, 1642.

Does the Earth Move

SALVIATUS: Now, let Simplicius propound those doubts which dissuade him from believing that the earth may move, as the other planets, round a fixed centre.

SIMPLICIUS: The first and greatest difficulty is that it is impossible both to be in a centre and to be far from it. If the earth move in a circle it cannot remain in the centre of the zodiac; but Aristotle, Ptolemy and others have proved that it is in the centre of the zodiac. [Pg 106]

SALVIATUS: There is no question that the earth cannot be in the centre of a circle round whose circumference it moves. But tell me what centre do you mean?

SIMPLICIUS: I mean the centre of the universe, of the whole world, of the starry sphere.

SALVIATUS: No one has ever proved that the universe is finite and figurative; but granting that it is finite and spherical, and has therefore a centre, we have still to give reasons why we should believe that the earth is at its centre.

SIMPLICIUS: Aristotle has proved in a hundred ways that the universe is finite and spherical.

SALVIATUS: Aristotle's proof that the universe was finite and spherical was derived essentially from the consideration that it moved; and seeing that centre and figure were inferred by Aristotle from its mobility, it will be reasonable if we endeavour to find from the circular motions of mundane bodies the centre's proper place. Aristotle himself came to the conclusion that all the celestial spheres revolve round the earth, which is placed at the centre of the universe. But tell me, Simplicius, supposing Aristotle found that one of the two propositions must be false, and that either the celestial spheres do not revolve or that the earth is not the centre round which they revolve, which proposition would he prefer to give up?

SIMPLICIUS: I believe that the Peripatetics——

SALVIATUS: I do not ask the Peripatetics, I ask Aristotle. As for the Peripatetics, they, as humble vassals of Aristotle, would deny all the experiments and all the observations in the world; nay, would also refuse to see them, and would say that the universe is as Aristotle writeth, and not as Nature will have it; for, deprived of the shield of his authority, with what do you think they would appear in the field? Tell me, therefore, what Aristotle himself would do.

SIMPLICIUS: To tell you the truth, I do not know how to decide which is the lesser inconvenience. [Pg 107]

SALVIATUS: Seeing you do not know, let us examine which would be the more rational choice, and let us assume that Aristotle would have chosen so. Granting with Aristotle that the universe has a spherical figure and moveth circularly round a centre, it is reasonable to believe that the starry orbs move round the centre of the universe or round some separate centre?

SIMPLICIUS: I would say that it were much more reasonable to believe that they move with the universe round the centre of the universe.

SALVIATUS: But they move round the sun and not round the earth; therefore the sun and not the earth is the centre of the universe.

SIMPLICIUS: Whence, then, do you argue that it is the sun and not the earth that is the centre of the planetary revolutions?

SALVIATUS: I infer that the earth is not the centre of the planetary revolutions because the planets are at different times at very different distances from the earth. For instance, Venus, when it is farthest off, is six times more remote from us than when it is nearest, and Mars rises almost eight times as high at one time as at another.

SIMPLICIUS: And what are the signs that the planets revolve round the sun as centre?

SALVIATUS: We find that the three superior planets—Mars, Jupiter, and Saturn—are always nearest to the earth when they are in opposition to the sun, and always farthest off when they are in conjunction; and so great is this approximation and recession that Mars, when near, appears very nearly sixty times greater than when remote. Venus and Mercury also certainly revolve round the sun, since they never move far from it, and appear now above and now below it.

SAGREDUS: I expect that more wonderful things depend on the annual revolution than upon the diurnal rotation of the earth. [Pg 108]

SALVIATUS: YOU do not err therein. The effect of the diurnal rotation of the earth is to make the universe seem to rotate in the opposite direction; but the annual motion complicates the particular motions of all the planets. But to return to my proposition. I affirm that the centre of the celestial convolutions of the five planets—Saturn, Jupiter, Mars, Venus, and Mercury, and likewise of the earth—is the sun.

As for the moon, it goes round the earth, and yet does not cease to go round the sun with the earth. It being true, then, that the five planets do move about the sun as a centre, rest seems with so much more reason to belong to the said sun than to the earth, inasmuch as in a movable sphere it is more reasonable that the centre stand still than any place remote from the centre.

To the earth, therefore, may a yearly revolution be assigned, leaving the sun at rest. And if that be so, it follows that the diurnal motion likewise belongs to the earth; for if the sun stood still and the earth did not rotate, the year would consist of six months of day and six months of night. You may consider, likewise, how, in conformity with this scheme, the precipitate motion of twenty-four hours is taken away from the universe; and how the fixed stars, which are so many suns, are made, like our sun, to enjoy perpetual rest.

SAGREDUS: The scheme is simple and satisfactory; but, tell me, how is it that Pythagoras and Copernicus, who first brought it forward, could make so few converts?

SALVIATUS: If you know what frivolous reasons serve to make the vulgar, contumacious and indisposed to hearken, you would not wonder at the paucity of converts. The number of thick skulls is infinite, and we need neither record their follies nor endeavour to interest [Pg 109] them in subtle and sublime ideas. No demonstrations can enlighten stupid brains.

My wonder, Sagredus, is different from yours. You wonder that so few are believers in the Pythagorean hypothesis; I wonder that there are any to embrace it. Nor can I sufficiently admire the super-eminence of those men's wits that have received and held it to be true, and with the sprightliness of their judgments have offered such violence to their senses that they have been able to prefer that which their reason asserted to that which sensible experience manifested. I cannot find any bounds for my admiration how that reason was able, in Aristarchus and Copernicus, to commit such a rape upon their senses, as in despite thereof to make herself mistress of their credulity.

SAGREDUS: Will there still be strong opposition to the Copernican system?

SALVIATUS: Undoubtedly; for there are evident and sensible facts to oppose it, requiring a sense more sublime than the common and vulgar senses to assist reason.

SAGREDUS: Let us, then, join battle with those antagonistic facts.

SALVIATUS: I am ready. In the first place, Mars himself charges hotly against the truth of the Copernican system. According to the Copernican system, that planet should appear sixty times as large when at its nearest as when at its farthest; but this diversity of magnitude is not to be seen. The same difficulty is seen in the case of Venus. Further, if Venus be dark, and shine only with reflected light, like the moon, it should show lunar phases; but these do not appear.

Further, again, the moon prevents the whole order of the Copernican system by revolving round the earth instead of round the sun. And there are other serious and curious difficulties admitted by Copernicus himself. But even the three great difficulties I have named are not [Pg 110] real. As a matter of fact, Mars and Venus do vary in magnitude as required by theory, and Venus does change its shape exactly like the moon.

SAGREDUS: But how came this to be concealed from Copernicus and revealed to you?

SIR FRANCIS GALTON [Pg 111]

Essays in Eugenics

Sir Francis Galton, born at Birmingham, England, in 1822, was a grandson of Dr. Erasmus Darwin. He graduated from Trinity College, Cambridge, in 1844. Galton travelled in the north of Africa, on the White Nile and in the western portion of South Africa between 1844 and 1850. Like his immortal cousin, Charles Darwin, Sir Francis Galton is a striking instance of a man of great and splendid inheritance, who, also inheriting wealth, devotes it and his powers to the cause of humanity. He published several books on heredity, the first of which was "Hereditary Genius." The next "Inquiries into Human Faculty," which was followed by "Natural Inheritance." The "Essays in Eugenics" include all the most recent work of Sir Francis Galton since his return to the subject of eugenics in 1901. This volume has just been published by the

Eugenics Education Society, of which Sir Francis Galton is the honorary president. As epitomised for this work, the "Essays" have been made to include a still later study by the author, which will be included in future editions of the book. The epitome has been prepared by special permission of the Eugenics Education Society, and those responsible hope that it will serve in some measure to neutralise the outrageous, gross, and often wilful misrepresentations of eugenics of which many popular writers are guilty.

I.—The Aims and Methods of Eugenics

The following essays help to show something of the progress of eugenics during the last few years, and to explain my own views upon its aims and methods, which often have been, and still sometimes are, absurdly misrepresented. The practice of eugenics has already obtained a considerable hold on popular estimation, and is steadily acquiring the status of a practical question, and not that of a mere vision in Utopia.

The power by which eugenic reform must chiefly be effected is that of public opinion, which is amply strong enough for that purpose whenever it shall be roused. Public opinion [Pg 112] has done as much as this on many past occasions and in various countries, of which much evidence is given in the essay on restrictions in marriage. It is now ordering our acts more intimately than we are apt to suspect, because the dictates of public opinion become so thoroughly assimilated that they seem to be the original and individual to those who are guided by them. By comparing the current ideas at widely different epochs and under widely different civilisations, we are able to ascertain what part of our convictions is really innate and permanent, and what part has been acquired and is transient.

It is, above all things, needful for the successful progress of eugenics that its advocates should move discreetly and claim no more efficacy on its behalf than the future will justify; otherwise a reaction will be justified. A great deal of investigation is still needed to show the limit of practical eugenics, yet enough has been already determined to justify large efforts being made to instruct the public in an authoritative way, with the results hitherto obtained by sound reasoning, applied to the undoubted facts of social experience.

The word "eugenics" was coined and used by me in my book "Human Faculty," published as long ago as 1883. In it I emphasised the essential brotherhood of mankind, heredity being to my mind a very real thing; also the belief that we are born to act, and not to wait for help like able-bodied idlers, whining for doles. Individuals appear to me as finite detachments from an infinite ocean of being, temporarily endowed with executive powers. This is the only answer I can give to myself in reply to the perpetually recurring questions of "why? whence? and whither?" The immediate "whither?" does not seem wholly dark, as some little information may be gleaned concerning the direction in which Nature, so far as we know of it, is now moving—namely, towards the evolution of mind, body, and character [Pg 113] in increasing energy and co-adaptation.

The ideas have long held my fancy that we men may be the chief, and perhaps the only executives on earth; that we are detached on active service with, it may be only illusory, powers of free-will. Also that we are in some way accountable for our success or failure to further certain obscure ends, to be guessed as best we can; that though our instructions are obscure they are sufficiently clear to justify our interference with the pitiless course of Nature whenever it seems possible to attain the goal towards which it moves by gentler and kindlier ways.

There are many questions which must be studied if we are to be guided aright towards the possible improvement of mankind under the existing conditions of law and sentiment. We must study human variety, and the distribution of qualities in a nation. We must compare the classification of a population according to social status with the classification which we would make purely in terms of natural quality. We must study with the utmost care the descent of qualities in a population, and the consequences of that marked tendency to marriage within the class which distinguishes all classes. Something is to be learnt from the results of examinations in universities and colleges.

It is desirable to study the degree of correspondence that may exist between promise in youth, as shown in examinations, and subsequent performance. Let me add that I think the neglect of this inquiry by the vast army of highly educated persons who are connected with the present huge system of competitive examination to be gross and unpardonable. Until this problem is solved we cannot possibly estimate the value of the present elaborate system of examinations.

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II.—Restrictions in Marriage

It is necessary to meet an objection that has been repeatedly urged against the possible adoption of any system of eugenics, namely, that human nature would never brook interference with the freedom of marriage. But the question is how far have marriage restrictions proved effective when sanctified by the religion of the time, by custom, and by law. I appeal from armchair criticism to historical facts. It will be found that, with scant exceptions, marriage customs are based on social expediency and not on natural instincts. This we learn when we study the fact of monogamy, and the severe prohibition of polygamy, in many times and places, due not to any natural instinct against the practice, but to consideration of the social well-being. We find the same when we study endogamy, exogamy, Australian marriages, and the control of marriage by taboo.

The institution of marriage, as now sanctified by religion and safeguarded by law in the more highly civilised nations, may not be ideally perfect, nor may it be universally accepted in future times, but it is the best that has hitherto been devised for the parties primarily concerned, for their children, for home life, and for society. The degree of kinship within which marriage is prohibited is, with one exception, quite in accordance with modern sentiment, the exception being the disallowal of marriage with the sister of a deceased wife, the propriety of which is greatly disputed and need not be discussed here. The marriage of a brother and sister would excite a feeling of loathing among us that seems implanted by nature, but which, further inquiry will show, has mainly arisen from tradition and custom.

The evidence proves that there is no instinctive repugnance felt universally by man to marriage within the prohibited degrees, but that its present strength is mainly due to what I [Pg 115] may call immaterial considerations. It is quite conceivable that a non-eugenic marriage should hereafter excite no less loathing than that of a brother and sister would do now.

The dictates of religion in respect to the opposite duties of leading celibate lives, and of continuing families, have been contradictory. In many nations it is and has been considered a disgrace to bear no children, and in other nations celibacy has been raised to the rank of a virtue of the highest order. During the fifty or so generations that have elapsed since the establishment of Christianity, the nunneries and monasteries, and the celibate lives of Catholic priests, have had vast social effects, how far for good and how far for evil need not be discussed here. The point I wish to enforce is the potency, not only of the religious sense in aiding or deterring marriage, but more especially the influence and authority of ministers of religion in enforcing celibacy. They have notoriously used it when aid has been invoked by members of the family on grounds that are not religious at all, but merely of family expediency. Thus at some times and in some Christian nations, every girl who did not marry while still young was practically compelled to enter a nunnery, from which escape was afterwards impossible.

It is easy to let the imagination run wild on the supposition of a whole-hearted acceptance of eugenics as a national religion; that is, of the thorough conviction by a nation that no worthier object exists for man than the improvement of his own race, and when efforts as great as those by which nunneries and monasteries were endowed and maintained should be directed to fulfil an opposite purpose. I will not enter further into this. Suffice it to say, that the history of conventual life affords abundant evidence on a very large scale of the power of religious authority in directing and withstanding the tendencies of human nature towards freedom in marriage.

Seven different forms of marriage restriction may be cited to show what is possible. They [Pg 116] are monogamy, endogamy, exogamy, Australian marriages, taboo, prohibited degrees, and celibacy. It can be shown under each of these heads how powerful are the various combinations of immaterial motives upon marriage selection, how they may all become hallowed by religion, accepted as custom, and enforced by law. Persons who are born under their various rules live under them without any objection. They are unconscious of their restrictions, as we are unaware of the tension of the atmosphere. The subservience of civilised races to their several religious superstitions, customs, authority, and the rest, is frequently as abject as that of barbarians.

The same classes of motives that direct other races direct ours; so a knowledge of their customs helps us to realise the wide range of what we may ourselves hereafter adopt, for reasons as satisfactory to us in those future times, as theirs are or were to them at the time when they prevailed.

III.—Eugenic Qualities of Primary Importance

The following is offered as a contribution to the art of justly appraising the eugenic values of different qualities. It may fairly be assumed that the presence of certain inborn traits is requisite before a claim to eugenic rank can be justified, because these qualities are needed to bring out the full values of such special faculties as broadly distinguish philosophers, artists, financiers, soldiers, and other representative classes. The method adopted for discovering the qualities in question is to consider groups of individuals, and to compare the qualities that distinguish such groups as flourish or prosper from others of the same kind that decline or decay. This method has the advantage of giving results more free from the possibility of bias than those derived from examples of individual cases.

In what follows I shall use the word "community" in its widest sense, as including any [Pg 117] group of persons who are connected by a common interest—families, schools, clubs, sects, municipalities, nations, and all intermediate social units. Whatever qualities increase the prosperity of most or every one of these, will, as I hold, deserve a place in the first rank of eugenic importance.

Most of us have experience, either by direct observation or through historical reading, of the working of several communities, and are capable of forming a correct picture in our minds of the salient characteristics of those that, on the one hand, are eminently prosperous, and of those that, on the other hand, are as eminently decadent. I have little doubt that the reader will agree with me that the members of prospering communities are, as a rule, conspicuously strenuous, and that those of decaying or decadent ones are conspicuously slack. A prosperous community is distinguished by the alertness of its members, by their busy occupations, by their taking pleasure in their work, by their doing it thoroughly, and by an honest pride in their community as a whole. The members of a decaying community are, for the most part, languid and indolent; their very gestures are dawdling and slouching, the opposite of smart. They shirk work when they can do so, and scamp what they undertake. A prosperous community is remarkable for the variety of the solid interests in which some or other of its members are eagerly engaged, but the questions that agitate a decadent community are for the most part of a frivolous order.

Prosperous communities are also notable for enjoyment of life; for though their members must work hard in order to procure the necessary luxuries of an advanced civilisation, they are endowed with so large a store of energy that, when their daily toil is over, enough of it remains unexpended to allow them to pursue their special hobbies during the remainder of the day. In a decadent community the men tire easily, and soon sink into drudgery; there is [Pg 118] consequently much languor among them, and little enjoyment of life.

I have studied the causes of civic prosperity in various directions and from many points of view, and the conclusion at which I have arrived is emphatic, namely, that chief among those causes is a large capacity for labour—mental, bodily, or both—combined with eagerness for work. The course of evolution in animals shows that this view is correct in general. The huge lizards, incapable of rapid action, unless it be brief in duration and associated with long terms of repose, have been supplanted by birds and mammals possessed of powers of long endurance. These latter are so constituted as to require work, becoming restless and suffering in health when precluded from exertion.

We must not, however, overlook the fact that the influence of circumstance on a community is a powerful factor in raising its tone. A cause that catches the popular feeling will often rouse a potentially capable nation from apathy into action. A good officer, backed by adequate supplies of food and with funds for the regular payment of his troops, will change a regiment even of ill-developed louts and hooligans into a fairly smart and well-disciplined corps. But with better material as a foundation, the influence of a favourable environment is correspondingly increased, and is less liable to impairment whenever the environment changes and becomes less propitious. Hence, it follows that a sound mind and body, enlightened, I should add, with an intelligence above the average, and combined with a natural capacity and zeal for work, are essential elements in eugenics. For however famous a man may become in other respects, he cannot, I think, be justly termed eugenic if deficient in the qualities I have just named.

Eugenists justly claim to be true philanthropists, or lovers of mankind, and should bestir themselves in their special province as eagerly as the philanthropists, in the current and very [Pg 119] restricted meaning of that word, have done in theirs. They should interest themselves in such families of civic worth as they come across, especially in those that are large, making friends both with the parents and the children, and showing themselves disposed to help to a reasonable degree, as opportunity may offer, whenever help is really needful. They should compare their own notes with those of others who are similarly engaged. They should regard such families as an eager horticulturist regards beds of seedlings of some rare variety of plant, but with an enthusiasm of a far more patriotic kind. For, since it has been shown that about 10 per cent. of the individuals born in one generation provide half the next generation, large families that are also eugenic may prove of primary importance to the nation and become its most valuable asset.

IV.—Practical Eugenics

The following are some views of my own relating to that large province of eugenics which is concerned with favouring the families of those who are exceptionally fit for citizenship. Consequently, little or nothing will here be said relating to what has been well termed by Dr. Saleeby "negative" eugenics, namely, the hindrance of the marriages and the production of offspring by the exceptionally unfit. The latter is unquestionably the more pressing subject, but it will soon be forced on the attention of the legislature by the recent report of the Royal Commission on the Feeble-minded.

Whatever scheme of action is proposed for adoption must be neither Utopian nor extravagant, but accordant throughout with British sentiment and practice.

By "worth" I mean the civic worthiness, or the value to the state, of a person. Speaking only for myself, if I had to classify persons according to worth, I should consider each of [Pg 120] them under the three heads of physique, ability and character, subject to the provision that inferiority in any one of the three should outweigh superiority in the other two. I rank physique first, because it is not only very valuable in itself and allied to many other good qualities, but has the additional merit of being easily rated. Ability I place second on similar grounds, and character third, though in real importance it stands first of all.

The power of social opinion is apt to be underrated rather than overrated. Like the atmosphere which we breathe and in which we move, social opinion operates powerfully without our being conscious of its weight. Everyone knows that governments, manners, and beliefs which were thought to be right, decorous, and true at one period have been judged wrong, indecorous, and false at another; and that views which we have heard expressed by those in authority over us in early life tend to become axiomatic and unchangeable in mature life.

In circumscribed communities especially, social approval and disapproval exert a potent force. Is it, then, I ask, too much to expect that when a public opinion in favour of eugenics has once taken sure hold of such communities, the result will be manifested in sundry and very effective modes of action which are as yet untried?

Speaking for myself only, I look forward to local eugenic action in numerous directions, of which I will now specify one. It is the accumulation of considerable funds to start young couples of "worthy" qualities in their married life, and to assist them and their families at critical times. The charitable gifts to those who are the reverse of "worthy" are enormous in amount. I am not prepared to say how much of this is judiciously spent, or in what ways, but merely quote the fact to justify the inference that many persons who are willing to give freely at the prompting of a sentiment based upon compassion might be persuaded to give [Pg 121] largely also in response to the more virile desire of promoting the natural gifts and the national efficiency of future generations.

V.—Eugenics as a Factor in Religion

Eugenics strengthen the sense of social duty in so many important particulars that the conclusions derived from its study ought to find a welcome home in every tolerant religion. It promotes a far-sighted philanthropy, the acceptance of parentage as a serious responsibility, and a higher conception of patriotism. The creed of eugenics is founded upon the idea of evolution; not on a passive form of it, but on one that can, to some extent, direct its own course.

Purely passive, or what may be styled mechanical evolution displays the awe-inspiring spectacle of a vast eddy of organic turmoil, originating we know not how, and travelling we know not whither. It forms a continuous whole, but it is moulded by blind and wasteful processes—namely, by an extravagant production of raw material and the ruthless rejection of all that is superfluous, through the blundering steps of trial and error.

The condition at each successive moment of this huge system, as it issues from the already quiet past and is about to invade the still undisturbed future, is one of violent internal commotion. Its elements are in constant flux and change.

Evolution is in any case a grand phantasmagoria, but it assumes an infinitely more interesting aspect under the knowledge that the intelligent action of the human will is, in some small measure, capable of guiding its course. Man has the power of doing this largely so far as the evolution of humanity is concerned; he has already affected the quality and distribution of organic life so widely that the changes on the surface of the earth, merely through his disforestings and agriculture, would be recognisable from a distance as great as [Pg 122] that of the moon.

As regards the practical side of eugenics, we need not linger to reopen the unending argument whether man possesses any creative power of will at all, or whether his will is not also predetermined by blind forces or by intelligent agencies behind the veil, and whether the belief that man can act independently is more than a mere illusion.

Eugenic belief extends the function of philanthropy to future generations; it renders its action more pervading than hitherto, by dealing with families and societies in their entirety, and it enforces the importance of the marriage covenant by directing serious attention to the probable quality of the future offspring. It sternly forbids all forms of sentimental charity that are harmful to the race, while it eagerly seeks opportunity for acts of personal kindness. It strongly encourages love and interest in family and race. In brief, eugenics is a virile creed, full of hopefulness, and appealing to many of the noblest feelings of our nature.

ERNST HAECKEL [Pg 123]

The Evolution of Man

Ernst Haeckel, who was born in Potsdam, Germany, Feb. 16, 1834, descends from a long line of lawyers and politicians. To his father's annoyance, he turned to science, and graduated in medicine. After a long tour in Italy in 1859, during which he wavered between art and science, he decided for zoology, and made a masterly study of a little-known group of sea-animalcules, the Radiolaria. In 1861 he began to teach zoology at

Jena University. Darwin's "Origin of Species" had just been translated into German, and he took up the defence of Darwinism against almost the whole of his colleagues. His first large work on evolution, "General Morphology," was published in 1866. He has since published forty-two distinct works. He is not only a master of zoology, but has a good command of botany and embryology. Haeckel's "Evolution of Man" (Anthropogenie), is generally accepted as being his most important production. Published in 1874, at a time when the theory of natural evolution had few supporters in Germany, the work was hailed with a storm of controversy, one celebrated critic declaring that it was a blot on the escutcheon of Germany. From the hands of English scientists, however, the treatise received a warm welcome. Darwin said he would probably never have written his "Descent of Man" had Haeckel published his work earlier.

I.—The Science of Man

The natural history of mankind, or anthropology, must always excite the most lively interest, and no part of the science is more attractive than that which deals with the question of man's origin. In order to study this with full profit, we must combine the results of two sciences, ontogeny (or embryology) and phylogeny (the science of evolution). We do this because we have now discovered that the forms through which the embryo passes in its development correspond roughly to the series of forms in its ancestral development. The correspondence is by no means complete or precise, since the embryonic life itself has been [Pg 124] modified in the course of time; but the general law is now very widely accepted. I have called it "the biogenetic law," and will constantly appeal to it in the course of this study.

It is only in recent times that the two sciences have advanced sufficiently to reveal the correspondence of the two series of forms. Aristotle provided a good foundation for embryology, and made some interesting discoveries, but no progress was made in the science for 2,000 years after him. Then the Reformation brought some liberty of research, and in the seventeenth century several works were written on embryology.

For more than a hundred years the science was still hampered by the lack of good microscopes. It was generally believed that all the organs of the body existed, packed in a tiny point of space, in the germ. About the middle of the eighteenth century, Caspar Friedrich Wolff discovered the true development; but his work was ignored, and it was only fifty years later that modern embryology began to work on the right line. K.E. von Baer made it clear that the fertilised ovum divides into a group of cells, and that the various organs of the body are developed from these layers of cells, in the way I shall presently describe.

The science of phylogeny, or, as it is popularly called, the evolution of species, had an equally slow growth. On the ground of the Mosaic narrative, no less than in view of the actual appearance of the living world, the great naturalist Linné (1735) set up the dogma of the unchangeability of species. Even when quite different remains of animals were discovered by the advancing science of geology, they were forced into the existing narrow framework of science by Cuvier. Sir Charles Lyell completely undid the fallacious work of Cuvier, but in the meantime the zoologists themselves were moving toward the doctrine of evolution.

Jean Lamarck made the first systematic attempt to expound the theory in his "Zoological [Pg 125] Philosophy" (1809). He suggested that animals modified their organs by use or disuse, and that the effect of this was inherited. In the course of time these inherited modifications reached such a pitch that the organism fell into a new "species." Goethe also made some remarkable contributions to the science of evolution. But it was reserved for Charles Darwin to win an enduring place in science for the theory. "The Origin of Species" (1859) not only sustained it with a wealth of positive knowledge which Lamarck did not command, but it provided a more luminous explanation in the doctrine of natural selection. Huxley (1863) followed with an application of the law to man, and in 1866 I gave a comprehensive sketch of its application throughout the whole animal world. In 1874 I published the first edition of the present work.

The doctrine of evolution is now a vital part of biology, and we might accept the evolution of man as a special deduction from the general law. Three great groups of evidence impose that law on us. The first group consists of the facts of palæontology, or the fossil record of past animal life. Imperfect as the record is, it shows us a broad divergence of successively changing types from a simple common root, and in some cases exhibits the complete transition from one type to another. The next document is the evidence of comparative anatomy. This science groups the forms of living animals in such a way that we seem to have the same gradual divergence of types from simple common ancestors. In particular, it discovers certain rudimentary organs in the higher animals, which can only be understood as the shrunken relics of organs that were once useful to a remote ancestor. Thus, man has still the rudiment of the third eyelid of his shark-ancestor. The third document is the evidence of embryology, which shows us the higher organism substantially reproducing, in its embryonic development, the long series of ancestral forms. [Pg 126]

II.—Man's Embryonic Development

The first stage in the development of any animal is the tiny speck of plasm, hardly visible to the naked eye, which we call the ovum, or egg-cell. It is a single cell, recalling the earliest single-celled ancestor of all animals. In its immature form it is not unlike certain microscopic animalcules known as *amœboe*. In its mature form it is about $\frac{1}{125}$th of an inch in diameter.

When the male germ has blended with the female in the ovum, the new cell slowly divides into two, with a very complicated division of the material composing its nucleus. The two cells divide into four, the four into eight, and so on until we have a round cluster of cells, something like a blackberry in shape.

This *morula*, as I have called it, reproduces the next stage in the development of life. As all animals pass through it, our biogenetic law forces us to see in it an ancestral stage; and in point of fact we have animals of this type living in Nature to-day. The round cluster becomes filled with fluid, and we have a hollow sphere of cells, which I call the *blastula*. The corresponding early ancestor I name the *Blastæa*, and again we find examples of it, like the *Volvox* of the ponds, in Nature to-day.

The next step is very important. The hollow sphere closes in on itself, as when an india rubber ball is pressed into the form of a cup. We have then a vase-shaped body with two layers of cells, an inner and an outer, and an opening. The inner layer we call the entoderm, the outer the ectoderm; and the "primitive mouth" is known as the blastopore. In the higher animals a good deal of food-yolk is stored up in the germ, and so the vase-shaped structure has been flattened and altered. It has, however, been shown that all embryos pass through [Pg 127] this stage (gastrulation), and we again infer the existence of a common ancestor of that type—the *Gastræa*. The lowest group of many-celled animals—the corals, jelly-fishes, and anemones—are essentially of that structure.

The embryo now consists of two layers of cells, the "germ-layers," an inner and outer. As the higher embryo develops, a third layer of cells now pushes between the two. We may say, broadly, that from this middle layer are developed most of the animal organs of the body; from the internal germ-layer is developed the lining of the alimentary canal and its dependent glands; from the outer layer are formed the skin and the nervous system—which developed originally in the skin.

The embryo of man and all the other higher animals now develops a cavity, a pair of pouches, by the folding of the layer at the primitive mouth. Sir E. Ray Lankester, and Professor Balfour, and other students, traced this formation through the whole embryonic world, and we are therefore again obliged to see in it a reminiscence of an ancestral form—a primitive worm-like animal, of a type we shall see later. The next step is the formation of the first trace of what will ultimately be the backbone. It consists at first of a membraneous tube, formed by the folding of the inner layer along the axis of the embryo-body. Later this tube will become cartilage, and in the higher animals the cartilage will give place to bone.

The other organs of the body now gradually form from the germ-layers, principally by the folding of the layers into tubes. A light area appears on the surface of the germ. A streak or groove forms along its axis, and becomes the nerve-cord running along the back. Cube-shaped structures make their appearance on either side of it; these prove to be the rudiments of the vertebræ—or separate bones of the backbone—and gradually close round the cord. [Pg 128] The heart is at first merely a spindle-shaped enlargement of the main ventral blood-vessel. The nose is at first only a pair of depressions in the skin above the mouth.

When the human embryo is only a quarter of an inch in length, it has gill-clefts and gill-arches in the throat like a fish, and no limbs. The heart—as yet with only the simple two-chambered structure of a fish's heart—is up in the throat—as in the fish—and the principal arteries run to the gill-slits. These structures never have any utility in man or the other land-animals, though the embryo always has them for a time. They point clearly to a fish ancestor.

Later, they break up, the limbs sprout out like blunt fins at the sides, and the long tail begins to decrease. By the twelfth week the human frame is perfectly formed, though less than two inches long. Last of all, it retains its resemblance to the ape. In the embryonic apparatus, too, man closely resembles the higher ape.

III.—Our Ancestral Tree

The series of forms which we thus trace in man's embryonic development corresponds to the ancestral series which we would assign to man on the evidence of palæontology and comparative anatomy. At one time, the tracing of this ancestral series encountered a very serious check. When we examined the groups of living animals, we found none that illustrated or explained the passage from the non-backboned—invertebrate—to the backboned—vertebrate—animals. This gap was filled some years ago by the discovery of the lancelet—*Amphioxus*—and the young of the sea-squirt—*Ascidia*. The lancelet has a slender rod of cartilage along its back, and corresponds very closely with the ideal I have sketched of our primitive backboned ancestor. It may be an offshoot from the same group. The sea-squirt further illustrates the origin of the backbone, since it has a similar rod of [Pg 129] cartilage in its youth, and loses it, by degeneration, in its maturity.

In this way the chief difficulty was overcome, and it was possible to sketch the probable series of our ancestors. It must be well understood that not only is the whole series conjectural, but no living animal must be regarded as an ancestral form. The parental types have long been extinct, and we may, at the most, use very conservative living types to illustrate their nature, just as, in the matter of languages, German is not the parent, but the cousin of Anglo-Saxon, or Greek of Latin. The original parental languages are lost. But a language like Sanscrit survives to give us a good idea of the type.

The law of evolution is based on such a mass of evidence that we may justly draw deductions from it, where the direct evidence is incomplete. This is especially necessary in the early part of our ancestral tree, because the fossil record quite fails us. For millions of years the early soft-bodied animals left no trace in the primitive mud, which time has hardened into rocks, and we are restricted to the evidence of embryology and of comparative zoology. This suffices to give us a general idea of the line of development.

In nature to-day, one of the lowest animal forms is a tiny speck of living plasm called the *amœba*. We have still more elementary forms, such as the minute particles which make up the bluish film on damp rocks, but they are of a vegetal character, or below it. They give us some idea of the very earliest forms of life; minute living particles, with no organs, down to the ten-thousandth part of an inch in diameter. The amoeba represents the lowest animal, and, as we saw, the ovum in many cases resembles an amoeba. We therefore take some such one-celled creature as our first animal ancestor. Taking food in at all parts of its surface, having no permanent organs of locomotion, and reproducing by merely splitting into two, it [Pg 130] exhibits the lowest level of animal life.

The next step in development would be the clustering together of these primitive microbes as they divided. This is actually the stage that comes next in the development of the germ, and it is the next stage upward in the existing animal world. We assume that these clusters of microbes—or cells, as we will now call them—bent inward, as we saw the embryo do, and became two-layered, cup-shaped organisms, with a hollow interior (primitive stomach) and an aperture (primitive mouth). The inner cells now do the work of digestion alone; the outer cells effect locomotion, by means of lashes like oars, and are sensitive. This is, in the main, the structure of the next great group of animals, the hydra, coral, meduca, and anemone. They have remained at this level, though they have developed, special organs for stinging their prey and bringing the food into their mouths.

Both zoology and the appearance of the embryo point to a worm-like animal as the next stage. Constant swimming in the water would give the animal a definite head, with special groups of nerve-cells, a definite tail, and a two-sided or evenly-balanced body.

We mean that those animals would be fittest to live, and multiply most, which developed this organisation. Sense-organs would now appear in the head, in the form of simple depressions, lined with sensitive cells, as they do in the embryo; and a clump of nerve-cells within would represent the primitive brain. In the vast and varied worm-group we find illustrations of nearly every step in this process of evolution.

The highest type of worm-like creature, the acorn-headed worm—*Balanoglossus*—takes us an important step further. It has gill-openings for breathing, and a cord of cartilage down its back. We saw that the human embryo has a gill-apparatus, and that, comparing the [Pg 131] lancelet and the sea-squirt, the backbone must have begun as a string of cartilage-cells. We are now on firmer ground, for there is no doubt that all the higher land-animals come from a fish ancestor. The shark, one of the most primitive of fishes in organisation, probably best suggests this ancestor to us. In fact, in the embryonic development of the human face there is a clear suggestion of the shark.

Up to this period the story of evolution had run its course in the sea. The area of dry land was now increasing, and certain of the primitive fishes adapted themselves to living on land. They walked on their fins, and used their floating-bladders—large air-bladders in the fish, for rising in the water—to breathe air. We not only have fishes of this type in Australia to-day, but we have the fossil remains of similar fishes in the Old Red Sandstone rocks. From mud-fish the amphibian would naturally develop, as it did in the coal-forest period. Walking on the fins would strengthen the main stem, the broad paddle would become useless, and we should get in time the bony five-toed limb. We have many of these giant salamander forms in the rocks.

The reptile now evolved from the amphibian, and a vast reptile population spread over the earth. From one of these early reptiles the birds were evolved. Geology furnishes the missing link between the bird and the reptile in the *Archæopteryx*, a bird with teeth, claws on its wings, and a reptilian tail. From another primitive reptile the important group of the mammals was evolved. We find what seem to be the transitional types in the rocks of South Africa. The scales gave way to tufts of hair, the heart evolved a fourth chamber, and thus supplied purer blood (warm blood), the brain profited by the richer food, and the mother began to suckle the young. We have still a primitive mammal of this type in the duck-mole, or duck-billed platypus (*Ornithorhyncus*) of Australia. There are grounds for thinking that [Pg 132] the next stage was an opossum-like animal, and this led on to the lowest ape-like being, the lemur. Judging from the fossil remains, the black lemur of Madagascar best suggests this ancestor.

The apes of the Old and New Worlds now diverged from this level, and some branch of the former gave rise to the man-like apes and man. In bodily structure and embryonic development the large apes come very close to man, and two recent discoveries have put their blood-relationship beyond question. One is that experiments in the transfusion of blood show that the blood of the man-like ape and man have the same action on the blood of lower animals. The other is that we have discovered, in Java, several bones of a being which stands just midway between the highest living ape and lowest living race of men. This ape-man (*Pithecanthropus*) represents the last of our animal and first of our human ancestors.

IV.—Evolution of Separate Organs

So far, we have seen how the human body as a whole develops through a long series of extinct ancestors. We may now take the various systems of organs one by one, and, if we are careful to consult embryology as well as zoology, we can trace the manner of their development. It is, in accordance with our biogenetic law, the same in the embryo, as a rule, as in the story of past evolution.

We take first the nervous system. In the lowest animals, as in the early stages of the embryo, there are no nerve-cells. In the embryo the nerve-cells develop from the outer, or skin layer, of cells. This, though strange as regards the human nervous system, is a correct preservation of the primitive seat of the nerves. It was the surface of the animal that needed to be sensitive in the primitive organism. Later, when definite connecting nerves were [Pg 133] formed, only special points in the surface, protected by coverings which did not interfere with the sensitiveness, needed to be exposed, and the nerves transmitted the impressions to the central brain.

This development is found in the animal world to-day. In such animals as the hydra we find the first crude beginning of unorganised nerve-cells. In the jelly-fish we find nerve-cells clustered into definite sensitive organs. In the lower worms we have the beginning of organs of smell and vision. They are at first merely blind, sensitive pits in the skin, as in the embryo. The ear has a peculiar origin. Up to the fish level there is no power of hearing. There is merely a little stone rolling in a sensitive bed, to warn the animal of its movement from side to side. In the higher animals this evolves into the ear.

The glands of the skin (sweat, fat, tears, etc.) appear at first as blunt, simple ingrowths. The hair first appears in tufts, representing the scales, from underneath which they were probably evolved. The thin coat of hair on the human body to-day is an ancestral inheritance. This is well shown by the direction of the hairs on the arm. As on the ape's arm, both on the upper and lower arm, they grow toward the elbow. The ape finds this useful in rain, using his arms like a thatched roof, and on our arm this can only be a reminiscence of the habits of an ape ancestor.

We have seen how the spinal cord first appears as a tube in the axis of the back, and the cartilaginous column closes round it. All bone appears first as membrane, then cartilage, and finally ossifies. This is the order both in past evolution and in present embryonic development. The brain is at first a bulbous expansion of the spinal nerve-cord. It is at first simple, but gradually, both in the scale of nature and in the embryo, divides into five parts. One of these parts, the cerebrum, is mainly connected with mental life. We find it increasing [Pg 134] in size, in proportion to the animal's intelligence, until in man it comes to cover the whole of the brain. When we remove it from the head of the mammal, without killing the animal, we find all mental life suspended, and the whole vitality used in vegetative functions.

In the evolution of the bony system we find the same correspondence of embryology and evolution. The main column is at first a rod of cartilage. In time the separate cubes appear which are to form the vertebræ of the flexible column. The skull develops in the same way. Just as the brain is a specially modified part of the nerve-rod, the skull is only a modified part of the vertebral column. The bones that compose it are modified vertebræ, as Goethe long ago suspected. The skull of the shark gives us a hint of the way in which the modification took place, and the formation of the skull in the embryo confirms it.

That adult man is devoid of that prolongation of the vertebral column which we call a tail is not a distinctive peculiarity. The higher apes are equally without it. We find, however, that the human embryo has a long tail, much longer than the legs, when they are developing. At times, moreover, children are born with tails—perfect tails, with nerves and muscles, which they move briskly under emotion, and these have to be amputated. The development of the limb from the fin offers no serious difficulty to the osteologist. All the higher animals descend from a five-toed ancestor. The whale has taken again to the water, and reconverted its limb into a paddle. The bones of the front feet still remain under the flesh. Animals of the horse type have had the central toe strengthened, for running purposes, at the expense of the rest. The serpent has lost its limbs from disuse, but in the python a rudimentary limb-bone is still preserved.

The alimentary system, blood-vessel system, and reproductive system have been evolved gradually in the same way. The stomach is at first the whole cavity in the animal. Later it becomes a straight, simple tube, strengthened by a gullet in front. The liver is an outgrowth from this tube; the stomach proper is a bulbous expansion of its central part, later provided with a valve. The kidneys are at first simple channels in the skin for drainage, then closed tubes, which branch out more and more, and then gather into our compact kidneys. We thus see that the building up of the human body from a single cell is a substantial epitome of the long story of evolution, which occupied many millions of years. We find man bearing in his body to-day traces of organs which were useful to a remote ancestor, but of no advantage, and often a source of mischief to himself. We learn that the origin of man, instead of being placed a few thousand years ago, must be traced back to the point where, hundreds of thousands of years ago, he diverged from his ape-cousins, though he retains to-day the plainest traces of that relationship. Body and mind—for the development of mind follows with the utmost precision on the development of brain—he is the culmination of a long process of development. His spirit is a form of energy inseparably bound up with the substance of his body. His evolution has been controlled by the same "eternal, iron laws" as the development of any other body—the laws of heredity and adaptation. [Pg 135]

WILLIAM HARVEY [Pg 136]

On the Motion of the Heart and Blood

William Harvey, the discoverer of the circulation of the blood, was born at Folkestone, England, on April 1, 1578. After graduating from Caius College, Cambridge, he studied at Padua, where he had the celebrated anatomist, Fabricius of Aquapendente, for his master. In 1615 he was elected Lumleian lecturer at the College of Physicians, and three years later was appointed physician extraordinary to King James I. In 1628, twelve years after his first statement of it in his lectures, he published at Frankfurt, in Latin, "An Anatomical Disquisition on the Motion of the Heart and Blood," in which he maintained that there is a circulation of the blood. Moreover, he distinguished between the pulmonary circulation, from the right side of the heart to the left through the lungs, and the systemic circulation from the left side of the heart to the right through the rest of the body. Further, he maintained that it was the office of the heart to maintain this circulation by its alternate *diastole* (expansion) and *systole* (contraction) throughout life. This discovery was, says Sir John Simon, the most important ever made in physiological science. It is recorded that after his publication of it Harvey lost most of his practice. Harvey died on June 3, 1657.

I.—Motions of the Heart in Living Animals

When first I gave my mind to vivisections as a means of discovering the motions and uses of the heart, I found the task so truly arduous that I was almost tempted to think, with Fracastorius, that the motion of the heart was only to be comprehended by God. For I could neither rightly perceive at first when the systole and when the diastole took place, nor when and where dilation and contraction occurred, by reason of the rapidity of the motion, which, in many animals, is accomplished in the twinkling of an eye, coming and going like a flash of lightning. At length it appeared that these things happen together or at the same instant: the tension of the heart, the pulse of its apex, which is felt externally by its striking against [Pg 137] the chest, the thickening of its walls, and the forcible expulsion of the blood it contains by the constriction of its ventricles.

Hence the very opposite of the opinions commonly received appears to be true; inasmuch as it is generally believed that when the heart strikes the breast and the pulse is felt without, the heart is dilated in its ventricles and is filled with blood. But the contrary of this is the fact; that is to say, the heart is in the act of contracting and being emptied. Whence the motion, which is generally regarded as the diastole of the heart, is in truth its systole. And in like manner the intrinsic motion of the heart is not the diastole but the systole; neither is it in the diastole that the heart grows firm and tense, but in the systole; for then alone when tense is it moved and made vigorous. When it acts and becomes tense the blood is expelled; when it relaxes and sinks together it receives the blood in the manner and wise which will by and by be explained.

From divers facts it is also manifest, in opposition to commonly received opinions, that the diastole of the arteries corresponds with the time of the heart's systole; and that the arteries are filled and distended by the blood forced into them by the contraction of the ventricles. It is in virtue of one and the same cause, therefore, that all the arteries of the body pulsate, *viz.*, the contraction of the left ventricle in the same way as the pulmonary artery pulsates by the contraction of the right ventricle.

I am persuaded it will be found that the motion of the heart is as follows. First of all, the auricle contracts and throws the blood into the ventricle, which, being filled, the heart raises itself straightway, makes all its fibres tense, contracts the ventricles and performs a beat, by which beat it immediately sends the blood supplied to it by the auricle into the arteries; the right ventricle sending its charge into the lungs by the vessel called *vena arteriosa*, but [Pg 138] which, in structure and function, and all things else, is an artery; the left ventricle sending its charge into the aorta, and through this by the arteries to the body at large.

The grand cause of hesitation and error in this subject appears to me to have been the intimate connection between the heart and the lungs. When men saw both the pulmonary artery and the pulmonary veins losing themselves in the lungs, of course it became a puzzle to them to know how the right ventricle should distribute the blood to the body, or the left draw it from the *venæ cavæ*. Or they have hesitated because they did not perceive the route by which the blood is transferred from the veins to the arteries, in consequence of the intimate connection between the heart and lungs. And that this difficulty puzzled anatomists not a little when in their dissections they found the pulmonary artery and left ventricle full of black and clotted blood, plainly appears when they felt themselves compelled to affirm that the blood made its way from the right to the left ventricle by sweating through the septum of the heart.

Had anatomists only been as conversant with the dissection of the lower animals as they are with that of the human body, the matters that have hitherto kept them in perplexity of doubt would, in my opinion, have met them freed from every kind of difficulty. And first in fishes, in which the heart consists of but a single ventricle, they having no lungs, the thing is sufficiently manifest. Here the sac, which is situated at the base of the heart, and is the part analogous to the auricle in man, plainly throws the blood into the heart, and the heart in its turn conspicuously transmits it by a pipe or artery, or vessel analogous to an artery; these are facts which are confirmed by simple ocular experiment. I have seen, farther, that the same thing obtained most obviously.

And since we find that in the greater number of animals, in all indeed at a certain period of their existence, the channels for the transmission of the blood through the heart are so conspicuous, we have still to inquire wherefore in some creatures—those, namely, that have warm blood and that have attained to the adult age, man among the number—we should not conclude that the same thing is accomplished through the substance of the lungs, which, in the embryo, and at a time when the functions of these organs is in abeyance, Nature effects by direct passages, and which indeed she seems compelled to adopt through want of a passage by the lungs; or wherefore it should be better (for Nature always does that which is best) that she should close up the various open routes which she had formerly made use of in the embryo, and still uses in all other animals; not only opening up no new apparent channels for the passage of the blood therefore, but even entirely shutting up those which formerly existed in the embryos of those animals that have lungs. For while the lungs are yet in a state of inaction, Nature uses the two ventricles of the heart as if they formed but one for the transmission of the blood. The condition of the embryos of those animals which have lungs is the same as that of those animals which have no lungs. [Pg 139]

Thus, by studying the structure of the animals who are nearer to and further from ourselves in their modes of life and in the construction of their bodies, we can prepare ourselves to understand the nature of the pulmonary circulation in ourselves, and of the systemic circulation also.

II.—Systemic Circulation

What remains to be said is of so novel and unheard of a character that I not only fear injury to myself from the envy of a few, but I tremble lest I have mankind at large for my enemies, so much do wont and custom that become as another nature, and doctrine once sown that hath struck deep root, and respect for antiquity, influence all men. [Pg 140]

And, sooth to say, when I surveyed my mass of evidence, whether derived from vivisections and my previous reflections on them, or from the ventricles of the heart and the vessels that enter into and issue from them, the symmetry and size of these conduits—for Nature, doing nothing in vain, would never have given them so large a relative size without a purpose; or from the arrangement and intimate structure of the valves in particular and of the many other parts of the heart in general, with many things besides; and frequently and seriously bethought me and long revolved in my mind what might be the quantity of blood which was transmitted, in how short a time its passage might be effected and the like; and not finding it possible that this could be supplied by the juices of the ingested aliment without the veins on the one hand becoming drained, and the arteries on the other getting ruptured through the excessive charge of blood, unless the blood should somehow find its way from the arteries into the veins, and so return to the right side of the heart; when I say, I surveyed all this evidence, I began to think whether there might not be *a motion as it were in a circle*.

Now this I afterwards found to be true; and I finally saw that the blood, forced by the action of the left ventricle into the arteries, was distributed to the body at large, and its several parts, in the same manner as it is sent through the lungs, impelled by the right ventricle into the pulmonary artery; and that it then passed through the veins and along the *vena cava*, and so round to the left ventricle in the manner already indicated; which motion we may be allowed to call circular, in the same way as Aristotle says that the air and the rain emulate the circular motion of the superior bodies. For the moist earth, warmed by the sun, evaporates; the vapours drawn upwards are condensed, and descending in the form of [Pg 141] rain moisten the earth again. And by this arrangement are generations of living things produced; and in like manner, too, are tempests and meteors engendered by the circular motion of the sun.

And so in all likelihood does it come to pass in the body through the motion of the blood. The various parts are nourished, cherished, quickened by the warmer, more perfect, vaporous, spirituous, and, as I may say, alimentive blood; which, on the contrary, in contact with these parts becomes cooled, coagulated, and, so to speak, effete; whence it returns to its sovereign, the heart, as if to its source, or to the inmost home of the body, there to recover its state of excellence or perfection. Here it resumes its due fluidity, and receives an infusion of natural heat—powerful, fervid, a kind of treasury of life—and is impregnated with spirits and, it might be said, with balsam; and thence it is again dispersed. And all this depends upon the motion and action of the heart.

Confirmations of the Theory

Three points present themselves for confirmation, which, being established, I conceive that the truth I contend for will follow necessarily and appear as a thing obvious to all.

The first point is this. The blood is incessantly transmitted by the action of the heart from the *vena cava* to the arteries in such quantity that it cannot be supplied from the ingesta, and in such wise that the whole mass must very quickly pass through the organ.

Let us assume the quantity of blood which the left ventricle of the heart will contain when distended to be, say, two ounces (in the dead body I have found it to contain upwards of two ounces); and let us suppose, as approaching the truth, that the fourth part of its charge is [Pg 142] thrown into the artery at each contraction. Now, in the course of half an hour the heart will have made more than one thousand beats. Multiplying the number of drachms propelled by the number of pulses, we shall have one thousand half-ounces sent from this organ into the artery; a larger quantity than is contained in the whole body. This truth, indeed, presents itself obviously before us when we consider what happens in the dissection of living animals. The great artery need not be divided, but a very small branch only (as Galen even proves in regard to man), to have the whole of the blood in the body, as well that of the veins as of the arteries, drained away in the course of no long time—some half hour or less.

The second point is this. The blood, under the influence of the arterial pulse, enters, and is impelled in a continuous, equable, and incessant stream through every part and member of the body in much larger quantity than were sufficient for nutrition, or than the whole mass of fluids could supply.

I have here to cite certain experiments. Ligatures are either very tight or of middling tightness. A ligature I designate as tight, or perfect, when it is drawn so close about an extremity that no vessel can be felt pulsating beyond it. Such ligatures are employed in the removal of tumours; and in these cases, all afflux of nutriment and heat being prevented by the ligature, we see the tumours dwindle and die, and finally drop off. Now let anyone make an experiment upon the arm of a man, either using such a fillet as is employed in bloodletting, or grasping the limb tightly with his hand; let a ligature be thrown about the extremity and drawn as tightly as can be borne. It will first be perceived that beyond the ligature the arteries do not pulsate, while above it the artery begins to rise higher at each diastole and to swell with a kind of tide as it strove to break through and overcome the obstacle to its current.

Then let the ligature be brought to that state of middling tightness which is used in bleeding, and it will be seen that the hand and arm will instantly become deeply suffused and extended, and the veins show themselves tumid and knotted. Which is as much as to say that when the arteries pulsate the blood is flowing through them, but where they do not pulsate they cease from transmitting anything. The veins again being compressed, nothing can flow through them; the certain indication of which is that below the ligature they are much more tumid than above it. [Pg 143]

Whence is this blood? It must needs arrive by the arteries. For that it cannot flow in by the veins appears from the fact that the blood cannot be forced towards the heart unless the ligature be removed. Further, when we see the veins below the ligature instantly swell up and become gorged when from extreme tightness it is somewhat relaxed, the arteries meanwhile continuing unaffected, this is an obvious indication that the blood passes from the arteries into the veins, and not from the veins into the arteries, and that there is either an anastomosis of the two orders of vessels, or pores in the flesh and solid parts generally that are permeable to the blood.

And now we understand wherefore in phlebotomy we apply our fillet above the part that is punctured, not below it. Did the flow come from above, not from below, the bandage in this case would not only be of no service, but would prove a positive hindrance. And further, if we calculate how many ounces flow through one arm or how many pass in twenty or thirty pulsations under the medium ligature, we shall perceive that a circulation is absolutely necessary, seeing that the quantity cannot be supplied immediately from the ingesta, and is vastly more than can be requisite for the mere nutrition of the parts.

And the third point to be confirmed is this. That the veins return this blood to the heart incessantly from all parts and members of the body. [Pg 144]

This position will be made sufficiently clear from the valves which are found in the cavities of the veins themselves, from the uses of these, and from experiments cognisable by the senses. The celebrated Hieronymus Fabricius, of Aquapendente, first gave representations of the valves in the veins, which consist of raised or loose portions of the inner membranes of these vessels of extreme delicacy and a sigmoid, or semi-lunar shape. Their office is by no means explained when we are told that it is to hinder the blood, by its weight, from flowing into inferior parts; for the edges of the valves in the jugular veins hang downwards, and are so contrived that they prevent the blood from rising upwards.

The valves, in a word, do not invariably look upwards, but always towards the trunks of the veins—towards the seat of the heart. They are solely made and instituted lest, instead of advancing from the extreme to the central parts of the body, the blood should rather proceed along the veins from the centre to the extremities; but the delicate valves, while they readily open in the right direction, entirely prevent all such contrary motion, being so situated and arranged that if anything escapes, or is less perfectly obstructed by the flaps of the one above, the fluid passing, as it were, by the chinks between the flaps, it is immediately received on the convexity of the one beneath, which is placed transversely with reference to the former, and so is effectually hindered from getting any farther. And this I have frequently experienced in my dissections of veins. If I attempted to pass a probe from the trunk of the veins into one of the smaller branches, whatever care I took I found it impossible to introduce it far any way by reason of the valves; whilst, on the contrary, it was most easy to push it along in the opposite direction, from without inwards, or from the branches towards the trunks and roots. [Pg 145]

And now I may be allowed to give in brief my view of the circulation of the blood, and to propose it for general adoption.

The Conclusion

Since all things, both argument and ocular demonstration, show that the blood passes through the lungs and heart by the action of the ventricles; and is sent for distribution to all parts of the body, where it makes its way into the veins and pores of the flesh; and then flows by the veins from the circumference on every side to the centre, from the lesser to the greater veins; and is by them finally discharged into the *vena cava* and right auricle of the heart, and this in such a quantity or in such a flux and reflux, thither by the arteries, hither by the veins, as cannot possibly be supplied by the ingesta, and is much greater than can be required for mere purposes of nutrition; therefore, it is absolutely necessary to conclude that the blood in the animal body is impelled in a circle and is in a state of ceaseless motion; and that this is the act, or function, which the heart performs by means of its pulse, and that it is the sole and only end of the motion and contraction of the heart. For it would be very difficult to explain in any other way to what purpose all is constructed and arranged as we have seen it to be.

SIR JOHN HERSCHEL [Pg 146]

Outlines of Astronomy

Sir John Frederick William Herschel, only child—and, as an astronomer, almost the only rival—of Sir William Herschel, was born at Slough, in Ireland, on March 7, 1792. At first privately educated, in 1813 he graduated from St. John's College, Cambridge, as senior wrangler and first Smith's prizeman. He chose the law as his profession; but in 1816 reported that, under his father's direction, he was going "to take up stargazing." He then began a re-examination of his father's double stars. In 1825 he wrote that he was going to take nebulæ under his especial charge. He embarked in 1833 with his family for the Cape; and his work at Feldhausen, six miles from Cape Town, marked the beginning of southern sidereal astronomy. The result of his four years' work there was published in 1847. From 1855 he devoted himself at Collingwood to the collection and revival of his father's and his own labours. His "Outlines of Astronomy," published in 1849, and founded on an earlier "Treatise on Astronomy" of 1833, was an outstanding success. Herschel's long and happy life, every day of which added its share to his scientific services, came to an end on May 11, 1871.

I.—The Wonders of the Milky Way

There is no science which draws more largely than does astronomy on that intellectual liberality which is ready to adopt whatever is demonstrated or concede whatever is rendered highly probable, however new and uncommon the points of view may be in which objects the most familiar may thereby become placed. Almost all its conclusions stand in open and striking contradiction with those of superficial and vulgar observation, and with what appears to everyone the most positive evidence of his senses.

There is hardly anything which sets in a stronger light the inherent power of truth over the mind of man, when opposed by no motives of interest or passion, than the perfect [Pg 147] readiness with which all its conclusions are assented to as soon as their evidence is clearly apprehended, and the tenacious hold they acquire over our belief when once admitted.

If the comparison of the apparent magnitude of the stars with their number leads to no immediately obvious conclusion, it is otherwise when we view them in connection with their local distribution over the heavens. If indeed we confine ourselves to the three or four brightest classes, we shall find them distributed with a considerable approach to impartiality over the sphere; a marked preference, however, being observable, especially in the southern hemisphere, to a zone or belt passing through *epsilon* Orionis and *alpha* Crucis. But if we take in the whole amount visible to the naked eye we shall perceive a great increase of numbers as we approach the borders of the Milky Way. And when we come to telescopic magnitudes we find them crowded beyond imagination along the extent of that circle and of the branches which it sends off from it; so that, in fact, its whole light is composed of nothing but stars of every magnitude from such as are visible to the naked eye down to the smallest points of light perceptible with the best telescopes.

These phenomena agree with the supposition that the stars of our firmament, instead of being scattered indifferently in all directions through space, form a stratum of which the thickness is small in comparison with its length and breadth; and in which the earth occupies a place somewhere about the middle of its thickness and near the point where it subdivides into two principal laminæ inclined at a small angle to each other. For it is certain that to an eye so situated the apparent density of the stars, supposing them pretty equally scattered through the space they occupy, would be least in the direction of the visual ray perpendicular to the lamina, and greatest in that of its breadth; increasing rapidly in passing [Pg 148] from one to the other direction, just as we see a slight haze in the atmosphere thickening into a decided fog-bank near the horizon by the rapid increase of the mere length of the visual ray.

Such is the view of the construction of the starry firmament taken by Sir William Herschel, whose powerful telescopes first effected a complete analysis of this wonderful zone, and demonstrated the fact of its entirely consisting of stars.

So crowded are they in some parts of it that by counting the stars in a single field of his telescope he was led to conclude that 50,000 had passed under his review in a zone two degrees in breadth during a single hour's observation. The immense distances at which the remoter regions must be situated will sufficiently account for the vast predominance of small magnitudes which are observed in it.

The process of gauging the heavens was devised by Sir William Herschel for this purpose. It consisted simply in counting the stars of all magnitudes which occur in single fields of view, of fifteen minutes in diameter, visible through a reflecting telescope of 18 inches aperture, and 20 feet focal length, with a magnifying power of 180 degrees, the points of observation being very numerous and taken indiscriminately in every part of the surface of the sphere visible in our latitudes.

On a comparison of many hundred such "gauges," or local enumerations, it appears that the density of starlight (or the number of stars existing on an average of several such enumerations in any one immediate neighbourhood) is least in the pole of the Galactic circle [*i.e.*, the great circle to which the course of the Milky Way most nearly conforms: *gala* = milk], and increases on all sides down to the Milky Way itself, where it attains its maximum. The progressive rate of increase in proceeding from the pole is at first slow, but becomes more and more rapid as we approach the plane of that circle, according to a law [Pg 149] from which it appears that the mean density of the stars in the galactic circle exceeds, in a ratio of very nearly 30 to 1, that in its pole, and in a proportion of more than 4 to 1 that in a direction 15 degrees inclined to its plane.

As we ascend from the galactic plane we perceive that the density decreases with great rapidity. So far we can perceive no flaw in this reasoning if only it be granted (1) that the level planes are continuous and of equal density throughout; and (2) that an absolute and definite limit is set to telescopic vision, beyond which, if stars exist, they elude our sight, and are to us as if they existed not. It would appear that, with an almost exactly similar law of apparent density in the two hemispheres, the southern were somewhat richer in stars than the northern, which may arise from our situation not being precisely in the middle of its thickness, but somewhat nearer to its northern surface.

II.—Penetrating Infinite Space

When examined with powerful telescopes, the constitution of this wonderful zone is found to be no less various than its aspect to the naked eye is irregular. In some regions the stars of which it is composed are scattered with remarkable uniformity over immense tracts, while in others the irregularity of their distribution is quite as striking, exhibiting a rapid succession of closely clustering rich patches separated by comparatively poor intervals, and indeed in some instances absolutely dark and *completely* void of any star even of the smallest telescopic magnitude. In some places not more than 40 or 50 stars on an average occur in a "gauge" field of 15 minutes, while in others a similar average gives a result of 400 or 500.

Nor is less variety observable in the character of its different regions in respect of the [Pg 150] magnitude of the stars they exhibit, and the proportional numbers of the larger and smaller magnitudes associated together, than in respect of their aggregate numbers. In some, for instance, extremely minute stars, though never altogether wanting, occur in numbers so moderate as to lead us irresistibly to the conclusion that in these regions we are *fairly through* the starry stratum, since it is impossible otherwise (supposing their light not intercepted) that the numbers of the smaller magnitudes should not go on increasing *ad infinitum*.

In such cases, moreover, the ground of the heavens, as seen between the stars, is for the most part perfectly dark, which again would not be the case if innumerable multitudes of stars, too minute to be individually discernible, existed beyond. In other regions we are presented with the phenomenon of an almost uniform degree of brightness of the individual stars, accompanied with a very even distribution of them over the ground of the heavens, both the larger and smaller magnitudes being strikingly deficient. In such cases it is equally impossible not to perceive that we are looking through a sheet of stars nearly of a size and of no great thickness compared with the distance which separates them from us. Were it otherwise we should be driven to suppose the more distant stars were uniformly the larger, so as to compensate by their intrinsic brightness for their greater distance, a supposition contrary to all probability.

In others again, and that not infrequently, we are presented with a double phenomenon of the same kind—*viz.*, a tissue, as it were, of large stars spread over another of very small ones, the intermediate magnitudes being wanting, and the conclusion here seems equally evident that in such cases we look through two sidereal sheets separated by a starless interval.

Throughout by far the larger portion of the extent of the Milky Way in both hemispheres [Pg 151] the general blackness of the ground of the heavens on which its stars are projected, and the absence of that innumerable multitude and excessive crowding of the smallest visible magnitudes, and of glare produced by the aggregate light of multitudes too small to affect the eye singly, which the contrary supposition would appear to necessitate, must, we think, be considered unequivocal indications that its dimensions, *in directions where those conditions obtain*, are not only not infinite, but that the space-penetrating power of our telescopes suffices fairly to pierce through and beyond it.

It is but right, however, to warn our readers that this conclusion has been controverted, and that by an authority not lightly to be put aside, on the ground of certain views taken by Olbers as to a defect of perfect transparency in the celestial spaces, in virtue of which the light of the more distant stars is enfeebled more than in proportion to their distance. The extinction of light thus originating proceeding in geometrical ratio, while the distance increases in arithmetical, a limit, it is argued, is placed to the space-penetrating power of telescopes far within that which distance alone, apart from such obscuration, would assign.

It must suffice here to observe that the objection alluded to, if applicable to any, is equally so to every part of the galaxy. We are not at liberty to argue that at one part of its circumference our view is limited by this sort of cosmical veil, which extinguishes the smaller magnitudes, cuts off the nebulous light of distant masses, and closes our view in impenetrable darkness; while at another we are compelled, by the clearest evidence telescopes can afford, to believe that star-strewn vistas *lie open*, exhausting their powers and stretching out beyond their utmost reach, as is proved by that very phenomenon which the existence of such a veil would render impossible—*viz.*, infinite increase of number and diminution of magnitude, terminating in complete irresolvable nebulosity. [Pg 152]

Such is, in effect, the spectacle afforded by a very large portion of the Milky Way in that interesting region near its point of bifurcation in Scorpio, where, through the hollows and deep recesses of its complicated structure, we behold what has all the appearance of a wide and indefinitely prolonged area strewed over with discontinuous masses and clouds of stars, which the telescope at last refuses to analyse. Whatever other conclusions we may draw, this must anyhow be regarded as the direction of the greatest linear extension of the ground-plan of the galaxy. And it would appear to follow also that in those regions where that zone is clearly resolved into stars well separated and *seen projected on a black ground*, and where, by consequence, it is certain, if the foregoing views be correct, that we look out beyond them into space, the smallest visible stars appear as such not by reason of excessive distance, but of inferiority of size or brightness.

III.—Variable, Temporary and Binary Stars

Wherever we can trace the law of periodicity we are strongly impressed with the idea of rotatory or orbitual motion. Among the stars are several which, though in no way distinguishable from others by any apparent change of place, nor by any difference of appearance in telescopes, yet undergo a more or less regular periodical increase and diminution of lustre, involving in one or two cases a complete extinction and revival. These are called periodic stars. The longest known, and one of the most remarkable, is the star *Omicron* in the constellation Cetus (sometimes called Mira Ceti), which was first noticed as variable by Fabricius in 1596. It appears about twelve times in eleven years, remains at its greatest brightness about a fortnight, being then on some occasions equal to a large star of [Pg 153] the second magnitude, decreases during about three months, till it becomes completely invisible to the naked eye, in which state it remains about five months, and continues increasing during the remainder of its period. Such is the general course of its phases. But the mean period above assigned would appear to be subject to a cyclical fluctuation embracing eighty-eight such periods, and having the effect of gradually lengthening and shortening alternately those intervals to the extent of twenty-five days one way and the other. The irregularities in the degree of brightness attained at the maximum are also periodical.

Such irregularities prepare us for other phenomena of stellar variation which have hitherto been reduced to no law of periodicity—the phenomena of temporary stars which have appeared from time to time in different parts of the heavens blazing forth with extraordinary lustre, and after remaining awhile, apparently immovable, have died away and left no trace. In the years 945, 1264, and 1572 brilliant stars appeared in the region of the heavens between Cepheus and Cassiopeia; and we may suspect them, with Goodricke, to be one and the same star with a period of 312, or perhaps 156 years. The appearance of the star of 1572 was so sudden that Tycho Brahe, a celebrated Dutch astronomer, returning one evening from his laboratory to his dwellinghouse, was surprised to find a group of country people gazing at a star which he was sure did not exist half an hour before. This was the star in question. It was then as bright as Sirius, and continued to increase till it surpassed Jupiter when brightest, and was visible at midday. It began to diminish in December of the same year, and in March 1574 had entirely disappeared.

In 1803 it was announced by Sir William Herschel that there exist sidereal systems composed of two stars revolving about each other in regular orbits, and constituting which [Pg 154] may be called, to distinguish them from double stars, which are only optically double, binary stars. That which since then has been most assiduously watched, and has offered phenomena of the greatest interest, is *gamma Virginis*. It is a star of the vulgar third magnitude, and its component individuals are very nearly equal, and, as it would seem, in some slight degree variable. It has been known to consist of two stars since the beginning of the eighteenth century, the distance being then between six and seven seconds, so that any tolerably good telescope would resolve it. When observed by Herschel in 1780 it was 5.66 seconds, and continued to decrease gradually and regularly, till at length, in 1836, the two stars had approached so closely as to appear perfectly round and single under the highest magnifying power which could be applied to most excellent instruments—the great refractor of Pulkowa alone, with a magnifying power of a thousand, continuing to indicate, by the wedge-shaped form of the disc of the star, its composite nature.

By estimating the ratio of its length to its breadth, and measuring the former, M. Struve concludes that at this epoch the distance of the two stars, centre from centre, might be stated at .22 seconds. From that time the star again opened, and is now again a perfectly easily separable star. This very remarkable diminution, and subsequent increase, of distance has been accompanied by a corresponding and equally remarkable increase and subsequent diminution of relative angular motion. Thus in 1783 the apparent angular motion hardly amounted to half a degree per annum; while in 1830 it had decreased to 5 degrees, in 1834 to 20 degrees, in 1835 to 40 degrees, and about the middle of 1836 to upwards of 70 degrees per annum, or at the rate of a degree in five days.

This is in entire conformity with the principles of dynamics, which establish a necessary connection between the angular velocity and the distance, as well in the apparent as in the [Pg 155] real orbit of one body revolving about another under the influence of mutual attraction; the former varying inversely as the square of the latter, in both orbits, whatever be the curve described and whatever the law of the attractive force.

It is not with the revolutions of bodies of a planetary or cometary nature round a solar centre that we are concerned; it is that of sun round sun—each perhaps, at least in some binary systems, where the individuals are very remote and their period of revolution very long, accompanied by its train of planets and their satellites, closely shrouded from our view by the splendour of their respective suns, and crowded into a space bearing hardly a greater proportion to the enormous interval which separates them than the distances of the satellites of our planets from their primaries bear to their distances from the sun itself.

A less distinctly characterised subordination would be incompatible with the stability of their systems and with the planetary nature of their orbits. Unless close under the protecting wing of their immediate superior, the sweep of their other sun, in its perihelion passage round their own, might carry them off or whirl them into orbits utterly incompatible with conditions necessary for the existence of their inhabitants.

IV.—The Nebulæ

It is to Sir William Herschel that we owe the most complete analysis of the great variety of those objects which are generally classed as nebulæ. The great power of his telescopes disclosed the existence of an immense number of these objects before unknown, and showed them to be distributed over the heavens not by any means uniformly, but with a marked preference to a certain district extending over the northern pole of the galactic [Pg 156] circle. In this region, occupying about one-eighth of the surface of the sphere, one-third of the entire nebulous contents of the heavens are situated.

The resolvable nebulæ can, of course, only be considered as clusters either too remote, or consisting of stars intrinsically too faint, to affect us by their individual light, unless where two or three happen to be close enough to make a joint impression and give the idea of a point brighter than the rest. They are almost universally round or oval, their loose appendages and irregularities of form being, as it were, extinguished by the distance, and only the general figure of the condensed parts being discernible. It is under the appearance of objects of this character that all the greater globular clusters exhibit themselves in telescopes of insufficient optical power to show them well.

The first impression which Halley and other early discoverers of nebulous objects received from their peculiar aspect was that of a phosphorescent vapour (like the matter of a comet's tail), or a gaseous and, so to speak, elementary form of luminous sidereal matter. Admitting the existence of such a medium, Sir W. Herschel was led to speculate on its gradual subsidence and condensation, by the effect of its own gravity, into more or less regular spherical or spheroidal forms, denser (as they must in that case be) towards the centre.

Assuming that in the progress of this subsidence local centres of condensation subordinate to the general tendency would not be wanting, he conceived that in this way solid nuclei might arise whose local gravitation still further condensing, and so absorbing the nebulous matter each in its immediate neighbourhood, might ultimately become stars, and the whole nebula finally take on the state of a cluster of stars.

Among the multitude of nebulæ revealed by his telescope every stage of this process might be considered as displayed to our eyes, and in every modification of form to which [Pg 157] the general principle might be conceived to apply. The more or less advanced state of a nebula towards its segregation into discrete stars, and of these stars themselves towards a denser state of aggregation round a central nucleus, would thus be in some sort an indication of age.

ALEXANDER VON HUMBOLDT [Pg 158]

Cosmos, a Sketch of the Universe

Frederick Henry Alexander von Humboldt was born in Berlin on September 14, 1769. In 1788 he made the acquaintance of George Forster, one of Captain Cook's companions, and geological excursions made with him were the occasion of his first publications, a book on the nature of basalt. His work in the administration of mines in the principalities of Bayreuth and Anspach furnished materials for a treatise on fossil flora; and in 1827, when he was residing in Paris, he gave to the world his "Voyage to the Equinoctial Regions of the New Continent," which embodies the results of his investigations in South America. Two years later he organised an expedition to Asiatic Russia, charging himself with all the scientific observations. But his principal interest lay in the accomplishment of that physical description of the universe for which all his previous studies had been a preparation, and which during the years 1845 to 1848 appeared under the comprehensive title of "Cosmos, or Sketch of a Physical Description of the Universe." Humboldt died on May 6, 1859.

I.—The Physical Study of the World

The natural world may be opposed to the intellectual, or nature to art taking the latter term in its higher sense as embracing the manifestations of the intellectual power of man; but these distinctions—which are indicated in most cultivated languages—must not be suffered to lead to such a separation of the domain of physics from that of the intellect as would reduce the physics of the universe to a mere assemblage of empirical specialities. Science only begins for man from the moment when his mind lays hold of matter—when he tries to subject the mass accumulated by experience to rational combinations.

Science is mind applied to nature. The external world only exists for us so far as we conceive it within ourselves, and as it shapes itself within us into the form of a [Pg 159] contemplation of nature. As intelligence and language, thought and the signs of thought, are united by secret and indissoluble links, so, and almost without our being conscious of it, the external world and our ideas and feelings melt into each other. "External phenomena are translated," as Hegel expresses it in his "Philosophy of History," "in our internal representation of them." The objective world, thought by us, reflected in us, is subjected to the unchanging, necessary, and all-conditioning forms of our intellectual being.

The activity of the mind exerts itself on the elements furnished to it by the perceptions of the senses. Thus, in the youth of nations there manifests itself in the simplest intuition of natural facts, in the first efforts made to comprehend them, the germ of the philosophy of nature.

If the study of physical phenomena be regarded in its bearings not on the material wants of man, but on his general intellectual progress, its highest result is found in the knowledge of those mutual relations which link together the general forces of nature. It is the intuitive and intimate persuasion of the existence of these relations which at once enlarges and elevates our views and enhances our enjoyment. Such extended views are the growth of observation, of meditation, and of the spirit of the age, which is ever reflected in the operations of the human mind whatever may be their direction.

From the time when man, in interrogating nature, began to experiment or to produce phenomena under definite conditions, and to collect and record the fruits of his experience—so that investigation might no longer be restricted by the short limits of a single life—the philosophy of nature laid aside the vague and poetic forms with which she had at first been clothed, and has adopted a more severe character.

The history of science teaches us how inexact and incomplete observations have led, through false inductions, to that great number of erroneous physical views which have been [Pg 160] perpetuated as popular prejudices among all classes of society. Thus, side by side with a solid and scientific knowledge of phenomena, there has been preserved a system of pretended results of observation, the more difficult to shake because it takes no account of any of the facts by which it is overturned.

This empiricism—melancholy inheritance of earlier times—invariably maintains whatever axioms it has laid down; it is arrogant, as is everything that is narrow-minded; while true physical philosophy, founded on science, doubts because it seeks to investigate thoroughly—distinguishes between that which is certain and that which is simply probable—and labours incessantly to bring its theories nearer to perfection by extending the circle of observation. This assemblage of incomplete dogmas bequeathed from one century to another, this system of physics made up of popular prejudices, is not only injurious because it perpetuates error with all the obstinacy of ill-observed facts, but also because it hinders the understanding from rising to the level of great views of nature.

Instead of seeking to discover the *mean* state around which, in the midst of apparent independence and irregularity, the phenomena really and invariably oscillate, this false science delights in multiplying apparent exceptions to the dominion of fixed laws, and seeks, in organic forms and the phenomena of nature, other marvels than those presented by internal progressive development, and by regular order and succession. Ever disinclined to recognise in the present the analogy of the past, it is always disposed to believe the order of nature suspended by perturbations, of which it places the seat, as if by chance, sometimes in the interior of the earth, sometimes in the remote regions of space.

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II.—The Inductive Method

The generalisation of laws which were first applied to smaller groups of phenomena advances by successive gradations, and their empire is extended, and their evidence strengthened, so long as the reasoning process is directed to really analogous phenomena. Empirical investigation begins by single perceptions, which are afterwards classed according to their analogy or dissimilarity. Observation is succeeded at a much later epoch by experiment, in which phenomena are made to arise under conditions previously determined on by the experimentalist, guided by preliminary hypotheses, or a more or less just intuition of the connection of natural objects and forces.

The results obtained by observation and experiment lead by the path of induction and analogy to the discovery of empirical laws, and these successive phases in the application of human intellect have marked different epochs in the life of nations. It has been by adhering closely to this inductive path that the great mass of facts has been accumulated which now forms the solid foundation of the natural sciences.

Two forms of abstraction govern the whole of this class of knowledge—*viz.*, the determination of quantitative relations, according to number and magnitude; and relations of quality, embracing the specific properties of heterogeneous matter.

The first of these forms, more accessible to the exercise of thought, belongs to the domain of mathematics; the other, more difficult to seize, and apparently more mysterious, to that of chemistry. In order to submit phenomena to calculation, recourse is had to a hypothetical construction of matter by a combination of molecules and atoms whose number, form, position, and polarity determine, modify, and vary the phenomena.

We are yet very far from the time when a reasonable hope could be entertained of [Pg 162] reducing all that is perceived by our senses to the unity of a single principle; but the partial solution of the problem—the tendency towards a general comprehension of the phenomena of the universe—does not the less continue to be the high and enduring aim of all natural investigation.

III.—Distribution of Matter in Space

A physical cosmography, or picture of the universe, should begin, not with the earth, but with the regions of space—the distribution of matter in the universe.

We see matter existing in space partly in the form of rotating and revolving spheroids, differing greatly in density and magnitude, and partly in the form of self-luminous vapour dispersed in shining nebulous spots or patches. The nebulæ present themselves to the eye in the form of round, or nebulous discs, of small apparent magnitude, either single or in pairs, which are sometimes connected by a thread of light; when their diameters are greater their forms vary—some are elongated, others have several branches, some are fan-shaped, some annular, the ring being well defined and the interior dark. They are supposed to be undergoing various and progressive changes of form, as condensation proceeds around one or more nuclei in conformity with the laws of gravitation. Between two and three thousand of such unresolvable nebulæ have already been counted, and their positions determined.

If we leave the consideration of the attenuated vaporous matter of the immeasurable regions of space, whether existing in a dispersed state as a cosmical ether without form or limits, or in the shape of nebulæ, and pass to those portions of the universe which are condensed into solid spheres or spheroids, we approach a class of phenomena exclusively designated as stars or as the sidereal universe. Here, too, we find different degrees of [Pg 163] solidity or density in the agglomerated matter.

If we compare the regions of space to one of the island-studded seas of our planet, we may imagine we see matter distributed in groups, whether of unresolvable nebulæ of different ages condensed around one or more nuclei, or in clusters of stars, or in stars scattered singly. Our cluster of stars, or the island in space to which we belong, forms a lens-shaped, flattened, and everywhere detached stratum, whose major axis is estimated at seven or eight hundred, and its minor axis at a hundred and fifty times, the distance of Sirius. If we assume that the parallax of Sirius does not exceed that accurately determined for the brightest stars in Centaur (0.9128 sec.), it will follow that light traverses one distance of Sirius in three years, while nine years and a quarter are required for the transmission of the light of the star 61 Cygni, whose considerable proper motion might lead to the inference of great proximity.

Our cluster of stars is a disc of comparatively small thickness divided, at about a third its length, into two branches; we are supposed to be near this division, and nearer to the region of Sirius than to that of the constellation of the Eagle; almost in the middle of the starry stratum in the direction of its thickness.

The place of our solar system and the form of the whole lens are inferred from a kind of scale—*i.e.*, from the different number of stars seen in equal telescopic fields of view. The greater or less number of stars measures the relative depth of the stratum in different directions; giving in each case, like the marks on a sounding-line, the comparative length of visual ray required to reach the bottom; or, more properly, as above and below do not here apply, the outer limit of the sidereal stratum.

In the direction of the major axis, where the greater number of stars are placed behind [Pg 164] each other, the remoter ones appear closely crowded together, and, as it were, united by a milky radiance, and present a zone or belt projected on the visible celestial vault. This narrow belt is divided into branches; and its beautiful, but not uniform brightness, is interrupted by some dark places. As seen by us on the apparent concave celestial sphere, it deviates only a few degrees from a great circle, we being near the middle of the entire starry cluster, and almost in the plane of the Milky Way. If out planetary system were far outside the cluster, the Milky Way would appear to telescopic vision as a ring, and at a still greater distance as a resolvable disc-shaped nebula.

IV.—On Earth History

The succession and relative age of different geological formations are traced partly by the order of superposition of sedimentary strata, of metamorphic beds, and of conglomerates, but most securely by the presence of organic remains and their diversities of structure. In the fossiliferous strata are inhumed the remains of the floras and faunas of past ages. As we descend from stratum to stratum to study the relations of superposition, we ascend in the order of time, and new worlds of animal and vegetable existence present themselves to the view.

In our ignorance of the laws under which new organic forms appear from time to time upon the surface of the globe, we employ the expression "new creations" when we desire to refer to the historical phenomena of the variations which have taken place at intervals in the animals and plants that have inhabited the basins of the primitive seas and the uplifted continents.

It has sometimes happened that extinct species have been preserved entire, even to the minutest details of their tissues and articulations. In the lower beds of the Secondary Period, [Pg 165] the lias of Lyme Regis, a sepia has been found so wonderfully preserved that a part of the black fluid with which the animal was provided myriads of years ago to conceal itself from its enemies has actually served at the present time to draw its picture. In other cases such traces alone remain as the impression which the feet of animals have left on wet sand or mud over which they passed when alive, or the remains of their undigested food (coprolites).

The analytical study of the animal and vegetable kingdoms of the primitive world has given rise to two distinct branches of science; one purely morphological, which occupies itself in natural and physiological descriptions, and in the endeavour to fill up from extinct forms the chasms which present themselves in the series of existing species; the other branch, more especially geological considers the relations of the fossil remains to the superposition and relative age of the sedimentary beds in which they are found. The first long predominated; and the superficial manner which then prevailed of comparing fossil and existing species led to errors of which traces still remain in the strange denominations which were given to certain natural objects. Writers attempted to identify all extinct forms with living species, as, in the sixteenth century, the animals of the New World were confounded by false analogies with those of the Old.

In studying the relative age of fossils by the order of superposition of the strata in which they are found, important relations have been discovered between families and species (the latter always few in numbers) which have disappeared and those which are still living. All observations concur in showing that the fossil floras and faunas differ from the present animal and vegetable forms the more widely in proportion as the sedimentary beds to which they belong are lower, or more ancient.

Thus great variations have successively taken place in the general types of organic life, [Pg 166] and these grand phenomena, which were first pointed out by Cuvier, offer numerical relations which Deshayes and Lyell have made the object of researches by which they have been conducted to important results, especially as regards the numerous and well-preserved fossils of the Tertiary formation. Agassiz, who has examined 1,700 species of fossil fishes, and who estimates at 8,000 the number of living species which have been described, or which are preserved in our collections, affirms that, with the exception of one small fossil fish peculiar to the argillaceous geodes of Greenland, he has never met in the Transition, Secondary, or Tertiary strata with any example of this class specifically identical with any living fish; and he adds the important remark that even in the lower Tertiary formations a third of the fossil fishes of the *calcaire grossier* and of the London clay belong to extinct families.

We have seen that fishes, which are the oldest vertebrates, first appear in the Silurian strata, and are found in all the succeeding formations up to the birds of the Tertiary Period. Reptiles begin in like manner in the magnesian limestone, and if we now add that the first mammalia are met with in Oolite, the Stonefield slate; and that the first remains of birds have been found in the deposits of the cretaceous period, we shall have indicated the inferior limits, according to our present knowledge, of the four great divisions of the vertebrates.

In regard to invertebrate animals, we find corals and some shells associated in the oldest formations with very highly organised cephalopodes and crustaceans, so that widely different orders of this part of the animal kingdom appear intermingled; there are, nevertheless, many isolated groups belonging to the same order in which determinate laws are discoverable. Whole mountains are sometimes found to consist of a single species of fossil goniatites, trilobites, or nummulites.

Where different genera are intermingled, there often exists a systematic relation between [Pg 167] the series of organic forms and the superposition of the formations; and it has been remarked that the association of certain families and species follows a regular law in the superimposed strata of which the whole constitutes one formation. It has been found that the waters in the most distant parts of the globe were inhabited at the same epochs by testaceous animals corresponding, at least in generic character, with European fossils.

Strata defined by their fossil contents, or by the fragments of other rocks which they include, form a geological horizon by which the geologist may recognise his position, and obtain safe conclusions in regard to the identity or relative antiquity of formations, the periodical repetition of certain strata—their parallelism—or their entire suppression. If we would thus comprehend in its greatest simplicity the general type of the sedentary formations, we find in proceeding successively from below upwards: (1) The Transition group, including the Silurian and Devonian (Old Red Sandstone) systems; (2) the Lower Trias, comprising mountain limestone, the coal measures, the lower new red sandstone, and the magnesian limestone; (3) the Upper Trias, composing the bunter, or variegated sandstone, the muschelkalk, and the Keuper sandstone; (4) the Oolitic, or Jurassic series, including Lias; (5) the Cretaceous series; (6) the Tertiary group, as represented in its three stages by the *calcaire grossier* and other beds of the Paris basin, the lignites, or brown coal of Germany, and the sub-Apennine group of Italy.

To these succeed transported soils (*alluvium*), containing the gigantic bones of ancient mammalia, such as the mastodons, the dinotherium, and the megatheroid animals, among which is the mylodon of Owen, an animal upwards of eleven feet in length, allied to the sloth. Associated with these extinct species are found the fossil remains of animals still [Pg 168] living: elephants, rhinoceroses, oxen, horses, and deer. Near Bogota, at an elevation of 8,200 French feet above the level of the sea, there is a field filled with the bones of mastodon (*Campo de Gigantes*), in which I have had careful excavations made. The bones found on the table-lands of Mexico belong to the true elephants of extinct species. The minor range of the Himalaya, the Sewalik hills, contain, besides numerous mastodons, the sivatherium and the gigantic land-tortoise (*Colossochelys*), more than twelve feet in length and six in height, as well as remains belonging to still existing species of elephants, rhinoceroses, and giraffes. It is worthy of notice that these fossils are found in a zone which enjoys the tropical climate supposed to have prevailed at the period of the mastodons.

V.—The Permanence of Science

It has sometimes been regarded as a discouraging consideration that, while works of literature being fast-rooted in the depths of human feeling, imagination and reason suffer little from the lapse of time, it is otherwise with works which treat of subjects dependent on the progress of experimental knowledge. The improvement of instruments, and the continued enlargement of the field of observation, render investigations into natural phenomena and physical laws liable to become antiquated, to lose their interest, and to cease to be read.

Let none who are deeply penetrated with a true and genuine love of nature, and with a lively appreciation of the true charm and dignity of the study of her laws, ever view with discouragement or regret that which is connected with the enlargement of the boundaries of our knowledge. Many and important portions of this knowledge, both as regards the phenomena of the celestial spaces and those belonging to our own planet, are already based [Pg 169] on foundations too firm to be lightly shaken; although in other portions general laws will doubtless take the place of those which are more limited in their application, new forces will be discovered, and substances considered as simple will be decomposed, while others will become known.

JAMES HUTTON [Pg 170]

The Theory of the Earth

James Hutton, the notable Scotch geologist, was born at Edinburgh on June 3, 1726. In 1743 he was apprenticed to a Writer to the Signet; but his apprenticeship was of short duration and in the following year he began to study medicine at Edinburgh University, and in 1749 graduated as an M.D. Later he determined to study agriculture, and went, in 1752, to live with a Norfolk farmer to learn practical farming. He did not devote himself entirely to agriculture, but gave a considerable amount of his time to chemical and geological researches. His geological researches culminated in his great work, "The Theory of the Earth," published at Edinburgh in 1795. In this work he propounds the theory that the present continents have been formed at the bottom of the sea by the precipitation of the detritus of former continents, and that the precipitate had been hardened by heat and elevated above the sea by the expansive power of heat. He died on March 26, 1797. Other works are his "Theory of Rain," "Elements of Agriculture," "Natural Philosophy," and "Nature of Coal."

I.—Origin and Consolidation of the Land

The solid surface of the earth is mainly composed of gravel, of calcareous, and argillaceous strata. Sand is separated by streams and currents, gravel is formed by the attrition of stones agitated in water, and argillaceous strata are deposited by water containing argillaceous material. Accordingly, the solid earth would seem to have been mainly produced by water, wind, and tides, and this theory is confirmed by the discovery that all the masses of marble and limestone are composed of the calcareous matter of marine bodies. All these materials were, in the first place, deposited at the bottom of the sea, and we have to consider, firstly, how they were consolidated; and secondly, how they came to be dry land, elevated above the sea.

It is plain that consolidation may have been effected either through the concretion of substances dissolved in water or through fusion by fire. Consolidation through the concretion of substances dissolved in the sea is unlikely, for, in the first place, there are strata, such as siliceous matter, which are insoluble, and which could not therefore have been in solution; and, in the second place, the appearance of the strata is contrary to this supposition. Consolidation was probably effected by heat and fusion. All the substances in the earth may be rendered fluid by heat, and all the appearances in the earth's crust are consistent with the consolidation and crystallisation of fused substances. Not only so, but we find rents and separations and veins in the strata, such as would naturally occur in strata consolidated by the cooling of fused masses, and other phenomena pointing to fusion by heat. We may conclude, then, that all the solid strata of the globe have been hardened from a state of fusion. [Pg 171]

But how were these strata raised up from the bottom of the sea and transformed into dry land? Even as heat was the consolidating power, so heat was also probably the elevating power. The power of heat for the expansion of bodies is, as we know, unlimited, and the expansive power of heat was certainly competent to raise the strata above the sea. Heat was certainly competent, and if we examine the crust of the earth we find evidence that heat was used.

If the strata cemented by the heat of fusion were created by the expansive power of heat acting from below, we should expect to find every species of fracture, dislocation, and contortion in those bodies, and every degree of departure from a horizontal towards a vertical position. And this is just what we do find. From horizontal, the strata are frequently found vertical; from continuous, broken, and separated in every possible direction; and from a plane, bent and doubled. The theory is confirmed by an examination of the veins and fissures of the earth which contain matter foreign to the strata they traverse, and evidently forced into them as a fluid under great pressure. Active volcanoes, and extinct volcanoes, and the marks everywhere of volcanic action likewise support the theory of expansion and elevation by heat. A volcano is not made on purpose to frighten superstitious people into fits of piety and devotion; it is to be considered as a spiracle of a subterranean furnace. [Pg 172]

Such being the manner of the formation of the crust of the world, can we form any judgment of its duration and durability? If we could measure the rate of the attrition of the present continents, we might estimate the duration of the older continents whose attrition supplied the material for the present dry land. But as we cannot measure the wearing-away of the land, we can merely state generally, first, that the present dry land required an indefinitely long period for its formation; second, that the previous dry land which supplied material for its formation required equal time to make; third, that there is at present land forming at the bottom of the sea which in time will appear above the surface; fourth, that we find no vestige of a beginning, or of an end.

Granite has in its own nature no claim to originality, for it is found to vary greatly in its composition. But, further, it is certain that granite, or a species of the same kind of stone, is found stratified. It is the *granit feuilletée* of M. de Sauffure, and, if I mistake not, is called *gneiss* by the Germans. Granite being thus found stratified, the masses of this stone cannot be allowed to any right of priority over the schistus, its companion in Alpine countries.

Lack of stratification, then, cannot be considered a proof of primitive rock. Nor can lack of organized bodies, such as shells, in these rocks, be considered a proof; for the traces of organized bodies may be obliterated by the many subsequent operations of the mineral region. In any case, signs of organized bodies are sometimes found in "primitive" mountains. [Pg 173]

Nor can metallic veins, found plentifully in "primitive" mountains, prove anything, for mineral veins are found in various strata.

We maintain that *all* the land was produced from fused substances elevated from the bottom of the sea. But we do not hold that all parts of the earth have undergone exactly similar and simultaneous vicissitudes; and in respect to the changes which various parts of the land have undergone we may distinguish between primary and secondary strata. Nothing is more certain than that there have been several repeated operations of the mineralising power exerted upon the strata in particular places, and all those mineral operations tend to consolidation. It is quite possible that "primitive" masses which differ from the ordinary strata of the globe have been twice subjected to mineral operations, having been first consolidated and raised as land, and then submerged in order to be again fused and elevated.

II.—The Nature of Mineral Coal

Mineral, or fossil, coal is a species of stratum distinguished by its inflammable and combustible nature. We find that it differs in respect to its purity, and also in respect to its inflammability. As is well known, some coals have almost no earthy ash, some a great deal; and, again, some coals burn with much smoke and fire, while others burn like coke. Where, then, did coal come from, and how can we account for its different species?

A substance proper for the formation of coaly matter is found in vegetable bodies. But how did it become mixed with earthy matter?

Vegetable bodies may be resolved into bituminous or coaly matter either by means of fire or by means of water. Both may be used by nature in the formation of coal. [Pg 174]

By the force of subterranean heat vegetable matter may have been charred at the bottom of the sea, and the oleaginous, bituminous, and fuliginous substances diffused through the sea as a result of the burning may have been deposited at the bottom of the sea as coal. Further, the bituminous matter from the smoke of vegetable substances burned on land would ultimately be deposited from the atmosphere and settle at the bottom of the sea.

Many of the rivers contain in solution an immense quantity of inflammable vegetable substance, and this is carried into the sea, and precipitated there.

From these two sources, then, the sea gets bituminous material, and this material, condensed and consolidated by compression and by heat, at the bottom of the sea, would form a black body of a most uniform structure, breaking with a polished surface, and burning with more or less smoke or flame in proportion as it be distilled less or more by subterranean heat. And such a body exactly represents our purest fossil coal, which gives the most heat and leaves the least ash.

In some cases the bituminous material in suspension in the sea would be mixed more or less with argillaceous, calcareous, and other earthy substances; and these being precipitated along with the bituminous matter would form layers of impure coal with a considerable amount of ash.

But there is still a third source of coal. Vegetable bodies macerated in water, and consolidated by compression, form a body almost indistinguishable from some species of coal, as is seen in peat compressed under a great load of earth; and there can be no doubt that coal sometimes originates in this way, for much fossil coal shows abundance of vegetable bodies in its composition.

There remains only to consider the change in the disposition of coal strata. Coal strata, [Pg 175] which had been originally in a horizontal position, are now found sometimes standing erect, even perpendicular. This, also, is consistent with our theory of the earth. Indeed, there is not a substance in the mineral kingdom in which the action of subterranean heat is better shown. These strata are evidently a deposit of inflammable substances which all come originally from vegetable bodies. In this stage of their formation they must all contain volatile oleaginous constituents. But some coal strata contain no volatile constituents, and the disappearance of the volatile oleaginous substances must have been produced by distillation, proceeding perhaps under the restraining force of immense compression.

We cannot doubt that such distillation does take place in the mineral regions, when we consider that in most places of the earth we find the evident effects of such distillation in the naphtha and petroleum that are constantly emitted along with water in certain springs. We have, therefore, sufficient proof of this operation of distillation.

III.—The Disintegration and Dissolution of Land

Whether we examine the mountain or the plain, whether we consider the disintegration of the rocks or the softer strata of the earth, whether we regard the shores of seas or the central plains of continents, whether we contemplate fertile lands or deserts, we find evidence of a general dissolution and decay of the solid surface of the globe. Every great river and deep valley gives evidence of the attrition of the land. The purpose of the dry land is to sustain a system of plants and animals; and for this purpose a soil is required, and to make a soil the solid strata must be crumbled down. The earth is nothing more than an indefinite number of soils and situations suitable for various animals and plants, and it must consist of both solid [Pg 176] rock and tender earth, of both moist and dry districts; for all these are requisite for the world we inhabit.

But not only is the solid rock crumbling into soil by the action of air and water, but the soil gradually progresses towards the sea, and sooner or later the sea must swallow up the land. Vegetation and masses of solid rock retard the seaward flow of the soil; but they merely retard, they cannot wholly prevent. In proportion as the mountains are diminished, the haugh, or plain, between them grows more wide, and also on a lower level; but while there is a river running on a plain, and floods produced in the seasons of rain, there is nothing stable in the constitution of the surface of the land.

The theory of the earth which I propound is founded upon the great catastrophes that can happen to the earth. It supposes strata raised from the bottom of the sea and elevated into mountainous continents. But, between the catastrophes, it requires nothing further than the ordinary everyday effects of air and water. Every shower of rain, every stream, participates in the dissolution of the land, and helps to transport to the sea the material for future continents.

The prodigious waste of the land we see in places has seemed to some to require some other explanation; but I maintain that the natural operations of air and water would suffice in time to produce the effects observed. It is true that the wastage would be slow; but slow destruction of rock with gradual formation of soil is just what is required in the economy of nature. A world sustaining plants and animals requires continents which endure for more than a day.

If this continent of land, first collected in the sea, is to remain a habitable earth, and to resist the moving waters of the globe, certain degrees of solidity or consolidation must be given to that collection of loose materials; and certain degrees of hardness must be given to [Pg 177] bodies which are soft and incoherent, and consequently so extremely perishable in the situation in which they are now placed.

But, at the same time that this earth must have solidity and hardness to resist the sudden changes which its moving fluids would occasion, it must be made subject to decay and waste upon the surface exposed to the atmosphere; for such an earth as were made incapable of change, or not subject to decay, would not afford that fertile soil which is required in the system of this world—a soil on which depends the growth of plants and life of animals—the end of its intention.

Now, we find this earth endued precisely with such degree of hardness and consolidation as qualifies it at the same time to be a fruitful earth, and to maintain its station with all the permanency compatible with the nature of things, which are not formed to remain unchangeable.

Thus we have a view of the most perfect wisdom in the contrivance of that constitution by which the earth is made to answer, in the best manner possible, the purpose of its intention, that is, to maintain and perpetuate a system of vegetation, or the various races of useful plants, or a system of living animals, which are in their turn subservient to a system still infinitely more important—I mean a system of intellect. Without fertility in the earth, many races of plants and animals would soon perish, or be extinct; and with permanency in our land it were impossible for the various tribes of plants and animals to be dispersed over the surface of a changing earth. The fact is that fertility, adequate to the various ends in view, is found in all the quarters of the world, or in every country of the earth; and the permanency of our land is such as to make it appear unalterable to mankind in general and even to impose upon men of science, who have endeavoured to persuade us that this earth is not to change.

[Pg 178] Nothing but supreme power and wisdom could have reconciled those two opposite ends of intention, so as both to be equally pursued in the system of nature, and so equally attained as to be imperceptible to common observation, and at the same time a proper object of the human understanding.

LAMARCK [Pg 179]

Zoological Philosophy

Jean Baptiste de Monet, Chevalier de Lamarck, was born in Picardy, France, Aug. I, 1744, the cadet of an ancient but impoverished house. It was his father's desire that he should enter the Church, but his inclination was for a military life; and having, at the age of seventeen, joined the French army under De Broglie, he had within twenty-four hours the good fortune so to distinguish himself as to win his commission. When the Museum of Natural History was brought into existence in 1794 he was sufficiently well-known as a naturalist to be entrusted with the care of the collections of invertebrates, comprising insects, molluscs, polyps, and worms. Here he continued to lecture until his death in 1829. Haeckel, classifying him in the front rank with Goethe and Darwin, attributes to him "the imperishable glory of having been the first to raise the theory of descent to the rank of an independent scientific theory." The form of his theory was announced in 1801, but was not given in detail to the world until 1809, by the publication of his "Zoological Philosophy" ("Philosophie Zoologique"). The Lamarckian theory of the hereditary transmission of characters acquired by use, disuse, etc., has still a following, though it is controverted by the schools of Darwin and Weissmann. Lamarck died on December 18, 1829.

I.—The Ladder of Life

If we look backwards down the ladder of animal forms we find a progressive degradation in the organisation of the creatures comprised; the organisation of their bodies becomes simpler, the number of their faculties less. This well-recognised fact throws a light upon the order in which nature has produced the animals; but it leaves unexplained the fact that this gradation, though sustained, is irregular. The reason will become clear if we consider the effects produced by the infinite diversity of conditions in different parts of the globe upon [Pg 180] the general form, the limbs, and the very organisation of the animals in question.

It will, in fact, be evident that the state in which we find all animals is the product, on the one hand, of the growing composition of the organisation which tends to form a regular gradation; and that, for the rest, it results from a multitude of circumstances which tend continually to destroy the regularity of the gradation in the increasingly composite nature of the organism.

Not that circumstances can effect any modification directly. But changed circumstances produce changed wants, changed wants changed actions. If the new wants become constant the animals acquire new habits, which are no less constant than the wants which gave rise to them. And such new habits will necessitate the use of one member rather than another, or even the cessation of the use of a member which has lost its utility.

We will look at some familiar examples of either case. Among vegetables, which have no actions, and therefore no habits properly so called, great differences in the development of the parts do none the less arise as a consequence of changed circumstances; and these differences cause the development of certain of them, while they attenuate others and cause them to disappear. But all this is caused by changes in the nutrition of the plant, in its absorptions and transpirations, in the quantity of heat and light, of air and moisture, which it habitually receives; and, lastly, by the superiority which certain of its vital movements may assert over the others. There may arise between individuals of the same species, of which some are placed in favourable, others amid unfavourable, conditions, a difference which by degrees becomes very notable.

Suppose that circumstances keep certain individuals in an ill-nourished or languid state. Their internal organisation will at length be modified, and these individuals will engender offspring which will perpetuate the modifications thus acquired, and thus will in the end [Pg 181] give place to a race quite distinct from that of which the individual members come together always under circumstances favourable to their development.

For instance, if a seed of some meadow flower is carried to dry and stony ground, where it is exposed to the winds and there germinates, the consequence will be that the plant and its immediate offspring, being always ill-nourished, will give rise to a race really different from that which lives in the field; yet this, none the less, will be its progenitor. The individuals of this race will be dwarfed; and their organs, some being increased at the expense of the rest, will show distinctive proportions. What nature does in a long time we do every day ourselves. Every botanist knows that the vegetables transplanted to our gardens out of their native soil undergo such changes as render them at last unrecognisable.

Consider, again, the varieties among our domestic fowls and pigeons, all of them brought into existence by being raised in diverse circumstances and different countries, and such as might be sought in vain in a state of nature. It is matter of common knowledge that if we raise a bird in a cage, and keep it there for five or six years, it will be unable to fly if restored to liberty. There has, indeed, been no change as yet in the form of its members; but if for a long series of generations individuals of the same race had been kept caged for a considerable time, there is no room for doubt that the very form of their limbs would little by little have undergone notable alteration. Much more would this be the case if their captivity had been accompanied by a marked change of climate, and if these individuals had by degrees accustomed themselves to other sorts of food and to other measures for acquiring it. Such circumstances, taken constantly together, would have formed insensibly a new and clearly denned race.

The following example shows, in regard to plants, how the change of some important [Pg 182] circumstance may tend to change the various parts of these living bodies.

So long as the *ranunculus aquatilis*, the water buttercup, is under water its leaves are all finely indented, and the divisions are furnished with capillaries; but as soon as the stalk of the plant reaches the surface the leaves, which develop in the air, are broadened out, rounded, and simply lobed. If the plant manages to spring up in a soil that is merely moist, and not covered with water, the stems will be short, and none of the leaves will show these indentations and capillaries. You have then the *ranunculus hederaceus*, which botanists regard as a distinct species.

Among animals changes take place more slowly, and it is therefore more difficult to determine their cause. The strongest influence, no doubt, is that of environment. Places far apart are different, and—which is too commonly ignored—a given place changes its climate and quality with time, though so slowly in respect of human life that we attribute to it perfect stability. Hence it arises that we have not only extreme changes, but also shadowy ones between the extremes.

Everywhere the order of things changes so gradually that man cannot observe the change directly, and the animal tribes in every place preserve their habits for a long time; whence arises the apparent constancy of what we call species—a constancy which has given birth in us to the idea that these races are as old as nature.

But the surface of the habitable globe varies in nature, situation, and climate, in every variety of degrees. The naturalist will perceive that just in proportion as the environment is notably changed will the species change their characters.

It must always be recognised:

(1) That every considerable and constant change in the environment of a race of animals works a real change in their wants.

(2) That every change in their wants necessitates new actions to supply them, and consequently new habits. [Pg 183]

(3) That every new want calling for new actions for its satisfaction affects the animal in one of two ways. Either it has to make more frequent use of some particular member, and this will develop the part and cause it to increase in size; or it must employ new members which will grow in the animal insensibly in response to the inward yearning to satisfy these wants. And this I will presently prove from known facts.

How the new wants have been able to attain satisfaction, and how the new habits have been acquired, it will be easy to see if regard be had to the two following laws, which observation has always confirmed.

> First Law.—In every animal which has not arrived at the term of its developments, the more frequent and sustained use of any organ strengthens, develops, and enlarges that organ, and gives it a power commensurate with the duration of this employment of it. On the other hand, constant disuse of such organ weakens it by degrees, causes it to deteriorate, and progressively diminishes its faculties, so that in the end it disappears.

> Second Law.—All qualities naturally acquired by individuals as the result of circumstances to which their race is exposed for a considerable time, or as a consequence of a predominant employment or the disuse of a certain organ, nature preserves to individual offspring; provided that the acquired modifications are common to the two sexes, or, at least, to both parents of the individual offspring.

Naturalists have observed that the members of animals are adapted to their use, and thence have concluded hitherto that the formation of the members has led to their appropriate employment. Now, this is an error. For observation plainly shows that, on the contrary, the development of the members has been caused by their need and use; that these have caused them to come into existence where they were wanting. [Pg 184]

But let us examine the facts which bear upon the effects of employment or disuse of organs resulting from the habits which a race has been compelled to form.

II.—The Penalties of Disuse

Permanent disuse of an organ as a consequence of acquired habits gradually impoverishes it, and in the end causes it to disappear, or even annihilates it altogether.

Thus vertebrates, which, in spite of innumerable particular distinctions, are alike in the plan of their organisation, are generally armed with teeth. Yet those of them which by circumstances have acquired the habit of swallowing their prey without mastication have been liable to leave their teeth undeveloped. Consequently, the teeth have either remained hidden between the bony plates of the jaws, or have even been, in the course of time, annihilated.

The whale was supposed to have no teeth at all till M. Geoffrey found them hidden in the jaws of the foetus. He has also found in birds the groove in which teeth might be placed, but without any trace of the teeth themselves. A similar case to that of the whale is the ant-eater (*nyomecophaga*), which has long given up the practice of mastication.

Eyes in the head are an essential part of the organisation of vertebrates. Yet the mole, which habitually makes no use of the sense of sight, has eyes so small that they can hardly be seen; and the aspalax, whose habits-resemble a mole's, has totally lost its sight, and shows but vestiges of eyes. So also the proteus, which inhabits dark caves under water.

In such cases, since the animals in question belong to a type of which eyes are an essential part, it is clear that the impoverishment, and even the total disappearance, of these organs are the results of long continued disuse. [Pg 185]

With hearing, the case is otherwise. Sound traverses everything. Therefore, wherever an animal dwells it may exercise this faculty. And so no vertebrate lacks it, and we never find it re-appearing in any of the lower ranges. Sight disappears, re-appears, and disappears again, according as circumstances deny or permit its exercise.

Four legs attached to its skeleton are part of the reptile type; and serpents, particularly as between them and the fishes come the batrachians—frogs, etc.—ought to have four legs.

But serpents, having acquired the habit of gliding along the ground, and concealing themselves amid the grass, their bodies, as a consequence of constantly repeated efforts to lengthen themselves out in order to pass through narrow passages, have acquired considerable length of body which is out of all proportion to their breadth.

Now, feet would have been useless to these animals, and consequently would have remained unemployed; for long legs would have interfered with their desire to go on their bellies; and short legs, being limited in number to four, would have been incapable of moving their bodies. Thus total disuse among these races of animals has caused the parts which have fallen into disuse totally to disappear.

Many insects, which by their order and genus should have wings, lack them more or less completely for similar reasons.

III.—The Advantages of Use

The frequent use of an organ, if constant and habitual, increases its powers, develops it, and makes it acquire dimensions and potency such as are not found among animals which use it less. [Pg 186]

Of this principle, the web-feet of some birds, the long legs and neck of the stork, are examples. Similarly, the elongated tongue of the ant-eater, and those of lizards and serpents.

Such wants, and the sustained efforts to satisfy them, have also resulted in the displacement of organs. Fishes which swim habitually in great masses of water, since they need to see right and left of them, have the eyes one upon either side of the head. Their bodies, more or less flat, according to species, have their edges perpendicular to the plane of the water; and their eyes are so placed as to be one on either side of the flattened body. But those whose habits bring them constantly to the banks, especially sloping banks, have been obliged to lie over upon the flattened surface in order to approach more nearly. In this position, in which more light falls on the upper than on the under surface, and their attention is more particularly fixed upon what is going on above than on what is going on below them, this want has forced one of the eyes to undergo a kind of displacement, and to keep the strange position which it occupies in the head of a sole or a turbot. The situation is not symmetrical because the mutation is not complete. In the case of the skate, however, it is complete; for in these fish the transverse flattening of the body is quite horizontal, no less than that of the head. And so the eyes of a skate are not only placed both of them on the upper surface, but have become symmetrical.

Serpents need principally to see things above them, and, in response to this need, the eyes are placed so high up at the sides of the head that they can see easily what is above them on either side, while they can see in front of them but a very little distance. To compensate for this, the tongue, with which they test bodies in their line of march, has been rendered by this habit thin, long, and very contractile, and even, in most species, has been split so as to be [Pg 187] able to test more than one object at a time. The same custom has resulted similarly in the formation of an opening at the end of the muzzle by which the tongue may be protruded without any necessity for the opening of the jaws.

The effect of use is curiously illustrated in the form and figure of the giraffe. This animal, the largest of mammals, is found in the interior of Africa, where the ground is scorched and destitute of grass, and has to browse on the foliage of trees. From the continual stretching thus necessitated over a great space of time in all the individuals of the race, it has resulted that the fore legs have become longer than the hind legs, and that the neck has become so elongated that the giraffe, without standing on its hind legs, can raise its head to a height of nearly twenty feet. Observation of all animals will furnish similar examples.

None, perhaps, is more striking than that of the kangaroo. This animal, which carries its young in an abdominal pouch, has acquired the habit of carrying itself upright upon its hind legs and tail, and of moving from place to place in a series of leaps, during which, in order not to hurt its little ones, it preserves its upright posture. Observe the result.

(1) Its front limbs, which it uses very little, resting on them only in the instant during which it quits its erect posture, have never acquired a development in proportion to the other parts; they have remained thin, little, and weak.

(2) The hind legs, almost continually in action, whether to bear the weight of the whole body or to execute its leaps, have, on the contrary, obtained a considerable development; they are very big and very strong.

(3) Finally, the tail, which we observe to be actively employed, both to support the animal's weight and to execute its principal movements, has acquired at its base a thickness [Pg 188] and a strength that are extremely remarkable.

When the will determines an animal to a certain action, the organs concerned are forthwith stimulated by a flow of subtle fluids, which are the determining cause of organic changes and developments. And multiplied repetitions of such acts strengthen, extend, and even call into being the organs necessary to them. Now, every change in an organ which has been acquired by habitual use sufficient to originate it is reproduced in the offspring if it is common to both the individuals which have come together for the reproduction of their species. In the end, this change is propagated and passes to all the individuals which come after and are submitted to the same conditions, without its being necessary that they should acquire it in the original manner.

For the rest, in the union of disparate couples, the disparity is necessarily opposed to the constant propagation of such qualities and outward forms. This is why man, who is exposed to such diversity of conditions, does not preserve and propagate the qualities or the accidental defects which he has been in the way of acquiring. Such peculiarities will be produced only in case two individuals who share them unite; these will produce offspring bearing similar characteristics, and, if successive generations restrict themselves to similar unions, a distinct race will then be formed. But perpetual intermixture will cause all characters acquired through particular circumstances to disappear. If it were not for the distances which separate the races of men, such intermixture would quickly obliterate all national distinctions.

IV.—The Conclusion

Here, then, is the conclusion to which we have come. It is a fact that every genus and species of animal has its characteristic habits combined with an organisation perfectly in harmony with them. [Pg 189] From the consideration of this fact one of two conclusions must follow, and that though neither of them can be proved.

(1) The conclusion admitted hitherto—that nature (or its Author) in creating the animals has foreseen all the possible sets of circumstances in which they would have to live, has given to each species a constant organisation, and has shaped its parts in a determined and invariable way so that every species is compelled to live in the districts and the climates where it is actually formed, and to keep the habits by which it is actually known.

(2) My own conclusion—that nature has produced in succession all the animal species, beginning with the more imperfect, or the simpler, and ending with the more perfect; that in so doing it has gradually complicated their organisation; and that of these animals, dispersed over the habitable globe, every species has acquired, under the influence of the circumstances amid which it is found, the habits and modifications of form which we associate with it.

To prove that the second of these hypotheses is unfounded, it will be necessary, first, to prove that the surface of the globe never varies in character, in exposure, situation, whether elevated or sheltered, climate, etc.; and, secondly, to prove that no part of the animal world undergoes, even in the course of long periods of time, any modification through change of circumstances, or as a consequence of a changed manner of life and action.

Now, a single fact which establishes that an animal, after a long period of domestication, differs from the wild stock from which it derives, and that among the various domesticated members of a species may be found differences no less marked between individuals which, have been subjected to one use and those which have been subjected to another, makes it certain that the former conclusion is not consistent with the laws of nature, and that the [Pg 190] second is.

Everything, therefore, concurs to prove my assertion, to wit—that it is not form, whether of the body or of the parts, which gives rise to the habits of animals and their manner of life;

but that, on the contrary, in the habits, the manner of living, and all the other circumstances of environment, we have those things which in the course of time have built up animal bodies with all their members. With new forms new faculties have been acquired, and little by little nature has come to shape animals and all living things in their present forms.

JOHANN LAVATER

[Pg 191]

Physiognomical Fragments

Johann Caspar Lavater, the Swiss theologian, poet, and physiognomist, was born at Zürich on November 15, 1741. He began his public life at the age of twenty-one as a political reformer. Five years later he appeared as a poet, and published a volume of poetry which was very favourably received. During the next five years he produced a religious work, which was considered heretical, although its mystic, religious enthusiasm appealed to a considerable audience. His fame, however, rests neither on his poetry nor on his theology, but on his physiognomical studies, published in four volumes between 1775–78 under the title "Physiognomical Fragments for the Advancement of Human Knowledge and Human Life" ("Physiognomische Fragmente zur Beförderung des Menschenkenntniss und Menschenliebe"). The book is diffuse and inconsequent, but it contains many shrewd observations with respect to physiognomy and has had no little influence on popular opinion in this matter. Lavater died on January 2, 1801.

I.—The Truth of Physiognomy

There can be no doubt of the truth of physiognomy. All countenances, all forms, all created beings, are not only different from each other in their classes, races, kinds, but are also individually distinct. It is indisputable that all men estimate all things whatever by their external temporary superficies—that is to say, by their physiognomy. Is not all nature physiognomy, superficies and contents, body and spirit, external effect and internal power? There is not a man who does not judge of all things that pass through his hands by their physiognomy—there is not a man who does not more or less, the first time he is in company with a stranger, observe, estimate, compare, judge him according to appearances. When each apple, each apricot, has a physiognomy peculiar to itself, shall man, the lord of the earth, have none? [Pg 192]

Man is the most perfect of all earthly creatures. In no other creature are so wonderfully united the animal, the intellectual, and the moral. And man's organisation peculiarly distinguishes him from all other beings, and shows him to be infinitely superior to all those other visible organisms by which he is surrounded. His head, especially his face, convinces the accurate observer, who is capable of investigating truth, of the greatness and superiority of his intellectual qualities. The eye, the expression, the cheeks, the mouth, the forehead, whether considered in a state of entire rest, or during their innumerable varieties of motion —in fine, whatever is understood by physiognomy—are the most expressive, the most convincing picture of interior sensations, desires, passions, will, and of all those properties which so much exalt moral above animal life.

Although the physiological, intellectual, and moral are united in man, yet it is plain that each of these has its peculiar station where it more especially unfolds itself and acts.

It is, beyond contradiction, evident that, though physiological or animal life displays itself through all the body, and especially through all the animal parts, yet it acts more conspicuously in the arm, from the shoulder to the ends of the fingers.

It is not less evident that intellectual life, or the powers of the understanding and the mind, make themselves most apparent in the circumference and form of the solid parts of the head, especially the forehead; though they will discover themselves to the attentive and accurate eye in every part and point of the human body, by the congeniality and harmony of the various parts. Is there any occasion to prove that the power of thinking resides not in the foot, nor in the hand, nor in the back, but in the head and its internal parts?

The moral life of man particularly reveals itself in the lines, marks, and transitions of the [Pg 193] countenance. His moral powers and desires, his irritability, sympathy, and antipathy, his facility of attracting or repelling the objects that surround him—these are all summed up in, and painted upon, his countenance when at rest.

Not only do mental and moral traits evince themselves in the physiognomy, but also health and sickness; and I believe that by repeatedly examining the firm parts and outlines of the bodies and countenances of the sick, disease might be diagnosed, and even that liability to disease might be predicted in particular cases.

The same vital powers that make the heart beat and the fingers move, roof the skull and arch the finger-nails. From the head to the back, from the shoulder to the arm, from the arm to the hand, from the hand to the finger, each depends on the other, and all on a determinate effect of a determinate power. Through all nature each determinate power is productive of only such and such determinate effects. The finger of one body is not adapted to the hand of another body. The blood in the extremity of the finger has the character of the blood in the heart. The same congeniality is found in the nerves and in the bones. One spirit lives in all. Each member of the body, too, is in proportion to the whole of which it is a part. As from the length of the smallest member, the smallest joint of the finger, the proportion of the whole, the length and breadth of the body may be found; so also may the form of the whole be found from the form of each single part. When the head is long, all is long; when the head is round, all is round; when the head is square, all is square.

One form, one mind, one root appertain to all. Each organised body is so much a whole that, without discord, destruction, or deformity, nothing can be added or subtracted. Those, therefore, who maintain that conclusion cannot be drawn from a part to the whole labour [Pg 194] under error, failing to comprehend the harmony of nature.

II.—Physiognomy and the Features

The Forehead. The form, height, arching, proportion, obliquity, and position of the skull, or bone of the forehead, show the propensity of thought, power of thought, and sensibility of man. The position, colour, wrinkles, tension of the skin of the forehead, show the passions and present state of the mind. The bones indicate the power, the skin the application of power.

I consider the outline and position of the forehead to be the most important feature in physiognomy. We may divide foreheads into three principal classes—the retreating, the perpendicular, and the projecting, and each of these classes has a multitude of variations.

A few facts with respect to foreheads may now be given.

The higher the forehead, the more comprehension and the less activity.

The more compressed, short, and firm the forehead, the more compression and firmness, and the less volatility in the man.

The more curved and cornerless the outline, the more tender and flexible the character; and the more rectilinear, the more pertinacious and severe the character.

Perfect perpendicularity implies lack of understanding, but gently arched at top, capacity for cold, tranquil, profound thought.

A projecting forehead indicates imbecility, immaturity, weakness, stupidity.

A retreating forehead, in general, denotes superior imagination, wit, acuteness.

A forehead round and prominent above, straight below, and, on the whole, perpendicular, shows much understanding, life, sensibility, ardour.

An oblique, rectilinear forehead is ardent and vigorous. [Pg 195]

Arched foreheads appear properly to be feminine.

A forehead neither too perpendicular nor too retreating, but a happy mean, indicates the post-perfect character of wisdom.

I might also state it as an axiom that straight lines considered as such, and curves considered as such, are related as power and weakness, obstinacy and flexibility, understanding and sensation.

I have seen no man with sharp, projecting eyebones who was not inclined to vigorous thinking and wise planning.

Yet, even lacking sharpness, a head may be excellent if the forehead sink like a perpendicular wall upon horizontal eyebrows, and be greatly rounded towards the temples.

Perpendicular foreheads, projecting so as not to rest immediately upon the nose, and small, wrinkled, short, and shining, indicate little imagination, little understanding, little sensation.

Foreheads with many angular, knotty protuberances denote perseverance and much vigorous, firm, harsh, oppressive, ardent activity.

It is a sure sign of a clear, sound understanding and a good temperament when the profile of the forehead has two proportionate arches, the lower of which projects.

Eyebones with well-marked, firm arches I never saw but in noble and great men.

Square foreheads with extensive temples and firm eyebones show circumspection and steadiness of character.

Perpendicular wrinkles, if natural, denote application and power. Horizontal wrinkles and those broken in the middle or at the extremities generally denote negligence or want of power.

Perpendicular, deep indentings in the forehead between the eyebrows, I never met save in men of sound understanding and free and noble minds, unless there were some positively contradictory feature. [Pg 196]

A blue frontal vein, in the form of a Y, when in an open, smooth, well-arched forehead, I have only found in men of extraordinary talents and of ardent and generous character.

The following are the traits of a perfectly beautiful, intelligent, and noble forehead.

In length it must equal the nose, or the under part of the face. In breadth it must be either oval at the top-like the foreheads of most of the great men of England—or nearly square. It must be free from unevenness and wrinkles, yet be able to wrinkle when deep in thought, afflicted by pain, or moved by indignation. It must retreat above and project beneath. The eyebones must be simple, horizontal, and, if seen from above, must present a simple curve. There should be a small cavity in the centre, from above to below, and traversing the forehead so as to separate it into four divisions perceptible in a clear descending light. The skin must be more clear on the forehead than in other parts of the countenance.

Foreheads short, wrinkled, and knotty, are incapable of durable friendship.

Be not discouraged though a friend, an enemy, a child, or a brother transgress, for so long as he have a good, well-proportioned, open forehead there is still hope of improvement.

The Eyes and Eyebrows. Blue eyes are generally more indicative of weakness and effeminacy than brown or black. Certainly there are many powerful men with blue eyes, but I find more strength, manhood, thought with brown.

Choleric men have eyes of every colour, but rather brown or greenish than blue. A propensity to green is an almost decisive token of ardour, fire, and courage.

Wide open eyes, with the white visible, I have often observed both in the timid and phlegmatic, and in the courageous and rash. [Pg 197]

Meeting eyebrows were supposed to be the mark of craft, but I do not believe them to have this significance. Angular, strong, interrupted eyebrows denote fire and productive activity. The nearer the eyebrows to the eyes, the more earnest, deep, and firm the character. Eyebrows remote from each other denote warm, open, quick sensations. White eyebrows signify weakness; and dark brown, firmness. The motion of the eyebrows contains numerous expressions, especially of ignoble passions.

The Nose. I have generally considered the nose the foundation or abutment of the brain, for upon this the whole power of the arch of the forehead rests. A beautiful nose will never be found accompanying an ugly countenance. An ugly person may have fine eyes, but not a handsome nose.

I have never seen a nose with a broad back, whether arched or rectilinear, that did not belong to an extraordinary man. Such a nose was possessed by Swift, Cæsar Borgia, Titian, etc. Small nostrils are usually an indubitable sign of unenterprising timidity. The open, breathing nostril is as certain a token of sensibility.

The Mouth and Lips. The contents of the mind are communicated to the mouth. How full of character is the mouth! As are the lips, so is the character. Firm lips, firm character; weak lips, weak character. Well-defined, large, and proportionate lips, the middle line of which is equally serpentine on both sides, and easy to be drawn, are never seen in a bad, mean, common, false, vicious countenance. A lipless mouth, resembling a single line, denotes coldness, industry, a love of order, precision, house-wifery, and, if it be drawn upwards at the two ends, affectation, pretension, vanity, malice. Very fleshy lips have always to contend with sensuality and indolence. Calm lips, well closed, without constraint, [Pg 198] and well delineated, certainly betoken consideration, discretion, and firmness. Openness of mouth speaks complaint, and closeness, endurance.

The Chin. From numerous experiments, I am convinced that the projecting chin ever denotes something positive, and the retreating something negative. The presence or absence of strength in man is often signified by the chin.

I have never seen sharp indentings in the middle of the chin save in men of cool understanding, unless when something evidently contradictory appeared in the countenance. The soft, fat, double chin generally points out the epicure; and the angular chin is seldom found save in discreet, well-disposed, firm men. Flatness of chin speaks the cold and dry; smallness, fear; and roundness, with a dimple, benevolence.

Skulls. HOW much may the anatomist see in the mere skull of man! How much more the physiognomist! And how much more still the anatomist who is a physiognomist! If shown the bald head of Cæsar, as painted by Rubens or Titian or Michael Angelo, what man would fail to notice the rocky capacity which characterises it, and to realise that more ardour and energy must be expected than from a smooth, round, flat head? How characteristic is the skull of Charles XII.! How different from the skull of his biographer Voltaire! Compare the skull of Judas with the skull of Christ, after Holbein, and I doubt whether anyone would fail to guess which is the skull of the wicked betrayer and which the skull of the innocent betrayed. And who is unacquainted with the statement in Herodotus that it was possible on the field of battle to distinguish the skulls of the effeminate Medes from the skulls of the manly Persians? Each nation, indeed, has its own characteristic skull.

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III.—Nation, Sex, and Family

National Physiognomy. It is undeniable that there is a national physiognomy as well as national character. Compare a negro and an Englishman, a native of Lapland and an Italian, a Frenchman and an inhabitant of Tierra del Fuego. Examine their forms, countenances, characters, and minds. This difference will be easily seen, though it will sometimes be very difficult to describe it scientifically.

The following infinitely little is what I have hitherto observed in the foreigners with whom I have conversed.

I am least able to characterise the French, They have no traits so bold as the English, nor so minute as the Germans. I know them chiefly by their teeth and their laugh. The Italians I discover by the nose, small eyes, and projecting chin. The English by their foreheads and eyebrows. The Dutch by the rotundity of their heads and the weakness of the hair. The Germans by the angles and wrinkles round the eyes and in the cheeks. The Russians by the snub nose and their light-coloured or black hair.

I shall now say a word concerning Englishmen in particular. Englishmen have the shortest and best-arched foreheads—that is to say, they are arched only upwards, and, towards the eyebrows, either gently recline or are rectilinear. They seldom have pointed, usually round, full noses. Their lips are usually large, well defined, beautifully curved. Their chins are round and full. The outline of their faces is in general large, and they never have those numerous angles and wrinkles by which the Germans are so especially distinguished. Their complexion is fairer than that of the Germans.

All Englishwomen whom I have known personally, or by portrait, appear to be composed of marrow and nerve. They are inclined to be tall, slender, soft, and as distant from all that is harsh, rigorous, or stubborn as heaven is from earth. [Pg 200]

The Swiss have generally no common physiognomy or national character, the aspect of fidelity excepted. They are as different from each other as nations the most remote.

The Physiognomical Relation of the Sexes. Generally speaking, how much more pure, tender, delicate, irritable, affectionate, flexible, and patient is woman than man. The primary matter of which woman is constituted appears to account for this difference. All her organs are tender, yielding, easily wounded, sensible, and receptive; they are made for maternity and affection. Among a thousand women, there is hardly one without these feminine characteristics.

This tenderness and sensibility, the light texture of their fibres and organs, render them easy to tempt and to subdue, and yet their charms are more potent than the strength of man. Truly sensible of purity, beauty and symmetry, woman does not always take time to reflect on spiritual life, spiritual death, spiritual corruption.

The woman does not think profoundly; profound thought is the prerogative of the man; but women feel more. They rule with tender looks, tears, and sighs, but not with passion and threats, unless they are monstrosities. They are capable of the sweetest sensibility, the deepest emotion, the utmost humility, and ardent enthusiasm. In their faces are signs of sanctity which every man honours.

Owing to their extreme sensibility and their incapacity for accurate inquiry and firm decision, they may easily become fanatics.

The love of women, strong as it is, is very changeable; but their hatred is almost incurable, and is only to be overcome by persistent and artful flattery. Men usually see things as a whole, whereas women take more interest in details.

Women have less physical courage than men. Man hears the bursting thunders, views the destructive bolt with serene aspect, and stands erect amid the fearful majesty of the torrent. But woman trembles at the lightning and thunder, and seeks refuge in the arms of man. [Pg 201]

Woman is formed for pity and religion; and a woman without religion is monstrous; and a woman who is a freethinker is more disgusting than a woman with a beard.

Woman is not a foundation on which to build. She is the gold, silver, precious stones, wood, hay, stubble—the materials for building on the male foundation. She is the leaven, or, more expressly, she is oil to the vinegar of man. Man singly is but half a man, only half human—a king without a kingdom. Woman must rest upon the man, and man can be what he ought to be only in conjunction with the woman.

Some of the principal physiognomical contrasts may be summarised here.

Man is the most firm; woman the most flexible.

Man is the straightest; woman the most bending.

Man stands steadfast; woman gently retreats.

Man surveys and observes; woman glances and feels.

Man is serious; woman is gay.

Man is the tallest and broadest; woman the smallest and weakest.

Man is rough and hard; woman is smooth and soft.

Man is brown; woman is fair.

The hair of the man is strong and short; the hair of woman is pliant and long.

Man has most straight lines; woman most curved.

The countenance of man, taken in profile, is not so often perpendicular as that of woman.

FAMILY PHYSIOGNOMY. The resemblance between parents and children is very commonly remarkable. Family physiognomical resemblance is as undeniable as national physiognomical resemblance. To doubt this is to doubt what is self-evident. [Pg 202]

When children, as they increase in years, visibly increase in their physical resemblance to their parents, we cannot doubt that resemblance in character also increases. Howsoever much the character of children may seem to differ from that of their parents, yet this difference will be found to be due to great difference in external circumstances.

JUSTUS VON LIEBIG [Pg 203]

Animal Chemistry

Baron Freiherr Justus von Liebig, one of the most illustrious chemists of his age, was born on May 12, 1803, at Darmstadt, Germany, the son of a drysalter. It was in his father's business that his interest in chemistry first awoke, and at fifteen he became an apothecary's assistant. Subsequently, he went to Erlangen, where he took his doctorate in 1822; and afterwards, in Paris, was admitted to the laboratory of Gay-Lussac as a private pupil. In 1824 he was appointed a teacher of chemistry in the University of Giessen in his native state. Here he lived for twenty-eight years a quiet life of incessant industry, while his fame spread throughout Europe. In 1845 he was raised to the hereditary rank of baron, and seven years later was appointed by the Bavarian government to the professorship of chemistry in the University of Munich. Here he died on April 18, 1873. The treatise on "Animal Chemistry, or Organic Chemistry in its Relations to Physiology and Pathology," published in 1842, sums up the results of Liebig's investigations into the immediate products of animal life. He was the first to demonstrate that the only source of animal heat is that produced by the oxidation of the tissues.

I.—Chemical Needs of Life

Animals, unlike plants, require highly organised atoms for nutriment; they can subsist only upon parts of an organism. All parts of the animal body are produced from the fluid circulating within its organism. A destruction of the animal body is constantly proceeding, every motion is the result of a transformation of its structure; every thought, every sensation is accompanied by a change in the composition of the substance of the brain. Food is applied either in the increase of the mass of a structure (nutrition) or in the replacement of a structure wasted (reproduction).

Equally important is the continual absorption of oxygen from the atmosphere. All vital activity results from the mutual action of the oxygen of the atmosphere and the elements of food. According to Lavoisier, an adult man takes into his system every year 827 lb. of oxygen, and yet he does not increase in weight. What, then, becomes of this oxygen?—for no part of it is again expired as oxygen. The carbon and hydrogen of certain parts of the body have entered into combination with the oxygen introduced through the lungs and through the skin, and have been given out in the form of carbonic acid and the vapour of water. [Pg 204]

Now, an adult inspires 32½ oz. of oxygen daily; this will convert the carbon of 24 lb. of blood (80 per cent. water) into carbonic acid. He must, therefore, take as much nutriment as will supply the daily loss. And, in fact, it is found that he does so; for the average amount of carbon in the daily food of an adult man is 14 oz., which requires 37 oz. of oxygen for its conversion into carbonic acid. The amount of food necessary for the support of the animal body must be in direct ratio to the quantity of oxygen taken into the system. A bird deprived of food dies on the third day; while a serpent, which inspires a mere trace of oxygen, can live without food for three months. The number of respirations is less in a state of rest than in exercise, and the amount of food necessary in both conditions must vary also.

The capacity of the chest being a constant quantity, we inspire the same volume of air whether at the pole or at the equator; but the weight of air, and consequently of oxygen, varies with the temperature. Thus, an adult man takes into the system daily 46,000 cubic inches of oxygen, which, if the temperature be 77° F., weighs 32½ oz., but when the temperature sinks to freezing-point will weigh 35 oz. It is obvious, also, that in an equal number of respirations we consume more oxygen at the level of the sea than on a mountain. The quantity of oxygen inspired and carbonic acid expired must, therefore, vary with the [Pg 205] height of the barometer. In our climate the difference between summer and winter in the carbon expired, and therefore necessary for food, is as much as one-eighth.

II.—The Cause of Animal Heat

Now, the mutual action between the elements of food and the oxygen of the air is the source of animal heat.

This heat is wholly due to the combustion of the carbon and hydrogen in the food consumed. Animal heat exists only in those parts of the body through which arterial blood (and with it oxygen in solution) circulates; hair, wool, or feathers, do not possess an elevated temperature.

As animal heat depends upon respired oxygen, it will vary according to the respiratory apparatus of the animal. Thus the temperature of a child is 102° F., while that of an adult is 99½° F. That of birds is higher than that of quadrupeds or that of fishes or amphibia, whose proper temperature is 3° F higher than the medium in which they live. All animals, strictly speaking, are warm-blooded; but in those only which possess lungs is their temperature quite independent of the surrounding medium. The temperature of the human body is the same in the torrid as in the frigid zone; but the colder the surrounding medium the greater the quantity of fuel necessary to maintain its heat.

The human body may be aptly compared to the furnace of a laboratory destined to effect certain operations. It signifies nothing what intermediate forms the food, or fuel, of the furnace may assume; it is finally converted into carbonic acid and water. But in order to sustain a fixed temperature in the furnace we must vary the quantity of fuel according to the external temperature.

In the animal body the food is the fuel; with a proper supply of oxygen we obtain the heat [Pg 206] given out during its oxidation or combustion. In winter, when we take exercise in a cold atmosphere, and when consequently the amount of inspired oxygen increases, the necessity for food containing carbon and hydrogen increases in the same ratio; and by gratifying the appetite thus excited, we obtain the most efficient protection against the most piercing cold. A starving man is soon frozen to death; and everyone knows that the animals of prey in the Arctic regions far exceed in voracity those in the torrid zone. In cold and temperate climates, the air, which incessantly strives to consume the body, urges man to laborious efforts in order to furnish the means of resistance to its action, while in hot climates the necessity of labour to provide food is far less urgent.

Our clothing is merely the equivalent for a certain amount of food.

The more warmly we are clothed the less food we require. If in hunting or fishing we were exposed to the same degree of cold as the Samoyedes we could with ease consume ten pounds of flesh, and perhaps half a dozen tallow candles into the bargain. The macaroni of the Italian, and the train oil of the Greenlander and the Russian, are fitted to administer to their comfort in the climate in which they have been born.

The whole process of respiration appears most clearly developed in the case of a man exposed to starvation. Currie mentions the case of an individual who was unable to swallow, and whose body lost 100 lb. in one month. The more fat an animal contains the longer will it be able to exist without food, for the fat will be consumed before the oxygen of the air acts upon the other parts of the body.

There are various causes by which force or motion may be produced. But in the animal body we recognise as the ultimate cause of all force only one cause, the chemical action which the elements of the food and the oxygen of the air mutually exercise on each other. [Pg 207] The only known ultimate cause of vital force, either in animals or in plants, is a chemical process. If this be prevented, the phenomena of life do not manifest themselves, or they cease to be recognisable by our senses. If the chemical action be impeded, the vital phenomena must take new forms.

The heat evolved by the combustion of carbon in the body is sufficient to account for all the phenomena of animal heat. The 14 oz. of carbon which in an adult are daily converted into carbonic acid disengage a quantity of heat which would convert 24 lb. of water, at the temperature of the body, into vapour. And if we assume that the quantity of water vaporised through the skin and lungs amounts to 3 lb., then we have still a large quantity of heat to sustain the temperature of the body.

III.—The Chemistry of Blood-Making

Physiologists conceive that the various organs in the body have originally been formed from blood. If this be admitted, it is obvious that those substances alone can be considered nutritious that are capable of being transformed into blood.

When blood is allowed to stand, it coagulates and separates into a watery fluid called serum, and into the clot, which consists principally of fibrine. These two bodies contain, in all, seven elements, among which sulphur, phosphorus, and nitrogen are found; they contain also the earth of bones. The serum holds in solution common salt and other salts of potash and soda, of which the acids are carbonic, phosphoric, and sulphuric acids. Serum, when heated, coagulates into a white mass called albumen. This substance, along with the fibrine and a red colouring matter in which iron is a constituent, constitute the globules of blood.

Analysis has shown that fibrine and albumen are perfectly identical in chemical composition. They may be mutually converted into each other. In the process of nutrition both may be converted into muscular fibre, and muscular fibre is capable of being reconverted into blood. [Pg 208]

All parts of the animal body which form parts of organs contain nitrogen. The principal ingredients of blood contain 17 per cent. of nitrogen, and there is no part of an active organ that contains less than 17 per cent. of this element.

The nutritive process is simplest in the case of the carnivora, for their nutriment is chemically identical in composition with their own tissues. The digestive apparatus of graminivorous animals is less simple, and their food contains very little nitrogen. From what constituents of vegetables is their blood produced?

Chemical researches have shown that all such parts of vegetables as can afford nutriment to animals contain certain constituents which are rich in nitrogen; and experience proves that animals require for their nutrition less of these parts of plants in proportion as they abound in the nitrogenised constituents. These important products are specially abundant in the seeds of the different kinds of grain, and of peas, beans, and lentils. They exist, however, in all plants, without exception, and in every part of plants in larger or smaller quantity. The nitrogenised compounds of vegetables are called vegetable fibrine, vegetable albumen, and vegetable casein. All other nitrogenised compounds occurring in plants are either rejected by animals or else they occur in the food in such very small proportion that they cannot possibly contribute to the increase of mass in the animal body.

The chemical analysis of these three substances has led to the interesting result that they contain the same organic elements, united in the same proportion by weight; and—which is more remarkable—that they are identical in composition with the chief constituents of blood—animal fibrine and animal albumen. By identity, be it remarked, is not here meant [Pg 209] merely similarity, but that even in regard to the presence and relative amounts of sulphur, phosphorus, and phosphate of lime no difference can be observed.

How beautifully simple then, by the aid of these discoveries, appears the process of nutrition in animals, the formation of their organs, in which vitality chiefly resides. Those vegetable constituents which are used by animals to form blood contain the essential ingredients of blood ready formed. In point of fact, vegetables produce in their organism the blood of all animals; for the carnivora, in consuming the blood and flesh of the graminivora, consume, strictly speaking, the vegetable principles which have served for the nourishment of the latter. In this sense we may say the animal organism gives to blood only its form; and, further, that it is incapable of forming blood out of other compounds which do not contain the chief ingredients of that fluid.

Animal and vegetable life are, therefore, closely related, for the first substance capable of affording nutriment to animals is the last product of the creative energy of vegetables. The seemingly miraculous in the nutritive power of vegetables disappears in a great degree, for the production of the constituents of blood cannot appear more surprising than the occurrence of the principal ingredient of butter in palm-oil and of horse-fat and train-oil in certain of the oily seeds.

IV.—Food the Fuel of Life

We have still to account for the use in food of substances which are destitute of nitrogen but are known to be necessary to animal life. Such substances are starch, sugar, gum, and pectine. In all of these we find a great excess of carbon, with oxygen and hydrogen in the same proportion as water. They therefore add an excess of carbon to the nitrogenised constituents of food, and they cannot possibly be employed in the production of blood, [Pg 210] because the nitrogenised compounds contained in the food already contain exactly the amount of carbon which is required for the production of fibrine and albumen. Now, it can be shown that very little of the excess of this carbon is ever expelled in the form either of solid or liquid compounds; it must be expelled, therefore, in the gaseous state. In short, these compounds are solely expended in the production of animal heat, being converted by the oxygen of the air into carbonic acid and water. The food of carnivorous animals does not contain non-nitrogenised matters, so that the carbon and hydrogen necessary for the production of animal heat are furnished in them from the waste of their tissues.

The transformed matters of the organs are obviously unfit for the further nourishment of the body—that is, for the increase or reproduction of the mass. They pass through the absorbent and lymphatic vessels into the veins, and their accumulation in these would soon put a stop to the nutritive process were it not that the blood has to pass through a filtering apparatus, as it were, before reaching the heart. The venous blood, before returning to the heart, is made to pass through the liver and the kidneys, which separate from it all substances incapable of contributing to nutrition. The new compounds containing the nitrogen of the transformed organs, being utterly incapable of further application in the system, are expelled from the body. Those which contain the carbon of the transformed tissues are collected in the gall-bladder as bile, a compound of soda which, being mixed with water, passes through the duodenum and mixes with chyme. All the soda of the bile, and ninety-nine-hundredths of the carbonaceous matter which it contains, retain the capacity of re-absorption by the absorbents of the small and large intestines—a capacity which has been proved by direct experiment.

The globules of the blood, which in themselves can be shown to take no share in the [Pg 211] nutritive process, serve to transport the oxygen which they give up in their passage through the capillary vessels. Here the current of oxygen meets with the carbonaceous substances of the transformed tissues, and converts their carbon into carbonic acid, their hydrogen into water. Every portion of these substances which escapes this process of oxidation is sent back into the circulation in the form of bile, which by degrees completely disappears.

It is obvious that in the system of the graminivora, whose food contains relatively so small a proportion of the constituents of blood, the process of metamorphosis in existing tissues, and consequently their restoration or reproduction, must go on far less rapidly than in the carnivora. Otherwise, a vegetation a thousand times as luxuriant would not suffice for their sustenance. Sugar, gum, and starch, which form so large a proportion of their food, would then be no longer necessary to support life in these animals, because in that case the products of waste, or metamorphosis of organised tissues, would contain enough carbon to support the respiratory process.

When exercise is denied to graminivorous and omnivorous animals this is tantamount to a deficient supply of oxygen. The carbon of the food, not meeting with a sufficient supply of oxygen to consume it, passes into other compounds containing a large excess of carbon—or, in other words, fat is produced. Fat is thus an abnormal production, resulting from a disproportion of carbon in the food to that of the oxygen respired by the lungs or absorbed by the skin. Wild animals in a state of nature do not contain fat. The production of fat is always a consequence of a deficient supply of oxygen, for oxygen is absolutely indispensable for the dissipation of excess of carbon in the food.

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V.—Animal Life-Chemistry

The substances of which the food of man is composed may be divided into two classes—into nitrogenised and non-nitrogenised. The former are capable of conversion into blood, the latter incapable of this transformation. Out of those substances which are adapted to the formation of blood are formed all the organised tissues. The other class of substances in the normal state of health serve to support the process of respiration. The former may be called the plastic elements of nutrition; the latter, elements of respiration.

Among the former we may reckon—vegetable fibrine, vegetable albumen, vegetable casein, animal flesh, animal blood.

Among the elements of respiration in our food are—fat, starch, gum, cane sugar, grape-sugar, sugar of milk, pectine, bassorine, wine, beer, spirits.

The nitrogenised constituents of vegetable food have a composition identical with that of the constituents of the blood.

No nitrogenised compound the composition of which differs from that of fibrine, albumen, and casein, is capable of supporting the vital process in animals.

The animal organism undoubtedly possesses the power of forming from the constituents of its blood the substance of its membranes and cellular tissue, of the nerves and brain, of the organic part of cartilages and bones. But the blood must be supplied to it ready in everything but its form—that is, in its chemical composition. If this is not done, a period is put to the formation of blood, and, consequently, to life.

The whole life of animals consists of a conflict between chemical forces and the vital power. In the normal state of the body of an adult these stand in equilibrium: that is, there is equilibrium between the manifestations of the causes of waste and the causes of supply. [Pg 213] Every mechanical or chemical agency which disturbs the restoration of this equilibrium is a cause of disease.

Death is that condition in which chemical or mechanical powers gain the ascendancy, and all resistance on the part of the vital force ceases. This resistance never entirely departs from living tissues during life. Such deficiency in resistance is, in fact, a deficiency in resistance to the action of the oxygen of the atmosphere.

Disease occurs when the sum of vital force, which tends to neutralise all causes of disturbance, is weaker than the acting cause of disturbance.

Should there be formed in the diseased parts, in consequence of the change of matter, from the elements of the blood or of the tissue, new products which the neighbouring parts cannot employ for their own vital functions; should the surrounding parts, moreover, be unable to convey these products to other parts where they may undergo transformation, then these new products will suffer, at the place where they have been formed, a process of decomposition analogous to putrefaction.

In certain cases, medicine removes these diseased conditions by exciting in the vicinity of the diseased part, or in any convenient situation, an artificial diseased state (as by blisters), thus diminishing by means of artificial disturbance the resistance offered to the external causes of change in these parts by the vital force. The physician succeeds in putting an end to the original diseased condition when the disturbance artificially excited (or the diminution of resistance in another part) exceeds in amount the diseased state to be overcome.

The accelerated change of matter and the elevated temperature in the diseased part show that the resistance offered by the vital force to the action of oxygen is feebler than in the healthy state. But this resistance only ceases entirely when death takes place. By the artificial diminution of resistance in another part, the resistance in the diseased organ is not, [Pg 214] indeed, directly strengthened; but the chemical action, the cause of the change of matter, is diminished in the diseased part, being directed to another part, where the physician has succeeded in producing a still more feeble resistance to the change of matter, to the action of oxygen.

SIR CHARLES LYELL [Pg 215]

The Principles of Geology

Sir Charles Lyell, the distinguished geologist, was born at Kinnordy, Forfarshire, Scotland, Nov. 14, 1797. It was at Oxford that his scientific interest was first aroused, and after taking an M.A. degree in 1821 he continued his scientific studies, becoming an active member of the Geological and Linnæan Societies of London. In 1826 he was elected a fellow of the Royal Society, and two years later went with Sir Roderick Murchison on a tour of Europe, and gathered evidence for the theory of geological uniformity which he afterwards promulgated. In 1830 he published his great work, "Principles of Geology: Being an Attempt to Explain the Former Changes of the Earth's Surface by References to Causes now in Action," which converted almost the whole geological world to the doctrine of uniformitarianism, and may be considered the foundation of modern geology. Lyell died in London on February 22, 1875. Besides his great work, he also published "The Elements of Geology," "The Antiquity of Man," "Travels in North America," and "The Student's Elements of Geology."

I.—Uniformity in Geological Development

ACCORDING to the speculations of some writers, there have been in the past history of the planet alternate periods of tranquillity and convulsion, the former enduring for ages, and resembling the state of things now experienced by man; the other brief, transient, and paroxysmal, giving rise to new mountains, seas, and valleys, annihilating one set of organic beings, and ushering in the creation of another. These theories, however, are not borne out by a fair interpretation of geological monuments; but, on the contrary, nature indicates no such cataclysms, but rather progressive uniformity.

Igneous rocks have been supposed to afford evidence of ancient paroxysms of nature, but we cannot consider igneous rocks proof of any exceptional paroxysms. Rather, we find [Pg 216] ourselves compelled to regard igneous rocks as an aggregate effect of innumerable eruptions, of various degrees of violence, at various times, and to consider mountain chains as the accumulative results of these eruptions. The incumbent crust of the earth is never allowed to attain that strength and coherence which would be necessary in order to allow the volcanic force to accumulate and form an explosive charge capable of producing a grand paroxysmal eruption. The subterranean power, on the contrary, displays, even in its most energetic efforts, an intermittent and mitigated intensity. There are no proofs that the igneous rocks were produced more abundantly at remote periods.

Nor can we find proof of catastrophic discontinuity when we examine fossil plants and fossil animals. On the contrary, we find a progressive development of organic life at successive geological periods.

In Palæozoic strata the entire want of plants of the most complex organisation is very striking, for not a single dicotyledonous angiosperm has yet been found, and only one undoubted monocotyledon. In Secondary, or Mesozoic, times, palms and some other monocotyledons appeared; but not till the Upper Cretaceous era do we meet with the principal classes and orders of the vegetable kingdom as now known. Through the Tertiary ages the forms were perpetually changing, but always becoming more and more like, generically and specifically, to those now in being. On the whole, therefore, we find progressive development of plant life in the course of the ages.

In the case of animal life, progression is equally evident. Palæontological research leads to the conclusion that the invertebrate animals flourished before the vertebrate, and that in the latter class fish, reptiles, birds, and mammalia made their appearance in a chronological order analogous to that in which they would be arranged zoologically according to an [Pg 217] advancing scale of perfection in their organisation. In regard to the mammalia themselves, they have been divided by Professor Owen into four sub-classes by reference to modifications of their brain. The two lowest are met with in the Secondary strata. The next in grade is found in Tertiary strata. And the highest of all, of which man is the sole representative, has not yet been detected in deposits older than the Post-Tertiary.

It is true that in passing from the older to the newer members of the Tertiary system we meet with many chasms, but none which separate entirely, by a broad line of demarcation, one state of the organic world from another. There are no signs of an abrupt termination of one fauna and flora, and the starting into life of new and wholly distinct forms. Although we are far from being able to demonstrate geologically an insensible transition from the Eocene to the Miocene, or even from the latter to the recent fauna, yet the more we enlarge and perfect our general survey the more nearly do we approximate to such a continuous series, and the more gradually are we conducted from times when many of the genera and nearly all the species were extinct to those in which scarcely a single species flourished which we do not know to exist at present. We must remember, too, that many gaps in animal and floral life were due to ordinary climatic and geological factors. We could, under no circumstances, expect to meet with a complete ascending series.

The great vicissitudes in climate which the earth undoubtedly experienced, as shown by geological records, have been held to be themselves proof of sudden violent revolutions in the life-history of the world. But all the great climatic vicissitudes can be accounted for by the action of factors still, in operation—subsidences and elevations of land, alterations in the relative proportions and position of land and water, variations in the relative position of [Pg 218] our planet to the sun and other heavenly bodies.

Altogether, the conclusion is inevitable that from the remotest period there has been one uniform and continuous system of change in the animate and inanimate world, and accordingly every fact collected respecting the factors at present at work in forming and changing the world, affords a key to the interpretation of its part. And thus, although we are mere sojourners on the surface of the planet, chained to a mere point in space, enduring but for a moment of time, the human mind is enabled not only to number worlds beyond the unassisted ken of mortal eye, but to trace the events of indefinite ages before the creation of our race, and to penetrate into the dark secrets of the ocean and the heart of the solid globe.

II.—Changes in the Inorganic World now in Progress

The great agents of change in the inorganic world may be divided into two principal classes—the aqueous and the igneous. To the aqueous belong rain, rivers, springs, currents, and tides, and the action of frost and snow; to the igneous, volcanoes and earthquakes. Both these classes are instruments of degradation as well as of reproduction. But they may also be regarded as antagonist forces, since the aqueous agents are incessantly labouring to reduce the inequalities of the earth's surface to a level; while the igneous are equally active in restoring the unevenness of the external crust, partly by heaping up new matter in certain localities, and partly by depressing one portion of the earth's envelope and forcing out another.

We will treat in the first place of the aqueous agents.

RAIN AND RIVERS. When one considers that in some parts of the world as much as 500 or 600 inches of rain may fall annually, it is easy to believe that rain *qua* rain may be a [Pg 219] denuding and plastic agent, and in some parts of the world we find evidence of its action in earth pillars or pyramids. The best example of earth pillars is seen near Botzen, in the Tyrol, where there are hundreds of columns of indurated mud, varying in height from 20 feet to 100 feet. These columns are usually capped by a single stone, and have been separated by rain from the terrace of which they once formed a part.

As a rule, however, rain acts through rivers. The power of rivers to denude and transport is exemplified daily. Even a comparatively small stream when swollen by rain may move rocks tons in weight, and may transport thousands of tons of gravel. The greatest damage is done when rivers are dammed by landslips or by ice. In 1818 the River Dranse was blocked by ice, and its upper part became a lake. In the hot season the barrier of ice gave way, and the torrent swept before it rocks, forests, houses, bridges, and cultivated land. For the greater part of its course the flood resembled a moving mass of rock and mud rather than of water. Some fragments of granite rock of enormous size, which might be compared to houses, were torn out and borne down for a quarter of a mile.

The rivers of unmelted ice called the glaciers act more slowly, but they also have the power of transporting gravel, sand, and boulders to great distances, and of polishing and scoring their rocky channels. Icebergs, too, are potent geological agents. Many of them are loaded with 50,000 to 100,000 tons of rock and earth, which they may carry great distances. Also in their course they must break, and polish, and scratch the peaks and points of submarine mountains.

Coast ice, likewise, may transport rocks and earth. Springs also must be considered as geological agents affecting the face of the globe.

But running water not only denudes it, but also creates land, for lakes, seas, rivers are seen to form deltas. That Egypt was the gift of the Nile was the opinion of the Egyptian priests, and there can be no doubt that the fertility of the alluvial plain above Cairo, and the very existence of the delta below that city, are due to the action of that great river, and to its power of transporting mud from the interior of Africa and depositing it on its inundated plains as well as on that space which has been reclaimed from the Mediterranean and converted into land. The delta of the Ganges and Brahmapootra is more than double that of the Nile. Even larger is the delta of the Mississippi, which has been calculated to be 12,300 square miles in area. [Pg 220]

Tides and Currents. The transporting and destroying and constructive power of tides and currents is, in many respects, analogous to that of rivers, but extends to wider areas, and is, therefore, of more geological importance. The chief influence of the ocean is exerted at moderate depths below the surface on all areas which are slowly rising, or attempting, as it were, to rise above the sea; but its influence is also seen round the coast of every continent and island.

We shall now consider the igneous agents that act on the earth's surface. These agents are chiefly volcanoes and earthquakes, and we find that both usually occur in particular parts of the world. At various times and at various places within historical times volcanic eruptions and earthquakes have both proved their potency to alter the face of the earth.

The principal geological facts and theories with regard to volcanoes and earthquakes are as follows.

The primary causes of the volcano and the earthquake are to a great extent the same, and connected with the development of heat and chemical action at various depths in the interior of the globe.

Volcanic heat has been supposed to be the result of the original high temperature of the molten planet, and the planet has been supposed to lose heat by radiation. Recent inquiries, however, suggest that the apparent loss of heat may arise from the excessive local development of volcanic action. [Pg 221]

Whatever the original shape of our planet, it must in time have become spheroidal by the gradual operation of centrifugal force acting on yielding materials brought successively within its action by aqueous and igneous causes.

The heat in mines and artesian wells increases as we descend, but not in uniform ratio in different regions. Increase at a uniform ratio would imply such heat in the central nucleus as must instantly fuse the crust.

Assuming that there are good astronomical grounds for inferring the original fluidity of the planet, yet such pristine fluidity need not affect the question of volcanic heat, for the volcanic action of successive periods belongs to a much more modern state of the globe, and implies the melting of different parts of the solid crust one after the other.

The supposed great energy of the volcanic forces in the remoter periods is by no means borne out by geological observations on the quantity of lava produced by single eruptions in those several periods.

The old notion that the crystalline rocks, whether stratified or unstratified, such as granite and gneiss, were produced in the lower parts of the earth's crust at the expense of a central nucleus slowly cooling from a state of fusion by heat has now had to be given up, now that granite is found to be of all ages, and now that we know the metamorphic rocks to be altered sedimentary strata, implying the denudation of a previously solidified crust.

The powerful agency of steam or aqueous vapour in volcanic eruptions leads us to compare its power of propelling lava to the surface with that which it exerts in driving water [Pg 222] up the pipe of an Icelandic geyser. Various gases also, rendered liquid by pressure at great depths, may aid in causing volcanic outbursts, and in fissuring and convulsing the rocks during earthquakes.

The chemical character of the products of recent eruptions suggests that large bodies of salt water gain access to the volcanic foci. Although this may not be the primary cause of volcanic eruptions, which are probably due to the aqueous vapour intimately mixed with molten rock, yet once the crust is shattered through, the force and frequency of eruptions may depend in some measure on the proximity of large bodies of water.

The permanent elevation and subsidence of land now observed, and which may have been going on through past ages, may be connected with the expansion and contraction of parts of the solid crust, some of which have been cooling from time to time, while others have been gaining heat.

In the preservation of the average proportion of land and sea, the igneous agents exert a conservative power, restoring the unevenness of the surface which the levelling power of water in motion would tend to destroy. If the diameter of the planet remains always the same, the downward movements of the crust must be somewhat in excess, to counterbalance the effects of volcanoes and mineral springs, which are always ejecting material so as to raise the level of the surface of the earth. Subterranean movements, therefore, however destructive they may be during great earthquakes, are essential to the well-being of the habitable surface, and even to the very existence of terrestrial and aquatic species.

III.—Changes of the Organic World now in Progress

In 1809 Lamarck introduced the idea of transmutation of species, suggesting that by changes in habitat, climate, and manner of living one species may, in the course of generations, be transformed into a new and distinct species. [Pg 223]

In England, however, the idea remained dormant till in 1844 a work entitled the "Vestiges of Creation" reinforced it with many new facts. In this work the unity of plan exhibited by the whole organic creation, fossil and recent, and the mutual affinities of all the different classes of the animal and vegetable kingdoms, were declared to be in harmony with the idea of new forms having proceeded from older ones by the gradually modifying influence of environment. In 1858 the theory was put on a new and sound basis by Wallace and Darwin, who added the conception of natural selection, suggesting that variations in species are naturally produced, and that the variety fittest to survive in the severe struggle for existence must survive, and transmit the advantageous variation, implying the gradual evolution of new species. Further, Darwin showed that other varieties may be perpetuated by sexual selection.

On investigating the geographical distribution of animals and plants we find that the extent to which the species of mammalia, birds, insects, landshells, and plants (whether flowering or cryptogamous) agree with continental species; or the degree in which those of different islands of the same group agree with each other has an unmistakable relation to the known facilities enjoyed by each class of crossing the ocean. Such a relationship accords well with the theory of variation and natural selection, but with no other hypothesis yet suggested for explaining the origin of species.

From what has been said of the changes which are always going on in the habitable surface of the world, and the manner in which some species are constantly extending their range at the expense of others, it is evident that the species existing at any particular period may, in the course of ages, become extinct one after the other.

If such, then, be the law of the organic world, if every species is continually losing some [Pg 224] of its varieties, and every genus some of its species, it follows that the transitional links which once, according to the doctrine of transmutation, must have existed, will, in the great majority of cases, be missing. We learn from geological investigations that throughout an indefinite lapse of ages the whole animate creation has been decimated again and again. Sometimes a single representative alone remains of a type once dominant, or of which the fossil species may be reckoned by hundreds. We rarely find that whole orders have disappeared, yet this is notably the case in the class of reptiles, which has lost some orders characterised by a higher organisation than any now surviving in that class. Certain genera of plants and animals which seem to have been wholly wanting, and others which were feebly represented in the Tertiary period, are now rich in species, and appear to be in such perfect harmony with the present conditions of existence that they present us with countless varieties, confounding the zoologist or botanist who undertakes to describe or classify them.

We have only to reflect on the causes of extinction, and we at once foresee the time when even in these genera so many gaps will occur, so many transitional forms will be lost, that there will no longer be any difficulty in assigning definite limits to each surviving species. The blending, therefore, of one generic or specific form into another must be an exception to the general rule, whether in our own time or in any period of the past, because the forms surviving at any given moment will have been exposed for a long succession of antecedent periods to those powerful causes of extinction which are slowly but incessantly at work in the organic and inorganic worlds.

They who imagine that, if the theory of transmutation be true, we ought to discover in a fossil state all the intermediate links by which the most dissimilar types have been formerly [Pg 225] connected together, expect a permanence and completeness of records such as is never found. We do not find even that all recently extinct plants have left memorials of their existence in the crust of the earth; and ancient archives are certainly extremely defective. To one who is aware of the extreme imperfection of the geological record, the discovery of one or two missing links is a fact of small significance; but each new form rescued from oblivion is an earnest of the former existence of hundreds of species, the greater part of which are irrevocably lost.

A somewhat serious cause of disquiet and alarm arises out of the supposed bearing of this doctrine of the origin of species by transmutation on the origin of man, and his place in nature. It is clearly seen that there is such a close affinity, such an identity in all essential points, in our corporeal structure, and in many of our instincts and passions with those of the lower animals—that man is so completely subjected to the same general laws of reproduction, increase, growth, disease, and death—that if progressive development, spontaneous variation, and natural selection have for millions of years directed the changes of the rest of the organic world, we cannot expect to find that the human race has been exempted from the same continuous process of evolution.

Such a near bond of connection between man and the rest of the animate creation is regarded by many as derogatory to our dignity. But we have already had to exchange the pleasing conceptions indulged in by poets and theologians as to the high position in the scale of being held by our early progenitors for humble and more lowly beginnings, the joint labours of the geologist and archæologist having left us in no doubt of the ignorance and barbarism of Palæolithic man.

It is well, too, to remember that the high place we have reached in the scale of being has been gained step by step, by a conscientious study of natural phenomena, and by fearlessly [Pg 226] teaching the doctrines to which they point. It is by faithfully weighing evidence without regard to preconceived notions, by earnestly and patiently searching for what is true, not what we wish to be true, that we have attained to that dignity, which we may in vain hope to claim through the rank of an ideal parentage.

JAMES CLERK MAXWELL [Pg 227]

A Treatise on Electricity and Magnetism

James Clerk Maxwell, the first professor of experimental physics at Cambridge, was born at Edinburgh on November 13, 1831, and before he was fifteen was already famous as a writer of scientific papers. In 1854 he graduated at Cambridge as second wrangler. Two years later he became professor of natural philosophy at Marischal College, Aberdeen. Vacating his chair in 1860 for one at King's College, London, Maxwell contributed largely to scientific literature. His great lifework, however, is his famous "Treatise on Electricity and Magnetism," which was published in 1873, and is, in the words of a critic, "one of the most splendid monuments ever raised by the genius of a single individual." It was in this work that he constructed his famous theory if electricity in which "action at a distance" should be replaced by "action through a medium," and first enunciated the principles of an electro-magnetic theory of light which has formed the basis of nearly all modern physical science. He died on November 5, 1879.

I.—The Nature of Electricity

LET a piece of glass and a piece of resin be rubbed together. They will be found to attract each other. If a second piece of glass be rubbed with a second piece of resin, it will be found that the two pieces of glass repel each other and that the two pieces of resin are also repelled from one another, while each piece of glass attracts each piece of resin. These phenomena of attraction and repulsion are called electrical phenomena, and the bodies which exhibit them are said to be "electrified," or to be "charged with electricity."

Bodies may be electrified in many other ways, as well as by friction. When bodies not previously electrified are observed to be acted on by an electrified body, it is because they have become "electrified by induction." If a metal vessel be electrified by induction, and a second metallic body be suspended by silk threads near it, and a metal wire be brought to [Pg 228] touch simultaneously the electrified body and the second body, this latter body will be found to be electrified. Electricity has been transferred from one body to the other by means of the wire.

There are many other manifestations of electricity, all of which have been more or less studied, and they lead to the formation of theories of its nature, theories which fit in, to a greater or less extent, with the observed facts. The electrification of a body is a physical quantity capable of measurement, and two or more electrifications can be combined experimentally with a result of the same kind as when two quantities are added algebraically. We, therefore, are entitled to use language fitted to deal with electrification as a quantity as well as a quality, and to speak of any electrified body as "charged with a certain quantity of positive or negative electricity."

While admitting electricity to the rank of a physical quantity, we must not too hastily assume that it is, or is not, a substance, or that it is, or is not, a form of energy, or that it belongs to any known category of physical quantities. All that we have proved is that it cannot be created or annihilated, so that if the total quantity of electricity within a closed surface is increased or diminished, the increase or diminution must have passed in or out through the closed surface.

This is true of matter, but it is not true of heat, for heat may be increased or diminished within a closed surface, without passing in or out through the surface, by the transformation of some form of energy into heat, or of heat into some other form of energy. It is not true even of energy in general if we admit the immediate action of bodies at a distance.

There is, however, another reason which warrants us in asserting that electricity, as a physical quantity, synonymous with the total electrification of a body, is not, like heat, a [Pg 229] form of energy. An electrified system has a certain amount of energy, and this energy can be calculated. The physical qualities, "electricity" and "potential," when multiplied together, produce the quantity, "energy." It is impossible, therefore, that electricity and energy should be quantities of the same category, for electricity is only one of the factors of energy, the other factor being "potential."

Electricity is treated as a substance in most theories of the subject, but as there are two kinds of electrification, which, being combined, annul each other, a distinction has to be drawn between free electricity and combined electricity, for we cannot conceive of two substances annulling each other. In the two-fluid theory, all bodies, in their unelectrified state, are supposed to be charged with equal quantities of positive and negative electricity. These quantities are supposed to be so great than no process of electrification has ever yet deprived a body of all the electricity of either kind. The two electricities are called "fluids" because they are capable of being transferred from one body to another, and are, within conducting bodies, extremely mobile.

In the one-fluid theory everything is the same as in the theory of two fluids, except that, instead of supposing the two substances equal and opposite in all respects, one of them, generally the negative one, has been endowed with the properties and name of ordinary matter, while the other retains the name of the electric fluid. The particles of the fluid are supposed to repel each other according to the law of the inverse square of the distance, and to attract those of matter according to the same law. Those of matter are supposed to repel each other and attract those of electricity. This theory requires us, however, to suppose the mass of the electric fluid so small that no attainable positive or negative electrification has yet perceptibly increased or diminished the mass or the weight of a body, and it has not yet been able to assign sufficient reasons why the positive rather than the negative [Pg 230] electrification should be supposed due to an *excess* quantity of electricity.

For my own part, I look for additional light on the nature of electricity from a study of what takes place in the space intervening between the electrified bodies. Some of the phenomena are explained equally by all the theories, while others merely indicate the peculiar difficulties of each theory. We may conceive the relation into which the electrified bodies are thrown, either as the result of the state of the intervening medium, or as the result of a direct action between the electrified bodies at a distance. If we adopt the latter conception, we may determine the law of the action, but we can go no further in speculating on its cause.

If, on the other hand, we adopt the conception of action through a medium, we are led to inquire into the nature of that action in each part of the medium. If we calculate on this hypothesis the total energy residing in the medium, we shall find it equal to the energy due to the electrification of the conductors on the hypothesis of direct action at a distance. Hence, the two hypotheses are mathematically equivalent.

On the hypothesis that the mechanical action observed between electrified bodies is exerted through and by means of the medium, as the action of one body on another by means of the tension of a rope or the pressure of a rod, we find that the medium must be in a state of mechanical stress. The nature of the stress is, as Faraday pointed out, a tension along the lines of force combined with an equal pressure in all directions at right angles to these lines. This distribution of stress is the only one consistent with the observed mechanical action on the electrified bodies, and also with the observed equilibrium of the fluid dielectric which surrounds them. I have, therefore, assumed the actual existence of this state of stress.

Every case of electrification or discharge may be considered as a motion in a closed circuit, such that at every section of the circuit the same quantity of electricity crosses in the same time; and this is the case, not only in the voltaic current, where it has always been recognised, but in those cases in which electricity has been generally supposed to be accumulated in certain places. We are thus led to a very remarkable consequence of the theory which we are examining, namely, that the motions of electricity are like those of an *incompressible* fluid, so that the total quantity within an imaginary fixed closed surface remains always the same. [Pg 231]

The peculiar features of the theory as developed in this book are as follows.

That the energy of electrification resides in the dielectric medium, whether that medium be solid or gaseous, dense or rare, or even deprived of ordinary gross matter, provided that it be still capable of transmitting electrical action.

That the energy in any part of the medium is stored up in the form of a constraint called polarisation, dependent on the resultant electromotive force (the difference of potentials between two conductors) at the place.

That electromotive force acting on a dielectric produces what we call electric displacement.

That in fluid dielectrics the electric polarisation is accompanied by a tension in the direction of the lines of force combined with an equal pressure in all directions at right angles to the lines of force.

That the surfaces of any elementary portion into which we may conceive the volume of the dielectric divided must be conceived to be electrified, so that the surface density at any point of the surface is equal in magnitude to the displacement through that point of the surface *reckoned inwards*.

That, whatever electricity may be, the phenomena which we have called electric displacement is a movement of electricity in the same sense as the transference of a definite quantity of electricity through a wire. [Pg 232]

II.—Theories of Magnetism

Certain bodies—as, for instance, the iron ore called loadstone, the earth itself, and pieces of steel which have been subjected to certain treatment—are found to possess the following properties, and are called magnets.

If a magnet be suspended so as to turn freely about a vertical axis, it will in general tend to set itself in a certain azimuth, and, if disturbed from this position, it will oscillate about it.

It is found that the force which acts on the body tends to cause a certain line in the body—called the axis of the magnet—to become parallel to a certain line in space, called the "direction of the magnetic force."

The ends of a long thin magnet are commonly called its poles, and like poles repel each other; while unlike poles attract each other. The repulsion between the two magnetic poles is in the straight line joining them, and is numerically equal to the products of the strength of the poles divided by the square of the distance between them; that is, it varies as the inverse square of the distance. Since the form of the law of magnetic action is identical with that of electric action, the same reasons which can be given for attributing electric phenomena to the action of one "fluid," or two "fluids" can also be used in favour of the existence of a magnetic matter, fluid or otherwise, provided new laws are introduced to account for the actual facts.

At all parts of the earth's surface, except some parts of the polar regions, one end of a magnet points in a northerly direction and the other in a southerly one. Now a bar of iron held parallel to the direction of the earth's magnetic force is found to become magnetic. Any piece of soft iron placed in a magnetic field is found to exhibit magnetic properties. These [Pg 233] are phenomena of *induced* magnetism. Poisson supposes the magnetism of iron to consist in a separation of the magnetic fluids within each magnetic molecule. Weber's theory differs from this in assuming that the molecules of the iron are always magnets, even before the application of the magnetising force, but that in ordinary iron the magnetic axes of the molecules are turned indifferently in every direction, so that the iron as a whole exhibits no magnetic properties; and this theory agrees very well with what is observed.

The theories establish the fact that magnetisation is a phenomenon, not of large masses of iron, but of molecules; that is to say, of portions of the substance so small that we cannot by any mechanical method cut them in two, so as to obtain a north pole separate from the south pole. We have arrived at no explanation, however, of the nature of a magnetic molecule, and we have therefore to consider the hypothesis of Ampère—that the magnetism of the molecule is due to an electric current constantly circulating in some closed path within it.

Ampère concluded that if magnetism is to be explained by means of electric currents, these currents must circulate within the molecules of the magnet, and cannot flow from one molecule to another. As we cannot experimentally measure the magnetic action at a point within the molecule, this hypothesis cannot be disproved in the same way that we can disprove the hypothesis of sensible currents within the magnet. In spite of its apparent complexity, Ampère's theory greatly extends our mathematical vision into the interior of the molecules.

III.—The Electro-Magnetic Theory of Light

We explain electro-magnetic phenomena by means of mechanical action transmitted from one body to another by means of a medium occupying the space between them. The [Pg 234] undulatory theory of light also assumes the existence of a medium. We have to show that the properties of the electro-magnetic medium are identical with those of the luminiferous medium.

To fill all space with a new medium whenever any new phenomena are to be explained is by no means philosophical, but if the study of two different branches of science has independently suggested the idea of a medium; and if the properties which must be attributed to the medium in order to account for electro-magnetic phenomena are of the same kind as those which we attribute to the luminiferous medium in order to account for the phenomena of light, the evidence for the physical existence of the medium is considerably strengthened.

According to the theory of emission, the transmission of light energy is effected by the actual transference of light-corpuscles from the luminous to the illuminated body. According to the theory of undulation there is a material medium which fills the space between the two bodies, and it is by the action of contiguous parts of this medium that the energy is passed on, from one portion to the next, till it reaches the illuminated body. The luminiferous medium is therefore, during the passage of light through it, a receptacle of energy. This energy is supposed to be partly potential and partly kinetic, and our theory agrees with the undulatory theory in assuming the existence of a medium capable of becoming a receptacle for two forms of energy.

Now, the properties of bodies are capable of quantitative measurement. We therefore obtain the numerical value of some property of the medium—such as the velocity with which a disturbance is propagated in it, which can be calculated from experiments, and also observed directly in the case of light. If it be found that the velocity of propagation of electro-magnetic disturbance is the same as the velocity of light, we have strong reasons for [Pg 235] believing that light is an electro-magnetic phenomenon.

It is, in fact, found that the velocity of light and the velocity of propagation of electro-magnetic disturbance are quantities of the same order of magnitude. Neither of them can be said to have been determined accurately enough to say that one is greater than the other. In the meantime, our theory asserts that the quantities are equal, and assigns a physical reason for this equality, and it is not contradicted by the comparison of the results, such as they are.

Lorenz has deduced from Kirchoff's equations of electric currents a new set of equations, indicating that the distribution of force in the electro-magnetic field may be considered as arising from the mutual action of contiguous elements, and that waves, consisting of transverse electric currents, may be propagated, with a velocity comparable with that of light, in non-conducting media. These conclusions are similar to my own, though obtained by an entirely different method.

The most important step in establishing a relation between electric and magnetic phenomena and those of light must be the discovery of some instance in which one set of phenomena is affected by the other. Faraday succeeded in establishing such a relation, and the experiments by which he did so are described in the nineteen series of his "Experimental Researches." Suffice it to state here that he showed that in the case of aray of plane-polarised light the effect of the magnetic force is to turn the plane of polarisation round the direction of the ray as an axis, through a certain angle.

The action of magnetism on polarised light leads to the conclusion that in a medium under the action of a magnetic force, something belonging to the same mathematical class as an angular velocity, whose axis is in the direction of the magnetic force, forms part of the phenomenon. This angular velocity cannot be any portion of the medium of sensible [Pg 236] dimensions rotating as a whole. We must, therefore, conceive the rotation to be that of very small portions of the medium, each rotating on its own axis.

This is the hypothesis of molecular vortices. The displacements of the medium during the propagation of light will produce a disturbance of the vortices, and the vortices, when so disturbed, may react on the medium so as to affect the propagation of the ray. The theory proposed is of a provisional kind, resting as it does on unproved hypotheses relating to the nature of molecular vortices, and the mode in which they are affected by the displacement of the medium.

IV.—Action at a Distance

There appears to be some prejudice, or *a priori* objection, against the hypothesis of a medium in which the phenomena of radiation of light and heat, and the electric actions at a distance, take place. It is true that at one time those who speculated as to the cause of physical phenomena were in the habit of accounting for each kind of action at a distance by means of a special æthereal fluid, whose function and property it was to produce these actions. They filled all space three and four times over with æthers of different kinds, the properties of which consisted merely to "save appearances," so that more rational inquirers were willing to accept not only Newton's definite law of attraction at a distance, but even the dogma of Cotes that action at a distance is one of the primary properties of matter, and that no explanation can be more intelligible than this fact. Hence the undulatory theory of light has met with much opposition, directed not against its failure to explain the phenomena, but against its assumption of the existence of a medium in which light is propagated.

The mathematical expression for electro-dynamic action led, in the mind of Gauss, to the conviction that a theory of the propagation of electric action would in time be found to be the very keystone of electro-dynamics. Now, we are unable to conceive of propagation in time, except either as the flight of a material substance through space or as the propagation of a condition of motion or stress in a medium already existing in space. [Pg 237]

In the theory of Neumann, the mathematical conception called potential, which we are unable to conceive as a material substance, is supposed to be projected from one particle to another, in a manner which is quite independent of a medium, and which, as Neumann has himself pointed out, is extremely different from that of the propagation of light. In other theories it would appear that the action is supposed to be propagated in a manner somewhat more similar to that of light.

But in all these theories the question naturally occurs: "If something is transmitted from one particle to another at a distance, what is its condition after it had left the one particle, and before it reached the other?" If this something is the potential energy of the two particles, as in Neumann's theory, how are we to conceive this energy as existing in a point of space coinciding neither with the one particle nor with the other? In fact, whenever energy is transmitted from one body to another in time, there must be a medium or substance in which the energy exists after it leaves one body, and before it reaches the other, for energy, as Torricelli remarked, "is a quintessence of so subtile a nature that it cannot be contained in any vessel except the inmost substance of material things."

Hence all these theories lead to the conception of a medium in which the propagation takes place, and if we admit this medium as an hypothesis, I think we ought to endeavour to construct a mental representation of all the details of its action, and this has been my constant aim in this treatise.

ELIE METCHNIKOFF

[Pg 238]

The Nature of Man

Elie Metchnikoff, Sub-Director of the Pasteur Institute in Paris, was born May 15, 1845, in the province of Kharkov, Russia, and has worked at the Pasteur Institute since 1888. The greater part of Metchnikoff's work is concerned with the most intimate processes of the body, and notably the means by which it defends itself from the living agents of disease. He is, indeed, the author of a standard treatise entitled "Immunity in Infective Diseases." His early work in zoology led him to study the water-flea, and thence to discover that the white cells of the human blood oppose, consume, and destroy invading microbes. Latterly, Metchnikoff has devoted himself in some measure to more general and especially philosophical studies, the outcome of which is best represented by the notable volume on "The Nature of Man," which was published at Paris in 1903.

I.—Disharmonies in Nature

NOTWITHSTANDING the real advance made by science, it cannot be disputed that a general uneasiness disturbs the whole world to-day, and the frequency of suicide is increased greatly among civilised peoples. Yet if science turns to study human nature, there may be grounds for hope. The Greeks held human nature and the human body in high esteem, and among the Romans such a philosopher as Seneca said, "Take nature as your guide, for so reason bids you and advises you; to live happily is to live naturally." In our own day Herbert Spencer has expressed again the Greek ideal, seeking the foundation of morality in human nature itself.

But it has often been taught that human nature is composed of two hostile elements, a body and a soul. The soul alone was to be honoured, while the body was regarded as the vile source of evils. This doctrine has had many disastrous consequences, and it is not surprising that in consequence of it celibacy should have been regarded as the ideal state. [Pg 239] Art fell from the Greek ideal until the Renaissance, with its return to that ideal, brought new vigour. When the ancient spirit was born again its influence reached science and even religion, and the Reformation was a defence of human nature. The Lutheran doctrines resumed the principle of a "development as complete as possible of all the natural powers" of man, and compulsory celibacy was abolished.

The historical diversity of opinion regarding human nature is what has led me to the attempt to give an exposition of human nature in its strength and in its weakness. But, before dealing with the man himself, we must survey the lower forms of life.

The facts of the organised world, before the appearnace of man, teach us that though we find change and development, development does not always take a progressive march. We are bound to believe, for instance, that the latest products of evolution are not human beings, but certain parasites which live only upon, or in, the human body. The law in nature is not of constant progress, but of constant tendency towards adaptation. Exquisite adaptations, or harmonies, in nature are constantly met with in the world of living beings. But, on the other hand, any close investigation of organisation and life reveals that beside many most perfect harmonies, there are facts which prove the existence of incomplete harmony, or even absolute disharmony. Rudimentary and useless organs are widely distributed. Many insects are exquisitely adapted for sucking the nectar of flowers; many others would wish to do the same, but their want of adaptation baffles them.

It is plain that an instinct, or any other form of disharmony, leading to destruction, cannot increase or even endure very long. The perversion of the maternal instinct, tending to abandonment of the young, is destructive to the stock. In consequence, individuals affected by it do not have the opportunity of transmitting the perversion. If all rabbits, or a majority of them, left their young to die through neglect, it is evident that the species would soon die out. On the contrary, mothers guided by their instinct to nourish and foster their offspring will produce a vigorous generation capable of transmitting the healthy maternal instinct so essential for the preservation of the species. For such a reason harmonious characters are more abundant in nature than injurious peculiarities. The latter, because they are injurious to the individual and to the species, cannot perpetuate themselves indefinitely. [Pg 240]

In this way there comes about a constant selection of characters. The useful qualities are handed down and preserved, while noxious characters perish and so disappear. Although disharmonies tend to the destruction of a species, they may themselves disappear without having destroyed the race in which they occur.

This continuous process of natural selection, which offers so good an explanation of the transmutation and origin of species by means of preservation of useful and destruction of harmful characters, was discovered by Darwin and Wallace, and was established by the splendid researches of the former of these.

Long before the appearance of man on the face of the earth, there were some happy beings well adapted to their environment, and some unhappy creatures that followed disharmonious instincts so as to imperil or to destroy their lives. Were such creatures capable of reflection and communication, plainly the fortunate among them, such as orchids and certain wasps, would be on the side of the optimists; they would declare this the best of all possible worlds, and insist that to secure happiness it is necessary only to follow natural instincts. On the other hand, the disharmonious creatures, those ill adapted to the conditions of life, would be pessimistic philosophers. Consider the case of the ladybird, driven by hunger and with a preference for honey, which searches for it on flowers and meets only [Pg 241] with failure, or of insects driven by their instincts into the flames, only to lose their wings and their lives; such creatures, plainly, would express as their idea of the world that it was fashioned abominably, and that existence was a mistake.

II.—Disharmonies in Man

As for man, the creature most interesting to us, in what category does he fall? Is he a being whose nature is in harmony with the conditions in which he has to live, or is he out of harmony with his environment? A critical examination is needed to answer these questions, and to such an examination the pages to follow are devoted.

Science has proved that man is closely akin to the higher monkeys or anthropoid apes—a fact which we must reckon with if we are to understand human nature. The details of anatomy which show the kinship between man and the apes are numerous and astonishing. All the facts brought to light during the last forty years have supported this truth, and no single fact has been brought against it. Quite lately it has been shown that there are remarkable characters in the blood, such that, though by certain tests the fluid part of human blood can be readily distinguished from that of any other creature, the anthropoid apes, and they alone, furnish an exception to this rule. There is thus verily a close blood-relationship between the human species and the anthropoid apes.

But how man arose we do not know. It is probable that he owes his origin to a mutation—a sudden change comparable with that which De Vries observed in the case of the evening primrose. The new creature possessed a brain of abnormal size placed in a spacious cranium which allowed a rapid development of intellectual faculties. This peculiarity would be transmitted to the descendants, and as it was a very considerable advantage in the struggle [Pg 242] for existence, the new race would hold its own, propagate, and prevail.

Although he is a recent arrival on the earth, man has already made great progress, as compared with his ancestors the anthropoid apes, and we learn the same if we compare the higher and lower races of mankind. Yet there remain many disharmonies in the organisation of man, as, for instance, in his digestive system. A simple instance of this kind is furnished by the wisdom teeth. The complete absence of all four wisdom teeth has no influence on mastication, and their presence is very frequently the source of illness and danger. In man they are indeed rudimentary organs, providing another proof of our simian origin. The vermiform appendix, so frequently the cause of illness and death, is another rudimentary organ in the human body, together with the part of the digestive canal to which it is attached. The organ is a very old part of the constitution of mammals, and it is because it has been preserved long after its function has disappeared that we find it occurring in the body of man.

I believe that not only the appendix, but a very large part of the alimentary canal is superfluous, and worse than superfluous. It is, of course, of great importance to the horse, the rabbit, and some other mammals that live exclusively on grain and herbage. The latter part of the alimentary canal, however, must be regarded as one of the organs possessed by man and yet harmful to his health and life. It is the cause of a series of misfortunes. The human stomach also is of little value, and can easily be dispensed with, as surgery has proved. It is because we inherit our alimentary canal from creatures of different dietetic habits that it is impossible for us to take our nutriment in the most perfect form. If we were only to eat substances that could be almost completely absorbed, serious complications would be produced. A satisfactory system of diet has to make allowance for this, and in [Pg 243] consequence of the structure of the alimentary canal has to include in the food bulky and indigestible materials, such as vegetables. Lastly, it may be noted that the instinct of appetite in man is largely aberrant. The widespread results of alcoholism show plainly the prevalent existence in man of a want of harmony between the instinct for choosing food and the instinct of preservation.

Far stronger than the social instinct, and far older, is the love of life and the instinct of self-preservation. Devices for the protection of life were developed long before the evolution of mankind, and it is quite certain that animals, even those highest in the scale of life, are unconscious of the inevitability of death and the ultimate fate of all living things. This knowledge is a human acquisition. It has long been recognised that the old attach a higher value to life than do the young. The instinctive love of life and fear of death are of importance in the study of human nature, impossible to over-estimate.

The instinctive love of life is preserved in the aged in its strongest form. I have carefully studied the aged to make certain on this point. It is a terrible disharmony that the instinctive love of life should manifest itself so strongly when death is felt to be so near at hand. Hence the religions of all times have been concerned with the problem of death.

III.—Science the Only Remedy for Human Disharmonies

In religion and in philosophy throughout their whole history we find attempts to combat the ills arising from the disharmonies of the human constitution.

Ancient and modern philosophies, like ancient and modern religions, have concerned themselves with the attempt to remedy the ills of human existence, and instinctive fear of [Pg 244] death has always ensured that great attention has been paid to the doctrine of immortality.

Science, the youngest daughter of knowledge, has begun to investigate the great problems affecting humanity. Her first steps, taken along the lines first clearly laid down by Bacon, were slow and halting. But medical science has lately made great progress, and has gone very far to control disease, especially in consequence of the work of Pasteur. It is said that science has failed because, for instance, tuberculosis persists, but tuberculosis is propagated not because of the failure of science, but because of the ignorance and stupidity of the population. To diminish the spread of tuberculosis, of typhoid fever, of dysentery, and of many other diseases, it is necessary only to follow the rules of scientific hygiene without waiting for specific remedies.

Science offers us much hope also when it is directed to the study of old age and the phenomena which lead to death.

Man, who is the descendant of some anthropoid ape, has inherited a constitution adapted to an environment very different from that which now surrounds him. He is possessed of a brain very much more highly developed than that of his ancestors, and has entered on a new path in the evolution of the higher organisms. The sudden change in his natural conditions has brought about a large series of organic disharmonies, which become more and more acutely felt as he becomes more intelligent and more sensitive; and thus there has arisen a number of sorrows which poor humanity has tried to relieve by all the means in its power. Humanity in its misery has put question after question to science, and has lost patience at the slowness of the advance of knowledge. It has declared that the answers already found by science are futile and of little interest. But science, confident of its methods, has quietly continued to work. Little by little the answers to some of the questions that have been set [Pg 245] have begun to appear.

Man, because of the fundamental disharmonies in his constitution, does not develop normally. The earlier phases of his development are passed through with little trouble; but after maturity greater or lesser abnormality begins, and ends in old age and death that are premature and pathological. Is not the goal of existence the accomplishment of a complete and physiological cycle in which occurs a normal old age, ending in the loss of the instinct of life and the appearance of the instinct of death? But before attaining the normal end, coming after the appearance of the instinct of death, a normal life must be lived; a life filled all through with the feeling that comes from the accomplishment of function. Science has been able to tell us that man, the descendant of animals, has good and evil qualities in his nature, and that his life is made unhappy by the evil qualities.

But the constitution of man is not immutable, and perhaps it may be changed for the better. Morality should be based not on human nature in its existing condition, but on ideal human nature, as it may be in the future. Before all things, it is necessary to try to amend the evolution of human life, that is to say, to transform its disharmonies into harmonies. This task can be undertaken only by science, and to science the opportunity of accomplishing it must be given. Before it is possible to reach the goal mankind must be persuaded that science is all-powerful and that the deeply-rooted existing superstitions are pernicious. It will be necessary to reform many customs and many institutions that now seem to rest on enduring foundations. The abandonment of much that is habitual, and a revolution in the mode of education, will require long and painful effort. But the conviction that science alone is able to redress the disharmonies of the human constitution will lead directly to the improvement of education and to the solidarity of mankind.

The Prolongation of Life

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Professor Metchnikoff's volume, on "The Prolongation of Life: Studies in Optimistic Philosophy," was published in 1907, and is in some respects the most original of his works. In it he carries much further the arguments and the studies to which he made brief allusion in "The Nature of Man," and he lays down certain principles for the prolongation of life which have been put into practice by a large number of people during the last two or three years, and are steadily gaining more attention. Sour milk as an article of diet appears to have a peculiar value in arresting the supposed senile changes which are largely due to auto-intoxication or self-poisoning.

I.—Senile Debility

When we study old age in man and the lower animals, we observe certain features common to both. But often among vertebrates there are found animals whose bodies withstand the ravages of time much better than that of man. I think it a fair inference that senility, that precocious senescence which is one of the greatest sorrows of humanity, is not so profoundly seated in the constitution of the higher animals as has generally been supposed. The first facts which we must accept are that human beings who reach extreme old age may preserve their mental qualities, notwithstanding serious physical decay, and that certain of the higher animals can resist the influence of time much longer than is the case with man under present conditions.

Many theories have been advanced regarding the cause of senility. It is certain that many parts of the body continue to thrive and grow even in old age, as, for instance, the nails and hair. But I believe that I have proved that in many parts of the body, especially the higher elements, such as nervous and muscular cells, there is a destruction due to the activity of the white cells of the blood. I have shown also that the blanching of the hair in old age is due to [Pg 247] the activity of these white cells, which destroy the hair pigment. Progressive muscular debility is an accompaniment of old age; physical work is seldom given to men over sixty years of age, as it is notorious that they are less capable of it. Their muscular movements are feebler, and soon bring on fatigue; their actions are slow and painful. Even old men whose mental vigour is unimpaired admit their muscular weakness. The physical correlate of this condition is an actual atrophy of the muscles, and has for long been known to observers. I have found that the cause of this atrophy is the consumption of the muscle fibres by what I call phagocytes, or eating cells, a certain kind of white blood cells.

In the case of certain diseases we find symptoms, which look like precocious senility, due to the poison of the disease. It is no mere analogy to suppose that human senescence is the result of a slow but chronic poisoning of the organism. Such poisons, if not completely destroyed or got rid of, weaken the tissues, the functions of which become altered or enfeebled in which the latter have the advantage. But we must make further studies before we can answer the question whether our senescence can be ameliorated.

The duration of the life of animals varies within very wide limits. As a general rule, small animals do not live so long as large ones, but there is no absolute relation between size and longevity, since parrots, ravens, and geese live much longer than many mammals, and than some much larger birds. Buffon long ago argued that the total duration of life bore some definite relation to the length of the period of growth, but further inquiry shows that such a relation cannot be established. Nevertheless, there is something intrinsic in each kind of animal which sets a definite limit to the length of years it can attain. The purely physiological conditions which determine this limit leave room for a considerable amount of variation in longevity. Duration of life, therefore, is a character which can be influenced [Pg 248] by the environment.

The duration of life in mammals is relatively shorter than in birds, and in the so-called cold-blooded vertebrates. No indication as to the cause of this difference can be found elsewhere than in the organs of digestion. Mammals are the only group of vertebrate animals in which the large intestine is much developed. This part of the alimentary canal is not important, for it fulfils no notable digestive function. On the other hand, it accommodates among the intestinal flora many microbes which damage health by poisoning the body with their products. Among the intestinal flora there are many microbes which are inoffensive, but others are known to have pernicious properties, and auto-intoxication, or self-poisoning, is the cause of the ill-health which may be traced to their activity. It is indubitable that the intestinal microbes or their poisons may reach the system generally, and bring harm to it. I infer from the facts that the more the digestive tract is charged with microbes, the more it is a source of harm capable of shortening life. As the large intestine not only is that part of the digestive tube most richly charged with microbes, but is relatively more capacious in mammals than in any other vertebrates, it is a just inference that the duration of life of mammals has been notably shortened as the result of chronic poisoning from an abundant intestinal flora.

When we come to study the duration of human life, it is impossible to accept the view that the high mortality between the ages of seventy and seventy-five indicates a natural limit to human life. The fact that many men from seventy to seventy-five years old are well preserved, both physically and intellectually, makes it impossible to regard that age as the natural limit of human life. Philosophers such as Plato, poets such as Goethe and Victor Hugo, artists such as Michael Angelo, Titian, and Franz Hals, produced some of their most important works when they had passed what some regard as the limit of life. Moreover, [Pg 249] deaths of people at that age are rarely due to senile debility. Centenarians are really not rare. In France, for instance, nearly 150 centenarians die every year, and extreme longevity is not limited to the white races. Women more frequently become centenarians than men—a fact which supports the general proposition that male mortality is always greater than that of the other sex.

It has been noticed that most centenarians have been people who were poor or in humble circumstances, and whose life has been extremely simple. It may well be said that great riches do not bring a very long life. Poverty generally brings with it sobriety, especially in old age, and sobriety is certainly favourable to long life.

II.—The Study of Natural Death

It is surprising to find how little science really knows about death. By natural death I mean to denote death due to the nature of the organism, and not to disease. We may ask whether natural death really occurs, since death so frequently comes by accident or by disease; and certainly the longevity of many plants is amazing. Such ages as three, four, and five thousand years are attributed to the baobab at Cape Verd, certain cypresses, and the sequoias of California. It is plain that among the lower and higher plants there are cases where natural death does not exist; and, further, so far as I can ascertain, it looks as if poisons produced by their own bodies were the cause of natural death among the higher plants where it does occur.

In the human race cases of what may be called natural death are extremely rare; the death of old people is usually due to infectious disease, particularly pneumonia, or to apoplexy. The close analogy between natural death and sleep supports my view that it is due to an auto-intoxication of the organism, since it is very probable that sleep is due to "poisoning" [Pg 250] by the products of organic activity.

Although the duration of the life of man is one of the longest amongst mammals, men find it too short. Ought we to listen to the cry of humanity that life is too short, and that it will be well to prolong it? If the question were merely one of prolonging the life of old people, without modifying old age itself, the answer would be doubtful. It must be understood, however, that the prolongation of life will be associated with the preservation of intelligence and of the power to work. When we have reduced or abolished such causes of precocious senility as intemperance and disease, it will no longer be necessary to give pensions at the age of sixty or seventy years. The cost of supporting the old, instead of increasing, will diminish progressively. We must use all our endeavors to allow men to complete their normal course of life, and to make it possible for old men to play their parts as advisers and judges, endowed with their long experience of life.

From time immemorial suggestions have been made for the prolongation of life. Many elixirs have been sought and supposed to have been found, but general hygienic measures have been the most successful in prolonging life and in lessening the ills of old age. That is the teaching of Sir Herman Weber, himself of very great age, who advises general hygienic principles, and especially moderation in all respects. He advises us to avoid alcohol and other stimulants, as well as narcotics and soothing drugs. Certainly the prolongation of life which has come to pass in recent centuries must be attributed to the advance of hygiene; and if hygiene was able to prolong life when little developed, as was the case until recently, we may well believe that with our greater knowledge a much better result will be obtained.

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III.—The Use of Lactic Acid

The general measures of hygiene directed against infectious diseases play a part in prolonging the lives of old people; but, in addition to the microbes which invade the body from outside, there is a rich source of harm in microbes which inhabit the body. The most important of these belong to the intestinal flora which is abundant and varied. Now the attempt to destroy the intestinal microbes by the use of chemical agents has little chance of success, and the intestine itself may be harmed more than the microbes. If, however, we observe the new-born child we find that, when suckled by its mother, its intestinal microbes are very different and much fewer than if it be fed with cows' milk. I am strongly convinced that it is advantageous to protect ourselves by cooking all kinds of food which, like cows' milk, are exposed to the air. It is well-known that other means—as, for instance, the use of lactic acid—will prevent food outside the body from going bad. Now as lactic fermentation serves so well to arrest putrefaction in general, why should it not be used for the same purpose within the digestive tube? It has been clearly proved that the microbes which produce lactic acid can, and do, control the growth of other microbes within the body, and that the lactic microbe is so much at home in the human body that it is to be found there several weeks after it has been swallowed.

From time immemorial human beings have absorbed quantities of lactic microbes by consuming in the uncooked condition substances such as soured milk, kephir, sauerkraut, or salted cucumbers, which have undergone lactic fermentation. By these means they have unknowingly lessened the evil consequences of intestinal putrefaction. The fact that so many races make soured milk and use it copiously is an excellent testimony to its [Pg 252] usefulness, and critical inquiry shows that longevity, with few traces of senility, is conspicuous amongst peoples who use sour milk extensively.

A reader who has little knowledge of such matters may be surprised by my recommendation to absorb large quantities of microbes, as the general belief is that microbes are all harmful. This belief, however, is erroneous. There are many useful microbes, amongst which the lactic bacilli have an honourable place. If it be true that our precocious and unhappy old age is due to poisoning of the tissues, the greater part of the poison coming from the large intestine, inhabited by numberless microbes, it is clear that agents which arrest intestinal putrefaction must at the same time postpone and ameliorate old age. This theoretical view is confirmed by the collection of facts regarding races which live chiefly on soured milk, and amongst which great ages are common.

IV.—An Ideal Old Age

As I have shown in the "Nature of Man," the human constitution as it exists to-day, being the result of a long evolution and containing a large animal element, cannot furnish the basis of rational morality. The conception which has come down from antiquity to modern times, of a harmonious activity of all the organs, is no longer appropriate to mankind. Organs which are in course of atrophy must not be re-awakened, and many natural characters which, perhaps, were useful in the case of animals, must be made to disappear in men.

Human nature which, like the constitutions of other organisms, is subject to evolution, must be modified according to a definite ideal. Just as a gardener or stock-raiser is not content with the existing nature of the plants and animals with which he is occupied, but modifies them to suit his purposes, so also the scientific philosopher must not think of existing human nature as immutable, but must try to modify it for the advantage of [Pg 253] mankind. As bread is the chief article in the human food, attempts to improve cereals have been made for a very long time, but in order to obtain results much knowledge is necessary. To modify the nature of plants, it is necessary to understand them well, and it is necessary to have an ideal to be aimed at. In the case of mankind the ideal of human nature, towards which we ought to press, may be formed. In my opinion this ideal is "orthobiosis"—that is to say, the development of human life, so that it passes through a long period of old age in active and vigorous health, leading to a final period in which there shall be present a sense of satiety of life, and a wish for death.

Just as we must study the nature of plants before trying to realise our ideal, so also varied and profound knowledge is the first requisite for the ideal of moral conduct. It is necessary not only to know the structure and functions of the human organism, but to have exact ideas on human life as it is in society. Scientific knowledge is so indispensable for moral conduct that ignorance must be placed among the most immoral acts. A mother who rears her child in defiance of good hygiene, from want of knowledge, is acting immorally towards her offspring, notwithstanding her feeling of sympathy. And this also is true of a government which remains in ignorance of the laws which regulate human life and human society.

If the human race come to adopt the principles of orthobiosis, a considerable change in the qualities of men of different ages will follow. Old age will be postponed so much that men of from sixty to seventy years of age will retain their vigour, and will not require to ask assistance in the fashion now necessary. On the other hand, young men of twenty-one years of age will no longer be thought mature or ready to fulfil functions so difficult as taking a share in public affairs. The view which I set forth in the "Nature of Man" regarding the [Pg 254] danger which comes from the present interference of young men in political affairs has since then been confirmed in the most striking fashion.

It is easily intelligible that in the new conditions such modern idols as universal suffrage, public opinion, and the *referendum*, in which the ignorant masses are called on to decide questions which demand varied and profound knowledge, will last no longer than the old idols. The progress of human knowledge will bring about the replacement of such institutions by others, in which applied morality will be controlled by the really competent persons. I permit myself to suppose that in these times scientific training will be much more general than it is just now, and that it will occupy the place which it deserves in education and in life.

Our intelligence informs us that man is capable of much, and, therefore, we hope that he may be able to modify his own nature and transform his disharmonies into harmonies. It is only human will that can attain this ideal.

HUGH MILLER [Pg 255]

The Old Red Sandstone

Hugh Miller was born in Cromarty, in the North of Scotland, October 10, 1802. From the time he was seventeen until he was thirty-four, he worked as a common stone-mason, although devoting his leisure hours to independent researches in natural history, for which he formed a taste early in life. He became interested in journalism, and was editor of the Edinburgh "Witness," when, in 1840, he published the contents of the volume issued a year later as "The Old Red Sandstone." The book deals with its author's most distinctive work, namely, finding fossils that tell much of the history of the Lower Old Red Sandstone, and fixing in the geological scale the place to which the larger beds of remains found in the system belong. Besides being a practical and original geologist, Miller had a fine imaginative power, which enabled him to reconstruct the past from its ruinous relics. The fact that he unfortunately set himself the task of combating the theory of evolution, which was fast gaining ground in his day, should not blind us to the high value of his geological experiences. The results of his observations provide some of the most cogent proofs of the theory he disputed. Late in life Miller's mind gave way, and he put an end to his own life on December 24, 1856.

I.—A Stone-mason's Researches

My advice to young working men desirous of bettering their circumstances, and adding to the amount of their enjoyment, is to seek happiness in study. Learn to make a right use of your eyes; the commonest things are worth looking at—even stones, weeds, and the most familiar animals. There are none of the intellectual or moral faculties, the exercise of which does not lead to enjoyment; hence it is that happiness bears so little reference to station.

Twenty years ago I made my first acquaintance with a life of labour and restraint. I was but a slim, loose-jointed boy at the time, fond of the pretty intangibilities of romance, and of [Pg 256] dreaming when broad awake; and, woful change! I was now going to work in a quarry. I was going to exchange all my day-dreams for the kind of life in which men toil every day that they may be enabled to eat, and eat every day that they may be enabled to toil!

That first day was no very formidable beginning of the course of life I had so much dreaded. To be sure, my hands were a little sore, and I felt nearly as much fatigued as if I had been climbing among the rocks; but I had wrought and been useful, and had yet enjoyed the day fully as much as usual. I was as light of heart next morning as any of my brother-workmen. That night, arising out of my employment, I found I had food enough for thought without once thinking of the unhappiness of a life of labour.

In the course of the day I picked up a nodular mass of blue limestone, and laid it open by a stroke of the hammer. Wonderful to relate, it contained inside a beautifully finished piece of sculpture, one of the volutes, apparently, of an Ionic capital. Was there another such curiosity in the whole world? I broke open a few other nodules of similar appearance, and found that there might be. In one of these there were what seemed to be scales of fishes and the impressions of a few minute bivalves, prettily striated; in the centre of another there was actually a piece of decayed wood.

Of all nature's riddles these seemed to me to be at once the most interesting and the most difficult to expound. I treasured them carefully up, and was told by one of the workmen to whom I showed them that there was a part of the shore, about two miles further to the west, where curiously shaped stones, somewhat like the heads of boarding-pikes, were occasionally picked up, and that in his father's day the country people called them thunderbolts. Our first half-holiday I employed in visiting the place where the thunderbolts had fallen so thickly, and found it a richer scene of wonder than I could have fancied even [Pg 257] in my dreams.

My first year of labour came to a close, and I found that the amount of my happiness had not been less than in the last of my boyhood. My knowledge had increased in more than the ratio of former seasons; and as I had acquired the skill of at least the common mechanic, I had fitted myself for independence.

My curiosity, once fully awakened, remained awake, and my opportunities of gratifying it have been tolerably ample. I have been an explorer of caves and ravines, a loiterer along sea-shores, a climber among rocks, a labourer in quarries. My profession was a wandering one. I remember passing direct, on one occasion, from the wild western coast of Ross-shire, where the Old Red Sandstone leans at a high angle against the prevailing quartz of the district, to where, on the southern skirts of Midlothian, the Mountain Limestone rises amid the coal. I have resided one season on a raised beach of the Moray Firth. I have spent the season immediately following amid the ancient granite and contorted schists of the central

Highlands. In the north I have laid open by thousands the shells and lignites of the oolite; in the south I have disinterred from their matrices of stone or of shale the huge reds and tree ferns of the carboniferous period.

I advise the stone-mason to acquaint himself with geology. Much of his time must be spent amid the rocks and quarries of widely separated localities, and so, in the course of a few years he may pass over the whole geological scale, and this, too, with opportunities of observation at every stage which can be shared with him by only the gentleman of fortune who devotes his whole time to study. Nay, in some respects, his advantages are superior to those of the amateur, for the man whose employments have to be carried on in the same formation for months, perhaps years, enjoys better opportunities of arriving at just [Pg 258] conclusions. There are formations which yield their organisms slowly to the discoverer, and the proofs which establish their place in the geological scale more tardily still. I was acquainted with the Old Red Sandstone of Ross and Cromarty for nearly ten years ere I ascertained that it is richly fossiliferous; I was acquainted with it for nearly ten years more ere I could assign its fossils to their exact place in the scale. Nature is vast and knowledge limited, and no individual need despair of adding to the general fund.

II.—Bridging Life's Gaps

"The Old Red Sandstone," says a Scottish geologist in a digest of some recent geological discoveries, "has hitherto been considered as remarkably barren of fossils." Only a few years have gone by since men of no low standing in the science disputed the very existence of this formation—or system, rather, for it contains at least three distinct formations. There are some of our British geologists who still regard it as a sort of debatable tract, entitled to no independent status, a sort of common which should be divided.

It will be found, however, that this hitherto neglected system yields in importance to none of the others, whether we take into account its amazing depth, the great extent to which it is developed both at home and abroad, the interesting links which it furnishes in the geological scale, or the vast period of time which it represents. There are localities in which the depth of the Old Red Sandstone fully equals the elevation of Mount Etna over the level of the sea, and in which it contains three distinct groups of organic remains, the one rising in beautiful progression over the other.

My first statement regarding the system must be much the reverse of the one just quoted, for the fossils are remarkably numerous and in a state of high preservation. I have a hundred [Pg 259] solid proofs by which to establish the truth of the assertion within less than a yard of me. Half my closet walls are covered with the peculiar fossils of the Lower Old Red Sandstone; and certainly a stranger assemblage of forms has rarely been grouped together—creatures whose very type is lost, fantastic and uncouth, which puzzle the naturalist to assign them even to their class; boat-like animals, furnished with oars and a rudder; fish, plated over, like the tortoise, above and below, with a strong armour of bone, and furnished with but one solitary rudder-like fin; other fish with the membranes of their fins thickly covered with scales; creatures bristling over with thorns; others glistening in an enamelled coat, as if beautifully japanned; the tail in every instance among the less equivocal shapes formed not equally, as in existing fish, on each side the central vertebral column, but chiefly on the lower side—the column sending out its diminished vertebræ to the extreme termination of the fin. All the forms testify of a remote antiquity. The figures on a Chinese vase or an

Egyptian obelisk are scarce more unlike what now exists in nature than are the fossils of the Lower Old Red Sandstone.

Lamarck, on the strength of a few striking facts which prove that to a certain extent the instincts of species may be improved and heightened, has concluded that there is a natural progress from the inferior orders of being towards the superior, and that the offspring of creatures low in the scale may belong to a different and nobler species a few thousand years hence. Never was there a fancy so wild and extravagant. The principle of adaptation still leaves the vegetable a vegetable, and the dog a dog. It is true that it is a law of nature that the chain of being is in some degree a continuous chain, and the various classes of existence shade into each other. All the animal families have their connecting links. Geology abounds with creatures of the intermediate class.

Fishes seem to have been the master existences of two great geological systems, mayhap [Pg 260] of three, ere the age of reptiles began. Now, fishes differ very much among themselves, some ranking nearly as low as worms, some nearly as high as reptiles; and we find in the Old Red Sandstone series of links which are wanting in the present creation, and the absence of which occasions a wide gap between the two grand divisions of fishes, the bony and the cartilaginous.

Of all the organisms of the system one of the most extraordinary is the pterichthys, or winged fish, which the writer had the pleasure of introducing to the acquaintance of geologists. Had Lamarck been the discoverer he would unquestionably have held that he had caught a fish almost in the act of wishing itself into a bird. There are wings which want only feathers, a body which seems to have been as well adapted for passing through the air as through water, and a tail with which to steer.

My first idea regarding it was that I had discovered a connecting link-between the tortoise and the fish. I submitted some of my specimens to Mr. Murchison, and they furnished him with additional data by which to construct the calculations he was then making respecting fossils, and they added a new and very singular link to the chain of existence in its relation to human knowledge. Agassiz confirmed the conclusions of Murchison in almost every particular, deciding at once that the creature must have been a fish.

Next to the pterichthys of the Lower Old Red Sandstone I shall place its contemporary the coccosteus of Agassiz—a fish which in some respects must have resembled it. Both were covered with an armour of thickly tubercled bony plates, and both furnished with a vertebrated tail. The coccosteus seems to have been most abundant. Another of the families of the ichthyolites of the Old Red Sandstone—the cephalaspis—seems almost to constitute [Pg 261] a connecting link between fishes and crustaceans. In the present creation fishes are either osseous or cartilaginous, that is, with bony skeletons, or with a framework of elastic, semi-transparent animal matter, like the shark; and the ichthyolites of the Old Red Sandstone unite these characteristics, resembling in some respects the osseous and in others the cartilaginous tribes. Agassiz at once confirmed my suspicion that the ichthyolites of the Old Red Sandstone were intermediate. Though it required skill to determine the place of the pterichthys and coccosteus there could be no mistaking the osteolepis—it must have been a fish, and a handsome one, too. But while its head resembled the heads of the bony fishes, its tail differed in no respects from the tails of the cartilaginous ones. And so through the discovery of extinct species the gaps between existing species have been bridged.

III.—Place-Fixing in the Dim Past

The next step was to fix the exact place of the ichthyolites in the geological scale, and this I was enabled to do by finding a large and complete bed *in situ*. Its true place is a little more than a hundred feet above the top, and not much more than a hundred yards above the base of the great conglomerate.

The Old Red Sandstone in Scotland and in England has its lower, middle, and upper groups—three distinct formations. As the pterichthys and coccosteus are the characteristic ichthyolites of the Lower Old Red formation, so the cephalaspis distinguishes the middle or coronstone division of the system in England. When we pass to the upper formation, we find the holoptychius the most characteristic fossil.

These fossils are found in a degree of entireness which depends less on their age than on the nature of the rock in which they occur. Limestone is the preserving salt of the geological [Pg 262] world, and the conservative qualities of the shales and stratified clays of the Lower Old Red Sandstone are not much inferior to limestone itself; while in the Upper Old Red the beds of consolidated sand are much less conservative of organic remains. The older fossils, therefore, can be described almost as minutely as the existence of the present creation, whereas the newer fossils exist, except in a few rare cases, as fragments, and demand the powers of a Cuvier or an Agassiz to restore them to their original combinations. On the other hand, while the organisms of the Lower Old Red are numerous and well preserved, those of the Upper Old Red are much greater in individual size. In short, the fish of the lower ocean must have ranged in size between a stickleback and a cod; whereas some of the fish of the ocean of the Upper Sandstone were covered with scales as large as oyster shells, and were armed with teeth that rivalled in size those of the crocodile.

IV.—Fish as Nature's Last Word

I will now attempt to present to the reader the Old Red Sandstone as it existed in time—during the succeeding periods of its formation, and when its existences lived and moved as the denizens of primeval oceans. We pass from the cemetery with its heaps of bones to the ancient city full of life and animation in all its streets and dwellings.

Before we commence our picture, two great geological periods have come to their close, and the floor of the widely spread ocean is occupied to the depth of many thousand feet by the remains of bygone existences. The rocks of these two earlier periods are those of the Cambrian and Silurian groups. The lower—Cambrian, representative of the first glimmering twilight of being—must be regarded as a period of uncertainty. It remains for future [Pg 263] discoverers to determine regarding the shapes of life that burrowed in its ooze or careered through the incumbent waters.

There is less doubt respecting the existences of the Silurian rocks. Four distinct platforms of being range in it, the one over the other, like the stories of a building. Life abounded on all these platforms, and in shapes the most wonderful. In the period of the Upper Silurian fish, properly so called, and of a very perfect organisation, had taken precedence of the crustacean. These most ancient beings of their class were cartilaginous fishes, and they appear to have been introduced by myriads. Such are the remains of what seem to have been the first vertebrata.

The history of the period represented by the Old Red Sandstone seems, in what now forms the northern half of Scotland, to have opened amid confusion and turmoil. The finely laminated Tilestones of England were deposited evidently in a calm sea. During the contemporary period the space which now includes Orkney, Lochness, Dingwall, Gamrie, and many a thousand square miles besides, was the scene of a shallow ocean, perplexed by powerful currents and agitated by waves. A vast stratum of water-rolled pebbles, varying in depth from a hundred feet to a hundred yards, remains, in a thousand different localities, to testify to the disturbing agencies of this time of commotion, though it is difficult to conceive how the bottom of any sea could have been so violently and equally agitated for so greatly extended a space.

The period of this shallow and stormy ocean passed, and the bottom, composed of the identical conglomerate which now forms the summit of some of our loftiest mountains, sank to a depth so profound as to be little affected by tides and tempests. During this second period there took place a vast deposit of coarse sandstone strata, and the subsidence continued until fully ninety feet had overlaid the conglomerate in waters perfectly [Pg 264] undisturbed. And here we find the first proof that this ancient ocean literally swarmed with life—that its bottom was covered with miniature forests of algae, and its waters darkened by immense shoals of fish. I have seen the ichthyolite bed where they were as thickly covered with fossil remains as I have ever seen a fishing-bank covered with herrings.

At this period some terrible catastrophe involved in sudden destruction the fish of an area at least a hundred miles from boundary to boundary, perhaps much more. The same platform in Orkney as in Cromarty is strewn thick with remains which exhibit unequivocally the marks of violent death. In what could it have originated? By what quiet but potent agency of destruction could the innumerable existences of an area perhaps ten thousand miles in extent be annihilated at once, and yet the medium in which they lived be left undisturbed by its operations? The thought has often struck me that calcined lime, cast out as ashes from some distant crater and carried by the winds, might have been the cause of the widely spread destruction to which the fossil organisms testify. I have seen the fish of a small trouting stream, over which a bridge was in the course of building, destroyed in a single hour, for a full mile below the erection, by a few troughfuls of lime that fell into the water when the centring was removed.

The period of death passed, and over the innumerable dead there settled a soft muddy sediment. For an unknown space of time, represented in the formation by a deposit about fifty feet in thickness, the waters of the depopulated area seem to have remained devoid of life. A few scales and plates then begin to appear. The fish that had existed outside the chasm seem to have gradually gained upon it as their numbers increased.

The work of deposition went on and sandstone was overlaid by stratified clay. This upper [Pg 265] bed had also its organisms, but the circumstances were less favourable to the preservation of entire ichthyolites than those in which the organisms were wrapped up in their stony coverings. Age followed age, generations were entombed in ever-growing depositions. Vast periods passed, and it seemed as if the power of the Creator had reached its extreme limit when fishes had been called into existence, and our planet was destined to be the dwelling-place of no nobler inhabitants.

The curtain rises, and the scene is new. The myriads of the lower formation have disappeared, and we are surrounded on an upper platform by the existences of a later creation. Shoals of cephalaspides, feathered with fins, sweep past. We see the distant gleam of scales, that some of the coats glitter with enamel, that others bristle over with minute thorny points. A huge crustacean, of uncouth proportions, stalks over the weedy bottoms, or burrows in the hollows of the banks. Ages and centuries pass—who can sum up their number?—for the depth of this middle formation greatly exceeds that of the other two.

The curtain rises. A last day had at length come to the period of the middle formation, and in an ocean roughened by waves and agitated by currents we find new races of existences. We may mark the clumsy bulk of the Holoptychius conspicuous in the group. The shark family have their representative as before; a new variety of the pterichthys spreads out its spear-like wings at every alarm, like its predecessor of the lower formation. Fish still remained the lords of creation, and their bulk, at least, had become immensely more great. We began with an age of dwarfs, we end with an age of giants, which is carried on into the lower coal measures. We pursue our history no further?

Has the last scene in the series arisen? Cuvier asked the question, hesitated, and then decided in the negative, for he was too intimately acquainted with the works of the Creator [Pg 266] to think of limiting His power, and he could anticipate a coming period in which man would have to resign his post of honour to some nobler and wiser creature, the monarch of a better and happier world.

SIR ISAAC NEWTON [Pg 267]

Principia

> Sir Isaac Newton was born at Woolsthorpe, Lincolnshire, England, Dec. 25, 1642, the son of a small landed proprietor. For the famous episode of the falling apple, Voltaire, who admirably explained his system for his countrymen, is responsible. It was in 1680 that Newton discovered how to calculate the orbit of a body moving under a central force, and showed that if the force varied as the inverse square of the distance, the orbit would be an ellipse with the centre of force in one focus. The great discovery, which made the writing of his "Philosophiæ Naturalis Principia Mathematica" possible, was that the attraction between two spheres is the same as it would be if we supposed each sphere condensed to a point at its centre. The book was published as a whole in 1687. Of its author it was said by Lagrange that not only was he the greatest genius that ever existed, but also the most fortunate, "for we cannot find more than once a system of the world to establish." Newton died on March 20, 1727.

Our design (writes Newton in his preface) not respecting arts but philosophy, and our subject not manual but natural powers, we consider those things which relate to gravity, levity, elastic force, the resistance of fluids and the like forces, whether attractive or impulsive; and, therefore, we offer this work as the mathematical principles of philosophy, for all the difficulty of philosophy seems to consist in this—from the phenomena of motions to investigate the forces of nature, and from these forces to demonstrate the other phenomena, and to this end the general propositions in the first and second book are directed. In the third book, we give an example of this in the explication of the system of the world; for by the propositions mathematically demonstrated in the former books, we in the third derive from the celestial phenomena the forces of gravity with which bodies tend to [Pg 268] the sun and the several planets. Then from these forces, by other propositions which are also mathematical, we deduce the motions of the planets, the comets, the moon, and the sea.

Upon this subject I had (he says) composed the third book in a popular method, that it might be read by many, but afterward, considering that such as had not sufficiently entered into the principles could not easily discern the strength of the consequences, nor lay aside the prejudices to which they had been many years accustomed, therefore, to prevent the disputes which might be raised upon such accounts, I chose to reduce the substance of this book into the form of Propositions (in the mathematical way). So that this third book is composed both "in popular method" and in the form of mathematical propositions.

Books I and II

The principle of universal gravitation, namely, "That every particle of matter is attracted by or gravitates to every other particle of matter with a force inversely proportional to the squares of their distances," is the discovery which characterises the "Principia." This principle the author deduced from the motion of the moon and the three laws of Kepler; and these laws in turn Newton, by his greater law, demonstrated to be true.

From the first law of Kepler, namely, the proportionality of the areas to the times of their description, Newton inferred that the force which retained the planet in its orbit was always directed to the sun. From the second, namely, that every planet moves in an ellipse with the sun as one of foci, he drew the more general inference that the force by which the planet moves round that focus varies inversely as the square of its distance therefrom. He demonstrated that a planet acted upon by such a force could not move in any other curve [Pg 269] than a conic section; and he showed when the moving body would describe a circular, an elliptical, a parabolic, or hyperbolic orbit. He demonstrated, too, that this force or attracting, gravitating power resided in even the least particle; but that in spherical masses it operates as if confined to their centres, so that one sphere or body will act upon another sphere or body with a force directly proportional to the quantity of matter and inversely as the square of the distance between their centres, and that their velocities of mutual approach will be in the inverse ratio of their quantities of matter. Thus he outlined the universal law.

The System of the World

It was the ancient opinion of not a few (writes Newton in Book III.) in the earliest ages of philosophy that the fixed stars stood immovable in the highest parts of the world; that under the fixed stars the planets were carried about the sun; that the earth, as one of the planets, described an annual course about the sun, while, by a diurnal motion, it was in the meantime revolved about its own axis; and that the sun, as the common fire which served to warm the whole, was fixed in the centre of the universe. It was from the Egyptians that the Greeks derived their first, as well as their soundest notions of philosophy. It is not to be denied that Anaxagoras, Democritus and others would have it that the earth possessed the centre of the world, but it was agreed on both sides that the motions of the celestial bodies were performed in spaces altogether free and void of resistance. The whim of solid orbs was[1] of later date, introduced by Endoxus, Calippus and Aristotle, when the ancient philosophy began to decline.

As it was the unavoidable consequence of the hypothesis of solid orbs while it prevailed [Pg 270] that the comets must be thrust down below the moon, so no sooner had the late observations of astronomers restored the comets to their ancient places in the higher heavens than these celestial spaces were at once cleared of the encumbrance of solid orbs, which by these observations were broken to pieces and discarded for ever.

Whence it was that the planets came to be retained within any certain bounds in these free spaces, and to be drawn off from the rectilinear courses, which, left to themselves, they should have pursued, into regular revolutions in curvilinear orbits, are questions which we do not know how the ancients explained; and probably it was to give some sort of satisfaction to this difficulty that solid orbs were introduced.

The later philosophers pretend to account for it either by the action of certain vortices, as Kepler and Descartes, or by some other principle of impulse or attraction, for it is most certain that these effects must proceed from the action of some force or other. This we will call by the general name of a centripetal force, as it is a force which is directed to some centre; and, as it regards more particularly a body in that centre, we call it circum-solar, circum-terrestrial, circum-jovial.

Centre-Seeking Forces

That by means of centripetal forces the planets may be retained in certain orbits we may easily understand if we consider the motions of projectiles, for a stone projected is by the pressure of its own weight forced out of the rectilinear path, which, by the projection alone, it should have pursued, and made to describe a curve line in the air; and through that crooked way is at last brought down to the ground, and the greater the velocity is with which it is projected the further it goes before it falls to earth. We can, therefore, suppose [Pg 271] the velocity to be so increased that it would describe an arc of 1, 2, 5, 10, 100, 1,000 miles before it arrived at the earth, till, at last, exceeding the limits of the earth, it should pass quite by it without touching it.

And because the celestial motions are scarcely retarded by the little or no resistance of the spaces in which they are performed, to keep up the parity of cases, let us suppose either that there is no air about the earth or, at least, that it is endowed with little or no power of resisting.

And since the areas which by this motion it describes by a radius drawn to the centre of the earth have previously been shown to be proportional to the times in which they are described, its velocity when it returns to the point from which it started will be no less than at first; and, retaining the same velocity, it will describe the same curve over and over by the same law.

But if we now imagine bodies to be projected in the directions of lines parallel to the horizon from greater heights, as from 5, 10, 100, 1,000 or more miles, or, rather, as many semi-diameters of the earth, those bodies, according to their different velocity and the different force of gravity in different heights, will describe arcs either concentric with the earth or variously eccentric, and go on revolving through the heavens in those trajectories just as the planets do in their orbs.

As when a stone is projected obliquely, the perpetual deflection thereof towards the earth is a proof of its gravitation to the earth no less certain than its direct descent when suffered to fall freely from rest, so the deviation of bodies moving in free spaces from rectilinear paths and perpetual deflection therefrom towards any place, is a sure indication of the existence of some force which from all quarters impels those bodies towards that place.

That there are centripetal forces actually directed to the bodies of the sun, of the earth, and other planets, I thus infer. [Pg 272]

The moon revolves about our earth, and by radii drawn to its centre describes areas nearly proportional to the times in which they are described, as is evident from its velocity compared with its apparent diameter; for its motion is slower when its diameter is less (and therefore its distance greater), and its motion is swifter when its diameter is greater.

The revolutions of the satellites of Jupiter about the planet are more regular; for they describe circles concentric with Jupiter by equable motions, as exactly as our senses can distinguish.

And so the satellites of Saturn are revolved about this planet with motions nearly circular and equable, scarcely disturbed by any eccentricity hitherto observed.

That Venus and Mercury are revolved about the sun is demonstrable from their moon-like appearances. And Venus, with a motion almost uniform, describes an orb nearly circular and concentric with the sun. But Mercury, with a more eccentric motion, makes remarkable approaches to the sun and goes off again by turns; but it is always swifter as it is near to the sun, and therefore by a radius drawn to the sun still describes areas proportional to the times.

Lastly, that the earth describes about the sun, or the sun about the earth, by a radius from one to the other, areas exactly proportional to the times is demonstrable from the apparent diameter of the sun compared with its apparent motion.

These are astronomical experiments; from which it follows that there are centripetal forces actually directed to the centres of the earth, of Jupiter, of Saturn, and of the sun.[2]

That these forces decrease in the duplicate proportion of the distances from the centre of every planet appears by Cor. vi., Prop. iv., Book I.[3] for the periodic times of the satellites of Jupiter are one to another in the sesquiplicate proportion of their distances from the centre of this planet. Cassini assures us that the same proportion is observed in the circum-Saturnal planets. In the circum-solar planets Mercury and Venus, the same proportional holds with great accuracy. [Pg 273]

That Mars is revolved about the sun is demonstrated from the phases which it shows and the proportion of its apparent diameters; for from its appearing full near conjunction with the sun and gibbous in its quadratures,[4] it is certain that it travels round the sun. And since its diameter appears about five times greater when in opposition to the sun than when in conjunction therewith, and its distance from the earth is reciprocally as its apparent diameter, that distance will be about five times less when in opposition to than when in conjunction with the sun; but in both cases its distance from the sun will be nearly about the same with the distance which is inferred from its gibbous appearance in the quadratures. [Pg 274] And as it encompasses the sun at almost equal distances, but in respect of the earth is very unequally distant, so by radii drawn to the sun it describes areas nearly uniform; but by radii drawn to the earth it is sometimes swift, sometimes stationary, and sometimes retrograde.

That Jupiter in a higher orbit than Mars is likewise revolved about the sun with a motion nearly equable as well in distance as in the areas described, I infer from Mr. Flamsted's observations of the eclipses of the innermost satellite; and the same thing may be concluded of Saturn from his satellite by the observations of Mr. Huyghens and Mr. Halley.

If Jupiter was viewed from the sun it would never appear retrograde or stationary, as it is seen sometimes from the earth, but always to go forward with a motion nearly uniform. And from the very great inequality of its apparent geocentric motion we infer—as it has been previously shown that we may infer—that the force by which Jupiter is turned out of a rectilinear course and made to revolve in an orbit is not directed to the centre of the earth. And the same argument holds good in Mars and in Saturn. Another centre of these forces is, therefore, to be looked for, about which the areas described by radii intervening may be equable; and that this is the sun, we have proved already in Mars and Saturn nearly, but accurately enough in Jupiter.

The distances of the planets from the sun come out the same whether, with Tycho, we place the earth in the centre of the system, or the sun with Copernicus; and we have already proved that, these distances are true in Jupiter. Kepler and Bullialdus have with great care determined the distances of the planets from the sun, and hence it is that their tables agree best with the heavens. And in all the planets, in Jupiter and Mars, in Saturn and the earth, as well as in Venus and Mercury, the cubes of their distances are as the squares of their periodic times; and, therefore, the centripetal circum-solar force throughout all the planetary [Pg 275] regions decreases in the duplicate proportion of the distances from the sun. Neglecting those little fractions which may have arisen from insensible errors of observation, we shall always find the said proportion to hold exactly; for the distances of Saturn, Jupiter, Mars, the Earth, Venus, and Mercury from the sun, drawn from the observations of astronomers, are (Kepler) as the numbers 951,000, 519,650, 152,350, 100,000, 70,000, 38,806; or (Bullialdus) as the numbers 954,198, 522,520, 152,350, 100,000, 72,398, 38,585; and from the periodic times they come out 953,806, 520,116, 152,399, 100,000, 72,333, 38,710. Their distances, according to Kepler and Bullialdus, scarcely differ by any sensible quantity, and where they differ most the differences drawn from the periodic times fall in between them.

Earth as a Centre

That the circum-terrestrial force likewise decreases in the duplicate proportion of the distances, I infer thus:

The mean distance of the moon from the centre of the earth is, we may assume, sixty semi-diameters of the earth; and its periodic time in respect of the fixed stars 27 days 7 hr. 43 min. Now, it has been shown in a previous book that a body revolved in our air, near the surface of the earth supposed at rest, by means of a centripetal force which should be to the same force at the distance of the moon in the reciprocal duplicate proportion of the distances from the centre of the earth, that is, as 3,600 to 1, would (secluding the resistance of the air) complete a revolution in 1 hr. 24 min. 27 sec.

Suppose the circumference of the earth to be 123,249,600 Paris feet, then the same body deprived of its circular motion and falling by the impulse of the same centripetal force as before would in one second of time describe 15$\frac{1}{12}$ Paris feet. This we infer by a calculus [Pg 276] formed upon Prop. xxxvi. ("To determine the times of the descent of a body falling from a given place"), and it agrees with the results of Mr. Huyghens's experiments of pendulums, by which he demonstrated that bodies falling by all the centripetal force with which (of whatever nature it is) they are impelled near the surface of the earth do in one second of time describe 15$\frac{1}{12}$ Paris feet.

But if the earth is supposed to move, the earth and moon together will be revolved about their common centre of gravity. And the moon (by Prop, lx.) will in the same periodic time, 27 days 7 hr. 43 min., with the same circum-terrestrial force diminished in the duplicate proportion of the distance, describe an orbit whose semi-diameter is to the semi-diameter of the former orbit, that is, to the sixty semi-diameters of the earth, as the sum of both the bodies of the earth and moon to the first of two mean proportionals between this sum and the body of the earth; that is, if we suppose the moon (on account of its mean apparent diameter 31½ min.) to be about $1/42$ of the earth, as 43 to $\sqrt[3]{42 + 42^2}$ or as about 128 to 127. And, therefore, the semi-diameter of the orbit—that is, the distance of the centres of the moon and earth—will in this case be 60½ semi-diameters of the earth, almost the same with that assigned by Copernicus; and, therefore, the duplicate proportion of the decrement of the force holds good in this distance. (The action of the sun is here disregarded as inconsiderable.)

This proportion of the decrement of the forces is confirmed from the eccentricity of the planets, and the very slow motion of their apsides; for in no other proportion, it has been established, could the circum-solar planets once in every revolution descend to their least, and once ascend to their greatest distance from the sun, and the places of those distances remain immovable. A small error from the duplicate proportion would produce a motion of [Pg 277] the apsides considerable in every revolution, but in many enormous.

The Tides

While the planets are thus revolved in orbits about remote centres, in the meantime they make their several rotations about their proper axes: the sun in 26 days, Jupiter in 9 hr. 56 min., Mars in 24⅔ hr., Venus in 23 hr., and in like manner is the moon revolved about its axis in 27 days 7 hr. 43 min.; so that this diurnal motion is equal to the mean motion of the moon in its orbit; upon which account the same face of the moon always respects the centre about which this mean motion is performed—that is, the exterior focus of the moon's orbit nearly.

By reason of the diurnal revolutions of the planets the matter which they contain endeavours to recede from the axis of this motion; and hence the fluid parts, rising higher towards the equator than about the poles, would lay the solid parts about the equator under water if those parts did not rise also; upon which account the planets are something thicker about the equator than about the poles.

And from the diurnal motion and the attractions of the sun and moon our sea ought twice to rise and twice to fall every day, as well lunar as solar. But the two motions which the two luminaries raise will not appear distinguished but will make a certain mixed motion. In the conjunction or opposition of the luminaries their forces will be conjoined and bring on the greatest flood and ebb. In the quadratures the sun will raise the waters which the moon depresseth and depress the waters which the moon raiseth; and from the difference of their forces the smallest of all tides will follow.

But the effects of the lumniaries depend upon their distances from the earth, for when they are less distant their effects are greater and when more distant their effects are less, and [Pg 278] that in the triplicate proportion of their apparent diameters. Therefore it is that the sun in winter time, being then in its perigee, has a greater effect, whether added to or subtracted from that of the moon, than in the summer season, and every month the moon, while in the perigee raiseth higher tides than at the distance of fifteen days before or after when it is in its apogee.

The fixed stars being at such vast distances from one another, can neither attract each other sensibly nor be attracted by our sun.

Comets

There are three hypotheses about comets. For some will have it that they are generated and perish as often as they appear and vanish; others that they come from the regions of the fixed stars, and are near by us in their passage through the sytem of our planets; and, lastly, others that they are bodies perpetually revolving about the sun in very eccentric orbits.

In the first case, the comets, according to their different velocities, will move in conic sections of all sorts; in the second they will describe hyperbolas; and in either of the two will frequent indifferently all quarters of the heavens, as well those about the poles as those towards the ecliptic; in the third their motions will be performed in eclipses very eccentric and very nearly approaching to parabolas. But (if the law of the planets is observed) their orbits will not much decline from the plane of the ecliptic; and, so far as I could hitherto observe, the third case obtains; for the comets do indeed chiefly frequent the zodiac, and scarcely ever attain to a heliocentric latitude of 40 degrees. And that they move in orbits very nearly parabolical, I infer from their velocity; for the velocity with which a parabola is described is everywhere to the velocity with which a comet or planet may be revolved about the sun in a circle at the same distance in the subduplicate ratio of 2 to 1; and, by my [Pg 279] computation, the velocity of comets is found to be much about the same. I examined the thing by inferring nearly the velocities from the distances, and the distances both from the parallaxes and the phenomena of the tails, and never found the errors of excess or defect in the velocities greater than what might have arisen from the errors in the distances collected after that manner.

SIR RICHARD OWEN [Pg 280]

Anatomy of Vertebrates

Sir Richard Owen, the great naturalist, was born July 20, 1804, at Lancaster, England, and received his early education at the grammar school of that town. Thence he went to Edinburgh University. In 1826 he was admitted a member of the English College of Surgeons, and in 1829 was lecturing at St. Bartholomew's Hospital, London, where he had completed his studies. His "Memoir on the Pearly Nautillus," published in 1832, placed him, says Huxley, "at a bound in the front rank of anatomical monographers," and for sixty-two years the flow of his contributions to scientific literature never ceased. In 1856 he was appointed to take charge of the natural history departments of the British Museum, and before long set forth views as to the inadequacy of the existing accommodation, which led ultimately to the foundation of the buildings now devoted to this purpose in South Kensington. Owen died on December 18, 1892. His great book, "Comparative Anatomy and Physiology of the Vertebrates," was completed in 1868, and since Cuvier's "Comparative Anatomy," is the most monumental treatise on the subject by any one man. Although much of the classification adopted by Owen has not been accepted by other zoologists, yet the work contains an immense amount of information, most of which was gained from Owen's own personal observations and dissections.

I.—Biological Questions of 1830

At the close of my studies at the Jardin des Plantes, Paris, in 1831, I returned strongly moved to lines of research bearing upon the then prevailing phases of thought on some biological questions.

The great master in whose dissecting rooms I was privileged to work held that species were not permanent as a fact established inductively on a wide basis of observation, by which comparative osteology had been created. Camper and Hunter suspected the species might be transitory; but Cuvier, in defining the characters of his anaplotherium and [Pg 281] palæotherium, etc., proved the fact. Of the relation of past to present species, Cuvier had not an adequate basis for a decided opinion. Observation of changes in the relative position of land and sea suggested to him one condition of the advent of new species on an island or continent where old species had died out. This view he illustrates by a hypothetical case of such succession, but expressly states: "I do not assert that a new creation was necessary to produce the species now existing, but only that they did not exist in the same regions, and must have come from elsewhere." Geoffrey Saint Hilaire opposed to Cuvier's inductive treatment of the question the following expression of belief: "I have no doubt that existing animals are directly descended from the animals of the antediluvian world," but added, "it is my belief that the season has not yet arrived for a really satisfying knowledge of geology."

The main collateral questions argued in their debates appeared to me to be the following:

Unity of plan or final purpose, as a governing condition of organic development?

Series of species, uninterrupted or broken by intervals?

Extinction, cataclysmal or regulated?

Development, by epigenesis or evolution?

Primary life, by miracle or secondary law?

Cuvier held the work of organisation to be guided and governed by final purpose or adaptation. Geoffrey denied the evidence of design and contended for the principle which he called "unity of composition," as the law of organisation. Most of his illustrations were open to the demonstration of inaccuracy; and the language by which disciples of the kindred school of Schelling illustrated in the animal structure the transcendental idea of the whole in every part seemed little better than mystical jargon. With Cuvier, answerable parts occurred in the zoological scale because they had to perform similar functions.

As, however, my observations and comparisons accumulated, they enforced a [Pg 282] reconsideration of Cuvier's conclusions. To demonstrate the evidence of the community of organisation I found the artifice of an archetype vertebrate animal essential; and from the demonstration of its principle, which I then satisfied myself was associated with and dominated by that of "adaptation to purpose," the step was inevitable to the conception of the operation of a secondary cause of the entire series of species, such cause being the servant of predetermining intelligent will.

But besides "derivation" or "filiation" another principle influencing organisation became recognisable, to which I gave the name of "irrelative repetition," or "vegetative repetition." The demonstrated constitution of the vertebrate endoskeleton as a series of essentially similar segments appeared to me to illustrate the law of irrelative repetition.

These results of inductive research swayed me in rejecting direct or miraculous creation, and in recognising a "natural law or secondary cause" as operative in the production of species "in orderly succession and progression."

II.—Succession of Species, Broken or Linked?

To the hypothesis that existing are modifications of extinct species, Cuvier replied that traces of modification were due from the fossil world. "You ought," he said, "to be able to show the intermediate forms between the palæotherium and existing hoofed quadrupeds."

The progress of palæontology since 1830 has brought to light many missing links unknown to the founder of the science. The discovery of the remains of the hipparion supplied one of the links required by Cuvier, and it is significant that the remains of such three-toed horses are found only in deposits of that tertiary period which intervene between [Pg 283] the older palæotherian one and the newer strata in which the modern horse first appears to have lost its lateral hooflets.

The molar series of the horse includes six large complex grinders individually recognisable by developmental characters. The representative of the first premolar is minute and soon shod. Its homologue in palæotherium is functionally developed and retained, that type-dentition being adhered to. In hipparion this tooth is smaller than in palæotherium, but functional and permanent. The transitory and singularly small and simple denticle in the horse exemplifies the rudiment of an ancestral structure in the same degree as do the hoofless splint-bones; just as the spurious hoofs dangling therefrom in hipparion are retained rudiments of the functionally developed lateral hoofs in the broader foot of palæotherium.

Other missing links of this series of species have also been supplied.

How then is the origin of these intermediate gradations to be interpreted? If the alternative—species by miracle or by law—be applied to palæotherium, paloplotherium, anchitherium, hipparion, equus, I accept the latter without misgiving, and recognise such law as continuously operative throughout tertiary time.

In respect to its law of operation we may suppose Lamarck to say, "as the surface of the earth consolidated, the larger and more produced mid-hoof of the old three-toed pachyderius took a greater share in sustaining the animal's weight; and more blood being required to meet the greater demand of the more active mid-toe, it grew; whilst, the side-toes, losing their share of nourishment and becoming more and more withdrawn from use, shrank"—and so on. Mr. Darwin, I conceive, would modify this by saying that some individuals of palæotherium happening to be born with a larger and longer middle toe, and with shorter and smaller side-toes, such variety was better adapted to prevailing altered conditions of the [Pg 284] earth's surface than the parental form; and so on, until finally the extreme equine modifications of foot came to be "naturally selected." But the hypothesis of appetency and volition, as of natural selection, are less applicable, less intelligible, in connection with the changes in the teeth.

I must further observe that to say the palæotherium has graduated into equus by "natural selection" is an explanation of the process of the same kind and value as that by which the secretion of bile was attributed to the "appetency" of the liver for the elements of bile. One's surprise is that such explanatory devices should not have died out with the "archeus faber," the "nisus formations," and other self-deceiving, world-beguiling simulacra of science, with the last century; and that a resuscitation should have had any success in the present.

What, then, are the facts on which any reasonable or intelligible conception can be formed of the mode of operation of the derivative law exemplified in the series linking on palæotherium to equus? A very significant one is the following. A modern horse occasionally comes into the world with the supplementary ancestral hoofs. From Valerius Maximus, who attributes the variety to Bucephalus downwards, such "polydactyle" horses have been noted as monsters and marvels. In one of the latest examples, the inner splint-bone, answering to the second metacarpal of the pentadactyle foot, supported phalanges and a terminal hoof resembling the corresponding one in hipparion. And the pairing of horses with the meterpodials bearing, according to type, phalanges and hoofs might restore the race of hipparions.

Now, the fact suggesting such possibility teaches that the change would be sudden and considerable; it opposes the idea that species are transmuted by minute and slow degrees. It also shows that a species might originate independently of the operation of any external influence; that change of structure would precede that of use and habit; that appetency, [Pg 285] impulse, ambient medium, fortuitous fitness of surrounding circumstances, or a personified "selecting nature" would have had no share in the transmutative act.

Thus I have been led to recognise species as exemplifying the continuous operation of natural law, or secondary cause; and that not only successively but progressively; "from the first embodiment of the vertebrate idea under its old ichthyic vestment until it became arrayed in the glorious garb of the human form."

III.—Extinction—Cataclysmal or Regulated

If the species of palæothere, paloplothere, anchithere, hipparion, and horse be severally deemed due to remotely and successively repeated acts of creation; the successive going out of such species must have been as miraculous as their coming in. Accordingly, in Cuvier's "Discourse on Revolutions of the Earth's Surface" we have a section of "Proofs that these revolutions have been numerous," and another of "Proofs that these revolutions have been sudden." But as the discoveries of palæontologists have supplied the links between the species held to have perished by the cataclysms, so each successive parcel of geological truth has tended to dissipate the belief in the unusually sudden and violent nature of the changes recognisable in the earth's surface. In specially directing my attention to this moot point, whilst engaged in investigations of fossil remains, I was led to recognise one cause of extinction as being due to defeat in the contest which the individual of each species had to maintain against the surrounding agencies which might militate against its existence. This principle has received a large and most instructive accession of illustrations from the labours of Charles Darwin; but he aims to apply it not only to the extinction but to the origin of species.

Although I fail to recognise proof of the latter bearing of the battle of life, the concurrence of so much evidence in favour of extinction by law is, in like measure, corroborative of the truth of the ascription of the origin of species to a secondary cause. [Pg 286]

What spectacle can be more beautiful than that of the inhabitants of the calm expanse of water of an atoll encircled by its ring of coral rock! Leaving locomotive frequenters of the calcarious basin out of the question, we may ask, Was direct creation after the dying out of its result as a "rugose coral" repeated to constitute the succeeding and superseding "tabulate coral"? Must we also invoke the miraculous power to initiate every distinct species of both rugosa and tabulata? These grand old groups have had their day and are utterly gone. When we endeavour to conceive or realise such mode of origin, not of them only but of their manifold successors, the miracle, by the very multiplication of its manifestations, becomes incredible—inconsistent with any worthy conception of an all-seeing, all-provident Omnipotence.

Being unable to accept the volitional hypothesis (of Lamarck) or the selective force exerted by outward circumstances (Darwin), I deem an innate tendency to deviate from parental type, operating through periods of adequate duration, to be the most probable way of operation of the secondary law whereby species have been derived one from another.

According to my derivative hypothesis a change takes place first in the structure of the animal, and this, when sufficiently advanced, may lead to modifications of habits. But species owe as little to the accidental concurrence of environing circumstances as kosmos depends upon a fortuitous concourse of atoms. A purposive route of development and change of correlation and inter-dependence, manifesting intelligent will, is as determinable in the succession of races as in the development and organisation of the individual.

Derivation holds that every species changes in time, by virtue of inherent tendencies thereto. Natural selection holds that no such change can take place without the influence of altered external circumstances educing or eliciting such change. [Pg 287]

Derivation sees among the effects of the innate tendency to change, irrespective of altered surrounding circumstances, a manifestation of creative power in the variety and beauty of the results; and, in the ultimate forthcoming of a being susceptible of appreciating such beauty, evidence of the preordaining of such relation of power to the appreciation. Natural selection acknowledges that if power or beauty, in itself, should be a purpose in creation, it would be absolutely fatal to it as a hypothesis.

Natural selection sees grandeur in the "view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one." Derivation sees, therein, a narrow invocation of a special miracle and an unworthy limitation of creative power, the grandeur of which is manifested daily, hourly, in calling into life many forms, by conversion of physical and chemical into vital modes of force, under as many diversified conditions of the requisite elements to be so combined.

Natural selection leaves the subsequent origin and succession of species to the fortuitous concurrence of outward conditions; derivation recognises a purpose in the defined and preordained course, due to innate capacity or power of change, by which homogeneously-created protozoa have risen to the higher forms of plants and animals.

The hypothesis of derivation rests upon conclusions from four great series of inductively established facts, together with a probable result of facts of a fifth class; the hypothesis of natural selection totters on the extension of a conjectural condition explanatory of extinction to the origination of species, inapplicable in that extension to the majority of organisms, and not known or observed to apply to the origin of any species.

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IV.—Epigenesis or Evolution?

The derivative origin of species, then, being at present the most admissible one, and the retrospective survey of such species showing convergence, as time recedes, to more simplified or generalised organisations, the result to which the suggested train of thought inevitably leads is very analogous in each instance. If to kosmos or the mundane system have been allotted powers equivalent to the development of the several grades of life, may not the demonstrated series of conversions of force have also included that into the vital form?

In the last century, physiologists were divided as to the principle guiding the work of organic development.

The "evolutionists" contended that the new being preexisted in a complete state of formation, needing only to be vivified by impregnation in order to commence the series of expansions or disencasings, culminating in the independent individual.

The "epigenesists" held that both the germ and its subsequent organs were built up of juxtaposed molecules according to the operation of a developmental force, or "nisus formations."

At the present day the question may seem hardly worth the paper on which it is referred to. Nevertheless, "pre-existence of germs" and evolution are logically inseparable from the idea of species by primary miraculously-created individuals. Cuvier, therefore, maintained both as firmly as did Haller. In the debates of 1830 I remained the thrall of that dogma in regard to the origin of single-celled organisms whether in or out of body. Every result of formfaction, I believed, with most physiologists, to be the genetic outcome of a pre-existing "cell." The first was due to miraculous interposition and suspension of ordinary laws; it contained potentially all future possible cells. Cell-development exemplified evolution of [Pg 289] pre-existing germs, the progeny of the primary cell. They progagated themselves by self-division, or by "proliferation" of minutes granules or atoms, which, when properly nourished, again multiplied by self-division, and grew to the likeness of the parent cells.

It seems to me more consistent with the present phase of dynamical science and the observed graduations of living things to suppose the sarcode or the "protogenal" jelly-speck should be formable through the concurrence of conditions favouring such combination of their elements, and involving a change of force productive of their contractions and extensions, molecular attractions, and repulsions—and the sarcode has so become, from the period when its irrelative repetitions resulted in the vast indefinite masses of the "eozoon," exemplifying the earliest process of "formification" or organic crystallisation—than that all existing sarcodes or "protogenes" are the result of genetic descent from a germ or cell due to a primary act of miraculous interposition.

I prefer, while indulging in such speculations, to consider the various daily nomogeneously developed forms of protozoal or protistal jellies, sarcodes, and single-celled organisms, to have been as many roots from which the higher grades have ramified than that the origin of the whole organic creation is to be referred, as the Egyptian priests did that of the universe, to a single egg.

Amber or steel, when magnetised, seem to exercise "selection"; they do not attract all substances alike. A speck of protogenal jelly or sarcode, if alive, shows analogous relations to certain substances; but the soft yielding tissue allows the part next the attractive matter to move thereto, and then, by retraction, to draw such matter into the sarcodal mass, which overspreads, dissolves, and assimilates it. The term "living" in the one case is correlative with the term "magnetic" in the other. A man perceives ripe fruit; he stretches out his hand, [Pg 290] plucks, masticates, swallows, and digests it.

The question then arises whether the difference between such series of actions in the man and the attractive and assimilative movement of the amæba be greater or less than the difference between these acts of the amæba and the attracting and retaining acts of the magnet.

The question, I think, may be put with some confidence as to the quality of the ultimate reply whether the amæbal phenomena are so much more different, or so essentially different, from the magnetic phenomena than they are from the mammalian phenomena, as to necessitate the invocation of a special miracle for their manifestation. It is analogically conceivable that the same cause which has endowed His world with power convertible into magnetic, electric, thermotic and other forms or modes of force, has also added the conditions of conversion into the vital force.

From protozoa or protista to plants and animals the graduation is closer than from magnetised iron to vitalised sarcode. From reflex acts of the nervous system animals rise to sentient and volitional ones. And with the ascent are associated brain-cells progressively increasing in size and complexity. Thought relates to the "brain" of man as does electricity to the nervous "battery" of the torpedo; both are forms of force and the results of action of their respective organs.

Each sensation affects a cerebral fibre, and, in so affecting it, gives it the faculty of repeating the action, wherein memory consists and sensation in a dream.

If the hypothesis of an abstract entity produces psychological phenomena by playing upon the brain as a musician upon his instrument be rejected, and these phenomena be held to be the result of cerebral actions, an objection is made that the latter view is "materialistic" and adverse to the notion of an independent, indivisible, "immaterial," mental principle or soul.

But in the endeavour to comprehend clearly and explain the functions of the combination [Pg 291] of forces called "brain," the physiologist is hindered and troubled by the views of the nature of those cerebral forces which the needs of dogmatic theology have imposed on mankind. How long physiologists would have entertained the notion of a "life," or "vital principle," as a distinct entity if freed from this baneful influence may be questioned; but it can be truly affirmed that physiology has now established and does accept the truth of that statement of Locke—"the life, whether of a material or immaterial substance, is not the substance itself, but an affection of it."

RUDOLF VIRCHOW

Cellular Pathology

Rudolf Virchow, the son of a small farmer and shopkeeper, was born at Schivelbein, in Pomerania, on October 13, 1821. He graduated in medicine at Berlin, and was appointed lecturer at the University, but his political enthusiasm brought him into disfavour. In 1849 he was removed to Wurzburg, where he was made professor of pathology, but in 1856 he returned to Berlin as Professor and Director of the Pathological Institute, and there acquired world-wide fame. His celebrated work, "Cellular Pathology as based on Histology," published in 1856, marks a distinct epoch in the science. Virchow established what Lord Lister describes as "the true and fertile doctrine that every morbid structure consists of cells which have been derived from pre-existing cells as a progeny." Virchow was not only distinguished as a pathologist, he also gained considerable fame as an archæologist and anthropologist. During the wars of 1866 and 1870–71, he equipped and drilled hospital corps and ambulance squads, and superintended hospital trains and the Berlin military hospital. War over, he directed his attention to sanitation and the sewage problems of Berlin. Virchow was a voluminous author on a variety of subjects, perhaps his most well-known works being "Famine Fever" and "Freedom of Science." He died on September 5, 1902.

The Cell and the Tissues

THE chief point in the application of Histology to Pathology is to obtain recognition of the fact that the cell is really the ultimate morphological element in which there is any manifestation of life.

In certain respects animal cells differ from vegetable cells; but in essentials they are the same; both consist of matter of a nitrogenous nature.

When we examine a simple cell, we find we can distinguish morphological parts. In the first place, we find in the cell a round or oval body known as the nucleus. Occasionally the nucleus is stallate or angular; but as a rule, so long as cells have vital power, the nucleus maintains a nearly constant round or oval shape. The nucleus in its turn, in completely developed cells, very constantly encloses another structure within itself—the so-called nucleolus. With regard to the question of vital form, it cannot be said of the nucleolus that it appears to be an absolute essential, and in a considerable number of young cells it has as yet escaped detection. On the other hand, we regularly meet with it in fully-developed, older forms, and it therefore seems to mark a higher degree of development in the cell.

According to the view which was put forward in the first instance by Schleiden, and accepted by Schwann, the connection between the three co-existent cell-constituents was long thought to be of this nature: that the nucleolus was the first to show itself in the development of tissues, by separating out of a formative fluid (blastema, cyto-blastema), that it quickly attained a certain size, that then fine granules were precipitated out of the blastema and settled around it, and that about these there condensed a membrane. In this way a nucleus was formed about which new matter gradually gathered, and in due time produced a little membrane. This theory of the formation of the cell is designated the theory of free cell formation—a theory which has been now almost entirely abandoned.

It is highly probable that the nucleus plays an extremely important part within the cell—a part less connected with the function and specific office of the cell, than with its maintenance and multiplication as a living part. The specific (animal) function is most distinctly manifested in muscles, nerves, and gland cells, the peculiar actions of which—contraction, sensation, and secretion—appear to be connected in no direct manner with the nuclei. But the permanency of the cell as an element seems to depend on nucleus, for all cells which lose their nuclei quickly die, and break up, and disappear.

Every organism, whether vegetable or animal, must be regarded as a progressive total, [Pg 294] made up of a larger or smaller number of similar or dissimilar cells. Just as a tree constitutes a mass arranged in a definite manner in which, in every single part, in the leaves as in the root, in the trunk as in the blossom, cells are discovered to be the ultimate elements, so it is with the forms of animal life. Every animal presents itself as a sum of vital unities, every one of which manifests all the characteristics of life. The characteristics and unity of life cannot be limited to any one particular spot in an organism (for instance, to the brain of a man) but are to be found only in the definite, constantly recurring structure, which every individual element displays. A so-called individual always represents an arrangement of a social kind, in which a number of individual existences are mutually dependent, but in such a way that every element has its own special action, and even though it derive its stimulus to activity from other parts, yet alone affects the actual performance of its duties.

Between cells there is a greater or less amount of a homogeneous substance—the *intercellular substance*. According to Schwann, the intercellular substance was cyto-blastema destined for the development of new cells; I believe this is not so, I believe that the intercellular substance is dependent in a certain definite manner upon the cells, and that certain parts of it belong to one cell and parts to another.

At various times, fibres, globules, and elementary granules, have been regarded as histological starting-points. Now, however, we have established the general principle that no development of any kind begins *de novo* and that as spontaneous generation is impossible in the case of entire organisms, so also it is impossible in the case of individual parts. No cell can build itself up out of non-cellular material. Where a cell arises, there a cell must have previously existed (omnis cellula e cellula), just as an animal can spring only from an [Pg 295] animal, and a plant only from a plant. No developed tissues can be traced back to anything but a cell.

If we wish to classify tissues, a very simple division offers itself. We have (a) tissues which consist exclusively of cells, where cell lies close to cell. (b) Tissues in which the cells are separated by a certain amount of intercellular substance. (c) Tissues of a high or peculiar type, such as the nervous and muscular systems and vessels. An example of the first class is seen in the *epithelial* tissues. In these, cell lies close to cell, with nothing between.

The second class is exemplified in the *connective* tissues—tissues composed of intercellular substance in which at certain intervals cells lie embedded.

Muscles, nerves, and vessels form a somewhat heterogeneous group. The idea suggests itself that we have in all three structures to deal with real tubes filled with more or less movable contents. This view is, however, inadequate, since we cannot regard the blood as analogous to the medullary substance of the nerve, or contractile substance of a muscular fasciculus.

The elements of muscle have generally been regarded as the most simple. If we examine an ordinary red muscle, we find it to be composed of a number of cylindrical fibres, marked with transverse and longitudinal striæ. If, now, we add acetic acid, we discover also tolerably large nuclei with nucleoli. Thus we obtain an appearance like an elongated cell, and there is a tendency to regard the primitive fasciculus as having sprung from a single cell. To this view I am much inclined.

Pathological tissues arise from normal tissues; and there is no form of morbid growth which cannot in its elements be traced back to some model which had previously maintained an independent existence in the economy. A classification, also, of pathological growths may be made on exactly the same plan as that which we have suggested in the case [Pg 296] of the normal tissues.

Nutrition, Blood, and Lymph. Pus

Nutritive material is carried to the tissues by the blood; but the material is accepted by the tissues only in accordance with their requirements for the moment, and is conveyed to the individual districts in suitable quantities. The muscular elements of the arteries have the most important influence upon the quantity of the blood distributed, and their elastic elements ensure an equable stream; but it is chiefly the simple homogeneous membrane of the capillaries that influences the permeation of the fluids. Not all the peculiarities, however, in the interchange of nutritive material are to be attributed to the capillary wall, for no doubt there are chemical affinities which enable certain parts specially to attract certain substances from the blood. We know, for example, that a number of substances are introduced into the body which have special affinities for the nerve tissues, and that certain materials are excreted by certain organs. We are therefore compelled to consider the individual elements as active agents of the attraction. If the living element be altered by disease, then it loses its power of specific attraction.

I do not regard the blood as the cause of chronic dyscrasiæ; for I do not regard the blood as a permanent tissue independently regenerating and propagating itself, but as a fluid in a state of constant dependence upon other parts. I consider that every dyscrasia *is dependent upon a permanent supply of noxious ingredients from certain sources*. As a continual ingestion of injurious food is capable of vitiating the blood, in like manner persistent disease in a definite organ is able to furnish the blood with a continual supply of morbid materials.

The essential point, therefore, is to search for the *local sources* of the different dyscrasiæ [Pg 297] which cause disorders of the blood, for every permanent change which takes place in the condition of the circulating juices must be derived from definite organs or tissues.

The blood contains certain morphological elements. It contains a substance, *fibrine*, which appears as fibrillac when the blood clots, and red and colourless blood corpuscles.

The red blood corpuscles contain no nuclei except at certain periods of the development of the embyro. They are lighter or darker red according to the oxygen they contain. When treated with concentrated fluids they shrivel; when treated with diluted fluids they swell. They are rather coin-shaped, and when a drop of blood is quiet they are usually found aggregated in rows, like rouleaux of money.

The colourless corpuscles are much less numerous than the red corpuscles—only one to 300—but they are larger, and contain nuclei. When blood coagulates the white corpuscles sink more slowly and appear as a lighter coloured layer on the top of the clot.

Pus cells are very like colourless corpuscles, and the relation between the two has been much debated. A pus cell can be distinguished from a colourless blood cell only by its mode of origin. If it have an origin external to the blood, it must be pus; if it originate in the blood, it must be considered to be a blood cell.

In the early stages of its development, a white blood corpuscle is seen to modify by division; but in fully-developed blood such division is never seen. It is probable that colourless white corpuscles are given to the adult blood by the lymphatic glands. Every irritation of a part which is freely connected with lymphatic glands increases the number of colourless cells in the blood. Any excessive increase from this source I have designated *leucocytosis*.

In the first months of the embryo the red cell multiplies by division. In adult life the mode [Pg 298] of its multiplication is unknown. They, also, are probably formed in the lymphatic glands and spleen.

In a disease I have named *leukæmia*, the colourless blood cells increase in number enormously. In such cases there is always disease of the spleen, and very often of the lymphatic glands.

These facts can hardly, I think, be interpreted in any other manner than by supposing that the spleen and lymphatic glands are intimately concerned in the production of the formed elements of the blood.

By *pyæmia* is meant pus corpuscles in the blood. But most cases of so-called pyæmia are really cases in which there is an increase of white blood corpuscles, and it is doubtful whether such a condition as pus in the blood does ever occur. In the extremely rare cases, in which pus breaks through into the veins, purulent ingredients may, without doubt, be conveyed into the blood, but in such cases the introduction of pus occurs for the most part but once, and there is no persistent pyæmia. Even when clots in veins break down and form matter like pus, it will be found that the matter is not really pus, and contains no pus cells.

Chlorosis is a condition in which there is a diminution of the cellular elements of the blood, due probably to their deficient formation in the spleen and lymphatic glands.

The Vital Processes and Their Relation to Disease. Inflammation

The study of the histology of the nervous system shows that in all parts of the body a splitting up into a number of small centres takes place, and that nowhere does a single central point susceptible of anatomical demonstration exist from which the operations of the body are directed. We find in the nervous systems definite little cells which serve as centres [Pg 299] of motion, but we do not find any single ganglion cell in which alone all movement in the end originates. The most various individual motor apparatuses are connected with the most various individual motor ganglion cells. Sensations are certainly collected in definite ganglion cells. Still, among them, too, we do not find any single ganglion cell which can be in any way designated the centre of all sensation, but we again meet with a great number of very minute centres. All the operations which have their source in the nervous system, and there certainly are a very great number of them, do not allow us to recognise a unity anywhere else than in our own consciousness. An anatomical or physiological unity has at least as yet been nowhere demonstrated.

When we talk of life we mean vital activity. Now, every vital action supposes an excitation or irritation. The irritability of the part is the criterion by which we judge whether it be alive or not. Our notion of the death of a part is based upon nothing more or less than this—that we can no longer detect any irritability in it. If we now proceed with our analysis of what is to be included in the notion of excitability, we at once discover, that the different actions which can be provoked by the influence of any external agency are essentially of three kinds. The result of an excitation or irritation may, according to circumstances, be either a merely functional process, or a more or less increased nutrition of the part, *or* a formative process giving rise to a greater or less number of new elements. These differences manifest themselves more or less distinctly according as the particular tissues are more or less capable of responding to the one or other kinds of excitation. It certainly cannot be denied that the processes may not be distinctly defined, and that between the nutritive and formative processes, and also between the functional and nutritive ones there are transitional stages; still, when they are typically performed, there is a very marked [Pg 300] difference between them, and considerable differences in the internal changes undergone by the excited parts.

In inflammation all three irritative processes occur side by side. Indeed, we may frequently see that when the organ itself is made up of different parts, one part of the tissue undergoes functional or nutritive, another formative, changes. If we consider what happens in a muscle we see that a chemical or traumatic stimulus produces a functional irritation of the primitive fasciculi, with contraction of the muscle followed by nutritive changes. On the other hand, in the interstitial connective tissue which binds the individual fasciculi of the muscle together, real new formations are readily produced, commonly pus. In this manner the three forms of irritation may be distinguished in one part.

The formative process is always preceded by nutritive enlargement due to irritation of the part, and has no connection with irritation of the nerves. Of course there may be also an irritation of the nerves, but this, if we do not take function into account, has no causal connection with the processes going on in the tissue proper, but is merely a collateral effect of the original disturbance.

Besides these active processes of function, nutrition, and new formation, there occur passive processes. Passive processes are called those changes in cells whereby they either lose a portion of their substance, or are so completely destroyed, that a loss of substance, a diminution of the sum total of the constituents of the body is produced. To this class belong fatty degeneration of cells, affection of arteries, calcification, and ossification of arteries, amyloid degeneration, and so forth.

It will now be necessary to consider inflammation at more length. The theory of inflammation has passed through various stages. At first heat was considered as its essential and dominant feature, then redness, then exudative swelling; while the speculative [Pg 301] neuropathologists consider pain the *fons et origo* of the condition.

Personally, I believe that irritation must be taken as the starting-point in the consideration of inflammation. We cannot conceive of inflammation without an irritating stimulus, and the first question is, what conception we are to form of such a stimulus.

An inflammatory stimulus is a stimulus which acts either directly or through the medium of the blood upon the composition and constitution of a part in such a way as to enable it to attract to itself a larger quantity of matter than usual and to transform it according to circumstances. Every form of inflammation with which we are acquainted may be explained in this way. It may be assumed that inflammation begins from the moment that this increased absorption of matters into the tissue takes place, and the further transformation of these matters commences.

It must be noticed that hyperæmia is not the essential feature of inflammation, for inflammation occurs in non-vascular as well as in vascular parts, and the inflammatory processes are practically the same in both instances.

Nor is inflammatory exudation the essential feature of inflammation. I am of the opinion that there is no specific inflammatory exudation at all, but that the exudation we meet with is composed essentially of the material which has been generated in the inflamed part itself, through the change in its condition, and of the transuded fluid derived from the vessels. If, therefore, a part possess a great number of vessels, and particularly if they are superficial, it will be able to furnish an exudation, since the fluid which transudes from the blood conveys the special product of the tissue along with it to the surface. If this is not the case, there will be no exudation, but the whole process will be limited to the occurrence in the real substance of the tissue of the special changes which have been induced by the inflammatory [Pg 302] stimulus.

In this manner, two forms of inflammation can be distinguished, the *purely parenchymatous inflammation*, where the process runs its course in the interior of the tissue, without our being able to detect the presence of any free fluid which has escaped from the blood; and the secretory (exudative) inflammation, where an increased escape of fluid takes place from the blood, and conveys the peculiar parenchymatous matters along with it to the surface of the organs. That there are two kinds of inflammation is shown by the fact that they occur for the most part in different organs. Every parenchymatous inflammation tends to alter the histological and functional character of an organ. Every inflammation with free exudation generally affords a certain relief to the parts by conveying away from it a great part of the noxious matters with which it is clogged.

New Formations

I at present entirely reject the blastema doctrine in its original form, and in its place I put the *doctrine of the continuous development of tissues out of one another*. My first doubts of the blastema doctrine date from my researches on tubercle. I found the tubercles never exhibited a discernible exudation; but always organised elements unpreceded by amorphous matter. I also found that the discharge from scrofulous glands and from inflamed lymphatic glands is not an exudation capable of organisation but merely débris, developed from the ordinary cells of the glands.

Until, however, the cellular nature of the body had been demonstrated, it seemed necessary in some instances to postulate a blastema or exudation to account for certain new formations. But the moment I could show the universality of cells—the moment I could show that bone corpuscles were real cells, and that connective tissues contained cells—from [Pg 303] that moment cellular material for the building of new formations was apparent. In fact, the more observers increased the more distinctly was it shown that by far the greater number of new formations arise from the connective tissue. In almost all cases new formations may be seen to be formed by a process of ordinary cell division from previously existing cells. In some cases the cells continue to resemble the parent cells; in other cases they become different. All new formations built of cells which continue true to the parent type we may call homologous new formations; while those which depart from the parent type or undergo degenerative changes we may designate heterologous. In a narrower sense of the word heterologous new formations are alone destructive. The homologous ones may accidentally become very injurious, but still they do not possess what can properly be called a destructive or malignant character. On the other hand, every kind of heterologous formation whenever it has not its seat in entirely superficial parts, has a certain degree of malignity, and even superficial affections, though entirely confined to the most external layers of epidermis, may gradually exercise a very detrimental effect. Indeed, suppuration is of this nature, for suppuration is simply a process of proliferation by means of which cells are produced which do not acquire that degree of consolidation or permanent connection with each other which is necessary for the existence of the body. Pus is not the solvent of cells: but is itself dissolved tissues. A part becomes soft and liquefies, while suppurating, but it is not the pus which causes this softening; on the contrary, it is the pus which is produced as the result of the proliferation of tissues.

A suppurative change of this nature takes place in all heterologous new formations. The form of ulceration which is presented by cancer in its latest stages bears so great a resemblance to suppurative ulceration that the two things have long since been compared. [Pg 304] The difference between suppuration and suppuration lies in the differing duration of the life of different cells. A cancer cell is capable of existing longer than a pus corpuscle, and a cancerous tumour may last for months yet still contain the whole of its elements intact. We are as yet able in the case of very few elements to state with absolute certainty the average length of their life. But among all pathological new formations with fluid intercellular substance there is not a single one which is able to preserve its existence for any length of time—not a single one whose elements can become permanent constituents of the body, or exist as long as the individual. The tumour as a whole may last; but its individual elements perish. If we examine a tumour after it has existed for perhaps a year, we usually find that the elements first formed no longer exist in the centre; but that in the centre they are disintegrating, dissolved by fatty changes. If a tumour be seated on a surface, it often presents in the centre of its most prominent part a navel-like depression, and the parts under this display a dense cicatrix which no longer bears the original character of the new formation. Heterologous new formations must be considered parasitical in their nature, since every one of their elements will withdraw matters from the body which might be used for better purposes, and since even its first development implies the destruction of its parent structures.

In view of origin of new formations it were well to create a nomenclature showing their histological basis; but new names must not be introduced too suddenly, and it must be noted that there are certain tumours whose histological pedigree is still uncertain.

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FOOTNOTES:

[1] Azure transparent spheres conceived by the ancients to surround the earth one within another, and to carry the heavenly bodies in their revolutions.

[2] Book I., Prop. i. The areas which revolving bodies describe by radii drawn to an immovable centre of force do lie in the same immovable planes and are proportional to the times in which they are described.

Prop. ii. Every body that moves in any curve line described in a plane and by a radius drawn to a point either immovable or moving forward with a uniform rectilinear motion describes about that point areas proportional to the times is urged by a centripetal force directed to that point.

Prop. iii. Every body that, by a radius drawn to another body, howsoever moved, describes areas about that centre proportional to the times is urged by a force compounded out of the centripetal force tending to that other body and of all the accelerative force by which that other body is impelled.

[3] If the periodic times are in the sesquiplicate ratio of the radii, and therefore the velocities reciprocally in the subduplicate ratio of the radii, the centripetal forces will be in the duplicate ratio of the radii inversely; and the converse.

[4] *i.e.*, showing convexity when in such a position as that, to an observer on the earth, a line drawn between it and the sun would subtend an angle of *90°* or thereabouts.

Transcriber Notes:

Variant spelling and punctuation have been preserved.

Image quality of the Frontispiece is poor.