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ON THE

PHYSICAL BASIS OF LIFE.

BY

T. H. HUXLEY, LL. D., F. R. S.

NEW HAVEN, CONN.:

CHARLES C. CHATFIELD & CO.

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PUBLISHER'S NOTE.

The constant and increasing demand for this lecture, which has exhausted five large editions, indicates the interest which it has awakened in this country. This series will consist of the ablest lectures and essays of the best minds of Europe and America. It is the intention of the publisher to admit nothing into it that is not worthy of the careful thought of every educated person in America.

INTRODUCTION.

The following remarkable discourse was originally delivered in Edinburg, November 18th, 1868, as the first of a series of Sunday evening addresses, upon non-religious topics, instituted by the Rev. J. Cranbrook. It was subsequently published in London as the leading article in the *Fortnightly Review*, for February, 1869, and attracted so much attention that five editions of that number of the magazine have already been issued. It is now re-printed in this country, in permanent form, for the first time, and will doubtless prove of great interest to American readers. The author is Thomas Henry Huxley, of London, Professor of Natural History in the Royal School of Mines, and of Comparative Anatomy and Physiology in the Royal College of Surgeons. He is also President of the Geological Society of London. Although comparatively a young man, his numerous and valuable contributions to Natural Science entitle him to be considered one of the first of living Naturalists, especially in the departments of Zoölogy and Paleontology, to which he has mainly devoted himself. He is undoubtedly the ablest English advocate of Darwin's theory of the Origin of Species, particularly with reference to its application to the human race, which he believes to be nearly related to the higher apes. It is, indeed, through his discussion of this question that he is, perhaps, best known to the general public, as his late work entitled "Man's Place in Nature," and other writings on similar topics, have been very widely read in this country and in Europe. In the present lecture Professor Huxley discusses a kindred subject of no less interest and importance, and should have an equally candid hearing.

YALE COLLEGE, *March 30th*, 1869.

On the Physical Basis of Life.

In order to make the title of this discourse generally intelligible, I have translated the term "Protoplasm," which is the scientific name of the substance of which I am about to speak, by the words "the physical basis of life." I suppose that, to many, the idea that there is such a thing as a physical basis, or matter, of life may be novel—so widely spread is the conception of life as a something which works through matter, but is independent of it; and even those who are aware that matter and life are inseparably connected, may not be prepared for the conclusion plainly suggested by the phrase "the physical basis or matter of life," that there is some one kind of matter which is common to all living beings, and that their endless diversities are bound together by a physical, as well as an ideal, unity. In fact, when first apprehended, such a doctrine as this appears almost shocking to common sense. What, truly, can seem to be more obviously different from one another in faculty, in form, and in substance, than the various kinds of living beings? What community of faculty can there be between the brightly-colored lichen, which so nearly resembles a mere mineral incrustation of the bare rock on which it grows, and the painter, to whom it is instinct with beauty, or the botanist, whom it feeds with knowledge?

Again, think of the microscopic fungus—a mere infinitesimal ovoid particle, which finds space and duration enough to multiply into countless millions in the body of a living fly; and then of the wealth of foliage, the luxuriance of flower and fruit, which lies between this bald sketch of a plant and the giant pine of California, towering to the dimensions of a cathedral spire, or the Indian fig, which covers acres with its profound shadow, and endures while nations and empires come and go around its vast circumference! Or, turning to the other half of the world of life, picture to yourselves the great finner whale, hugest of beasts that live, or have lived, disporting his eighty or ninety feet of bone, muscle and blubber, with easy roll, among waves in which the stoutest ship that ever left dockyard would founder hopelessly; and contrast him with the invisible animalcules—mere gelatinous specks, multitudes of which could, in fact, dance upon the point of a needle with the same ease as the angels of the schoolmen could, in imagination. With these images before your minds, you may well ask what community of form, or structure, is there between the animalcule and the whale, or between the fungus and fig-tree? And, *a fortiori*, between all four?

Finally, if we regard substance, or material composition, what hidden bond can connect the flower which a girl wears in her hair and the blood which courses through her youthful veins; or, what is there in common between the dense and resisting mass of the oak, or the strong fabric of the tortoise, and those broad disks of glassy

jelly which may be seen pulsating through the waters of a calm sea, but which drain away to mere films in the hand which raises them out of their element? Such objections as these must, I think, arise in the mind of every one who ponders, for the first time, upon the conception of a single physical basis of life underlying all the diversities of vital existence; but I propose to demonstrate to you that, notwithstanding these apparent difficulties, a threefold unity—namely, a unity of power or faculty, a unity of form, and a unity of substantial composition—does pervade the whole living world. No very abstruse argumentation is needed, in the first place, to prove that the powers, or faculties, of all kinds of living matter, diverse as they may be in degree, are substantially similar in kind. Goethe has condensed a survey of all the powers of mankind into the well-known epigram:

"Warum treibt sich das Volk so und schreit? Es will sich ernähren
Kinder zeugen, und sie nähren so gut es vermag.
* * * * * * * *
Weiter bringt es kein Mensch, stell' er sich, wie er auch will."

In physiological language this means, that all the multifarious and complicated activities of man are comprehensible under three categories. Either they are immediately directed towards the maintenance and development of the body, or they effect transitory changes in the relative positions of parts of the body, or they tend towards the continuance of the species. Even those manifestations of intellect, of feeling, and of will, which we rightly name the higher faculties, are not excluded from this classification, inasmuch as to every one but the subject of them, they are known only as transitory changes in the relative positions of parts of the body. Speech, gesture, and every other form of human action are, in the long run, resolvable into muscular contraction, and muscular contraction is but a transitory change in the relative positions of the parts of a muscle. But the scheme, which is large enough to embrace the activities of the highest form of life, covers all those of the lower creatures. The lowest plant, or animalcule, feeds, grows and reproduces its kind. In addition, all animals manifest those transitory changes of form which we class under irritability and contractility; and it is more than probable, that when the vegetable world is thoroughly explored, we shall find all plants in possession of the same powers, at one time or other of their existence. I am not now alluding to such phenomena, at once rare and conspicuous, as those exhibited by the leaflets of the sensitive plant, or the stamens of the barberry, but to much more widely-spread, and, at the same time, more subtle and hidden, manifestations of vegetable contractility. You are doubtless aware that the common nettle owes its stinging property to the innumerable stiff and needle-like, though exquisitely delicate, hairs which cover its surface. Each stinging-needle tapers from a broad base to a slender summit, which, though rounded at the end, is of such microscopic fineness that it readily penetrates, and breaks off in, the skin. The whole hair consists of a very delicate outer case of wood, closely applied to the inner surface of which is a layer of semi-fluid matter, full of innumerable granules of extreme minuteness. This semi-fluid lining is protoplasm, which thus constitutes a kind of bag, full of a limpid liquid,

and roughly corresponding in form with the interior of the hair which it fills. When viewed with a sufficiently high magnifying power, the protoplasmic layer of the nettle hair is seen to be in a condition of unceasing activity. Local contractions of the whole thickness of its substance pass slowly and gradually from point to point, and give rise to the appearance of progressive waves, just as the bending of successive stalks of corn by a breeze produces the apparent billows of a corn-field. But, in addition to these movements, and independently of them, the granules are driven, in relatively rapid streams, through channels in the protoplasm which seem to have a considerable amount of persistence. Most commonly, the currents in adjacent parts of the protoplasm take similar directions; and, thus, there is a general stream up one side of the hair and down the other. But this does not prevent the existence of partial currents which take different routes; and, sometimes, trains of granules may be seen coursing swiftly in opposite directions, within a twenty-thousandth of an inch of one another; while, occasionally, opposite streams come into direct collision, and, after a longer or shorter struggle, one predominates. The cause of these currents seem to lie in contractions of the protoplasm which bounds the channels in which they flow, but which are so minute that the best microscopes show only their effects, and not themselves.

The spectacle afforded by the wonderful energies prisoned within the compass of the microscopic hair of a plant, which we commonly regard as a merely passive organism, is not easily forgotten by one who has watched its display continued hour after hour, without pause or sign of weakening. The possible complexity of many other organic forms, seemingly as simple as the protoplasm of the nettle, dawns upon one; and the comparison of such a protoplasm to a body with an internal circulation, which has been put forward by an eminent physiologist, loses much of its startling character. Currents similar to those of the hairs of the nettle have been observed in a great multitude of very different plants, and weighty authorities have suggested that they probably occur, in more or less perfection, in all young vegetable cells. If such be the case, the wonderful noonday silence of a tropical forest is, after all, due only to the dullness of our hearing; and could our ears catch the murmur of these tiny maelstroms, as they whirl in the innumerable myriads of living cells which constitute each tree, we should be stunned, as with the roar of a great city.

Among the lower plants, it is the rule rather than the exception, that contractility should be still more openly manifested at some periods of their existence. The protoplasm of *Algæ* and *Fungi* becomes, under many circumstances, partially, or completely, freed from its woody case, and exhibits movements of its whole mass, or is propelled by the contractility of one or more hair-like prolongations of its body, which are called vibratile cilia. And, so far as the conditions of the manifestation of the phenomena of contractility have yet been studied, they are the same for the plant as for the animal. Heat and electric shocks influence both, and in the same way, though it may be in different degrees. It is by no means my intention to suggest that there is no

difference in faculty between the lowest plant and the highest, or between plants and animals. But the difference between the powers of the lowest plant, or animal, and those of the highest is one of degree, not of kind, and depends, as Milne-Edwards long ago so well pointed out, upon the extent to which the principle of the division of labor is carried out in the living economy. In the lowest organism all parts are competent to perform all functions, and one and the same portion of protoplasm may successively take on the function of feeding, moving, or reproducing apparatus. In the highest, on the contrary, a great number of parts combine to perform each function, each part doing its allotted share of the work with great accuracy and efficiency, but being useless for any other purpose. On the other hand, notwithstanding all the fundamental resemblances which exist between the powers of the protoplasm in plants and in animals, they present a striking difference (to which I shall advert more at length presently,) in the fact that plants can manufacture fresh protoplasm out of mineral compounds, whereas animals are obliged to procure it ready made, and hence, in the long run, depend upon plants. Upon what condition this difference in the powers of the two great divisions of the world of life depends, nothing is at present known.

With such qualification as arises out of the last-mentioned fact, it may be truly said that the acts of all living things are fundamentally one. Is any such unity predicable of their forms? Let us seek in easily verified facts for a reply to this question. If a drop of blood be drawn by pricking one's finger, and viewed with proper precautions and under a sufficiently high microscopic power, there will be seen, among the innumerable multitude of little, circular, discoidal bodies, or corpuscles, which float in it and give it its color, a comparatively small number of colorless corpuscles, of somewhat larger size and very irregular shape. If the drop of blood be kept at the temperature of the body, these colorless corpuscles will be seen to exhibit a marvelous activity, changing their forms with great rapidity, drawing in and thrusting out prolongations of their substance, and creeping about as if they were independent organisms. The substance which is thus active is a mass of protoplasm, and its activity differs in detail, rather than in principle, from that of the protoplasm of the nettle. Under sundry circumstances the corpuscle dies and becomes distended into a round mass, in the midst of which is seen a smaller spherical body, which existed, but was more or less hidden, in the living corpuscle, and is called its *nucleus*. Corpuscles of essentially similar structure are to be found in the skin, in the lining of the mouth, and scattered through the whole frame work of the body. Nay, more; in the earliest condition of the human organism, in that state in which it has just become distinguishable from the egg in which it arises, it is nothing but an aggregation of such corpuscles, and every organ of the body was, once, no more than such an aggregation. Thus a nucleated mass of protoplasm turns out to be what may be termed the structural unit of the human body. As a matter of fact, the body, in its earliest state, is a mere multiple of such units; and, in its perfect condition, it is a multiple of such units, variously

modified. But does the formula which expresses the essential structural character of the highest animal cover all the rest, as the statement of its powers and faculties covered that of all others? Very nearly. Beast and fowl, reptile and fish, mollusk, worm, and polype, are all composed of structural units of the same character, namely, masses of protoplasm with a nucleus. There are sundry very low animals, each of which, structurally, is a mere colorless blood-corpuscle, leading an independent life. But, at the very bottom of the animal scale, even this simplicity becomes simplified, and all the phenomena of life are manifested by a particle of protoplasm without a nucleus. Nor are such organisms insignificant by reason of their want of complexity. It is a fair question whether the protoplasm of those simplest forms of life, which people an immense extent of the bottom of the sea, would not outweigh that of all the higher living beings which inhabit the land, put together. And in ancient times, no less than at the present day, such living beings as these have been the greatest of rock builders.

What has been said of the animal world is no less true of plants. Imbedded in the protoplasm at the broad, or attached, end of the nettle hair, there lies a spheroidal nucleus. Careful examination further proves that the whole substance of the nettle is made up of a repetition of such masses of nucleated protoplasm, each contained in a wooden case, which is modified in form, sometimes into a woody fibre, sometimes into a duct or spiral vessel, sometimes into a pollen grain, or an ovule. Traced back to its earliest state, the nettle arises as the man does, in a particle of nucleated protoplasm. And in the lowest plants, as in the lowest animals, a single mass of such protoplasm may constitute the whole plant, or the protoplasm may exist without a nucleus. Under these circumstances it may well be asked, how is one mass of non-nucleated protoplasm to be distinguished from another? why call one "plant" and the other "animal?" The only reply is that, so far as form is concerned, plants and animals are not separable, and that, in many cases, it is a mere matter of convention whether we call a given organism an animal or a plant.

There is a living body called *Æthalium septicum*, which appears upon decaying vegetable substances, and in one of its forms, is common upon the surface of tan pits. In this condition it is, to all intents and purposes, a fungus, and formerly was always regarded as such; but the remarkable investigations of De Bary have shown that, in another condition, the *Æthalium* is an actively locomotive creature, and takes in solid matters, upon which, apparently, it feeds, thus exhibiting the most characteristic feature of animality. Is this a plant, or is it an animal? Is it both, or is it neither? Some decide in favor of the last supposition, and establish an intermediate kingdom, a sort of biological No Man's Land for all these questionable forms. But, as it is admittedly impossible to draw any distinct boundary line between this no man's land and the vegetable world on the one hand, or the animal, on the other, it appears to me that this proceeding merely doubles the difficulty which, before, was single. Protoplasm, simple or nucleated, is the formal basis of all life. It is the clay of the potter;

which, bake it and paint it as he will, remains clay, separated by artifice, and not by nature, from the commonest brick or sun-dried clod. Thus it becomes clear that all living powers are cognate, and that all living forms are fundamentally of one character.

The researches of the chemist have revealed a no less striking uniformity of material composition in living matter. In perfect strictness, it is true that chemical investigation can tell us little or nothing, directly, of the composition of living matter, inasmuch as such matter must needs die in the act of analysis, and upon this very obvious ground, objections, which I confess seem to me to be somewhat frivolous, have been raised to the drawing of any conclusions whatever respecting the composition of actually living matter from that of the dead matter of life, which alone is accessible to us. But objectors of this class do not seem to reflect that it is also, in strictness, true that we know nothing about the composition of any body whatever, as it is. The statement that a crystal of calc-spar consists of carbonate of lime, is quite true, if we only mean that, by appropriate processes, it may be resolved into carbonic acid and quicklime. If you pass the same carbonic acid over the very quicklime thus obtained, you will obtain carbonate of lime again; but it will not be calc-spar, nor anything like it. Can it, therefore, be said that chemical analysis teaches nothing about the chemical composition of calc-spar? Such a statement would be absurd; but it is hardly more so than the talk one occasionally hears about the uselessness of applying the results of chemical analysis to the living bodies which have yielded them. One fact, at any rate, is out of reach of such refinements, and this is, that all the forms of protoplasm which have yet been examined contain the four elements, carbon, hydrogen, oxygen, and nitrogen, in very complex union, and that they behave similarly towards several re-agents. To this complex combination, the nature of which has never been determined with exactness, the name of Protein has been applied. And if we use this term with such caution as may properly arise out of our comparative ignorance of the things for which it stands, it may be truly said, that all protoplasm is proteinaceous; or, as the white, or albumen, of an egg is one of the commonest examples of a nearly pure proteine matter, we may say that all living matter is more or less albuminoid. Perhaps it would not yet be safe to say that all forms of protoplasm are affected by the direct action of electric shocks; and yet the number of cases in which the contraction of protoplasm is shown to be affected by this agency increases, every day. Nor can it be affirmed with perfect confidence that all forms of protoplasm are liable to undergo that peculiar coagulation at the temperature of 40 degrees—50 degrees centigrade, which has been called "heat-stiffening," though Kühne's beautiful researches have proved this occurrence to take place in so many and such diverse living beings, that it is hardly rash to expect that the law holds good for all. Enough has, perhaps, been said to prove the existence of a general uniformity in the character of the protoplasm, or physical basis of life, in whatever group of living beings it may be studied. But it will be understood that this general uniformity by no means excludes any amount of

special modifications of the fundamental substance. The mineral, carbonate of lime, assumes an immense diversity of characters, though no one doubts that under all these Protean changes it is one and the same thing.

And now, what is the ultimate fate, and what the origin of the matter of life? Is it, as some of the older naturalists supposed, diffused throughout the universe in molecules, which are indestructible and unchangeable in themselves; but, in endless transmigration, unite in innumerable permutations, into the diversified forms of life we know? Or, is the matter of life composed of ordinary matter, differing from it only in the manner in which its atoms are aggregated? Is it built up of ordinary matter, and again resolved into ordinary matter when its work is done? Modern science does not hesitate a moment between these alternatives. Physiology writes over the portals of life,

"Debemur morti nos nostraque,"

with a profounder meaning than the Roman poet attached to that melancholy line. Under whatever disguise it takes refuge, whether fungus or oak, worm or man, the living protoplasm not only ultimately dies and is resolved into its mineral and lifeless constituents, but is always dying, and, strange as the paradox may sound, could not live unless it died. In the wonderful story of the "Peau de Chagrin," the hero becomes possessed of a magical wild ass's skin, which yields him the means of gratifying all his wishes. But its surface represents the duration of the proprietor's life; and for every satisfied desire the skin shrinks in proportion to the intensity of fruition, until at length life and the last handbreadth of the

"Peau de Chagrin," disappear with the gratification of a last wish. Balzac's studies had led him over a wide range of thought and speculation, and his shadowing forth of physiological truth in this strange story may have been intentional. At any rate, the matter of life is a veritable "Peau de Chagrin," and for every vital act it is somewhat the smaller. All work implies waste, and the work of life results, directly or indirectly, in the waste of protoplasm. Every word uttered by a speaker costs him some physical loss; and, in the strictest sense, he burns that others may have light — so much eloquence, so much of his body resolved into carbonic acid, water and urea. It is clear that this process of expenditure cannot go on forever. But, happily, the protoplasmic *peau de chagrin* differs from Balzac's in its capacity of being repaired, and brought back to its full size, after every exertion. For example, this present lecture, whatever its intellectual worth to you, has a certain physical value to me, which is, conceivably, expressible by the number of grains of protoplasm and other bodily substance wasted in maintaining my vital processes during its delivery. My *peau de chagrin* will be distinctly smaller at the end of the discourse than it was at the beginning. By-and-by, I shall probably have recourse to the substance commonly called mutton, for the purpose of stretching it back to its original size. Now this mutton was once the living protoplasm, more or less modified, of another animal—a sheep. As I shall eat it, it is the same matter altered, not only by death, but by exposure to sundry artificial operations in the process of cooking. But these changes, whatever be their extent,

have not rendered it incompetent to resume its old functions as matter of life. A singular inward laboratory, which I possess, will dissolve a certain portion of the modified protoplasm, the solution so formed will pass into my veins; and the subtle influences to which it will then be subjected will convert the dead protoplasm into living protoplasm, and transubstantiate sheep into man. Nor is this all. If digestion were a thing to be trifled with, I might sup upon lobster, and the matter of life of the crustacean would undergo the same wonderful metamorphosis into humanity. And were I to return to my own place by sea, and undergo shipwreck, the crustacea might, and probably would, return the compliment, and demonstrate our common nature by turning my protoplasm into living lobster. Or, if nothing better were to be had, I might supply my wants with mere bread, and I should find the protoplasm of the wheat-plant to be convertible into man, with no more trouble than that of the sheep, and with far less, I fancy, than that of the lobster. Hence it appears to be a matter of no great moment what animal, or what plant, I lay under contribution for protoplasm, and the fact speaks volumes for the general identity of that substance in all living beings. I share this catholicity of assimilation with other animals, all of which, so far as we know, could thrive equally well on the protoplasm of any of their fellows, or of any plant; but here the assimilative powers of the animal world cease.

A solution of smelling-salts in water with an infinitesimal proportion of some other saline matters, contains all the elementary bodies which enter into the composition of protoplasm; but, as I need hardly say, a hogs-head of that fluid would not keep a hungry man from starving, nor would it save any animal whatever from a like fate. An animal cannot make protoplasm, but must take it ready-made from some other animal, or some plant—the animal's highest feat of constructive chemistry being to convert dead protoplasm into that living matter of life which is appropriate to itself. Therefore, in seeking for the origin of protoplasm, we must eventually turn to the vegetable world. The fluid containing carbonic acid, water, and ammonia, which offers such a barmecide feast to the animal, is a table richly spread to multitudes of plants; and with a due supply of only such materials, many a plant will not only maintain itself in vigor, but grow and multiply until it has increased a million-fold, or a million million-fold, the quantity of protoplasm which it originally possessed; in this way building up the matter of life, to an indefinite extent, from the common matter of the universe. Thus the animal can only raise the complex substance of dead protoplasm to the higher power, as one may say, of living protoplasm; while the plant can raise the less complex substances—carbonic acid, water, and ammonia—to the same stage of living protoplasm, if not to the same level. But the plant also has its limitations. Some of the fungi, for example, appear to need higher compounds to start with, and no known plant can live upon the uncompounded elements of protoplasm. A plant supplied with pure carbon, hydrogen, oxygen, and nitrogen, phosphorus, sulphur, and the like, would as infallibly die as the animal in his bath of smelling-salts, though it would be surrounded by all the constituents of protoplasm. Nor,

indeed, need the process of simplification of vegetable food be carried so far as this, in order to arrive at the limit of the plant's thaumaturgy.

Let water, carbonic acid, and all the other needful constituents, be supplied without ammonia, and an ordinary plant will still be unable to manufacture protoplasm. Thus the matter of life, so far as we know it (and we have no right to speculate on any other) breaks up in consequence of that continual death which is the condition of its manifesting vitality, into carbonic acid, water, and ammonia, which certainly possess no properties but those of ordinary matter; and out of these same forms of ordinary matter and from none which are simpler, the vegetable world builds up all the protoplasm which keeps the animal world agoing. Plants are the accumulators of the power which animals distribute and disperse.

But it will be observed, that the existence of the matter of life depends on the preëxistence of certain compounds, namely, carbonic acid, water, and ammonia. Withdraw any one of these three from the world and all vital phenomena come to an end. They are related to the protoplasm of the plant, as the protoplasm of the plant is to that of the animal. Carbon, hydrogen, oxygen, and nitrogen are all lifeless bodies. Of these, carbon and oxygen unite in certain proportions and under certain conditions, to give rise to carbonic acid; hydrogen and oxygen produce water; nitrogen and hydrogen give rise to ammonia. These new compounds, like the elementary bodies of which they are composed, are lifeless. But when they are brought together, under certain conditions they give rise to the still more complex body, protoplasm, and this protoplasm exhibits the phenomena of life. I see no break in this series of steps in molecular complication, and I am unable to understand why the language which is applicable to any one term of the series may not be used to any of the others. We think fit to call different kinds of matter carbon, oxygen, hydrogen, and nitrogen, and to speak of the various powers and activities of these substances as the properties of the matter of which they are composed. When hydrogen and oxygen are mixed in a certain proportion, and the electric spark is passed through them, they disappear and a quantity of water, equal in weight to the sum of their weights, appears in their place. There is not the slightest parity between the passive and active powers of the water and those of the oxygen and hydrogen which have given rise to it. At 32 degrees Fahrenheit, and far below that temperature, oxygen and hydrogen are elastic gaseous bodies, whose particles tend to rush away from one another with great force. Water, at the same temperature, is a strong though brittle solid, whose particles tend to cohere into definite geometrical shapes, and sometimes build up frosty imitations of the most complex forms of vegetable foliage. Nevertheless we call these, and many other strange phenomena, the properties of the water, and we do not hesitate to believe that, in some way or another, they result from the properties of the component elements of the water. We do not assume that a something called "aquosity" entered into and took possession of the oxide of hydrogen as soon as it was formed, and then guided the aqueous

particles to their places in the facets of the crystal, or amongst the leaflets of the hoar-frost. On the contrary, we live in the hope and in the faith that, by the advance of molecular physics, we shall by-and-by be able to see our way as clearly from the constituents of water to the properties of water, as we are now able to deduce the operations of a watch from the form of its parts and the manner in which they are put together. Is the case in any way changed when carbonic acid, water and ammonia disappear, and in their place, under the influence of preëxisting living protoplasm, an equivalent weight of the matter of life makes its appearance? It is true that there is no sort of parity between the properties of the components and the properties of the resultant, but neither was there in the case of the water. It is also true that what I have spoken of as the influence of preëxisting living matter is something quite unintelligible; but does any body quite comprehend the *modus operandi* of an electric spark, which traverses a mixture of oxygen and hydrogen? What justification is there, then, for the assumption of the existence in the living matter of a something which has no representative or correlative in the not living matter which gave rise to it? What better philosophical status has "vitality" than "aquosity?" And why should "vitality" hope for a better fate than the other "itys" which have disappeared since Martinus Scriblerus accounted for the operation of the meat-jack by its inherent "meat roasting quality," and scorned the "materialism" of those who explained the turning of the spit by a certain mechanism worked by the draught of the chimney? If scientific language is to possess a definite and constant signification whenever it is employed, it seems to me that we are logically bound to apply to the protoplasm, or physical basis of life, the same conceptions as those which are held to be legitimate elsewhere. If the phenomena exhibited by water are its properties, so are those presented by protoplasm, living or dead, its properties. If the properties of water may be properly said to result from the nature and disposition of its component molecules, I can find no intelligible ground for refusing to say that the properties of protoplasm result from the nature and disposition of its molecules. But I bid you beware that, in accepting these conclusions, you are placing your feet on the first rung of a ladder which, in most people's estimation, is the reverse of Jacob's, and leads to the antipodes of heaven. It may seem a small thing to admit that the dull vital actions of a fungus, or a foraminifer, are the properties of their protoplasm, and are the direct results of the nature of the matter of which they are composed.

But if, as I have endeavored to prove to you, their protoplasm is essentially identical with, and most readily converted into, that of any animal, I can discover no logical halting place between the admission that such is the case, and the further concession that all vital action may, with equal propriety, be said to be the result of the molecular forces of the protoplasm which displays it. And if so, it must be true, in the same sense and to the same extent, that the thoughts to which I am now giving utterance, and your thoughts regarding them, are the expression of molecular changes in that matter of life which is the source of our other vital phenomena. Past

experience leads me to be tolerably certain that, when the propositions I have just placed before you are accessible to public comment and criticism, they will be condemned by many zealous persons, and perhaps by some few of the wise and thoughtful. I should not wonder if "gross and brutal materialism" were the mildest phrase applied to them in certain quarters. And most undoubtedly the terms of the propositions are distinctly materialistic. Nevertheless, two things are certain: the one, that I hold the statements to be substantially true; the other, that I, individually, am no materialist, but, on the contrary, believe materialism to involve grave philosophical error.

This union of materialistic terminology with the repudiation of materialistic philosophy I share with some of the most thoughtful men with whom I am acquainted. And, when I first undertook to deliver the present discourse, it appeared to me to be a fitting opportunity to explain how such an union is not only consistent with, but necessitated by sound logic. I purposed to lead you through the territory of vital phenomena to the materialistic slough in which you find yourselves now plunged, and then to point out to you the sole path by which, in my judgment, extrication is possible. An occurrence, of which I was unaware until my arrival here last night, renders this line of argument singularly opportune. I found in your papers the eloquent address "On the Limits of Philosophical Inquiry," which a distinguished prelate of the English Church delivered before the members of the Philosophical Institution on the previous day. My argument, also, turns upon this very point of limits of philosophical inquiry; and I cannot bring out my own views better than by contrasting them with those so plainly, and, in the main, fairly stated by the Archbishop of York. But I may be permitted to make a preliminary comment upon an occurrence that greatly astonished me. Applying the name of "the New Philosophy" to that estimate of the limits of philosophical inquiry which I, in common with many other men of science, hold to be just, the Archbishop opens his address by identifying this "new philosophy" with the positive philosophy of M. Comte (of whom he speaks as its "founder"); and then proceeds to attack that philosopher and his doctrine vigorously. Now, so far as I am concerned, the most Reverend prelate might dialectically hew M. Comte in pieces, as a modern Agag, and I should not attempt to stay his hand. In so far as my study of what specially characterizes the Positive Philosophy has led me, I find therein little or nothing of any scientific value, and a great deal which is as thoroughly antagonistic to the very essence of science as anything in ultramontane Catholicism. In fact, M. Comte's philosophy in practice might be compendiously described as Catholicism *minus* Christianity. But what has Comptism to do with the "New Philosophy," as the Archbishop defines it in the following passage?

"Let me briefly remind you of the leading principles of this new philosophy.

"All knowledge is experience of facts acquired by the senses. The traditions of older philosophies have obscured our experience by mixing with it much that the senses cannot observe, and until these additions are discarded our knowledge is impure. Thus, metaphysics tells us that one fact which we observe is a cause, and another is the effect of that cause; but upon a rigid analysis we find that our senses observe nothing of cause or effect; they observe, first, that one fact succeeds another, and, after some opportunity, that this fact has never failed to follow—that for cause and effect we should substitute invariable succession. An older philosophy teaches us to define an object by distinguishing its essential from its accidental qualities; but experience knows nothing of essential and accidental; she sees only that certain marks attach to an object, and, after many observations, that some of them attach invariably, whilst others may at times be absent. * * * * * As all knowledge is relative, the notion of anything being necessary must be banished with other traditions."

There is much here that expresses the spirit of the "New Philosophy," if by that term be meant the spirit of modern science; but I cannot but marvel that the assembled wisdom and learning of Edinburg should have uttered no sign of dissent, when Comte was declared to be the founder of these doctrines. No one will accuse Scotchmen of habitually forgetting their great countrymen; but it was enough to make David Hume turn in his grave, that here, almost within ear-shot of his house, an instructed audience should have listened, without a murmur, while his most characteristic doctrines were attributed to a French writer of fifty years later date, in whose dreary and verbose pages we miss alike the vigor of thought and the exquisite clearness of the style of the man whom I make bold to term the most acute thinker of the eighteenth century—even though that century produced Kant. But I did not come to Scotland to vindicate the honor of one of the greatest men she has ever produced. My business is to point out to you that the only way of escape out of the crass materialism in which we just now landed is the adoption and strict working out of the very principles which the Archbishop holds up to reprobation.

Let us suppose that knowledge is absolute, and not relative, and therefore, that our conception of matter represents that which it really is. Let us suppose, further, that we do know more of cause and effect than a certain definite order of succession among facts, and that we have a knowledge of the necessity of that succession—and hence, of necessary laws—and I, for my part, do not see what escape there is from utter materialism and necessitarianism. For it is obvious that our knowledge of what we call the material world is, to begin with, at least as certain and definite as that of the spiritual world, and that our acquaintance with the law is of as old a date as our knowledge of spontaneity.

Further, I take it to be demonstrable that it is utterly impossible to prove that anything whatever may not be the effect of a material and necessary cause, and that human logic is equally incompetent to prove that any act is really spontaneous. A really spontaneous act is one which, by the assumption, has no cause; and the attempt to prove such a negative as this is, on the face of the matter, absurd. And while it is thus a philosophical impossibility to demonstrate that any given phenomenon is not the effect of a material cause, any

one who is acquainted with the history of science will admit, that its progress has, in all ages, meant, and now more than ever means, the extension of the province of what we call matter and causation, and the concomitant gradual banishment from all regions of human thought of what we call spirit and spontaneity.

I have endeavored, in the first part of this discourse, to give you a conception of the direction towards which modern physiology is tending; and I ask you, what is the difference between the conception of life as the product of a certain disposition of material molecules, and the old notion of an Archæus governing and directing blind matter within each living body, except this—that here, as elsewhere, matter and law have devoured spirit and spontaneity? And as surely as every future grows out of past and present, so will the physiology of the future gradually extend the realm of matter and law until it is coëxtensive with knowledge, with feeling, and with action. The consciousnes of this great truth weighs like a nightmare, I believe, upon many of the best minds of these days. They watch what they conceive to be the progress of materialism, in such fear and powerless anger as a savage feels, when, during an eclipse, the great shadow creeps over the face of the sun. The advancing tide of matter threatens to drown their souls; the tightening grasp of law impedes their freedom; they are alarmed lest man's moral nature be debased by the increase of his wisdom.

If the "New Philosophy" be worthy of the reprobation with which it is visited, I confess their fears seem to me to be well founded. While, on the contrary, could

David Hume be consulted, I think he would smile at their perplexities, and chide them for doing even as the heathen, and falling down in terror before the hideous idols their own hands have raised. For, after all, what do we know of this terrible "matter," except as a name for the unknown and hypothetical cause of states of our own consciousness? And what do we know of that "spirit" over whose threatened extinction by matter a great lamentation is arising, like that which was heard at the death of Pan, except that it is also a name for an unknown and hypothetical cause, or condition, of states of consciousness? In other words, matter and spirit are but names for the imaginary substrata of groups of natural phenomena. And what is the dire necessity and "iron" law under which men groan? Truly, most gratuitously invented bugbears. I suppose if there be an "iron" law, it is that of gravitation; and if there be a physical necessity, it is that a stone, unsupported, must fall to the ground. But what is all we really know and can know about the latter phenomenon? Simply, that, in all human experience, stones have fallen to the ground under these conditions; that we have not the smallest reason for believing that any stone so circumstanced will not fall to the ground, and that we have, on the contrary, every reason to believe that it will so fall. It is very convenient to indicate that all the conditions of belief have been fulfilled in this case, by calling the statement that unsupported stones will fall to the ground, "a law of nature." But when, as commonly happens, we change will into must, we introduce an idea of necessity which most assuredly does not lie in the observed facts, and has no

warranty that I can discover elsewhere. For my part, I utterly repudiate and anathematize the intruder. Fact, I know; and Law I know; but what is this Necessity, save an empty shadow of my own mind's throwing? But, if it is certain that we can have no knowledge of the nature of either matter or spirit, and that the notion of necessity is something illegitimately thrust into the perfectly legitimate conception of law, the materialistic position that there is nothing in the world but matter, force, and necessity, is as utterly devoid of justification as the most baseless of theological dogmas.

The fundamental doctrines of materialism, like those of spiritualism, and most other "isms," lie outside "the limits of philosophical inquiry," and David Hume's great service to humanity is his irrefragable demonstration of what these limits are. Hume called himself a sceptic, and therefore others cannot be blamed if they apply the the same title to him; but that does not alter the fact that the name, with its existing implications, does him gross injustice. If a man asks me what the politics of the inhabitants of the moon are, and I reply that I do not know; that neither I, nor any one else have any means of knowing; and that, under these circumstances I decline to trouble myself about the subject at all, I do not think he has any right to call me a sceptic. On the contrary, in replying thus, I conceive that I am simply honest and truthful, and show a proper regard for the economy of time. So Hume's strong and subtle intellect takes up a great many problems about which we are naturally curious, and shows us that they are essentially questions of lunar politics, in their essence incapable of being answered, and therefore not worth the attention of men who have work to do in the world. And thus ends one of his essays:

"If we take in hand any volume of Divinity, or school metaphysics, for instance, let us ask, *Does it contain any abstract reasoning concerning quantity or number?* No. *Does it contain any experimental reasoning concerning matter of fact and existence?* No. Commit it then to the flames; for it can contain nothing but sophistry and illusion."

Permit me to enforce this most wise advice. Why trouble ourselves about matters of which, however important they may be, we do know nothing, and can know nothing? We live in a world which is full of misery and ignorance, and the plain duty of each and all of us is to try to make the little corner he can influence somewhat less miserable and somewhat less ignorant than it was before he entered it. To do this effectually it is necessary to be fully possessed of only two beliefs: the first, that the order of nature is ascertainable by our faculties to an extent which is practically unlimited; the second, that our volition counts for something as a condition of the course of events. Each of these beliefs can be verified experimentally, as often as we like to try. Each, therefore, stands upon the strongest foundation upon which any belief can rest; and forms one of our highest truths.

If we find that the ascertainment of the order of nature is facilitated by using one terminology, or one set of symbols, rather than another, it is our clear duty to use the former, and no harm can accrue so long as we bear in mind that we are dealing merely with terms and symbols.

In itself it is of little moment whether we express the phenomena of matter in terms of spirit, or the phenomena of spirit in terms of matter; matter may be regarded as a form of thought, thought may be regarded as a property of matter—each statement has a certain relative truth. But with a view to the progress of science, the materialistic terminology is in every way to be preferred. For it connects thought with the other phenomena of the universe, and suggests inquiry into the nature of those physical conditions or concomitants of thought, which are more or less accessible to us, and a knowledge of which may, in future, help us to exercise the same kind of control over the world of thought as we already possess in respect of the material world; whereas, the alternative, or spiritualistic, terminology is utterly barren, and leads to nothing but obscurity and confusion of ideas. Thus there can be little doubt that the further science advances, the more extensively and consistently will all the phenomena of nature be represented by materialistic formulæ and symbols. But the man of science, who, forgetting the limits of philosophical inquiry, slides from these formulæ and symbols into what is commonly understood by materialism, seems to me to place himself on a level with the mathematician, who should mistake the *x's* and *y's*, with which he works his problems, for real entities—and with this further disadvantage as compared with the mathematician, that the blunders of the latter are of no practical consequence, while the errors of systematic materialism may paralyze the energies and destroy the beauty of a life.

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ON THE

HYPOTHESIS OF EVOLUTION:

PHYSICAL AND METAPHYSICAL.

"Man shall not live by bread alone, but by every word that proceedeth out of the mouth of God shall man live."

There is apparently considerable repugnance in the minds of many excellent people to the acceptance, or even consideration, of the hypothesis of development, or that of the gradual creation by descent, with modification from the simplest beginnings, of the different forms of the organic world. This objection probably results from two considerations: first, that the human species is certainly involved, and man's descent from an ape asserted; and, secondly, that the scheme in general seems to conflict with that presented by the Mosaic account of the Creation, which is regarded as communicated to its author by an infallible inspiration.

As the truth of the hypothesis is held to be infinitely probable by a majority of the exponents of the natural sciences at the present day, and is held as absolutely demonstrated by another portion, it behooves those interested to restrain their condemnation, and on the other hand to examine its evidences, and look any consequent necessary modification of our metaphysical or theological views squarely in the face.

The following pages state a few of the former; if they suggest some of the latter, it is hoped that they may be such as any logical mind would deduce from the premises. That they will coincide with the spirit of the most advanced Christianity, I have no doubt; and that they will add an appeal through the reason to that direct influence of the Divine Spirit which should control the motives of human action, seems an unavoidable conclusion.

I. Physical Evolution.

It is well known that a species is usually represented by a great number of individuals, distinguished from all other similar associations by more or less numerous points of structure, color, size, etc., and by habits and instincts also, to a certain extent; that the individuals of such associations reproduce their like, and cannot be produced by individuals of associations or species which present differences of structure, color, etc., as defined by naturalists; that the individuals of any such series or species are incapable of reproducing with those of any other species, with some exceptions; and that in the latter cases the offspring are usually entirely infertile.

The hypothesis of Cuvier assumes that each species was created by Divine power as we now find it at some definite point of geologic time. The paleontologist holding this view sees, in accordance therewith, a succession of creations and destructions marking the history of life on our planet from its commencement.

The development hypothesis states that all existing species have been derived from species of preëxistent

geological periods, as offspring or by direct descent; that there have been no total destructions of life in past time, but only a transfer of it from place to place, owing to changes of circumstance; that the types of structure become simpler and more similar to each other as we trace them from later to earlier periods; and that finally we reach the simplest forms consistent with one or several original parent types of the great divisions into which living beings naturally fall.

It is evident, therefore, that the hypothesis does not include change of species by hybridization, nor allow the descent of living species from any other *living* species: both these propositions are errors of misapprehension or misrepresentation.

In order to understand the history of creation of a complex being, it is necessary to analyze it and ascertain of what it consists. In analyzing the construction of an animal or plant we readily arrange its characters into those which it possesses in common with other animals or plants, and those in which it resembles none other: the latter are its *individual* characters, constituting its individuality. Next we find a large body of characters, generally of a very obvious kind, which it possesses in common with a generally large number of individuals, which, taken collectively, all men are accustomed to call a species; these characters we consequently name *specific*. Thirdly, we find characters, generally in parts of the body which are of importance in the activities of the animal, or which lie in near relation to its mechanical construction in details, which are shared by a still larger number of individuals than those which were similar in specific characters. In other words, it is common to a large number of species. This kind of character we call *generic*, and the grouping it indicates is a genus.

Farther analysis brings to light characters of organism which are common to a still greater number of individuals; this we call a *family* character. Those which are common to still more numerous individuals are the *ordinal*: they are usually found in parts of the structure which have the closest connection with the whole life-history of the being. Finally, the individuals composing many orders will be found identical in some important character of the systems by which ordinary life is maintained, as in the nervous and circulatory: the divisions thus outlined are called *classes*.

By this process of analysis we reach in our animal or plant those peculiarities which are common to the whole animal or vegetable kingdom, and then we have exhausted the structure so completely that we have nothing remaining to take into account beyond the cell-structure or homogeneous protoplasm by which we know that it is organic, and not a mineral.

The history of the origin of a type, as species, genus, order, etc., is simply the history of the origin of the structure or structures which define those groups respectively. It is nothing more nor less than this, whether a man or an insect be the object of investigation.

EVIDENCES OF DERIVATION.

α. *Of Specific Characters.*

The evidences of derivation of species from species, within the limits of the genus, are abundant and conclusive. In the first place, the rule which naturalists

observe in defining species is a clear consequence of such a state of things. It is not amount and degree of difference that determine the definition of species from species, but it is the *permanency* of the characters in all cases and under all circumstances. Many species of the systems include varieties and extremes of form, etc., which, were they at all times distinct, and not connected by intermediate forms, would be estimated as species by the same and other writers, as can be easily seen by reference to their works.

Thus, species are either "restricted" or "protean," the latter embracing many, the former few variations; and the varieties included by the protean species are often as different from each other in their typical forms as are the "restricted" species. As an example, the species *Homo sapiens* (man) will suffice. His primary varieties are as distinct as the species of many well-known genera, but cannot be defined, owing to the existence of innumerable intermediate forms between them.

As to the common origin of such "varieties" of the protean species, naturalists never had any doubt, yet when it comes to the restricted "species," the anti-developmentalist denies it *in toto*. Thus the varieties of most of the domesticated animals are some of them known—others held with great probability to have had a common origin. Varieties of plumage in fowls and canaries are of every-day occurrence, and are produced under our eyes. The cart-horse and racer, the Shetland pony and the Norman, are without doubt derived from the same parentage. The varieties of pigeons and ducks are of the same kind, but not every one is aware of the extent and amount of such variations. The varieties in many characters seen in hogs and cattle, especially when examples from distant countries are compared, are very striking, and are confessedly equal in degree to those found to *define* species in a state of nature: here, however, they are not *definitive.*

It is easy to see that all that is necessary to produce in the mind of the anti-developmentalist the illusion of distinct origin by creation of many of these forms, would be to destroy a number of the intermediate conditions of specific form and structure, and thus to leave remaining definable groups of individuals, and therefore "species."

That such destructions and extinctions have been going on ever since the existence of life on the globe is well known. That it should affect intermediate forms, such as bind together the types of a protean species as well as restricted species, is equally certain. That its result has been to produce *definable* species cannot be denied, especially in consideration of the following facts: Protean species nearly always have a wide geographical distribution. They exist under more varied circumstances than do individuals of a more restricted species. The subordinate variations of the protean species are generally, like the restricted species, confined to distinct subdivisions of the geographical area which the whole occupies. As in geological time changes of level have separated areas once continuous by bodies of water or high mountain ranges, so have vast numbers of individuals occupying such areas been destroyed. Important alterations of temperature, or great changes in abundance or character of vegetable life over given areas, would produce the same result.

This part of the subject might be prolonged, were it necessary, but it has been ably discussed by Darwin. The *rationale* of the "origin of species" as stated by him may be examined a few pages farther on.

β. *Of the Characters of Higher Groups.*

a. Relations of Structures. The evidences of derivative origin of the structures defining the groups called genera, and all those of higher grade, are of a very different character from those discussed in relation to specific characters; they are more difficult of observation and explanation.

Firstly: It would appear to be supposed by many that the creation of organic types was an irregular and capricious process, variously pursued by its Author as regards time and place, and without definite final aim; and this notwithstanding the wonderful evidences we possess, in the facts of astronomy, chemistry, sound, etc., of His adhesion to harmonious and symmetrical sequences in His modes and plans.

Such regularity of plan is found to exist in the relations of the great divisions of the animal and vegetable kingdoms as at present existing on the earth. Thus, with animals we have a great class of species which consists of nothing more than masses or cells of protoplasmic matter, without distinct organs; or the Protozoa. We have then the Cœlenterata (example, corals,) where the organism is composed of many cells arranged in distinct parts, but where a single very simple system of organs, forming the only internal cavity of the body, does the work of the many systems of the more complex animals. Next, the Echinodermata (such as starfish) present us with a body containing distinct systems of organs enclosed in a visceral cavity, including a rudimental nervous system in the form of a ring. In the Molluscs to this condition is added additional complication, including extensions of the nervous system from the ring as a starting-point, and a special organ for a heart. In the Articulates (crabs, insects,) we have like complications, and a long distinct nervous axis on the lower surface of the body. The last branch or division of animals is considered to be higher, because all the systems of life organs are most complex or specialized. The nervous ring is almost obliterated by a great enlargement of its usual ganglia, thus become a brain, which is succeeded by a long axis on the upper side of the body. This and other points define the Vertebrata.

Plans of structure, independent of the simplicity or perfection of the special arrangement or structure of organs, also define these great groups. Thus the Protozoa present a spiral, the Cœlenterata a radiate, the Echinodermata a bilateral radiate plan. The Articulates are a series of external rings, each in one or more respects repeating the others. The Molluscs are a sac, while a ring above a ring, joined together by a solid center-piece, represents the plan of each of the many segments of the Vertebrates which give the members of that branch their form.

These bulwarks of distinction of animal types are entered into here simply because they are the most inviolable and radical of those with which we have to deal, and to give the anti-developmentalist the best foothold for his position. I will only allude to the relations of their points of approach as these are affected by considerations afterward introduced.

The Vertebrates approach the Molluscs closely at the lowest extreme of the former and higher of the latter. The lamprey eels of the one possess several characters in common with the cuttle-fish or squids of the latter. The amphioxus is called the lowest Vertebrate, and though it is nothing else, the definition of the division must be altered to receive it; it has no brain!

The lowest forms of the Moluscs and Articulates are scarcely distinguishable from each other, so far as adhesion to the "plan" is concerned, and some of the latter division are very near certain Echinodermata. As we approach the boundary-lines of the two lowest divisions, the approaches become equally close.

More instructive is the evidence of the relation of the subordinate classes of any one of these divisions. The conditions of those organs or parts which define classes exhibit a regular relation, commencing with simplicity and ending with complication; first associated with weak exhibitions of the highest functions of the nervous system—at the last displaying the most exalted traits found in the series.

For example: In the classes of Vertebrates we find the lowest nervous system presents great simplicity—the brain cannot be recognized; next (in lampreys), the end of the nervous axis is subdivided, but scarcely according to the complex type that follows. In fishes the cerebellum and cerebral hemispheres are minute; and the intermediate or optic lobes very large: in the reptiles the cerebral hemispheres exceed the optic lobes, while the cerebellum is smaller. In birds the cerebellum becomes complex and the cerebrum greatly increases. In mammals the cerebellum increases in complexity or number of parts, the optic lobes diminish, while the cerebral hemispheres become wonderfully complex and enlarged, bringing us to the highest development, in man.

The history of the circulatory system in the Vertebrates is the same. First, a heart with one chamber, then one with two divisions: three divisions belong to a large series, and the highest possess four. The origins of the great artery of the body, the aorta, are first five on each side: they lose one in the succeeding class in the ascending scale, and one in each succeeding class or order, till the Mammalia, including man, present us with but one on one side.

From an infinitude of such considerations as the above, we derive the certainty that the general arrangement of the various groups of the organic world is in scales, the subordinate within the more comprehensive divisions. The identification of all the parts in such a complexity of organism as the highest animals present, is a matter requiring much care and attention, and constitutes the study of homologies. Its pursuit has resulted in the demonstration that every individual of every species of a given branch of the animal kingdom is composed of elements common to all, and that the differences which are so radical in the higher groups are but the modifications of the same elemental parts, representing completeness or incompleteness, obliteration or subdivision. Of the former character are rudimental organs, of which almost every species possesses an example in some part of its structure.

But we have other and still more satisfactory evidence of the meaning of these relations. By the study of embryology we can prove most indubitably that the simple and less complex are inferior to the more complex.

Selecting the Vertebrates again as an example, the highest form of mammal—*e. g.*, man—presents in his earliest stages of embryonic growth a skeleton of cartilage, like that of the lamprey: he also possesses five origins of the aorta and five slits on the neck, both which characters belong to the lamprey and the shark. If the whole number of these parts does not coëxist in the embryonic man, we find in embryos of lower forms more nearly related to the lamprey that they do. Later in the life of the mammal but four aortic origins are found, which arrangement, with the heart now divided into two chambers, from a beginning as a simple tube, is characteristic of the class of Vertebrates next in order—the bony fishes. The optic lobes of the human brain have also at this time a great predominance in size—a character above stated to be that of the same class. With advancing development the infant mammal follows the scale already pointed out. Three chambers of the heart and three aortic origins follow, presenting the condition permanent in the batrachia; and two origins, with enlarged cerebral hemispheres of the brain, resemble the reptilian condition. Four heart-chambers, and one aortic root on each side, with slight development of the cerebellum, follow all characters defining the crocodiles, and immediately precede the special conditions defining the mammals. These are, the single aorta root from one side, and the full development of the cerebellum: later comes that of the cerebrum also in its higher mammalian and human traits.

Thus we see the order already pointed out to be true, and to be an ascending one. This is the more evident as each type or class passes through the conditions of those below it, as did the mammal; each scale being shorter as its highest terminus is lower. Thus the crocodile passes through the stage of the lamprey, the fish, the batrachian and the reptile proper.

b. In Time. We have thus a scale of relations of existing forms of animals and plants of a remarkable kind, and such as to stimulate greatly our inquiries as to its significance. When we turn to the remains of the past creation preserved to us in the deposits continued throughout geologic time, we are not disappointed, for great light is at once thrown upon the subject.

We find, in brief, that the lowest division of the animal kingdom appeared first, and long before any type of a higher character was created. The Protozoön, Eozoön, is the earliest of animals in geologic time, and represents the lowest type of animal life now existing. We learn also that the highest branch appeared last. No remains of Vertebrates have been found below the lower Devonian period, or not until the Echinoderms and Molluscs had reached a great preëminence. It is difficult to be sure whether the Protozoa had a greater numerical extent in the earliest periods than now, but there can be no doubt that the Cœlenterata (corals) and Echinoderms (crinoids) greatly exceeded their present bounds, in Paleozoic time, so that those at present existing are but a feeble remnant. If we examine the subdivisions known as classes, evidence of the nature of the succession of creation is still more conclusive. The most polyp-like of the Moluscs (brachiopoda) constituted the great mass of its representatives during Paleozic time. Among Vertebrates the fishes appear first, and had their greatest development in size and numbers during the earliest periods of the existence of the division. Batrachia were much the largest and

most important of land animals during the Carboniferous period, while the higher Vertebrates were unknown. The later Mesozoic periods saw the reign of reptiles, whose position in structural development has been already stated. Finally, the most perfect, the mammal, came upon the scene, and in his humblest representatives. In Tertiary times mammalia supplanted the reptiles entirely, and the unspiritual mammals now yield to man, the only one of his class in whom the Divine image appears.

Thus the structural relations, the embryonic characters, and the successive appearance in time of animals coincide. The same is very probably true of plants.

That the existing state of the geological record of organic types should be regarded as anything but a fragment is, from our stand-point, quite preposterous. And more, it may be assumed with safety that when completed it will furnish us with a series of regular successions, with but slight and regular interruptions, if any, from the species which represented the simplest beginnings of life at the dawn of creation, to those which have displayed complication and power in later or in the present period.

For the labors of the paleontologist are daily bringing to light structures intermediate between those never before so connected, and thus creating lines of succession where before were only interruptions. Many such instances might be adduced: two might be selected as examples from American paleontology;* *i. e.*, the near

* Professor Huxley, in the last anniversary lecture before the Geological Society of London, recalls his opinion, enunciated in 1862, that "the positively-ascertained truths of Paleontology" negative "the doctrines of progressive modification, which suppose

approach to birds made by the reptiles Lælaps and Megadactylus, and the combination of characters of the old genera Ichthyosaurus and Plesiosaurus in the Polycotylus of Kansas.

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that modification to have taken place by a necessary progress from more to less embryonic forms, from more to less generalized types, within the limits of the period represented by the fossiliferous rocks; that it shows no evidence of such modification; and as to the nature of that modification, it yields no evidence whatsoever that the earlier members of any long-continued group were more generalized in structure than the later ones."

Respecting this position, he says: "Thus far I have endeavored to expand and enforce by fresh arguments, but not to modify in any important respect, the ideas submitted to you on a former occasion. But when I come to the propositions respecting progressive modification, it appears to me, with the help of the new light which has broken from various quarters, that there is much ground for softening the somewhat Brutus-like severity with which I have dealt with a doctrine for the truth of which I should have been glad enough to be able to find a good foundation in 1862. So far indeed as the Invertebrata and the lower Vertebrata are concerned, the facts, and the conclusions which are to be drawn from them, appear to me to remain what they were. For anything that as yet appears to the contrary, the earliest known marsupials may have been as highly organized as their living congeners; the Permian lizards show no signs of inferiority to those of the present day; the labyrinthodonts cannot be placed below the living salamander and triton; the Devonian ganoids are closely related to polypterus and lepidosiren."

To this it may be replied: 1. The scale of progression of the Vertebrata is measured by the conditions of the circulatory system, and in some measure by the nervous, and not by the osseous: tested by this scale, there has been successional complication of structure among Vertebrata in time. 2. The question with the evolutionist is, not what types have persisted to the present day, but the order in which types appeared in time. 3. The Marsupials, Permian saurians, labyrinthodonts and Devonian ganoids are remarkably generalized groups, and predecessors of types widely separated in the present period. 4. Professor Huxley adduces

We had no more reason to look for intermediate or connecting forms between such types as these, than between any others of similar degree of remove from each other with which we are acquainted. And inasmuch as almost all groups, as genera, orders, etc., which are held to be distinct, but adjacent, present certain points of approximation to each other, the almost daily discovery of intermediate forms gives us confidence to believe that the pointings in other cases will also be realized.

γ. *Of Transitions.*

The preceding statements were necessary to the comprehension of the supposed mode of metamorphosis or development of the various types of living beings, or, in other words, of the single structural features which define them.

As it is evident that the groups of highest rank have

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many such examples among the mammalian subdivisions in the remaining portion of his lecture. 5. Two alternatives are yet open in the explanation of the process of evolution: since generalized types, which combine the characters of higher and lower groups of later periods, must thus be superior to the lower, the lower must (first) be descended from such a generalized form by degradation; or (second) not descended from it at all, but from some lower contemporaneous type by advance; the higher only of the two being derived from the first-mentioned. The last I suspect to be a true explanation, as it is in accordance with the homologous groups. This law will shorten the demands of paleontologists for time, since, instead of deriving all reptilia, batrachia, etc., from common origins, it points to the derivation of higher reptilia of a higher order from higher reptilia of a lower order, lower reptilia of the first from lower reptilia of the second; finally, the several groups of the lowest or most generalized order of reptilia from a parallel series of the class below, or batrachia.

had their origin in remote ages, cases of transition from one to the other by change of character cannot be witnessed at the present day. We therefore look to the most nearly related divisions, or those of the lowest rank, for evidence of such change.

It is necessary to premise that embryology teaches that all the species of a given branch of the animal kingdom (*e. g.*, Vertebrate, Mollusc, etc.) are quite identical in structural character at their first appearance on the germinal layer of the yolk of the parent egg. It shows that the character of the respective groups of high rank appear first, then those of less grade, and last of all those structures which distinguish them as genera. But among the earliest characters which appear are those of the species, and some of those of the individual.

We find the characters of different *genera* to bear the same relation to each other that we have already seen in the case of those definitive of orders, etc. In a natural assemblage of related genera we discover that some are defined by characters found only in the embryonic stages of others; while a second will present a permanent condition of its definitive part, which marks a more advanced stage of that highest. In this manner many stages of the highest genus appear to be represented by permanent genera in all natural groups. Generally, however, this resemblance does not involve an entire identity, there being some other immaturities found in the highest genus at the time it presents the character preserved in permanency by the lower, which the lower loses. Thus (to use a very coarse example) a frog at one stage of growth has four legs and a tail: the salamander always preserves four legs and a tail, thus resembling the young frog. The latter is, however, not a

salamander at that time, because, among other things, the skeleton is represented by cartilage only, and the salamander's is ossified. This relation is therefore an imitation only, and is called *inexact parallelism.*

As we compare nearer and nearer relations—*i. e.*, the genera which present fewest points of difference—we find the differences between undeveloped stages of the higher and permanent conditions of the lower to grow fewer and fewer, until we find numerous instances where the lower genus is exactly the same as the undeveloped stage of the higher. This relation is called that of *exact parallelism.*

It must now be remembered that the permanence of a character is what gives it its value in defining genus, order, etc., in the eyes of the systematist. So long as the condition is permanent no transition can be seen: there is therefore no development. If the condition is transitional, it defines nothing, and nothing is developed; at least, so says the anti-developmentalist. It is the old story of the settler and the Indian: "Will you take owl and I take turkey, or I take turkey and you owl?"

If we find a relation of *exact parallelism* to exist between two sets of species in the condition of a certain organ, and the difference so expressed the only one which distinguishes them as sets from each other—if that condition is always the same in each set—we call them two genera: if in any species the condition is variable at maturity, or sometimes the undeveloped condition of the part is persistent and sometimes transitory, the sets characterized by this difference must be united by the systematist, and the whole is called a single genus.

We know numerous cases where different individuals of the same species present this relation of *exact parallelism* to each other; and as we ascribe common origin to the individuals of a species, we are assured that the condition of the inferior individual is, in this case, simply one of repressed growth, or a failure to fulfill the course accomplished by the highest. Thus, certain species of the salamandrine genus amblystoma undergo a metamorphosis involving several parts of the osseous and circulatory systems, etc., while half grown; others delay it till fully grown; one or two species remain indifferently unchanged or changed, and breed in either condition, while another species breeds unchanged, and has never been known to complete a metamorphosis.

The nature of the relation of *exact parallelism* is thus explained to be that of checked or advanced growth of individuals having a common origin. The relation of *inexact parallelism* is readily explained as follows: With a case of *exact parallelism* in the mind, let the repression producing the character of the lower, parallelize the latter with a stage of the former in which a second part is not quite mature: we will have a slight want of correspondence between the two. The lower will be immature in but one point, the incompleteness of the higher being seen in two points. If we suppose the immaturity to consist in a repression at a still earlier point in the history of the higher, the latter will be undeveloped in other points also: thus, the spike-horned deer of South America have the horn of the second year of the North American genus. They would be generically identical with that stage of the latter, were it not that these still possess their milk dentition at two years of age. In the same way the nature of the parallelisms seen in higher groups, as orders, etc., may be accounted for.

The theory of homologous groups furnishes important evidence in favor of derivation. Many orders of animals (probably all, when we come to know them) are divisible into two or more sections, which I have called *homologous*. These are series of genera or families, which differ from each other by some marked character, but whose contained genera or families differ from each other in the same points of detail, and in fact correspond exactly. So striking is this correspondence that were it not for the general and common character separating the homologous series, they would be regarded as the same, each to each. Now it is remarkable that where studied the difference common to all the terms of two homologous groups is found to be one of *inexact parallelism*, which has been shown above to be evidence of descent. Homologous groups always occupy different geographical areas on the earth's surface, and their relation is precisely that which holds between successive groups of life in the periods of geologic time.

In a word, we learn from this source that distinct geologic epochs coëxist at the same time on the earth. I have been forced to this conclusion* by a study of the structure of terrestrial life, and it has been remarkably confirmed by the results of recent deep-sea dredgings made by the United States Coast Survey in the Gulf Stream, and by the British naturalists in the North Atlantic. These have brought to light types of Tertiary life, and of even the still more ancient Cretaceous periods, living at the present day. That this discovery invalidates in any wise the conclusions of geology re-

* *Origin of Genera*, pages 70, 77, 79.

specting lapse of time is an unwarranted assumption that some are forward to make. If it changes the views of some respecting the parallelism or coëxistence of faunæ in different regions of the earth, it is only the anti-developmentalists whose position must be changed.

For, if we find distinct geologic faunæ, or epochs defined by faunæ, coëxisting during the present period, and fading or emerging into one another as they do at their geographical boundaries, it is proof positive that the geologic epochs and periods of past ages had in like manner no trenchant boundaries, but also passed the one into the other. The assumption that the apparent interruptions are the result of transfer of life rather than destruction, or of want of opportunities of preservation, is no doubt the true one.

δ. *Rationale of Development.*

a. In Characters of Higher Groups. It is evident in the case of the species in which there is an irregularity in the time of completion of metamorphosis that some individuals traverse a longer developmental line than those who remain more or less incomplete. As both accomplish growth in the same length of time, it is obvious that it proceeds with greater rapidity in one sense in that which accomplishes most: its growth is said to be accelerated. This phenomenon is especially common among insects, where the females of perfect males are sometimes larvæ or nearly so, or pupæ, or lack wings or some character of final development. Quite as frequently, some males assume characters in advance of others, sometimes in connection with a peculiar geographical range.

In cases of *exact parallelism* we reasonably suppose the cause to be the same, since the conditions are identical, as has been shown; that is, the higher conditions have been produced by a crowding back of the earlier characters and an acceleration of growth, so that a given succession in order of advance has extended over a longer range of growth than its predecessor in the same allotted time. That allotted time is the period before maturity and reproduction, and it is evident that as fast as modifications or characters should be assumed sufficiently in advance of that period, so certainly would they be conferred upon the offspring by reproduction. The *acceleration* in the assumption of a character, progressing more rapidly than the same in another character, must soon produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of *inexact parallelism*. As all the more comprehensive groups present this relation to each other, we are compelled to believe that *acceleration* has been the principle of their successive evolution during the long ages of geologic time.

Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has no doubt followed a law the reverse of acceleration, which has been called *retardation*. By the increasing slowness of the growth of the individuals of a genus, and later and later assumption of the characters of the latter, they would be successively lost.

To what power shall we ascribe this acceleration, by which the first beginnings of structure have accumulated to themselves through the long geologic ages complication and power, till from the germ that was scarcely born into a sand-lance, a human being climbed the complete scale, and stood easily the chief of the whole ?

In the cases of species, where some individuals develop farther than others, we say the former possess more growth-force, or "vigor," than the latter. We may therefore say that higher types of structure possess more "vigor" than the lower. This, however, we do not know to be true, nor can we readily find means to demonstrate it.

The food which is taken by an adult animal is either assimilated, to be consumed in immediate activity of some kind, or stored for future use, and the excess is rejected from the body. We have no reason to suppose that the same kind of material could be made to subserve the production of force by any other means than that furnished by a living animal organism. The material from which this organism is constructed is derived first from the parent, and afterward from the food, etc., assimilated by the individual itself so long as growth continues. As it is the activity of assimilation directed to a special end during this latter period which we suppose to be increased in accelerated development, the acceleration is evidently not brought about by increased facilities for obtaining the means of life which the same individual possesses as an adult. That it is not in consequence of such increased facilities possessed by its parents over those of the type preceding it, seems equally improbable when we consider that the characters in which the parent's advance has appeared are rarely of a nature to increase those facilities.

The nearest approach to an explanation that can be offered appears to be somewhat in the following direction:

There is every reason to believe that the character of the atmosphere has gradually changed during geologic time, and that various constituents of the mixture have been successively removed from it, and been stored in the solid material of the earth's crust in a state of combination. Geological chemistry has shown that the cooling of the earth has been accompanied by the precipitation of many substances only gaseous at high temperatures. Hydrochloric and sulphuric acids have been transferred to mineral deposits or aqueous solutions. The removal of carbonic acid gas and the vapor of water has been a process of much slower progress, and after the expiration of all the ages a proportion of both yet remains. Evidence of the abundance of the former in the earliest periods is seen in the vast deposits of limestone rock ; later, in the prodigious quantities of shells which have been elaborated from the same in solution. Proof of its abundance in the atmosphere in later periods is seen in the extensive deposits of coal of the Carboniferous, Triassic and Jurassic periods. If the most luxuriant vegetation of the present day takes but fifty tons of carbon from the atmosphere in a century, per acre, thus producing a layer over that extent of less than a third of an inch in thickness, what amount of carbon must be abstracted in order to produce strata of thirty-five feet in depth ? No doubt it occupied a long period, but the atmosphere, thus deprived of a large proportion of carbonic acid, would in subsequent periods undoubtedly possess an improved capacity for the support of animal life.

The successively higher degree of oxidization of the blood in the organs designed for that function, whether performing it in water or air, would certainly accelerate the performances of all the vital functions, and among others that of growth. Thus it may be that *acceleration* can be accounted for, and the process of the development of the orders and sundry lesser groups of the Vertebrate kingdom indicated; for, as already pointed out, the definitions of such are radically placed in the different structures of the organs which aerate the blood and distribute it to its various destinations.

But the great question, What determined the direction of this acceleration? remains unanswered. One cannot understand why more highly-oxidized blood should hasten the growth of partition of the ventricle of the heart in the serpent, the more perfectly to separate the aerated from the impure fluid; nor can we see why a more perfectly-constructed circulatory system, sending purer blood to the brain, should direct accelerated growth to the cerebellum or cerebral hemispheres in the crocodile.

b. In Characters of the Specific Kind. Some of the characters usually placed in the specific category have been shown to be the same in kind as those of higher categories. The majority are, however, of a different kind, and have been discussed several pages back.

The cause of the origin of these characters is shrouded in as much mystery as that of those which have occupied the pages immediately preceding. As in that case, we have to assume, as Darwin has done, a tendency in Nature to their production. This is what he terms "the principle of variation." Against an unlimited variation the great law of heredity or atavism has ever been opposed, as a conservator and multiplier of type. This principle is exemplified in the fact that like produces like—that children are like their parents, frequently even

in minutiæ. It may be compared to habit in metaphysical matters, or to that singular love of time or rhythm seen in man and lower animals, in both of which the tendency is to repeat in continual cycles a motion or state of the mind or sense.

Further, but a proportion of the lines of variation is supposed to have been perpetuated, and the extinction of intermediate forms, as already stated, has left isolated groups or species.

The effective cause of these extinctions is stated by Darwin to have been a "natural selection"—a proposition which distinguishes his theory from other development hypotheses, and which is stated in brief by the expression, "the preservation of the fittest." Its meaning is this: that those characters appearing as results of this spontaneous variation which are little adapted to the conflict for subsistence, with the nature of the supply, or with rivals in its pursuit, dwindle and are sooner or later extirpated; while those which are adapted to their surroundings, and favored in the struggle for means of life and increase, predominate, and ultimately become the centers of new variation. "I am convinced," says Darwin, "that natural selection has been the main, but not exclusive, means of modification."

That it has been to a large extent the means of preservation of those structures known as specific, must, I think, be admitted. They are related to their peculiar surroundings very closely, and are therefore more likely to exist under their influence. Thus, if a given genus extends its range over a continent, it is usually found to be represented by peculiar species—one in a maritime division, another in the desert, others in the forest, in the swamp or the elevated areas of the region. The wonderful interdependence shown by Darwin to exist between insects and plants in the fertilization of the latter, or between animals and their food-plants, would almost induce one to believe that it were the true expression of the whole law of development.

But the following are serious objections to its universal application:

First: The characters of the higher groups, from genera up, are rarely of a character to fit their possessors especially for surrounding circumstances; that is, the differences which separate genus from genus, order from order, etc., in the ascending scale of each, do not seem to present a superior adaptation to surrounding circumstances in the higher genus to that seen in the lower genus, etc. Hence, superior adaptation could scarcely have caused their selection above other forms not existing. Or, in other words, the very differences in structure which indicate successional relation, or which measure the steps of progress, seem to be equally well fitted for their surroundings.

Second: The higher groups, as orders, classes, etc., have been in each geologic period alike distributed over the whole earth, under all the varied circumstances offered by climate and food. Their characters do not seem to have been modified in reference to these. Species, and often genera, are, on the other hand, eminently restricted according to climate, and consequently vegetable and animal food.

The law of development which we seek is indeed not that which preserves the higher forms and rejects the lower after their creation, but that which explains why higher forms were created at all. Why in the results of a creation we see any relation of higher and lower,

and not rather a world of distinct types, each perfectly adapted to its situation, but none properly higher than another in an ascending scale, is the primary question. Given the principle of advance, then natural selection has no doubt modified the details; but in the successive advances we can scarcely believe such a principle to be influential. We look rather upon a progress as the result of the expenditure of some force fore-arranged for that end.

It may become, then, a question whether in characters of high grade the habit or use is not rather the result of the acquisition of the structure than the structure the result of the encouragement offered to its assumed beginnings by use, or by liberal nutrition derived from the increasingly superior advantages it offers.

ε. *The Physical Origin of Man.*

If the hypothesis here maintained be true, man is the descendant of some preëxistent generic type, the which, if it were now living, we would probably call an ape.

Man and the chimpanzee were in Linnæus' system only two species of the same genus, but a truer anatomy places them in separate genera and distinct families. There is no doubt, however, that Cuvier went much too far when he proposed to consider Homo as the representative of an order distinct from the quadrumana, under the name of bimana. The structural differences will not bear any such interpretation, and have not the same value as those distinguishing the orders of mammalia; as, for instance, between carnivora and bats, or the cloven-footed animals and the rodents, or rodents and edentates. The differences between man and the chimpanzee are, as Huxley well puts it, much less than those between the chimpanzee and lower quadrumana, as lemurs, etc. In fact, man is the type of a family, Hominidæ, of the order Quadrumana, as indicated by the characters of the dentition, extremities, brain, etc. The reader who may have any doubts on this score may read the dissections of Geoffroy St. Hilaire, made in 1856, before the issue of Darwin's *Origin of Species*. He informs us that the brain of man is nearer in structure to that of the orang than the orang's is to that of the South American howler, and that the orang and howler are more nearly related in this regard than are the howler and the marmoset.

The modifications presented by man have, then, resulted from an acceleration in development in some respects, and retardation perhaps in others. But until the *combination* now characteristic of the genus Homo was attained the being could not properly be called man.

And here it must be observed that as an organic type is characterized by the coëxistence of a number of peculiarities which have been developed independently of each other, its distinctive features and striking functions are not exhibited until that coëxistence is attained which is necessary for these ends.

Hence, the characters of the human genus were probably developed successively; but few of the indications of human superiority appeared until the combination was accomplished. Let the opposable thumb be first perfected, but of what use would it be in human affairs without a mind to direct? And of what use a mind without speech to unlock it? And speech could not be possible though all the muscles of the larynx but one were developed, or but a slight abnormal convexity in one pair of cartilages remained.

It would be an objection of little weight could it be truly urged that there have as yet no remains of apelike men been discovered, for we have frequently been called upon in the course of paleontological discovery to bridge greater gaps than this, and greater remain, which we expect to fill. But we *have* apelike characters exhibited by more than one race of men yet existing.

But the remains of that being which is supposed to have been the progenitor of man may have been discovered a short time since in the cave of Naulette, Belgium, with the bones of the extinct rhinoceros and elephant.

We all admit the existence of higher and lower races, the latter being those which we now find to present greater or less approximations to the apes. The peculiar structural characters that belong to the negro in his most typical form are of that kind, however great may be the distance of his remove therefrom. The flattening of the nose and prolongation of the jaws constitute such a resemblance; so are the deficiency of the calf of the leg, and the obliquity of the pelvis, which approaches more the horizontal position than it does in the Caucasian. The investigations made at Washington during the war with reference to the physical characteristics of the soldiers show that the arms of the negro are from one to two inches longer than those of the whites: another approximation to the ape. In fact, this race is a species of the genus Homo, as distinct in character from the Caucasian as those we are accustomed to recognize in other departments of the animal kingdom; but he is not distinct by isolation, since intermediate forms between him and the other species can be abundantly found.

And here let it be particularly observed that two of the most prominent characters of the negro are those of immature stages of the Indo-European race in its characteristic types. The deficient calf is the character of infants at a very early stage; but, what is more important, the flattened bridge of the nose and shortened nasal cartilages are universally immature conditions of the same parts in the Indo-European. Any one may convince himself of that by examining the physiognomies of infants. In some races—*e. g.*, the Slavic—this undeveloped character persists later than in some others. The Greek nose, with its elevated bridge, coincides not only with æsthetic beauty, but with developmental perfection.

This is, however, only "*inexact* parallelism," as the characters of the hair, etc., cannot be explained on this principle *among existing races*. The embryonic characters mentioned are probably a remnant of those characteristic of the primordial race or species.

But the man of Naulette, if he be not a monstrosity, in a still more distinct and apelike species. The chin, that marked character of other species of men, is totally wanting, and the dentition is quite approximate to the man-like apes, and different from that of modern men. The form is very massive, as in apes. That he was not abnormal is rendered probable by approximate characters seen in a jaw from the cave of Puy-sur-Aube, and less marked in the lowest races of Australia and New Caledonia.

As to the single or multiple origin of man, science as yet furnishes no answer. It is very probable that, in many cases, the species of one genus have descended from corresponding species of another by change of

generic characters only. It is a remarkable fact that the orang possesses the peculiarly developed malar bones and the copper color characteristic of the Mongolian inhabitants of the regions in which this animal is found, while the gorilla exhibits the prognathic jaws and black hue of the African races near whom he dwells. This kind of geographical imitation is very common in the animal kingdom.

ζ. *The Mosaic Account.*

As some persons imagine that this hypothesis conflicts with the account of the creation of man given in Genesis, a comparison of some of the points involved is made below.

First: In Genesis i. 26, 27, we read, "And God said, Let us make man in our image, after our likeness," etc. "So God created man in his own image, in the image of God created he him; male and female created he them." Those who believe that this "image" is a physical, material form, are not disposed to admit the entrance of anything ape-like into its constitution, for the ascription of any such appearance to the Creator would be impious and revolting. But we are told that "God is a Spirit," and Christ said to his disciples after his resurrection, "A spirit hath not flesh and bones, as ye see me have." Luke xxiv. 39. It will require little further argument to show that a mental and spiritual image is what is meant, as it is what truly exists. Man's conscience, intelligence and creative ingenuity show that he possesses an "image of God" within him, the possession of which is really necessary to his limited comprehension of God and of God's ways to man.

Second: In Genesis ii. 7, the text reads, "And the Lord God formed man of the dust of the ground, and breathed into his nostrils the breath of life; and man became a living soul." The fact that man is the result of the modification of an ape-like predecessor nowise conflicts with the above statement as to the materials of which his body is composed. Independently of origin, if the body of man be composed of dust, so must that of the ape be, since the composition of the two is identical. But the statement simply asserts that man was created of the same materials which compose the earth: their condition as "dust" depending merely on temperature and subdivision. The declaration, "Dust thou art, and unto dust thou shalt return," must be taken in a similar sense, for we know that the decaying body is resolved not only into its earthly constituents, but also into carbonic acid gas and water.

When God breathed into man's nostrils the breath of life, we are informed that he became, not a living body, but "a living soul." His descent from a preëxistent being involved the possession of a living body; but when the Creator breathed into him we may suppose that He infused into this body the immortal part, and at that moment man became a conscientious and responsible being.

II. Metaphysical Evolution.

It is infinitely improbable that a being endowed with such capacities for gradual progress as man has exhibited, should have been full fledged in accomplishments at the moment when he could first claim his high title, and abandon that of his simious ancestors. We are

therefore required to admit the growth of human intelligence from a primitive state of inactivity and absolute ignorance; including the development of one important mode of its expression—speech; as well as that of the moral qualities, and of man's social system—the form in which his ideas of morality were first displayed.

The expression "evolution of morality" need not offend, for the question in regard to the *laws* of this evolution is the really important part of the discussion, and it is to the opposing views on this point that the most serious interest attaches.

That the theory of physical development is consistent with Genesis will, I think, before long be admitted by most persons; but the correlation of the facts of metaphysical evolution with the theologies of some of the churches will require more care.

The two views of evolution already treated of, held separately, are quite opposed to each other. The first (and generally received) lays stress on the influence of external surroundings, as the stimulus to and guidance of development: it is the counterpart of Darwin's principle called Natural Selection in material progress. This might be called the *Conflict theory*. The second view recognizes the workings of a force whose nature we do not know, whose exhibitions accord perfectly with their external surroundings (or other exhibitions of itself), without being under their influence or more related to them, as effect to cause, than the notes of the musical octave or the colors of the spectrum are to each other. This is the *Harmonic theory*. In other words, the first principle deduces perfection from struggle and discord; the second, from the coincident progress of many parts, forming together a divine harmony comparable to music. That these principles are both true is rendered extremely probable by the actual phenomena of development, material and immaterial. In other words, struggle and discord ever await that which is not in the advance, and which fails to keep pace with the harmonious development of the whole.

All who have studied the phenomena of the creation believe that there exists in it a grand and noble harmony, such as was described to Job when he was told that "the morning stars sang together, and all the sons of God shouted for joy."

α. Development of Intelligence.

If the brain is the organ of mind, we may be surprised to find that the brain of the intelligent man scarcely differs in structure from that of the ape. Whence, then, the difference of power? Though no one will now deny that many of the Mammalia are capable of reasoning upon observed facts, yet how greatly the results of this capacity differ in number and importance from those achieved by human intelligence! Like water at the temperatures of 50° and 53°, where we perceive no difference in essential character, so between the brains of the lower and higher monkeys no difference of function or of intelligence is perceptible. But what a difference do the two degrees of temperature from 33° to 31° produce in water! In like manner the difference between the brain of the higher ape and that of man is accompanied by a difference in function and power, on which, man's earthly destiny depends. In development, as with the water so with the higher ape: some Rubicon has been crossed, some floodgate

has been opened, which marks one of Nature's great transitions, such as have been called "Expression points" of progress.

What point of progress in such a history would account for this accession of the powers of the human intelligence? It has been answered, with considerable confidence, The power of speech. Let us picture man without speech. Each generation would learn nothing from its predecessors. Whatever originality or observation might yield to a man would die with him. Each intellectual life would begin where every other life began, and would end at a point only differing with its original capacity. Concert of action, by which man's power over the material world is maintained, would not exceed, if it equaled, that which is seen among the bees; and the material results of his labors would not extend beyond securing the means of life and the employment of the simplest modes of defence and attack.

The first men, therefore, are looked upon by the developmentalists as extremely embryonic in all that characterizes humanity, and they appeal to the facts of history in support of this view. If they do not derive much assistance from written history, evidence is found in the more enduring relics of human handiwork.

The opposing view is, that the races which present or have presented this condition of inferiority or savagery have reached it by a process of degradation from a higher state—as some believe, through moral delinquency. This position may be true in certain cases, which represent perhaps a condition of senility, but in general we believe that savagery was the condition of the first man, which has in some races continued to the present day.

β. *Evidence from Archæology.*

As the object of the present essay is not to examine fully into the evidences for the theories of evolution here stated, but rather to give a sketch of such theories and their connection, a few facts only will be noticed.

Improvement in the use of Materials. As is well known, the remains of human handiwork of the earliest periods consist of nothing but rude implements of stone and bone, useful only in procuring food and preparing it for use. Even when enterprise extended beyond the ordinary routine, it was restrained by the want of proper instruments. Knives and other cutting implements of flint still attest the skill of the early races of men from Java to the Cape of Good Hope, from Egypt to Ireland, and through North and South America. Hatchets, spear-heads and ornaments of serpentine, granite, silex, clay slates, and all other suitable rock materials, are found to have been used by the first men, to the exclusion of metals, in most of the regions of the earth.

Later, the probably accidental discovery of the superiority of some of the metals resulted in the substitution of them for stone as a material for cutting implements. Copper—the only metal which, while malleable, is hard enough to bear an imperfect edge—was used by succeeding races in the Old World and the New. Implements of this material are found scattered over extensive regions. So desirable, however, did the hardening of the material appear for the improvement of the cutting edge that combinations with other metals were sought for and discovered. The alloy with tin, forming bronze and brass, was discovered and used in Europe, while that with silver appears to have been most readily pro-

duced in America, and was consequently used by the Peruvians and other nations.

The discovery of the modes of reducing iron ores placed in the hands of man the best material for bringing to a shape convenient for his needs the raw material of the world. All improvements in this direction made since that time have been in the quality of iron itself, and not through the introduction of any new metal.

The prevalent phenomena of any given period are those which give it its character, and by which we distinguish it. But this fact does not exclude the coëxistence of other phenomena belonging to prior or subsequent stages. Thus, during the many stages of human progress there have been men more or less in advance of the general body, and their characteristics have given a peculiar stamp to the later and higher condition of the whole. It furnishes no objection to this view that we find, as might have been anticipated, the stone, bronze and iron periods overlaping one another, or men of an inferior culture supplanting in some cases a superior people. A case of this kind is seen in North America, where the existing "Indians," stone-men, have succeeded the mound-builders, copper-men. The successional relation of discoveries is all that it is necessary to prove, and this seems to be established.

The period at which the use of metallic implements was introduced is unknown, but Whitney says that the language of the Aryans, the ancestors of all the modern Indo-Europeans, indicates an acquaintance with such implements, though it is not certain whether those of iron are to be included. The dispersion of the daughter races, the Hindoos, the Pelasgi, Teutons, Celts, etc., could not, it is thought, have taken place later than 3000 B. C.—a date seven hundred years prior to that assigned by the old chronology to the Deluge. Those races coëxisted with the Egyptian and Chinese nations, already civilized, and as distinct from each other in feature as they are now.

Improvement in Architecture. The earliest periods, then, were characterized by the utmost simplicity of invention and construction. Later, the efforts for defence from enemies and for architectural display, which have always employed so much time and power, began to be made. The megalithic period has left traces over much of the earth. The great masses of stone piled on each other in the simplest form in Southern India, and the circles of stones planted on end in England at Stonehenge and Abury, and in Peru at Sillustani, are relics of that period. More complex are the great Himyaritic walls of Arabia, the works of the ancestors of the Phœnicians in Asia Minor, and the titanic workmanship of the Pelasgi in Greece and Italy. In the iron age we find granitic hills shaped or excavated into temples; as, for example, everywhere in Southern India. Near Madura the circumference of an acropolis-like hill is cut into a series of statues in high relief, of sixty feet in elevation. Easter Island, composed of two volcanic cones, one thousand miles from the west coast of South America, in the bosom of the Pacific, possesses several colossi cut from the intrusive basalt, some in high relief on the face of the rock, others in detached blocks removed by human art from their original positions and brought nearer the sea-shore.

Finally, at a more advanced stage, the more ornate and complex structures of Central America, of Cambodia, Nineveh and Egypt, represent the period of greatest display of architectural expenditure. The same amount of human force has perhaps never been expended in this direction since, though higher conceptions of beauty have been developed in architecture with increasing intellectuality.

Man has passed through the block-and-brick building period of his boyhood, and should rise to higher conceptions of what is the true disposition of power for "him who builds for aye," and learn that "spectacle" is often the unwilling friend of progress.

No traces of metallic implements have ever been found in the salt-mines of Armenia, the turquoise-quarries in Arabia, the cities of Central America or the excavations for mica in North Carolina, while the direct evidence points to the conclusion that in those places flint was exclusively used.

The simplest occupations, as requiring the least exercise of mind, are the pursuit of the chase and the tending of flocks and herds. Accordingly, we find our first parents engaged in these occupations. Cain, we are told, was, in addition, a tiller of the ground. Agriculture in its simplest forms requires but little more intelligence than the pursuits just mentioned, though no employment is capable of higher development. If we look at the savage nations at present occupying nearly half the land surface of the earth, we shall find many examples of the former industrial condition of our race preserved to the present day. Many of them had no knowledge of the use of metals until they obtained it from civilized men who visited them, while their pursuits were and are those of the chase, tending domestic animals, and rudimental agriculture.

γ. *The Development of Language.*

In this department the fact of development from the simple to the complex has been so satisfactorily demonstrated by philologists as scarcely to require notice here. The course of that development has been from monosyllabic to polysyllabic forms, and also in a process of differentiation, as derivative races were broken off from the original stock and scattered widely apart. The evidence is clear that simple words for distinct objects formed the bases of the primal languages, just as the ground, tree, sun and moon represent the character of the first words the infant lisps. In this department also the facts point to an infancy of the human race.

δ. *Development of the Fine Arts.*

If we look at representation by drawing or sculpture, we find that the efforts of the earliest races of which we have any knowledge were quite similar to those which the untaught hand of infancy traces on its slate or the savage depicts on the rocky faces of hills. The circle or triangle for the head and body, and straight lines for the limbs, have been preserved as the first attempts of the men of the stone period, as they are to this day the sole representations of the human form which the North American Indian places on his buffalo robe or mountain precipice. The stiff, barely-outlined form of the deer, the turtle, etc., are literally those of the infancy of civilized man.

The first attempts at sculpture were marred by the influence of modism. Thus the idols of Coban and Palenque, with human faces of some merit, are overloaded with absurd ornament, and deformed into frightful asymmetry, in compliance with the demand of some imperious mode. In later days we have the stiff, conventionalized figures of the palaces of Nineveh and the temples of Egypt, where the representation of form has somewhat improved, but is too often distorted by false fashion or imitation of some unnatural standard, real or artistic. This is distinguished as the day of archaic sculpture, which disappeared with the Etruscan nation. So the drawings of the child, when he abandons the simple lines, are stiff and awkward, and but a stage nearer true representation; and how often does he repeat some peculiarity or absurdity of his own! So much easier is it to copy than to conceive.

The introduction of the action and pose of life into sculpture was not known before the early days of Greece, and it was there that the art was brought to perfection. When art rose from its mediæval slumber, much the same succession of development may be discovered. First, the stiff figures, with straightened limbs and cylindric drapery, found in the old Northern churches—then the forms of life that now adorn the porticoes and palaces of the cities of Germany.

ε. *Rationale of the Development of Intelligence.*

The history of material development shows that the transition from stage to stage of development, experienced by the most perfect forms of animals and plants in their growth from the primordial cell, is similar to the succession of created beings which the geological epochs produced. It also shows that the slow assumption of main characters in the line of succession in early geological periods produced the condition of inferiority, while an increased rapidity of growth in later days has resulted in an attainment of superiority. It is not to be supposed that in "acceleration" the period of growth is shortened: on the contrary, it continues the same. Of two beings whose characters are assumed at the same rate of succession, that with the quickest or shortest growth is necessarily inferior. "Acceleration" means a gradual increase of the rate of assumption of successive characters in the same period of time. A fixed rate of assumption of characters, with gradual increase in the length of the period of growth, would produce the same result—viz., a longer developmental scale and the attainment of an advanced position. The first is in part the relation of sexes of a species; the last of genera, and of other types of creation. If from an observed relation of many facts we derive a law, we are permitted, when we see in another class of facts similar relations, to suspect that a similar law has operated, differing only in its objects. We find a marked resemblance between the facts of structural progress in matter and the phenomena of intellectual and spiritual progress.

If the facts entering into the categories enumerated in the preceding section bear us out, we conclude that in the beginning of human history the progress of the individual man was very slow, and that but little was attained to; that through the profitable direction of human energy, means were discovered from time to time by which the process of individual development in all metaphysical qualities has been accelerated; and that up to the present time the consequent advance of the whole race has been at an increasing rate of progress.

This is in accordance with the general principle, that high development in intellectual things is accomplished by rapidity in traversing the preliminary stages of inferiority common to all, while low development signifies sluggishness in that progress, and a corresponding retention of inferiority.

How much meaning may we not see, from this standpoint, in the history of the intelligence of our little ones! First they crawl, they walk on all fours: when they first assume the erect position they are generally speechless, and utter only inarticulate sounds. When they run about, stones and dirt, the objects that first meet the eye, are the delight of their awakening powers, but these are all cast aside when the boy obtains his first jackknife. Soon, however, reading and writing open a new world to him; and finally as a mature man he seizes the forces of nature, and steam and electricity do his bidding in the active pursuit of power for still better and higher ends.

So with the history of the species: first the quadrumane—then the speaking man, whose humble industry was, however, confined to the objects that came first to hand, this being the "stone age" of pre-historic time. When the use of metals was discovered, the range of industries expanded wonderfully, and the "iron age" saw many striking efforts of human power. With the introduction of letters it became possible to record events and experiences, and the spread of knowledge was thereby greatly increased, and the delays and mistakes of ignorance correspondingly diminished in the fields of the world's activity.

From the first we see in history a slow advance as knowledge gained by the accumulation of tradition and by improvements in habit based on experience; but how slow was this advance while the use of the metals was still unknown! The iron age brought with it not only new conveniences, but increased means of future progress; and here we have an acceleration in the rate of advance. With the introduction of letters this rate was increased many fold, and in the application of steam we have a change equal in utility to any that has preceded it, and adding more than any to the possibilities of future advance in many directions. By it power, knowledge and means of happiness were to be distributed among the many.

The uses to which human intelligence has successively applied the materials furnished by nature have been— First, subsistence and defence: second, the accumulation of power in the shape of a representative of that labor which the use of matter involves; in other words, the accumulation of wealth. The possession of this power involves new possibilities, for opportunity is offered for the special pursuits of knowledge and the assistance of the weak or undeveloped part of mankind in its struggles.

Thus, while the first men possessed the power of speech, and could advance a little in knowledge through the accumulation of the experiences of their predecessors, they possessed no means of accumulating the power of labor, no control over the activity of numbers —in other words, no wealth.

But the accumulation of knowledge finally brought this advance about. The extraction and utilization of the metals, especially iron, formed the most important step, since labor was thus facilitated and its productiveness increased in an incalculable degree. We have

little evidence of the existence of a medium of exchange during the first or stone period, and no doubt barter was the only form of trade. Before the use of metals, shells and other objects were used: remains of money of baked clay have been found in Mexico. Finally, though in still ancient times, the possession of wealth in money gradually became possible and more common, and from that day to this avenues for reaching this stage in social progress has ever been opening.

But wealth merely indicates a stage of progress, since it is but a comparative term. All men could not become rich, for in that case all would be equally poor. But labor has a still higher goal; for, thirdly, as capital, it constructs and employs machinery, which does the work of many hands, and thus cheapens products, which is equivalent in effect to an accumulation of wealth to the consumer. And this increase of power may be used for the intellectual and spiritual advance of men, or otherwise, at the will of the men thus favored. Machinery places man in the position of a creator, operating on Nature through an increased number of "secondary causes."

Development of intelligence is seen, then, in the following directions: First, in the knowledge of facts, including science; second, in language; third, in the apprehension of beauty; and, as consequences of these, the accumulation of power by development—First, of means of subsistence; and second, of mechanical invention.

Thus we have two terms to start with in estimating the beginning of human development in knowledge and power: First, the primary capacities of the human mind itself; second, a material world, whose infinitely varied components are so arranged as to yield results to the energies of that mind. For example, the transition points of vaporization and liquefaction are so placed as to be within the reach of man's agents; their weights are so fixed as to accord with the muscular or other forces which he is able to exert; and other living organizations are subject to his convenience and rule, and not, as in previous geological periods, entirely beyond his control. These two terms being given, it is maintained that the present situation of the most civilized men has been attained through the operation of a law of mutual action and reaction—a law whose results, seen at the present time, have depended on the acceleration or retardation of its rate of action; which rate has been regulated, according to the degree in which a third great term, viz., the law of moral or (what is the same thing) true religious development has been combined in the plan. What it is necessary to establish in order to prove the above hypothesis is—

I. That in each of the particulars above enumerated the development of the human species is similar to that of the individual from infancy to maturity.

II. That from a condition of subserviency to the laws of matter, man's intelligence enables him, by an accumulation of power, to become in a sense independent of those laws, and to pursue a course of intellectual and spiritual progress.

III. That failure to accomplish a moral or spiritual development will again reduce him to a subserviency to the laws of matter.

This brings us to the subject of moral development. And here I may be allowed to suggest that the weight of the evidence is opposed to the philosophy, "falsely

so called," of necessitarianism, which asserts that the first two terms alone were sufficient to work out man's salvation in this world and the next; and, on the other hand, to that anti-philosophy which asserts that all things in human progress, intellectual and moral, are regulated by immediate Divine interposition instead of through instrumentalities. Hence the subject divides itself at once into two great departments—viz., that of the development of mind or intelligence, and that of the development of morality.

That these laws are distinct there can be no doubt, since in the individual man one of them may produce results without the aid of the other. Yet it can be shown that each is the most invaluable aid and stimulant to the other, and most favorable to the rapid advance of the mind in either direction.

III. Spiritual or Moral Development.

In examining this subject, we first inquire (Sect. *a*) whether there is any connection between physical and moral or religious development; then (β), what indications of moral development may be derived from history. Finally (γ), a correlation of the results of these inquiries, with the nature of the religious development in the individual, is attempted. Of course in so stupendous an inquiry but a few leading points can be presented here.

If it be true that the period of human existence on the earth has seen a gradually increasing predominance of higher motives over lower ones among the mass of mankind, and if any parts of our metaphysical being have been derived by inheritance from preëxistent beings, we are incited to the inquiry whether any of the moral qualities are included among the latter; and whether there be any resemblance between moral and intellectual development.

Thus, if there have been a physical derivation from a preëxistent genus, and an embryonic condition of those physical characters which distinguish Homo—if there has been also an embryonic or infantile stage in intellectual qualities—we are led to inquire whether the development of the individual in moral nature will furnish us with a standard of estimation of the successive conditions or present relations of the human species in this aspect also.

a. Relations of Physical and Moral Nature.

Although, *cæteris paribus*, men are much alike in the deeper qualities of their nature, there is a range of variation which is best understood by a consideration of the extremes of such variation, as seen in men of different latitudes, and women and children.

(a.) In Children. Youth is distinguished by a peculiarity, which no doubt depends upon an immature condition of the nervous center concerned, which might be called *nervous impressibility*. It is exhibited in a greater tendency to tearfulness, in timidity, less mental endurance, a greater facility in acquiring knowledge, and more ready susceptibility to the influence of sights, sounds and sensations. In both sexes the emotional nature predominates over the intelligence and judgment. In those years the *character* is said to be in embryo, and theologians in using the phrase, "reaching years of religious understanding," mean that in early years the

religious *capacities* undergo development coincidentally with those of the body.

(b.) In Women. If we examine the metaphysical characteristics of women, we observe two classes of traits—namely, those which are also found in men, and those which are absent or but weakly developed in men. Those of the first class are very similar in essential nature to those which men exhibit at an early stage of development. This may be in some way related to the fact that physical maturity occurs earlier in women.

The gentler sex is characterized by a greater impressibility, often seen in the influence exercised by a stronger character, as well as by music, color or spectacle generally; warmth of emotion, submission to its influence rather than that of logic; timidity and irregularity of action in the outer world. All these qualities belong to the male sex, as a general rule, at some period of life, though different individuals lose them at very various periods. Ruggedness and sternness may rarely be developed in infancy, yet at some still prior time they certainly do not exist in any.

Probably most men can recollect some early period of their lives when the emotional nature predominated—a time when emotion at the sight of suffering was more easily stirred than in maturer years. I do not now allude to the benevolence inspired, kept alive or developed by the influence of the Christian religion on the heart, but rather to that which belongs to the natural man. Perhaps all men can recall a period of youth when they were hero-worshipers—when they felt the need of a stronger arm, and loved to look up to the powerful friend who could sympathize with and aid them. This is the "woman stage" of character: in a large number of cases it is early passed; in some it lasts longer; while in a very few men it persists through life. Severe discipline and labor are unfavorable to its persistence. Luxury preserves its bad qualities without its good, while Christianity preserves its good elements without its bad.

It is not designed to say that woman in her emotional nature does not differ from the undeveloped man. On the contrary, though she does not differ in kind, she differs greatly in degree, for her qualities grow with her growth, and exceed in *power* many fold those exhibited by her companion at the original point of departure. Hence, since it might be said that man is the undeveloped woman, a word of explanation will be useful. Embryonic types abound in the fields of nature, but they are not therefore immature in the usual sense. Maintaining the lower essential quality, they yet exhibit the usual results of growth in individual characters; that is, increase of strength, powers of support and protection, size and beauty. In order to maintain that the masculine character coincides with that of the undeveloped woman, it would be necessary to show that the latter during her infancy possesses the male characters predominating—that is, unimpressibility, judgment, physical courage, and the like.

If we look at the second class of female characters—namely, those which are imperfectly developed or absent in men, and in respect to which man may be called undeveloped woman—we note three prominent points: facility in language, tact or finesse, and the love of children. The first two appear to me to be altogether developed results of "impressibility," already considered as an indication of immaturity. Imagina-

tion is also a quality of impressibility, and, associated with finesse, is apt to degenerate into duplicity and untruthfulness—a peculiarity more natural to women than men.

The third quality is different. It generally appears at a very early period of life. Who does not know how soon the little girl selects the doll, and the boy the toy-horse or machine? Here man truly never gets beyond undeveloped woman. Nevertheless, "impressibility" seems to have a great deal to do with this quality also.

Thus the metaphysical relation of the sexes would appear to be one of *inexact parallelism*, as defined in Sect. I. That the physical relation is a remote one of the same kind, several characters seem to point out. The case of the vocal organs will suffice. Their structure is identical in both sexes in early youth, and both produce nearly similar sounds. They remain in this condition in the woman, while they undergo a metamorphosis and change both in structure and vocal power in the man. In the same way, in many of the lower creation, the females possess a majority of embryonic features, though not invariably. A common example is to be found in the plumage of birds, where the females and young males are often undistinguishable.* But there are few points in the physical struc-

* Meehan states that the upper limbs and strong laterals in coniferæ and other trees produce female flowers and cones, and the lower and more interior branches the male flowers. He calls the former condition one of greater "vigor," and the latter one of "weakness," and argues that the vigorous condition of growth produces females, and the weaker males. What he points out, however, is in harmony with the position here maintained—namely, that the female characters include more of those which are embryonic in the males than the male characters include of those which

ture of man also in which the male condition is the immature one. In regard to structure, the point at which the relation between the sexes is that of *exact parallelism*, or where the mature condition of the one sex accords with the undeveloped condition of the other, is when reproduction is no longer accomplished by budding or gemmation, but requires distinct organs. Metaphysically, this relation is to be found where distinct individuality of the sexes first appears; that is, where we pass from the hermaphrodite to the bisexual condition.

But let us put the whole interpretation on this partial undevelopment of woman.

The types or conditions of organic life which have been the most prominent in the world's history—the Ganoids of the first, the Dinosaurs of the second, and the Mammoths of the third period—have generally died with their day. The line of succession has not been from them. The law of anatomy and paleontology is, that we must seek the point of departure of the type which is to predominate in the future, at lower stages on the line, in less decided forms, or in what, in scientific parlance, are called generalized types. In the same

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are embryonic in the female: the female flowers are the product of the younger and more growing portions of the tree—that is, those last produced (the upper limbs and new branches)—while the male flowers are produced by the older or more mature portions—that is, lower limbs or more axial regions. Further, we are not accustomed to regard the condition of rapid growth as that of great vigor in animals, but rather ascribe that quality to maturity, after such growth has ceased.

Meehan's observations coincide with those of Thury and others on the origin of sexes in animals and plants, which it appears to me admit of a similar explanation.

way, though the adults of the tailless apes are in a physical sense more highly developed than their young, yet the latter far more closely resemble the human species in their large facial angle and shortened jaws.

How much significance, then, is added to the law uttered by Christ!—"Except ye become as little children, ye cannot enter the kingdom of heaven." Submission of will, loving trust, confiding faith—these belong to the child: how strange they appear to the executing, commanding, reasoning man! Are they so strange to the woman? We all know the answer. Woman is nearer to the point of departure of that development which outlives time and peoples heaven; and if man would find it, he must retrace his steps, regain something he lost in youth, and join to the powers and energies of his character the submission, love and faith which the new birth alone can give.

Thus the summing up of the metaphysical qualities of woman would be thus expressed: In the emotional world, man's superior; in the moral world, his equal; in the laboring world, his inferior.

There are, however, vast differences in women in respect to the number of masculine traits they may have assumed before being determined into their own special development. Woman also, under the influence of necessity, in later years of life, may add more or less to those qualities in her which are fully developed in the man.

The relation of these facts to the principles stated as the two opposing laws of development is, it appears to me, to be explained thus: First, that woman's most inherent peculiarities are *not* the result of the external circumstances with which she has been placed in contact, as the *conflict theory* would indicate. Such circumstances are said to be her involuntary subserviency to the physically more powerful man, and the effect of a compulsory mode of life in preventing her from attaining a position of equality in the activities of the world. Second, that they *are* the result of the different distributions of qualities as already indicated by the *harmonic theory* of development; that is, of the unequal possession of features which belong to different periods in the developmental succession of the highest. There is then another beautiful harmony which will ever remain, let the development of each sex be extended as far as it may.

(c.) In Men. If we look at the male sex, we shall find various exceptional approximations to the female in mental constitution. Further, there can be little doubt that in the Indo-European race maturity in some respects appears earlier in tropical than in northern regions; and though subject to many exceptions, this is sufficiently general to be looked upon as a rule. Accordingly, we find in that race—at least in the warmer regions of Europe and America—a larger proportion of certain qualities which are more universal in women; as greater activity of the emotional nature when compared with the judgment; an impressibility of the nervous center, which, *cæteris paribus*, appreciates quickly the harmonies of sound, form and color; answers most quickly to the friendly greeting or the hostile menace; is more careless of consequences in the material expression of generosity or hatred, and more indifferent to truth under the influence of personal relations. The movements of the body and expressions of the countenance answer to the temperament. More of grace and

elegance in the bearing marks the Greek, the Italian and the Creole, than the German, the Englishman or the Green Mountain man. More of vivacity and fire, for better or for worse, is displayed in the countenance.

Perhaps the more northern type left all that behind in its youth. The rugged, angular character which appreciates force better than harmony, the strong intellect which delights in forethought and calculation, the less impressibility, reaching stolidity in the uneducated, are its well-known traits. If there be in such a character less generosity and but little chivalry, there is persistency and unwavering fidelity, not readily obscured by the lightning of passion or the dark surmises of an active imagination.

All these peculiarities appear to result, *first*, from different degrees of quickness and depth in appreciating impressions from without; and, *second*, from differing degrees of attention to the intelligent judgment in consequent action. (I leave conscience out, as not belonging to the category of inherited qualities.)

The first is the basis of an emotional nature, and the predominance of the second is the usual indication of maturity. That the first is largely dependent on an impressible condition of the nervous system can be asserted by those who reduce their nervous centers to a sensitive condition by a rapid consumption of the nutritive materials necessary to the production of thought-force, and perhaps of brain tissue itself, induced by close and prolonged mental labor. The condition of overwork, though but an imitation of immaturity, without its joy-giving nutrition, is nevertheless very instructive. The sensitiveness, both physically, emotionally and morally, is often remarkable, and a weakening of the understanding is often coincident with it.

The above observations have been confined to the Indo-European race. It may be objected to the theory that savagery means immaturity in the senses above described, as dependent largely on "impressibility," while savages in general display the least "impressibility," as that word is generally understood. This cannot be asserted of the Africans, who, so far as we know them, possess this peculiarity in a high degree. Moreover, it must be remembered that the state of indifference which precedes that of impressibility in the individual may characterize many savages; while their varied peculiarities may be largely accounted for by recollecting that many combinations of different species of emotions and kinds of intelligence go to make up the complete result in each case.

(d.) Conclusions. Three types of religion may be selected from the developmental conditions of man: first, an absence of sensibility (early infancy); second, an emotional stage more productive of faith than of works; thirdly, an intellectual type, more favorable to works than to faith. Though in regard to responsibility these states may be equal, there is absolutely no gain to laboring humanity from the first type, and a serious loss in actual results from the second, taken alone, as compared with the third.

These, then, are the *physical vehicles of religion*—if the phrase may be allowed—which give character and tone to the deeper spiritual life, as the color of the transparent vessel is communicated to the light which radiates from within.

But if evolution has taken place, there is evidently a provision for the progress from the lower to the higher states, either in the education of circumstances ("conflict,") or in the power of an interior spiritual influence ("harmony,") or both.

β. *Evidence Derived from History.*

We trace the development of Morality in—First, the family or social order; second, the civil order, or government.

Whatever may have been the extent of moral ignorance before the Deluge, it does not appear that the earth was yet prepared for the permanent habitation of the human race. All nations preserve traditions of the drowning of the early peoples by floods, such as have occurred frequently during geologic time. At the close of each period of dry land, a period of submergence has set in, and the depression of the level of the earth, and consequent overflow by the sea, has caused the death and subsequent preservation of the remains of the fauna and flora living upon it, while the elevation of the same has produced that interruption in the process of deposit in the same region which marks the intervals between geologic periods. Change in these respects do not occur to any very material extent at the present time in the regions inhabited by the most highly developed portions of the human race; and as the last which occurred seems to have been expressly designed for the preparation of the earth's surface for the occupation of organized human society, it may be doubted whether many such changes are to be looked for in the future. The last great flooding was that which stratified the drift materials of the north, and carried the finer portions far over the south, determining the minor topography of the surface and supplying it with soils.

The existence of floods which drowned many races of men may be considered as established. The men destroyed by the one recorded by Moses are described by him as exceedingly wicked, so that "the earth was filled with violence." In his eyes the Flood was designed for their extermination.

That their condition was evil must be fully believed if they were condemned by the executive of the Jewish law. This law, it will be remembered, permitted polygamy, slavery, revenge, aggressive war. The Jews were expected to rob their neighbors the Egyptians of jewels, and they were allowed "an eye for an eye and a tooth for a tooth." They were expected to butcher other nations, with their women and children, their flocks and their herds. If we look at the lives of men recorded in the Old Testament as examples of distinguished excellence, we find that their standard, however superior to that of the people around them, would ill accord with the morality of the present day. They were all polygamists, slaveholders and warriors. Abraham treated Hagar and Ishmael with inhumanity. Jacob, with his mother's aid, deceived Isaac, and received thereby a blessing which extended to the whole Jewish nation. David, a man whom Paul tells us the Lord found to be after his own heart, slew the messenger who brought tidings of the death of Saul, and committed other acts which would stain the reputation of a Christian beyond redemption. It is scarcely necessary to turn to other nations if this be true of the chosen men of a chosen people. History indeed presents us with no people prior to, or contemporary with, the Jews who were not morally their inferiors.

If we turn to more modern periods, an examination

of the morality of Greece and Rome reveals a curious intermixture of lower and higher moral conditions. While each of these nations produced excellent moralists, the influence of their teachings was not sufficient to elevate the masses above what would now be regarded as a very low standard. The popularity of those scenes of cruelty, the gladiatorial shows and the combats with wild beasts, sufficiently attests this. The Roman virtue of patriotism, while productive of many noble deeds, is in itself far from being a disinterested one, but partakes rather of the nature of partisanship and selfishness. If the Greeks were superior to the Romans in humanity, they were apparently their inferiors in the social virtues, and were much below the standard of Christian nations in both respects.

Ancient history points to a state of chronic war, in which the social relations were in confusion, and the development of the useful arts was almost impossible. Savage races, which continue to this day in a similar moral condition, are, we may easily believe, most unhappy. They are generally divided into tribes, which are mutually hostile, or friendly only with the view of injuring some other tribe. Might is their law, and robbery, rapine and murder express their mutual relations. This is the history of the lowest grade of barbarism, and the history of primeval man so far as it has come down to us in sacred and profane records. Man as a species first appears in history as a sinful being. Then a race maintaining a contest with the prevailing corruption and exhibiting a higher moral ideal is presented to us in Jewish history. Finally, early Christian society exhibits a greatly superior condition of things. In it polygamy scarcely existed, and slavery and war were condemned. But progress did not end here, for our Lord said, "I have yet many things to say unto you, but ye cannot bear them now. Howbeit, when He, the spirit of truth, is come, He will guide you into all truth."

The progress revealed to us by history is truly great, and if a similar difference existed between the first of the human species and the first of whose condition we have information, we can conceive how low the origin must have been. History begins with a considerable progress in civilization, and from this we must infer a long preceding period of human existence, such as a gradual evolution would require.

γ. *Rationale of Moral Development.*

I. *Of the Species.* Let us now look at the moral condition of the infant man of the present time. We know his small accountability, his trust, his innocence. We know that he is free from the law that when he "would do good, evil is present with him," for good and evil are alike unknown. We know that until growth has progressed to a certain degree he fully deserves the praise pronounced by Our Saviour, that "of such is the kingdom of heaven." Growth, however, generally sees a change. We know that the buddings of evil appear but too soon: the lapse of a few months sees exhibitions of anger, disobedience, malice, falsehood, and their attendants—the fruit of a corruption within not manifested before.

In early youth it may be said that moral susceptibility is often in inverse ratio to physical vigor. But with growth the more physically vigorous are often sooner taught the lessons of life, for their energy brings

them into earlier conflict with the antagonisms and contradictions of the world. Here is a beautiful example of the benevolent principle of compensation.

1. *Innocence and the Fall.* If physical evolution be a reality, we have reason to believe that the infantile stage of human morals, as well as of human intellect, was much prolonged in the history of our first parents. This constitutes the period of human purity, when we are told by Moses that the first pair dwelt in Eden. But the growth to maturity saw the development of all the qualities inherited from the irresponsible denizen of the forest. Man inherits from his predecessors in the creation the buddings of reason: he inherits passions, propensities and appetites. His corruption is that of his animal progenitors, and his sin is the low and bestial instinct of the brute creation. Thus only is the origin of sin made clear—a problem which the pride of man would have explained in any other way had it been possible.

But how startling the exhibition of evil by this new being as compared with the scenes of the countless ages already past! Then the right of the strongest was God's law, and rapine and destruction were the history of life. But into man had been "breathed the breath of life," and he had "become a living soul." The law of right, the Divine Spirit, was planted within him, and the laws of the beast were in antagonism to that law. The natural development of his inherited qualities necessarily brought him into collision with that higher standard planted within him, and that war was commenced which shall never cease "till He hath put all things under His feet." The first act of man's disobedience constituted the Fall, and with it would come the first *intellectual* "knowledge of good and of evil"—an apprehension up to that time derived exclusively from the divinity within, or conscience.*

2. *Free Agency*. Heretofore development had been that of physical types, but the Lord had rested on the seventh day, for man closed the line of the physical creation. Now a new development was to begin—the development of mind, of morality and of grace.

On the previous days of Creation all had progressed in accordance with inevitable law apart from its objects. Now two lines of development were at the disposal of this being, between which his *free will* was to choose. Did he choose the courses dictated by the spirit of the brute, he was to be subject to the old law of the brute creation—the right of the strongest and spiritual death. Did he choose the guidance of the Divine Guest in his heart, he became subject to the laws which are to guide—I. the human species to an ultimate perfection, so far as consistent with this world; and II. the individual man to a higher life, where a new existence awaits him as a spiritual being, freed from the laws of terrestrial matter.

* In our present translation of Genesis, the Fall is ascribed to the influence of Satan assuming the form of the serpent, and this animal was cursed in consequence, and compelled to assume a prone position. This rendering may well be revised, since serpents, prone like others, existed in both America and Europe during the Eocene epoch, five times as great a period before Adam as has elapsed since his day. Clark states, with great probability, that "serpent" should be translated monkey or ape—a conclusion, it will be observed, exactly coinciding with our inductions on the basis of evolution. The instigation to evil by an ape merely states inheritance in another form. His curse, then, refers to the retention of the horizontal position retained by all other quadrumana, as we find it at the present day.

The charge brought against the theory of development, that it implies a necessary progress of man to all perfection without his coöperation—or *necessitarianism*, as it is called—is unfounded.

The free will of man remains the source alike of his progress and his relapse. But the choice once made, the laws of spiritual development are apparently as inevitable as those of matter. Thus men whose religious capacities are increased by attention to the Divine Monitor within are in the advance of progress—progress coinciding with that which in material things is called the *harmonic*. On the other hand, those whose motives are of the lower origin fall under the working of the law of *conflict*.

The lesson derivable from the preceeding considerations would seem to be "necessitarian" as respects the whole human race, considered by itself; and I believe it is to be truly so interpreted. That is, the Creator of all things has set agencies at work which will slowly develop a perfect humanity out of His lower creation, and nothing can thwart the process or alter the result. "My word shall not return unto Me void, but it shall accomplish that which I please, and it shall prosper in the thing whereto I sent it." This is our great encouragement, our noblest hope—second only to that which looks to a blessed inheritance in another world. It is this thought that should inspire the farmer, who as he toils wonders, "Why all this labor? The Good Father could have made me like the lilies, who, though they toil not, neither spin, are yet clothed in glory; and why should I, a nobler being, be subject to the dust and the sweat of labor?" This thought should enlighten every artisan of the thousands that people the factories and guide their whirling machinery in our modern cities. Every revolution of a wheel is moving the car of progress, and the timed stroke of the crank and the rhythmic throw of the shuttle are but the music the spheres have sung since time began. A new significance then appears in the prayer of David: "Let the beauty of the Lord our God be upon us, and establish Thou the work of our hands upon us: the work of our hands, O Lord, establish Thou it." But beware of the catastrophe, for "He will sit as a refiner:" "the wheat shall be gathered into barns, but the chaff shall be burned with unquenchable fire." If this be true, let us look for—

3. *The Extinction of Evil.* How is necessitarianism to be reconciled with free will? It appears to me, thus: When a being whose safety depends on the perfection of a system of laws abandons the system by which he lives, he becomes subject to that lower grade of laws which govern lower intelligences. Man, falling from the laws of right, comes under the dominion of the laws of brute force; as said our Saviour: "Salt is good, but if the salt have lost his savor, it is thenceforth good for nothing but to be cast forth and trodden under foot of men."

In estimating the practical results to man of the actions prompted by the lower portion of our nature, it is only necessary to carry out to its full development each of those animal qualities which may in certain states of society be restrained by the social system. In human history those qualities have repeatedly had this development, and the battle of progress is fought to decide whether they shall overthrow the system that restrains them, or be overthrown by it.

Entire obedience to the lower instincts of our nature ensures destruction to the weaker, and generally to the stronger also. A most marked case of this kind is seen where the developed vices of civilization are introduced among a savage people—as, for example, the North American Indians. These seem in consequence to be hastening to extinction.

But a system or a circuit of existence has been allotted to the civil associations of the animal species man, independently of his moral development. It may be briefly stated thus: Races begin as poor offshoots or emigrants from a parent stock. The law of labor develops their powers, and increases their wealth and numbers. These will be diminished by their various vices; but on the whole, in proportion as the intellectual and economical elements prevail, wealth will increase; that is, they accumulate power. When this has been accomplished, and before activity has slackened its speed, the nation has reached the culminating point, and then it enters upon the period of decline. The restraints imposed by economy and active occupation being removed, the beastly traits find in accumulated power only increased means of gratification, and industry and prosperity sink together. Power is squandered, little is accumulated, and the nation goes down to its extinction amid scenes of internal strife and vice. Its cycle is soon fulfilled, and other nations, fresh from scenes of labor, assault it, absorb its fragments, and it dies. This has been the world's history, and it remains to be seen whether the virtues of the nations now existing will be sufficient to save them from a like fate.

Thus the history of the animal man in nations is wonderfully like that of the type or families of the animal and vegetable kingdoms during geologic ages. They rise, they increase and reach a period of multiplication and power. The force allotted to them becoming exhausted, they diminish and sink and die.

II. *Of the Individual.* In discussing physical development, we are as yet compelled to restrict ourselves to the evidence of its existence and some laws observed in the operation of its causative force. What that force is, or what are its primary laws, we know not.

So in the progress of moral development we endeavor to prove its existence and the mode of its operation, but why that mode should exist, rather than some other mode, we cannot explain.

The moral progress of the species depends, of course, on the moral progress of the individuals embraced in it. Religion is the sum of those influences which determine the motives of men's actions into harmony with the Divine perfection and the Divine will.

Obedience to these influences constitutes the practice of religion, while the statement of the growth and operation of these influences constitutes the theory of religion, or doctrine.

The Divine Spirit planted in man shows him that which is in harmony with the Divine Mind, and it remains for his free will to conform to it or reject it. This harmony is man's highest ideal of happiness, and in seeking it, as well as in desiring to flee from dissonance or pain, he but obeys the disposition common to all conscious beings. If, however, he attempts to conform to it, he will find the law of evil present, and frequently obtaining the mastery. If now he be in any degree observing, he will find that the laws of morality and right are the only ones by which human society exists in a

condition superior to that of the lower animals, and in which the capacities of man for happiness can approach a state of satisfaction. He may be then said to be "awakened" to the importance of religion. If he carry on the struggle to attain to the high goal presented to his spiritual vision, he will be deeply grieved and humbled at his failures: then he is said to be "convicted." Under these circumstances the necessity of a deliverance becomes clear, and is willingly accepted in the only way in which it has pleased the Author of all to present it, which has been epitomized by Paul as "the washing of regeneration and renewal of the Holy Spirit through Jesus Christ." Thus a life of advanced and ever-advancing moral excellence becomes possible, and the man makes nearer approaches to the "image of God."

Thus is opened a new era in spiritual development, which we are led to believe leads to an ultimate condition in which the nature inherited from our origin is entirely overcome, and an existence of moral perfection entered on. Thus in the book of Mark the simile occurs: "First the blade, then the ear, after that the full corn in the ear;" and Solomon says that the development of righteousness "shines more and more unto the perfect day."

8. *Summary.*

If it be true that general development in morality proceeds in spite of the original predominance of evil in the world, through the self-destructive nature of the latter, it is only necessary to examine the reasons why the excellence of the good may have been subject also to progress, and how the remainder of the race may have been influenced thereby.

The development of morality is then probably to be understood in the following sense: Since the Divine Spirit, as the prime force in human progress, cannot in itself be supposed to have been in any way under the influence of natural laws, its capacities were no doubt as eternal and unerring in the first man as in the last. But the facts and probabilities discussed above point to development of *religious sensibility*, or capacity to appreciate moral good, or to receive impressions from the source of good.

The evidence of this is supposed to be seen in—*First*, improvement in man's views of his duty to his neighbor; and *Second*, the substitution of spiritual for symbolic religions: in other words, improvement in the capacity for receiving spiritual impressions.

What the primary cause of this supposed development of religious sensibility may have been, is a question we reverently leave untouched. That it is intimately connected in some way with, and in part dependent on, the evolution of the intelligence, appears very probable: for this evolution is seen—*First*, in a better understanding of the consequences of action, and of good and of evil in many things; and *Second*, in the production of means for the spread of the special instrumentalities of good. The following may be enumerated as such instrumentalities:

1. Furnishing literary means of record and distribution of the truths of religion, morality and science.

2. Creating and increasing modes of transportation of teachers and literary means of disseminating truth.

3. Facilitating the migration and the spread of nations holding the highest position in the scale of morality.

4. The increase of wealth, which multiplies the extent of the preceding means.

And now, let no man attempt to set bounds to this development. Let no man say even that morality accomplished is all that is required of mankind, since that is not necessarily the evidence of a spiritual development. If a man possess the capacity for progress beyond the condition in which he finds himself, in refusing to enter upon it he declines to conform to the Divine law. For "from those to whom little is given, little is required, but from those to whom much is given, much shall be required."

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[OVER.]

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THE DEVELOPMENT OF HUMAN RACES UNDER THE LAW OF NATURAL SELECTION.

Among the most advanced students of man, there exists a wide difference of opinion on some of the most vital questions respecting his nature and origin. Anthropologists are now, indeed, pretty well agreed that man is not a recent introduction into the earth. All who have studied the question now admit that his antiquity is very great; and that, though we have to some extent ascertained the minimum of time during which he *must* have existed, we have made no approximation towards determining that far greater period during which he *may* have, and probably *has* existed. We can with tolerable certainty affirm that man must have inhabited the earth a thousand centuries ago, but we cannot assert that he positively did not exist, or that there is any good evidence against his having existed, for a period of ten thousand centuries. We know positively that he was contemporaneous with many now extinct animals, and has survived changes of the earth's surface fifty or a hundred times greater than any that have occurred during the historical period; but we cannot place any definite limit to the number of species he may have outlived, or to the amount of terrestrial change he may have witnessed.

WIDE DIFFERENCE OF OPINION AS TO MAN'S ORIGIN.

But while on this question of man's antiquity there is a very general agreement,—and all are waiting eagerly for fresh evidence to clear up those points which all admit to be full of doubt,—on other, and not less obscure and difficult questions, a considerable amount of dogmatism is exhibited; doctrines are put forward as established truths, no doubt or hesitation is admitted, and it seems to be supposed that no other further evidence is required, or that any new facts can modify our convictions. This is especially the case when we inquire—Are the various forms under which man now exists primitive, or derived from pre-existent forms; in other words, is man of one or many species? To this question we immediately obtain distinct answers diametrically opposed to each other: the one party positively maintaining that man is a *species* and is essentially *one*—that all differences are but local and temporary variations, produced by the different physical and moral conditions by which he is surrounded; the other party maintaining with equal confidence, that man is a genus of *many species*, each of which is practically unchangeable, and has ever been as distinct, or even more distinct, than we now behold them. This difference of opinion is somewhat remarkable, when we consider that both parties are well acquainted with the subject; both use the same vast accumulation of facts; both reject those

early traditions of mankind which profess to give an account of his origin; and both declare that they are seeking fearlessly after truth alone; yet each will persist in looking only at the portion of truth on his own side of the question, and at the error which is mingled with his opponent's doctrine. It is my wish to show how the two opposing views can be combined, so as to eliminate the error and retain the truth in each, and it is by means of Mr. Darwin's celebrated theory of "Natural Selection" that I hope to do this, and thus to harmonize the conflicting theories of modern anthropologists.

Let us first see what each party has to say for itself. In favor of the unity of mankind it is argued, that there are no races without transitions to others; that every race exhibits within itself variations of color, of hair, of feature, and of form, to such a degree as to bridge over, to a large extent, the gap that separates it from other races. It is asserted that no race is homogeneous; that there is a tendency to vary; the climate, food, and habits produce, and render permanent, physical peculiarities, which, though slight in the limited periods allowed to our observation, would, in the long ages during which the human race has existed, have sufficed to produce all the differences that now appear. It is further asserted that the advocates of the opposite theory do not agree among themselves; that some would make three, some five, some fifty or a hundred and fifty species of man; some would have had each species created in pairs, while others require nations to have at once sprung into existence, and that there is no stability or consistency in any doctrine but that of one primitive stock.

The advocates of the original diversity of man, on the other hand, have much to say for themselves. They argue that proofs of change in man have never been brought forward except to the most trifling amount, while evidence of his permanence meets us everywhere. The Portuguese and Spaniards, settled for two or three centuries in South America, retain their chief physical, mental, and moral characteristics; the Dutch boers at the Cape, and the descendants of the early Dutch settlers in the Moluccas, have not lost the features or the color of the Germanic races; the Jews, scattered over the world in the most diverse climates, retain the same characteristic lineaments everywhere; the Egyptian sculptures and paintings show us that, for at least 4000 or 5000 years, the strongly contrasted features of the Negro and Semitic races have remained altogether unchanged; while more recent discoveries prove, that the mound-builders of the Mississippi valley, and the dwellers on Brazilian mountains, had, even in the very infancy of the human race, some traces of the same peculiar and characteristic type of cranial formation that now distinguishes them.

If we endeavor to decide impartially on the merits of this difficult controversy, judging solely by the evidence that each party has brought forward, it certainly seems that the best of the argument is on the side of those who maintain the primitive diversity of man. Their opponents have not been able to refute the permanence of existing races as far back as we can trace them, and have failed to show, in a single case, that at any former epoch the well marked varieties of mankind approximated more closely than they do at the present day. At the same time this is but negative evidence. A condition of immobility for four or five thousand

years, does not preclude an advance at an earlier epoch, and—if we can show that there are causes in nature which would check any further physical change when certain conditions were fulfilled—does not even render such an advance improbable, if there are any general arguments to be adduced in its favor. Such a cause, I believe, does exist; and I shall now endeavor to point out its nature and its mode of operation.

OUTLINE OF THE THEORY OF NATURAL SELECTION.

In order to make my article intelligible, it is necessary for me to explain very briefly the theory of "Natural Selection" promulgated by Mr. Darwin, and the power which it possesses of modifying the forms of animals and plants. The grand feature in the multiplication of organic life is, that close general resemblance is combined with more or less individual variation. The child resembles its parents or ancestors more or less closely in all its peculiarities, deformities or beauties; it resembles them in general more than it does any other individuals; yet children of the same parents are not all alike, and it often happens that they differ very considerably from their parents and from each other. This is equally true of man, of all animals, and of all plants. Moreover, it is found that individuals do not differ from their parents in certain particulars only, while in all others they are exact duplicates of them. They differ from them and from each other in every particular: in form, in size, in color; in the structure of internal as well as of external organs; in those subtle peculiarities which produce differences of constitution, as well as in those still more subtle ones which lead to modifications of mind and character. In other words, in every possible way, in every organ and in every function, individuals of the same stock vary.

Now, health, strength, and long life are the results of a harmony between the individual and the universe that surrounds it. Let us suppose that at any given moment this harmony is perfect. A certain animal is exactly fitted to secure its prey, to escape from its enemies, to resist the inclemencies of the seasons, and to rear a numerous and healthy offspring. But a change now takes place. A series of cold winters, for instance, come on, making food scarce, and bringing an immigration of some other animals to compete with the former inhabitants of the district. The new immigrant is swift of foot, and surpasses its rivals in the pursuit of game; the winter nights are colder, and require a thicker fur as a protection, and more nourishing food to keep up the heat of the system. Our supposed perfect animal is no longer in harmony with its universe; it is in danger of dying of cold or of starvation. But the animal varies in its offspring. Some of these are swifter than others—they still manage to catch food enough; some are hardier and more thickly furred—they manage in the cold nights to keep warm enough; the slow, the weak, and the thinly clad soon die off. Again and again, in each succeeding generation, the same thing takes place. By this natural process, which is so inevitable that it cannot be conceived not to act, those best adapted to live, live; those least adapted, die. It is sometimes said that we have no direct evidence of the action of this selecting power in nature. But it seems to me we have better evidence than even direct observation would be, because it is more universal, viz., the evidence of necessity. It must be so; for, as all wild animals

increase in a geometrical ratio, while their actual numbers remain on the average stationary, it follows that as many die annually as are born. If, therefore, we deny natural selection, it can only be by asserting that, in such a case as I have supposed, the strong, the healthy, the swift, the well clad, the well organized animals in every respect, have no advantage over,—do not on the average live longer than the weak, the unhealthy, the slow, the ill-clad, and the imperfectly organized individuals; and this no sane man has yet been found hardy enough to assert. But this is not all; for the offspring on the average resemble their parents, and the selected portion of each succeeding generation will therefore be stronger, swifter, and more thickly furred than the last; and if this process goes on for thousands of generations, our animal will have again become thoroughly in harmony with the new conditions in which it is placed. But it will now be a different creature. It will be not only swifter and stronger, and more furry, it will also probably have changed in color, in form, perhaps have acquired a longer tail, or differently shaped ears; for it is an ascertained fact, that when one part of an animal is modified, some other parts almost always change, as it were in sympathy with it. Mr. Darwin calls this "correlation of growth," and gives as instances, that hairless dogs have imperfect teeth; white cats, when blue-eyed, are deaf; small feet accompany short beaks in pigeons; and other equally interesting cases.

Grant, therefore, the premises: 1st. That peculiarities of every kind are more or less hereditary. 2nd. That the offspring of every animal vary more or less in all parts of their organization. 3rd. That the universe in which these animals live, is not absolutely invariable; —none of which propositions can be denied; and then consider that the animals in any country (those at least which are not dying out) must at each successive period be brought into harmony with the surrounding conditions; and we have all the elements for a change of form and structure in the animals, keeping exact pace with changes of whatever nature in the surrounding universe. Such changes must be slow, for the changes in the universe are very slow; but just as these slow changes become important, when we look at results after long periods of action, as we do when we perceive the alterations of the earth's surface during geological epochs; so the parallel changes in animal form become more and more striking, in proportion as the time they have been going on is great; as we see when we compare our living animals with those which we disentomb from each successively older geological formation.

This is, briefly, the theory of "natural selection," which explains the changes in the organic world as being parallel with, and in part dependent on, those in the inorganic. What we now have to inquire is,—Can this theory be applied in any way to the question of the origin of the races of man? or is there anything in human nature that takes him out of the category of those organic existences, over whose successive mutations it has had such powerful sway.

DIFFERENT EFFECTS OF NATURAL SELECTION ON ANIMALS AND ON MAN.

In order to answer these questions, we must consider why it is that "natural selection" acts so powerfully upon animals; and we shall, I believe, find that its effect

depends mainly upon their self-dependence and individual isolation. A slight injury, a temporary illness, will often end in death, because it leaves the individual powerless against its enemies. If an herbivorous animal is a little sick and has not fed well for a day or two, and the herd is then pursued by a beast of prey, our poor invalid inevitably falls a victim. So, in a carniverous animal, the least deficiency of vigor prevents its capturing food, and it soon dies of starvation. There is, as a general rule, no mutual assistance between adults, which enables them to tide over a period of sickness. Neither is there any division of labor; each must fulfil *all* the conditions of its existence, and, therefore, "natural selection" keeps all up to a pretty uniform standard.

But in man, as we now behold him, this is different. He is social and sympathetic. In the rudest tribes the sick are assisted, at least with food; less robust health and vigor than the average does not entail death. Neither does the want of perfect limbs, or other organs, produce the same effects as among animals. Some division of labor takes place; the swiftest hunt, the less active fish, or gather fruits; food is, to some extent, exchanged or divided. The action of natural selection is therefore checked; the weaker, the dwarfish, those of less active limbs, or less piercing eyesight, do not suffer the extreme penalty which falls upon animals so defective.

In proportion as these physical characteristics become of less importance, mental and moral qualities will have increasing influence on the well-being of the race. Capacity for acting in concert for protection, and for the acquisition of food and shelter; sympathy, which leads all in turn to assist each other; the sense of right, which checks depredations upon our fellows; the smaller development of the combative and destructive propensities; self-restraint in present appetites; and that intelligent foresight which prepares for the future, are all qualities, that from their earliest appearance must have been for the benefit of each community, and would, therefore, have become the subjects of "natural selection." For it is evident that such qualities would be for the well-being of man; would guard him against external enemies, against internal dissensions, and against the effects of inclement seasons and impending famine, more surely than could any merely physical modification. Tribes in which such mental and moral qualities were predominant, would therefore have an advantage in the struggle for existence over other tribes in which they were less developed, would live and maintain their numbers, while the others would decrease and finally succumb.

Again, when any slow changes of physical geography, or of climate, make it necessary for an animal to alter its food, its clothing, or its weapons, it can only do so by the occurrence of a corresponding change in its own bodily structure and internal organization. If a larger or more powerful beast is to be captured and devoured, as when a carnivorous animal which has hitherto preyed on antelopes is obliged from their decreasing numbers to attack buffaloes, it is only the strongest who can hold, those with most powerful claws, and formidable canine teeth, that can struggle with and overcome such an animal. Natural selection immediately comes into play, and by its action these organs gradually become adapted to their new requirements. But man, under similar circumstances, does not require longer nails or

teeth, greater bodily strength or swiftness. He makes sharper spears, or a better bow, or he constructs a cunning pitfall, or combines in a hunting party to circumvent his new prey. The capacities which enable him to do this are what he requires to be strengthened, and these will, therefore, be gradually modified by "natural selection," while the form and structure of his body will remain unchanged. So, when a glacial epoch comes on, some animals must acquire a warmer fur, or a covering of fat, or else die of cold. Those best clothed by nature are, therefore, preserved by natural selection. Man, under the same circumstances, will make himself warmer clothing, and build better houses; and the necessity of doing this will react upon his mental organization and social condition—will advance them while his natural body remains naked as before.

When the accustomed food of some animal becomes scarce or totally fails, it can only exist by becoming adapted to a new kind of food, a food perhaps less nourishing and less digestible. "Natural selection" will now act upon the stomach and intestines, and all their individual variations will be taken advantage of, to modify the race into harmony with its new food. In many cases, however, it is probable that this cannot be done. The internal organs may not vary quick enough, and then the animal will decrease in numbers, and finally become extinct. But man guards himself from such accidents by superintending and guiding the operations of nature. He plants the seed of his most agreeable food, and thus procures a supply, independent of the accidents of varying seasons or natural extinction. He domesticates animals, which serve him either to capture food or for food itself, and thus, changes of any great extent in his teeth or digestive organs are rendered unnecessary. Man, too, has everywhere the use of fire, and by its means can render palatable a variety of animal and vegetable substances, which he could hardly otherwise make use of; and thus obtains for himself a supply of food far more varied and abundant than that which any animal can command.

Thus man, by the mere capacity of clothing himself, and making weapons and tools, has taken away from nature that power of slowly but permanently changing the external form and structure, in accordance with changes in the external world, which she exercises over all other animals. As the competing races by which they are surrounded, the climate, the vegetation, or the animals which serve them for food, are slowly changing, they must undergo a corresponding change in their structure, habits, and constitution, to keep them in harmony with the new conditions—to enable them to live and maintain their numbers. But man does this by means of his intellect alone, the variations of which enable him, with an unchanged body, still to keep in harmony with the changing universe.

There is one point, however, in which nature will still act upon him as it does on animals, and, to some extent, modify his external characters. Mr. Darwin has shown that the color of the skin is correlated with constitutional peculiarities both in vegetables and animals, so that liability to certain diseases or freedom from them is often accompanied by marked external characters. Now, there is every reason to believe that this has acted, and, to some extent, may still continue to act, on man. In

localties where certain diseases are prevalent, those individuals of savage races which were subject to them would rapidly die off; while those who were constitutionally free from the disease would survive, and form the progenitors of a new race. These favored individuals would probably be distinguished by peculiarities of *color*, with which again peculiarities in the texture or the abundance of *hair* seem to be correlated, and thus may have been brought about those racial differences of color, which seem to have no relation to mere temperature or other obvious peculiarities of climate.

From the time, therefore, when the social and sympathetic feelings came into active operation, and the intellectual and moral faculties became fairly developed, man would cease to be influenced by "natural selection" in his physical form and structure. As an animal he would remain almost stationary, the changes of the surrounding universe ceasing to produce in him that powerful modifying effect which they exercise over other parts of the organic world. But from the moment that the form of his body became stationary, his mind would become subject to those very influences from which his body had escaped; every slight variation in his mental and moral nature which should enable him better to guard against adverse circumstances, and combine for mutual comfort and protection, would be preserved and accumulated; the better and higher specimens of our race would therefore increase and spread, the lower and more brutal would give way and successively die out, and that rapid advancement of mental organization would occur, which has raised the very lowest races of man so far above the brutes (although differing so little from some of them in physical structure), and, in conjunction with scarcely perceptible modifications of form, has developed the wonderful intellect of the European races.

INFLUENCE OF EXTERNAL NATURE IN THE DEVELOPMENT OF THE HUMAN MIND.

But from the time when this mental and moral advance commenced, and man's physical character became fixed and almost immutable, a new series of causes would come into action, and take part in his mental growth. The diverse aspects of nature would now make themselves felt, and profoundly influence the character of the primitive man.

When the power that had hitherto modified the body had its action transferred to the mind, then races would advance and become improved, merely by the harsh discipline of a sterile soil and inclement seasons. Under their influence, a hardier, a more provident, and a more social race would be developed, than in those regions where the earth produces a perennial supply of vegetable food, and where neither foresight nor ingenuity are required to prepare for the rigors of winter. And is it not the fact that in all ages, and in every quarter of the globe, the inhabitants of temperate have been superior to those of hotter countries? All the great invasions and displacements of races have been from north to south, rather than the reverse; and we have no record of there ever having existed, any more than there exists to-day, a solitary instance of an indigenous inter-tropical civilization. The Mexican civilization and government came from the north, and, as well as the Peruvian, was established, not in the rich and tropical plains, but on the lofty and sterile plateaux of the Andes. The

religion and civilization of Ceylon were introduced from North India; the successive conquerors of the Indian peninsula came from the north-west; the northern Monguls conquered the more southern Chinese; and it was the bold and adventurous tribes of the north that overran and infused new life into southern Europe.

EXTINCTION OF THE LOWER RACES.

It is the same great law of "the preservation of favored races in the struggle for life," which leads to the inevitable extinction of all those low and mentally undeveloped populations with which Europeans come in contact. The red Indian in North America and in Brazil; the Tasmanian, Australian, and New Zealander in the southern hemisphere, die out, not from any one special cause, but from the inevitable effects of an unequal mental and physical struggle. The intellectual and moral, as well as the physical qualities of the European are superior; the same powers and capacities which have made him rise in a few centuries from the condition of the wandering savage with a scanty and stationary population, to his present state of culture and advancement, with a greater average longevity, a greater average strength, and a capacity of more rapid increase, —enable him when in contact with the savage man, to conquer in the struggle for existence, and to increase at his expense, just as the better adapted increase at the expense of the less adapted varieties in the animal and vegetable kingdoms,—just as the weeds of Europe overrun North America and Australia, extinguishing native productions by the inherent vigor of their organization, and by their greater capacity for existence and multiplication.

THE ORIGIN OF THE RACES OF MAN.

If these views are correct; if in proportion as man's social, moral, and intellectual faculties became developed, his physical structure would cease to be affected by the operation of "natural selection," we have a most important clue to the origin of races. For it will follow that those great modifications of structure and of external form, which resulted in the development of man out of some lower type of animal, must have occurred before his intellect had raised him above the condition of the brutes, at a period when he was gregarious, but scarcely social, with a mind perceptive but not reflective, ere any sense of *right* or feelings of *sympathy* had been developed in him. He would be still subject, like the rest of the organic world, to the action of "natural selection," which would retain his physical form and constitution in harmony with the surrounding universe. He was probably at a very early period a dominant race, spreading widely over the warmer regions of the earth as it then existed, and in agreement with what we see in the case of other dominant species, gradually becoming modified in accordance with local conditions. As he ranged farther from his original home, and became exposed to greater extremes of climate, to greater changes of food, and had to contend with new enemies, organic and inorganic, slight useful variations in his constitution would be selected and rendered permanent, and would, on the principle of "correlation of growth," be accompanied by corresponding external physical changes. Thus might have arisen those striking characteristics and special modifications which still distinguish the chief races of mankind. The red, black,

yellow, or blushing white skin; the straight, the curly, the woolly hair; the scanty or abundant beard; the straight or oblique eyes; the various forms of the pelvis, the cranium, and other parts of the skeleton.

But while these changes had been going on, his mental development had, from some unknown cause, greatly advanced, and had now reached that condition in which it began powerfully to influence his whole existence, and would therefore become subject to the irresistible action of "natural selection." This action would quickly give the ascendancy to mind: speech would probably now be first developed, leading to a still further advance of the mental faculties; and from that moment man, as regards the form and structure of most parts of his body, would remain almost stationary. The art of making weapons, division of labor, anticipation of the future, restraint of the appetites, moral, social and sympathetic feelings, would now have a preponderating influence on his well-being, and would therefore be that part of his nature on which "natural selection" would most powerfully act; and we should thus have explained that wonderful persistence of mere physical characteristics, which is the stumbling block of those who advocate the unity of mankind.

We are now, therefore, enabled to harmonise the conflicting views of anthropologists on this subject. Man may have been—indeed I believe must have been—once a homogeneous race; but it was at a period of which we have as yet discovered no remains, at a period so remote in his history that he had not yet acquired that wonderfully developed brain, the organ of the mind, which now, even in his lowest examples, raises him far above the highest brutes; at a period when he had the form but hardly the nature of man, when he neither possessed human speech, nor those sympathetic and moral feelings which in a greater or less degree everywhere now distinguish the race. Just in proportion as these truly human faculties became developed in him, would his physical features become fixed and permanent, because the latter would be of less importance to his well-being; he would be kept in harmony with the slowly changing universe around him, by an advance in mind, rather than by a change in body. If, therefore, we are of opinion that he was not really man till these higher faculties were fully developed, we may fairly assert that there were many originally distinct races of men; while, if we think that a being closely resembling us in form and structure, but with mental faculties scarcely raised above the brute, must still be considered to have been human, we are fully entitled to maintain the common origin of all mankind.

THE BEARING OF THESE VIEWS ON THE ANTIQUITY OF MAN.

These considerations, it will be seen, enable us to place the origin of man at a much more remote geological epoch than has yet been thought possible. He may even have lived in the Miocene or Eocene period, when not a single mammal was identical in form with any existing species. For, in the long series of ages during which these primeval animals were being slowly changed into the species which now inhabit the earth, the power which acted to modify them would only affect the mental organization of man. His brain alone would have increased in size and complexity, and his cranium have undergone corresponding changes of form, while the

whole structure of lower animals was being changed. This will enable us to understand how the fossil crania of Denise and Engis agree so closely with existing forms, although they undoubtedly existed in company with large mammalia now extinct. The Neanderthal skull may be a specimen of one of the lowest races then existing, just as the Australians are the lowest of our modern epoch. We have no reason to suppose that mind and brain and skull modification, could go on quicker than that of the other parts of the organization; and we must therefore look back very far in the past to find man in that early condition in which his mind was not sufficiently developed to remove his body from the modifying influence of external conditions and the cumulative action of "natural selection." I believe, therefore, that there is no *à priori* reason against our finding the remains of man or his works in the tertiary deposits. The absence of all such remains in the European beds of this age has little weight, because, as we go further back in time, it is natural to suppose that man's distribution over the surface of the earth was less universal than at present.

Besides, Europe was in a great measure submerged during the tertiary epoch; and though its scattered islands may have been uninhabited by man, it by no means follows that he did not at the same time exist in warm or tropical continents. If geologists can point out to us the most extensive land in the warmer regions of the earth, which has not been submerged since Eocene or Miocene times, it is there that we may expect to find some traces of the very early progenitors of man. It is there that we may trace back the gradually decreasing brain of former races, till we come to a time when the body also begins materially to differ. Then we shall have reached the starting point of the human family. Before that period he had not mind enough to preserve his body from change, and would, therefore, have been subject to the same comparatively rapid modifications of form as the other mammalia.

THEIR BEARING ON THE DIGNITY AND SUPREMACY OF MAN.

If the views I have here endeavored to sustain have any foundation, they give us a new argument for placing man apart, as not only the head and culminating point of the grand series of organic nature, but as in some degree a new and distinct order of being. From those infinitely remote ages, when the first rudiments of organic life appeared upon the earth, every plant and every animal has been subject to one great law of physical change. As the earth has gone through its grand cycles of geological, climatal and organic progress, every form of life has been subject to its irresistible action, and has been continually, but imperceptibly moulded into such new shapes as would preserve their harmony with the ever-changing universe. No living thing could escape this law of its being; none (except, perhaps, the simplest and most rudimentary organisms), could remain unchanged and live, amid the universal change around it.

At length, however, there came into existence a being in whom that subtle force we term *mind*, became of greater importance than his mere bodily structure. Though with a naked and unprotected body, *this* gave him clothing against the varying inclemencies of the seasons. Though unable to compete with the deer in

swiftness, or with the wild bull in strength, *this* gave him weapons with which to capture or overcome both. Though less capable than most other animals of living on the herbs and the fruits that unaided nature supplies, this wonderful faculty taught him to govern and direct nature to his own benefit, and make her produce food for him, when and where he pleased. From the moment when the first skin was used as a covering, when the first rude spear was formed to assist in the chase, when fire was first used to cook his food, when the first seed was sown or shoot planted, a grand revolution was effected in nature, a revolution which in all the previous ages of the earth's history had had no parallel, for a being had arisen who was no longer necessarily subject to change with the changing universe—a being who was in some degree superior to nature, inasmuch as he knew how to control and regulate her action, and could keep himself in harmony with her, not by a change in body, but by an advance of mind.

Here, then, we see the true grandeur and dignity of man. On this view of his special attributes, we may admit, that even those who claim for him a position as an order, a class, or a sub-kingdom by himself, have some show of reason on their side. He is, indeed, a being apart, since he is not influenced by the great laws which irresistibly modify all other organic beings. Nay, more; this victory which he has gained for himself, gives a directing influence over other existences. Man has not only escaped "natural selection" himself, but he is actually able to take away some of that power from nature which before his appearance she universally exercised. We can anticipate the time when the earth will produce only cultivated plants and domestic animals; when man's selection shall have supplanted "natural selection"; and when the ocean will be the only domain in which that power can be exerted, which for countless cycles of ages ruled supreme over all the earth.

THEIR BEARING ON THE FUTURE DEVELOPMENT OF MAN.

We now find ourselves enabled to answer those who maintain that if Mr. Darwin's theory of the Origin of Species is true, man too must change in form, and become developed into some other animal as different from his present self as he is from the gorilla or the chimpanzee; and who speculate on what this form is likely to be. But it is evident that such will not be the case; for no change of conditions is conceivable, which will render any important alteration of his form and organization so universally useful and necessary to him as to give those possessing it always the best chance of surviving, and thus lead to the development of a new species, genus, or higher group of man. On the other hand, we know that far greater changes of conditions and of his entire environment have been undergone by man than any other highly organized animal could survive unchanged, and have been met by mental, not corporeal adaptation. The difference of habits, of food, clothing, weapons and enemies, between savage and civilized man, is enormous. Difference in bodily form and structure there is practically none, except a slightly increased size of brain, corresponding to his higher mental development.

We have every reason to believe, then, that man may have existed and may continue to exist, through a series of geological periods which shall see all other

forms of animal life again and again changed; while he himself remains unchanged, except in the two particulars already specified—the head and face, as immediately connected with the organ of the mind and as being the medium of expressing the most refined emotions of his nature,—and to a slight extent in color, hair, and proportions, so far as they are correlated with constitutional resistance to disease.

SUMMARY.

Briefly to recapitulate the argument;—in two distinct ways has man escaped the influence of those laws which have produced unceasing change in the animal world. 1. By his superior intellect he is enabled to provide himself with clothing and weapons, and by cultivating the soil to obtain a constant supply of congenial food. This renders it unnecessary for his body, like those of the lower animals, to be modified in accordance with changing conditions—to gain a warmer natural covering, to acquire more powerful teeth or claws, or to become adapted to obtain and digest new kinds of food, as circumstances may require. 2. By his superior sympathetic and moral feelings, he becomes fitted for the social state; he ceases to plunder the weak and helpless of his tribe: he shares the game which he has caught with less active or less fortunate hunters, or exchanges it for weapons which even the weak or the deformed can fashion; he saves the sick and wounded from death; and thus the power which leads to the rigid destruction of all animals who cannot in every respect help themselves, is prevented from acting on him.

This power is "natural selection"; and, as by no other means can it be shown that individual variations can ever become accumulated and rendered permanent so as to form well-marked races, it follows that the differences which now separate mankind from other animals, must have been produced before he became possessed of a human intellect or human sympathies. This view also renders possible, or even requires, the existence of man at a comparatively remote geological epoch. For, during the long periods in which other animals have been undergoing modification in their whole structure, to such an amount as to constitute distinct genera and families, man's *body* will have remained generically, or even specifically, the same, while his *head* and *brain* alone will have undergone modification equal to theirs. We can thus understand how it is that, judging from the head and brain, Professor Owen places man in a distinct sub-class of mammalia, while as regards the bony structure of his body, there is the closest anatomical resemblance to the anthropoid apes, "every tooth, every bone, strictly homologous—which makes the determination of the difference between *Homo* and *Pithecus* the anatomist's difficulty." The present theory fully recognises and accounts for these facts; and we may perhaps claim as corroborative of its truth, that it neither requires us to depreciate the intellectual chasm which separates man from the apes, nor refuses full recognition of the striking resemblances to them, which exist in other parts of his structure.

CONCLUSION.

In concluding this brief sketch of a great subject, I would point out its bearing upon the future of the human race. If my conclusions are just, it must inevitably follow that the higher—the more intellectual and moral

—must displace the lower and more degraded races; and the power of "natural selection," still acting on his mental organization, must ever lead to the more perfect adaptation of man's higher faculties to the conditions of surrounding nature, and to the exigencies of the social state. While his external form will probably ever remain unchanged, except in the development of that perfect beauty which results from a healthy and well organized body, refined and ennobled by the highest intellectual faculties and sympathetic emotions, his mental constitution may continue to advance and improve, till the world is again inhabited by a single nearly homogeneous race, no individual of which will be inferior to the noblest specimens of existing humanity.

Our progress towards such a result is very slow, but it still seems to be a progress. We are just now living at an abnormal period of the world's history, owing to the marvellous developments and vast practical results of science, having been given to societies too low morally and intellectually, to know how to make the best use of them, and to whom they have consequently been curses as well as blessings. Among civilized nations at the present day, it does not seem possible for natural selection to act in any way, so as to secure the permanent advancement of morality and intelligence; for it is indisputably the mediocre, if not the low, both as regards morality and intelligence, who succeed best in life and multiply fastest. Yet there is undoubtedly an advance—on the whole a steady and a permanent one—both in the influence on public opinion of a high morality, and in the general desire for intellectual elevation; and as I cannot impute this in any way to "survival of the fittest," I am forced to conclude that it is due to the inherent progressive power of those glorious qualities which raise us so immeasurably above our fellow animals, and at the same time afford us the surest proof that there are other and higher existences than ourselves, from whom these qualities may have been derived, and towards whom we may be ever tending.

THE LIMITS OF NATURAL SELECTION AS APPLIED TO MAN.

Throughout I have endeavored to show that the known laws of variation, multiplication, and heredity, resulting in a "struggle for existence" and the "survival of the fittest," have probably sufficed to produce all the varieties of structure, all the wonderful adaptations, all the beauty of form and of color, that we see in the animal and vegetable kingdoms. To the best of my ability I have answered the most obvious and the most often repeated objections to this theory, and have, I hope, added to its general strength, by showing how color — one of the strongholds of the advocates of special creation—may be, in almost all its modifications, accounted for by the combined influence of sexual selection and the need of protection. I have also endeavored to show how the same power which has modified animals has acted on man; and have, I believe, proved that, as soon as the human intellect became developed above a certain low stage, man's body would cease to be materially affected by natural selection, because the development of his mental faculties would render important modifications of its form and structure unnecessary. It will, therefore, probably excite some surprise among my readers to find that I do not consider that all nature can be explained on the principles of which I am so ardent an advocate; and that I am now myself going to state objections, and to place limits, to the power of "natural selection." I believe, however, that there are such limits; and that just as surely as we can trace the action of natural laws in the development of organic forms, and can clearly conceive that fuller knowledge would enable us to follow step by step the whole process of that development, so surely can we trace the action of some unknown higher law, beyond and independent of all those laws of which we have any knowledge. We can trace this action more or less distinctly in many phenomena, the two most important of which are: the origin of sensation or consciousness, and the development of man from the lower animals. I shall first consider the latter difficulty as more immediately connected with the subjects discussed here.

WHAT NATURAL SELECTION CAN NOT DO.

In considering the question of the development of man by known natural laws, we must ever bear in mind the first principle of "natural selection," no less than of the general theory of evolution, that all changes of form or structure, all increase in the size of an organ or in its complexity, all greater specialization or physiological division of labor, can only be brought about, in as much as it is for the good of the being so modified. Mr. Darwin himself has taken care to impress upon us, that "natural selection" has no power to produce absolute perfection but only relative perfection, no power to advance any being much beyond his fellow beings, but only just so much beyond them as to enable it to survive them in the struggle for existence. Still less has it any power to produce modifications which are in any degree injurious to its possessor, and Mr. Darwin frequently

uses the strong expression, that a single case of this kind would be fatal to his theory. If, therefore, we find in man any characters, which all the evidence we can obtain goes to show would have been actually injurious to him on their first appearance, they could not possibly have been produced by natural selection. Neither could any specially developed organ have been so produced if it had been merely useless to him, or if its use were not proportionate to its degree of development. Such cases as these would prove, that some other law, or some other power, than "natural selection" had been at work. But if, further, we could see that these very modifications, though hurtful or useless at the time when they first appeared, became in the highest degree useful at a much later period, and are now essential to the full moral and intellectual development of human nature, we should then infer the action of mind, foreseeing the future and preparing for it, just as surely as we do when we see the breeder set himself to work with the determination to produce a definite improvement in some cultivated plant or domestic animal. I would further remark that this inquiry is as thoroughly scientific and legitimate as that into the origin of species itself. It is an attempt to solve the inverse problem, to deduce the existence of a new power of definite character, in order to account for facts which according to the theory of natural selection ought not to happen. Such problems are well known to science, and the search after their solution has often led to the most brilliant results. In the case of man, there are facts of the nature above alluded to, and in calling attention to them, and in inferring a cause for them, I believe that I am as strictly within the bounds of scientific investigation as I have been in any other portion of my work.

THE BRAIN OF THE SAVAGE SHOWN TO BE LARGER THAN HE NEEDS IT TO BE.

Size of Brain an Important Element of Mental Power.— The brain is universally admitted to be the organ of the mind; and it is almost as universally admitted, that size of brain is one of the most important of the elements which determine mental power or capacity. There seems to be no doubt that brains differ considerably in quality, as indicated by greater or less complexity of the convolutions, quantity of grey matter, and perhaps unknown peculiarities of organization; but this difference of quality seems merely to increase or diminish the influence of quantity, not to neutralize it. Thus, all the most eminent modern writers see an intimate connection between the diminished size of the brain in the lower races of mankind, and their intellectual inferiority. The collections of Dr. J. B. Davis and Dr. Morton give the following as the average internal capacity of the cranium in the chief races:—Teutonic family, 94 cubic inches; Esquimaux, 91 cubic inches; Negroes, 85 cubic inches; Australians and Tasmanians, 82 cubic inches; Bushmen, 77 cubic inches. These last numbers, however, are deduced from comparatively few specimens, and may be below the average, just as a small number of Finns and Cossacks give 98 cubic inches, or considerably more than that of the German races. It is evident, therefore, that the absolute bulk of the brain is not necessarily much less in savage than in civilized man, for Esquimaux skulls are known with a capacity of 113 inches, or hardly less than the largest among Europeans. But what is still more extraordinary, the few remains yet known of pre-historic man do not indicate

any material diminution in the size of the brain case. A Swiss skull of the stone age, found in the lake dwelling of Meilen, corresponded exactly to that of a Swiss youth of the present day. The celebrated Neanderthal skull had a larger circumference than the average, and its capacity, indicating actual mass of brain, is estimated to have been not less than 75 cubic inches, or nearly the average of existing Australian crania. The Engis skull, perhaps the oldest known, and which, according to Sir John Lubbock, "there seems no doubt was really contemporary with the mammoth and the cave bear," is yet, according to Professor Huxley, "a fair average skull, which might have belonged to a philosopher, or might have contained the thoughtless brains of a savage." Of the cave men of Les Eyzies, who were undoubtedly contemporary with the reindeer in the South of France, Professor Paul Broca says (in a paper read before the Congress of Pre-historic Archæology in 1868) —"The great capacity of the brain, the development of the frontal region, the fine elliptical form of the anterior part of the profile of the skull, are incontestible characteristics of superiority, such as we are accustomed to meet with in civilized races;" yet the great breadth of the face, the enormous development of the ascending ramus of the lower jaw, the extent and roughness of the surfaces for the attachment of the muscles, especially of the masticators, and the extraordinary development of the ridge of the femur, indicate enormous muscular power, and the habits of a savage and brutal race.

These facts might almost make us doubt whether the size of the brain is in any direct way an index of mental power, had we not the most conclusive evidence that it is so, in the fact that, whenever an adult male European has a skull less than nineteen inches in circumference, or has less than sixty-five cubic inches of brain, he is invariably idiotic. When we join with this the equally undisputed fact, that great men—those who combine acute perception with great reflective power, strong passions, and general energy of character, such as Napoleon, Cuvier and O'Connell—have always heads far above the average size, we must feel satisfied that volume of brain is one, and perhaps the most important, measure of intellect; and this being the case, we cannot fail to be struck with the apparent anomaly, that so many of the lowest savages should have as much brain as average Europeans. The idea is suggested of a surplusage of power; an instrument beyond the needs of its possessor.

Comparison of the Brains of Man and of Anthropoid Apes.—In order to discover if there is any foundation for this notion, let us compare the brain of man with that of animals. The adult Orang-utan is quite as bulky as a small sized man, while the Gorilla is considerably above the average size of man, as estimated by bulk and weight; yet the former has a brain of only 28 cubic inches, the latter, one of 30, or, in the largest specimen yet known, of 34½ cubic inches. We have seen that the average cranial capacity of the lowest savages is probably not less than *five-sixths* of that of the highest civilized races, while the brain of the anthropoid apes scarcely amounts to *one-third* of that of man, in both cases taking the average; or the proportions may be clearly represented by the following figures—anthropoid apes, 10; savages, 26; civilized man, 32. But do these figures at all approximately represent the relative intellect of the three groups? Is the savage really no further removed from the philosopher, and so much removed from the ape, as these figures would indicate? In considering this question, we must not forget that the heads of savages vary in size, almost as much as those of civilized Europeans. Thus, while the largest Teutonic skull in Dr. Davis' collection is 112.4 cubic inches, there is an Araucanian of 115.5, an Esquimaux of 113.1, a Marquesan of 110.6, a Negro of 105.8, and even an Australian of 104.5 cubic inches. We may, therefore, fairly compare the savage with the highest European on the one side, and with the Orang, Chimpanzee, or Gorilla, on the other, and see whether there is any relative proportion between brain and intellect.

Range of Intellectual Power in Man.—First let us consider what this wonderful instrument, the brain, is capable of in its higher developments. In Mr. Galton's interesting work on "Hereditary Genius," he remarks on the enormous difference between the intellectual power and grasp of the well-trained mathematician or man of science, and the average Englishman. The number of marks obtained by high wranglers, is often more than thirty times as great as that of the men at the bottom of the honor list, who are still of fair mathematical ability; and it is the opinion of skilled examiners that even this does not represent the full difference of intellectual power. If, now, we descend to those savage tribes who only count to three or five, and who find it impossible to comprehend the addition of two or three without having the objects actually before them, we feel that the chasm between them and the good mathematician is so vast, that a thousand to one will probably not fully express it. Yet we know that the mass of brain might be nearly the same in both, or might not differ in a greater proportion than as 5 to 6 ; whence we may fairly infer that the savage possesses a brain capable, if cultivated and developed, of performing work of a kind and degree far beyond what he ever requires it to do.

Again, let us consider the power of the higher or even the average civilized man, of forming abstract ideas, and carrying on more or less complex trains of reasoning. Our languages are full of terms to express abstract conceptions. Our business and our pleasures involve the continual foresight of many contingencies. Our law, our government, and our science, continually require us to reason through a variety of complicated phenomena to the expected result. Even our games, such as chess, compel us to exercise all these faculties in a remarkable degree. Compare this with the savage languages, which contain no words for abstract conceptions ; the utter want of foresight of the savage man beyond his simplest necessities ; his inability to combine, or to compare, or to reason on any general subject that does not immediately appeal to his senses. So, in his moral and æsthetic faculties, the savage has none of those wide sympathies with all nature, those conceptions of the infinite, of the good, of the sublime and beautiful, which are so largely developed in civilized man. Any considerable development of these would, in fact, be useless or even hurtful to him, since they would to some extent interfere with the supremacy of those perceptive and animal faculties on which his very existence often depends, in the severe struggle he has to carry on against nature and his fellow-man. Yet the rudiments of all these powers and feelings undoubtedly exist in him, since one or other of them frequently manifest themselves in exceptional

cases, or when some special circumstances call them forth. Some tribes, such as the Santals, are remarkable for as pure a love of truth as the most moral among civilized men. The Hindoo and the Polynesian have a high artistic feeling, the first traces of which are clearly visible in the rude drawings of the palæolithic men who were the contemporaries in France of the Reindeer and the Mammoth. Instances of unselfish love, of true gratitude, and of deep religious feeling, sometimes occur among most savage races.

On the whole, then, we may conclude, that the general moral and intellectual development of the savage, is not less removed from that of civilized man than has been shown to be the case in the one department of mathematics ; and from the fact that all the moral and intellectual faculties do occasionally manifest themselves, we may fairly conclude that they are always latent, and that the large brain of the savage man is much beyond his actual requirements in the savage state.

Intellect of Savages and of Animals compared.—Let us now compare the intellectual wants of the savage, and the actual amount of intellect he exhibits, with those of the higher animals. Such races as the Andaman Islanders, the Australians, and the Tasmanians, the Digger Indians of North America, or the natives of Fuegia, pass their lives so as to require the exercise of few faculties not possessed in an equal degree by many animals. In the mode of capture of game or fish, they by no means surpass the ingenuity or forethought of the jaguar, who drops saliva into the water, and seizes the fish as they come to eat it ; or of wolves and jackals, who hunt in packs ; or of the fox, who buries his surplus food till he requires it. The sentinels placed by antelopes and by monkeys, and the various modes of building adopted by field mice and beavers, as well as the sleeping place of the orang-utan, and the tree-shelter of some of the African anthropoid apes, may well be compared with the amount of care and forethought bestowed by many savages in similar circumstances. His possession of free and perfect hands, not required for locomotion, enable man to form and use weapons and implements which are beyond the physical powers of brutes; but having done this, he certainly does not exhibit more mind in using them than do many lower animals. What is there in the life of the savage, but the satisfying of the cravings of appetite in the simplest and easiest way? What thoughts, ideas or actions are there that raise him many grades above the elephant or the ape? Yet he possesses, as we have seen, a brain vastly superior to theirs in size and complexity; and this brain gives him, in an undeveloped state, faculties which he never requires to use. And if this is true of existing savages, how much more true must it have been of the men whose sole weapons were rudely chipped flints, and some of whom, we may fairly conclude, were lower than any existing race; while the only evidence yet in our possession shows them to have had brains fully as capacious as those of the average of the lower savage races.

We see, then, that whether we compare the savage with the higher developments of man, or with the brutes around him, we are alike driven to the conclusion that in his large and well-developed brain he possesses an organ quite disproportionate to his actual requirements —an organ that seems prepared in advance, only to be fully utilized as he progresses in civilization. A brain slightly larger than that of the gorilla would, according

to the evidence before us, fully have sufficed for the limited mental development of the savage; and we must therefore admit, that the large brain he actually possesses could never have been solely developed by any of those laws of evolution, whose essence is that they lead to a degree of organization exactly proportionate to the wants of each species, never beyond those wants—that no preparation can be made for the future development of the race—that one part of the body can never increase in size or complexity, except in strict co-ordination to the pressing wants of the whole. The brain of prehistoric and of savage man seems to me to prove the existence of some power, distinct from that which has guided the development of the lower animals through their ever-varying forms of being.

THE USE OF THE HAIRY COVERING OF MAMMALIA.

Let us now consider another point in man's organization, the bearing of which has been almost entirely overlooked by writers on both sides of the question. One of the most general external characters of the terrestrial mammalia is the hairy covering of the body, which, whenever the skin is flexible, soft, and sensitive, forms a natural protection against the severities of climate, and particularly against rain. That this is its most important function, is well shown by the manner in which the hairs are disposed so as to carry off the water, by being invariably directed downwards from the most elevated parts of the body. Thus, on the under surface the hair is always less plentiful, and, in many cases, the belly is almost bare. The hair lies downwards, on the limbs of all walking mammals, from the shoulder to the toes, but in the orang-utan it is directed from the shoulder to the elbow, and again from the wrist to the elbow, in a reverse direction. This corresponds to the habits of the animal, which, when resting, holds its long arms upwards over its head or clasping a branch above it, so that the rain would flow down both the arm and fore-arm to the long hair which meets at the elbow. In accordance with this principle, the hair is always longer or more dense along the spine or middle of the back from the nape to the tail, often rising into a crest of hair or bristles on the ridge of the back. This character prevails through the entire series of the mammalia, from the marsupials to the quadrumana, and by this long persistence it must have acquired such a powerful hereditary tendency, that we should expect it to reappear continually even after it had been abolished by ages of the most rigid selection; and we may feel sure that it never could have been completely abolished under the law of natural selection, unless it had become so positively injurious as to lead to the almost invariable extinction of individuals possessing it.

THE CONSTANT ABSENCE OF HAIR FROM CERTAIN PARTS OF MAN'S BODY A REMARKABLE PHENOMENON.

In man the hairy covering of the body has almost totally disappeared, and, what is very remarkable, it has disappeared more completely from the back than from any other part of the body. Bearded and beardless races alike have the back smooth, and even when a considerable quantity of hair appears on the limbs and breast, the back, and especially the spinal region, is absolutely free, thus completely reversing the characteristics of all other mammalia. The Ainos of the Kurile Islands and Japan are said to be a hairy race; but Mr.

Bickmore, who saw some of them, and described them in a paper read before the Ethnological Society, gives no details as to where the hair was most abundant, merely stating generally, that "their chief peculiarity is their great abundance of hair, not only on the head and face, but over the whole body." This might very well be said of any man who had hairy limbs and breast, unless it was specially stated that his back was hairy, which is not done in this case. The hairy family in Birmah have, indeed, hair on the back rather longer than on the breast, thus reproducing the true mammalian character, but they have still longer hair on the face, forehead, and inside the ears, which is quite abnormal; and the fact that their teeth are all very imperfect, shows that this is a case of monstrosity rather than one of true reversion to the ancestral type of man before he lost his hairy covering.

SAVAGE MAN FEELS THE WANT OF THIS HAIRY COVERING.

We must now enquire if we have any evidence to show, or any reason to believe, that a hairy covering to the back would be in any degree hurtful to savage man, or to man in any stage of his progress from his lower animal form; and if it were merely useless, could it have been so entirely and completely removed as not to be continually reappearing in mixed races? Let us look to savage man for some light on these points. One of the most common habits of savages is to use some covering for the back and shoulders, even when they have none on any other part of the body. The early voyagers observed with surprise, that the Tasmanians, both men and women, wore the kangaroo-skin, which was their only covering, not from any feeling of modesty, but over the shoulders to keep the back dry and warm. A cloth over the shoulders was also the national dress of the Maories. The Patagonians wear a cloak or mantle over the shoulders, and the Fuegians often wear a small piece of skin on the back, laced on, and shifted from side to side as the wind blows. The Hottentots also wore a somewhat similar skin over the back, which they never removed, and in which they were buried. Even in the tropics most savages take precautions to keep their backs dry. The natives of Timor use the leaf of a fan palm, carefully stitched up and folded, which they always carry with them, and which, held over the back, forms an admirable protection from the rain. Almost all the Malay races, as well as the Indians of South America, make great palm-leaf hats, four feet or more across, which they use during their canoe voyages to protect their bodies from heavy showers of rain; and they use smaller hats of the same kind when traveling by land.

We find then, that so far from there being any reason to believe that a hairy covering to the back could have been hurtful or even useless to pre-historic man, the habits of modern savages indicate exactly the opposite view, as they evidently feel the want of it, and are obliged to provide substitutes of various kinds. The perfectly erect posture of man may be supposed to have something to do with the disappearance of the hair from his body, while it remains on his head; but when walking, exposed to rain and wind, a man naturally stoops forwards, and thus exposes his back; and the undoubted fact that most savages feel the effects of cold and wet most severely in that part of the body, sufficiently demonstrates that the hair could not have

ceased to grow there merely because it was useless, even if it were likely that a character so long persistent in the entire order of mammalia could have so completely disappeared, under the influence of so weak a selective power as a diminished usefulness.

MAN'S NAKED SKIN COULD NOT HAVE BEEN PRODUCED BY NATURAL SELECTION.

It seems to me, then, to be absolutely certain, that "Natural Selection" could not have produced man's hairless body by the accumulation of variations from a hairy ancestor. The evidence all goes to show that such variations could not have been useful, but must, on the contrary, have been to some extent hurtful. If, even, owing to an unknown correlation with other hurtful qualities, it had been abolished in the ancestral tropical man, we cannot conceive that, as man spread into colder climates, it should have not returned under the powerful influence of reversion to such a long persistent ancestral type. But the very foundation of such a supposition as this is untenable; for we cannot suppose that a character which, like hairiness, exists throughout the whole of the mammalia, can have become, in one form only, so constantly correlated with an injurious character as to lead to its permanent suppression —a suppression so complete and effectual that it never, or scarcely ever, reappears in mongrels of the most widely different races of man.

Two characters could hardly be wider apart than the size and development of man's brain, and the distribution of hair upon the surface of his body; yet they both lead us to the same conclusion—that some other power than Natural Selection has been engaged in his production.

FEET AND HANDS OF MAN, CONSIDERED AS DIFFICULTIES ON THE THEORY OF NATURAL SELECTION.

There are a few other physical characteristics of man, that may just be mentioned as offering similar difficulties, though I do not attach the same importance to them as to those I have already dwelt on. The specialization and perfection of the hands and feet of man seems difficult to account for. Throughout the whole of the quadrumana the foot is prehensile; and a very rigid selection must therefore have been needed to bring about that arrangement of the bones and muscles, which has converted the thumb into a great toe, so completely that the power of opposability is totally lost in every race, whatever some travelers may vaguely assert to the contrary. It is difficult to see why the prehensile power should have been taken away. It must certainly have been useful in climbing, and the case of the baboons shows that it is quite compatible with terrestrial locomotion. It may not be compatible with perfectly easy erect locomotion; but then, how can we conceive that early man, *as an animal*, gained anything by purely erect locomotion? Again, the hand of man contains latent capacities and powers which are unused by savages, and must have been even less used by palæolithic man and his still ruder predecessors. It has all the appearance of an organ prepared for the use of civilized man, and one which was required to render civilization possible. Apes make little use of their separate fingers and opposable thumbs. They grasp objects rudely and clumsily, and look as if a much less specialized extremity would have served their purpose as well. I do not lay much stress on this, but, if it be proved that some intelligent power has guided or deter-

mined the development of man, then we may see indications of that power, in facts which, by themselves, would not serve to prove its existence.

The voice of man.—The same remark will apply to another peculiarly human character, the wonderful power, range, flexibility, and sweetness, of the musical sounds producible by the human larynx, especially in the female sex. The habits of savages give no indication of how this faculty could have been developed by natural selection; because it is never required or used by them. The singing of savages is a more or less monotonous howling, and the females seldom sing at all. Savages certainly never choose their wives for fine voices, but for rude health, and strength, and physical beauty. Sexual selection could not therefore have developed this wonderful power, which only comes into play among civilized people. It seems as if the organ had been prepared in anticipation of the future progress of man, since it contains latent capacities which are useless to him in his earlier condition. The delicate correlations of structure that give it such marvelous powers could not therefore have been acquired by means of natural selection.

THE ORIGIN OF SOME OF MAN'S MENTAL FACULTIES, BY THE PRESERVATION OF USEFUL VARIATIONS, NOT POSSIBLE.

Turning to the mind of man, we meet with many difficulties in attempting to understand how those mental faculties, which are especially human, could have been acquired by the preservation of useful variations. At first sight, it would seem that such feelings as those of abstract justice and benevolence could never have been so acquired, because they are incompatible with the law of the strongest, which is the essence of natural selection. But this is, I think, an erroneous view, because we must look, not to individuals but to societies; and justice and benevolence, exercised toward members of the same tribe, would certainly tend to strengthen that tribe, and give it a superiority over another in which the right of the strongest prevailed, and where consequently the weak and the sickly were left to perish, and the few strong ruthlessly destroyed the many who were weaker.

But there is another class of human faculties that do not regard our fellow men, and which cannot, therefore, be thus accounted for. Such are the capacity to form ideal conceptions of space and time, of eternity and infinity—the capacity for intense artistic feelings of pleasure, in form, color, and composition—and for those abstract notions of form and number which render geometry and arithmetic possible. How were all or any of these faculties first developed, when they could have been of no possible use to man in his early stages of barbarism? How could "natural selection," or survival of the fittest in the struggle for existence, at all favor the development of mental powers so entirely removed from the material necessities of savage men, and which even now, with our comparatively high civilization, are, in their farthest developments, in advance of the age, and appear to have relation rather to the future of the race than to its actual status?

DIFFICULTY AS TO THE ORIGIN OF THE MORAL SENSE.

Exactly the same difficulty arises, when we endeavor to account for the development of the moral sense or

conscience in savage man; for although the *practice* of benevolence, honesty, or truth, may have been useful to the tribe possessing these virtues, that does not at all account for the peculiar *sanctity*, attached to actions which each tribe considers right and moral, as contrasted with the very different feelings with which they regard what is merely *useful*. The utilitarian hypothesis (which is the theory of natural selection applied to the mind) seems inadequate to account for the development of the moral sense. This subject has been recently much discussed, and I will here only give one example to illustrate my argument. The utilitarian sanction for truthfulness is by no means very powerful or universal. Few laws enforce it. No very severe reprobation follows untruthfulness. In all ages and countries, falsehood has been thought allowable in love, and laudable in war; while, at the present day, it is held to be venial by the majority of mankind, in trade, commerce, and speculation. A certain amount of untruthfulness is a necessary part of politeness in the east and west alike, while even severe moralists have held a lie justifiable, to elude an enemy or prevent a crime. Such being the difficulties with which this virtue has had to struggle, with so many exceptions to its practice, with so many instances in which it brought ruin or death to its too ardent devotee, how can we believe that considerations of utility could ever invest it with the mysterious sanctity of the highest virtue,—could ever induce men to value truth for its own sake, and practice it regardless of consequences?

Yet, it is a fact, that such a mystical sense of wrong does attach to untruthfulness, not only among the higher classes of civilized people, but among whole tribes of utter savages. Sir Walter Elliott tells us (in his paper "On the Characteristics of the Population of Central and Southern India," published in the Journal of the Ethnological Society of London, vol. i., p. 107) that the Kurubars and Santals, barbarous hill-tribes of Central India, are noted for veracity. It is a common saying that "a Kurubar *always* speaks the truth;" and Major Jervis says, "the Santals are the most truthful men I ever met with." As a remarkable instance of this quality the following fact is given. A number of prisoners, taken during the Santal insurrection, were allowed to go free on parole, to work at a certain spot for wages. After some time cholera attacked them and they were obliged to leave, but every man of them returned and gave up his earnings to the guard. Two hundred savages with money in their girdles, walked thirty miles back to prison rather than break their word! My own experience among savages has furnished me with similar, although less severely tested, instances; and we cannot avaid asking how is it, that in these few cases "experiences of utility" have left such an overwhelming impression, while in so many others they have left none? The experiences of savage men as regards the utility of truth, must, in the long run, be pretty nearly equal. How is it, then, that in some cases the result is a sanctity which overrides all considerations of personal advantage, while in others there is hardly a rudiment of such a feeling?

The intuitional theory, which I am now advocating, explains this by the supposition, that there is a feeling —a sense of right or wrong—in our nature, antecedent to and independent of experiences of utility. Where free play is allowed to the relations between man and

man, this feeling attaches itself to those acts of universal utility or self-sacrifice, which are the products of our affections and sympathies, and which we term moral; while it may be, and often is perverted, to give the same sanction to acts of narrow and conventional utility which are really immoral,—as when the Hindoo will tell a lie, but will sooner die than eat unclean food; and looks upon the marriage of adult females as gross immorality.

The strength of the moral feeling will depend upon individual or racial constitution, and on education and habit;—the acts to which its sanctions are applied, will depend upon how far the simple feelings and affections of our nature have been modified by custom, by law, or by religion.

It is difficult to conceive that such an intense and mystical feeling of right and wrong, (so intense as to overcome all ideas of personal advantage or utility), could have been developed out of accumulated ancestral expreiences of utility; and still more difficult to understand, how feelings developed by one set of utilities, could be transferred to acts of which the utility was partial, imaginary, or altogether absent. But if a moral sense is an essential part of our nature, it is easy to see that its sanction may often be given to acts which are useless or immoral; just as the natural appetite for drink, is perverted by the drunkard into the means of his destruction.

SUMMARY OF THE ARGUMENT AS TO THE INSUFFICIENCY OF NATURAL SELECTION TO ACCOUNT FOR THE DEVELOPMENT OF MAN.

Briefly to resume my argument—I have shown that the brain of the lowest savages, and, as far as we yet know, of the pre-historic races, is little inferior in size to that of the highest types of man, and immensely superior to that of the higher animals; while it is universally admitted that quantity of brain is one of the most important, and probably the most essential, of the elements which determine mental power. Yet the mental requirements of savages, and the faculties actually exercised by them, are very little above those of animals. The higher feelings of pure morality and refined emotion, and the power of abstract reasoning and ideal conception, are useless to them, are rarely if ever manifested, and have no important relations to their habits, wants, desires, or well-being. They possess a mental organ beyond their needs. Natural Selection could only have endowed savage man with a brain a little superior to that of an ape, whereas he actually possesses one very little inferior to that of a philosopher.

The soft, naked, sensitive skin of man, entirely free from the hairy covering which is so universal among other mammalia, cannot be explained on the theory of natural selection. The habits of savages show that they feel the want of this covering, which is most completely absent in man exactly where it is thickest in other animals. We have no reason whatever to believe, that it could have been hurtful, or even useless to primitive man; and, under these circumstances, its complete abolition, shown by its never reverting in mixed breeds, is a demonstration of the agency of some other power

than the law of the survival of the fittest, in the development of man from the lower animals.

Other characters show difficulties of a similar kind, though in perhaps not an equal degree. The structure of the human foot and hand seem unnecessarily perfect for the needs of savage man, in whom they are as completely and as humanly developed as in the highest races. The structure of the human larynx, giving the power of speech and of producing musical sounds, and especially its extreme development in the female sex, are shown to be beyond the needs of savages, and from their known habits, impossible to have been acquired either by sexual selection, or by survival of the fittest.

The mind of man offers arguments in the same direction, hardly less strong than those derived from his bodily structure. A number of his mental faculties have no relation to his fellow men, or to his material progress. The power of conceiving eternity and infinity, and all those purely abstract notions of form, number, and harmony, which play so large a part in the life of civilized races, are entirely outside of the world of thought of the savage, and have no influence on his individual existence or on that of his tribe. They could not, therefore, have been developed by any preservation of useful forms of thought; yet we find occasional traces of them amidst a low civilization, and at a time when they could have had no practical effect on the success of the individual, the family, or the race; and the development of a moral sense or conscience by similar means is equally inconceivable.

But, on the other hand, we find that every one of these characteristics is necessary for the full development of human nature. The rapid progress of civilization under favorable conditions, would not be possible, were not the organ of the mind of man prepared in advance, fully developed as regards size, structure and proportions, and only needing a few generations of use and habit to co-ordinate its complex functions. The naked and sensitive skin, by necessitating clothing and houses, would lead to the more rapid development of man's inventive and constructive faculties; and, by leading to a more refined feeling of personal modesty, may have influenced, to a considerable extent, his moral nature. The erect form of man, by freeing the hands from all locomotive uses, has been necessary for his intellectual advancement; and the extreme perfection of his hands has alone rendered possible that excellence in all the arts of civilization which raises him so far above the savage, and is perhaps but the forerunner of a higher intellectual and moral advancement. The perfection of his vocal organs has first led to the formation of articulate speech, and then to the development of those exquisitely toned sounds, which are only appreciated by the higher races, and which are probably destined for more elevated uses and more refined enjoyment, in a higher condition than we have yet attained to. So, those faculties which enable us to transcend time and space, and to realize the wonderful conceptions of mathematics and philosophy, or which give us an intense yearning for abstract truth, (all of which were occasionally manifested at such an early period of human history as to be far in advance of any of the few practical applications which have since grown out of them), are evidently essential to the perfect development of man as a spiritual being, but are utterly inconceivable as having been produced through the action of

a law which looks only, and can look only, to the immediate material welfare of the individual or the race.

The inference I would draw from this class of phenomena is, that a superior intelligence has guided the development of man in a definite direction, and for a special purpose, just as man guides the development of many animal and vegetable forms. The laws of evolution alone would, perhaps, never have produced a grain so well adapted to man's use as wheat and maize; such fruits as the seedless banana and bread-fruit; or such animals as the Guernsey milch cow, or the London dray-horse. Yet these so closely resemble the unaided productions of nature, that we may well imagine a being who has mastered the laws of development of organic forms through past ages, refusing to believe that any new power had been concerned in their production, and scornfully rejecting the theory (as my theory will be rejected by many who agree with me on other points), that in these few cases a controlling intelligence had directed the action of the laws of variation, multiplication, and survival, for his own purposes. We know, however, that this has been done; and we must therefore admit the possibility that, if we are not the highest intelligences in the universe, some higher intelligence may have directed the process by which the human race was developed, by means of more subtle agencies than we are acquainted with. At the same time I must confess, that this theory has the advantage of requiring the intervention of some distinct individual intelligence, to aid in the production of what we can hardly avoid considering as the ultimate aim and outcome of all organized existence—intellectual, ever-advancing, spiritual man. It therefore implies, that the great laws which govern the material universe were insufficient for his production, unless we consider (as we may fairly do) that the controlling action of such higher intelligences is a necessary part of those laws, just as the action of all surrounding organisms is one of the agencies in organic development. But even if my particular view should not be the true one, the difficulties I have put forward remain, and I think prove, that some more general and fundamental law underlies that of "natural selection." The law of "unconscious intelligence" pervading all organic nature, put forth by Dr. Laycock and adopted by Mr. Murphy, is such a law; but to my mind it has the double disadvantage of being both unintelligible and incapable of any kind of proof. It is more probable, that the true law lies too deep for us to discover it; but there seems to me to be ample indications that such a law does exist, and is probably connected with the absolute origin of life and organization.

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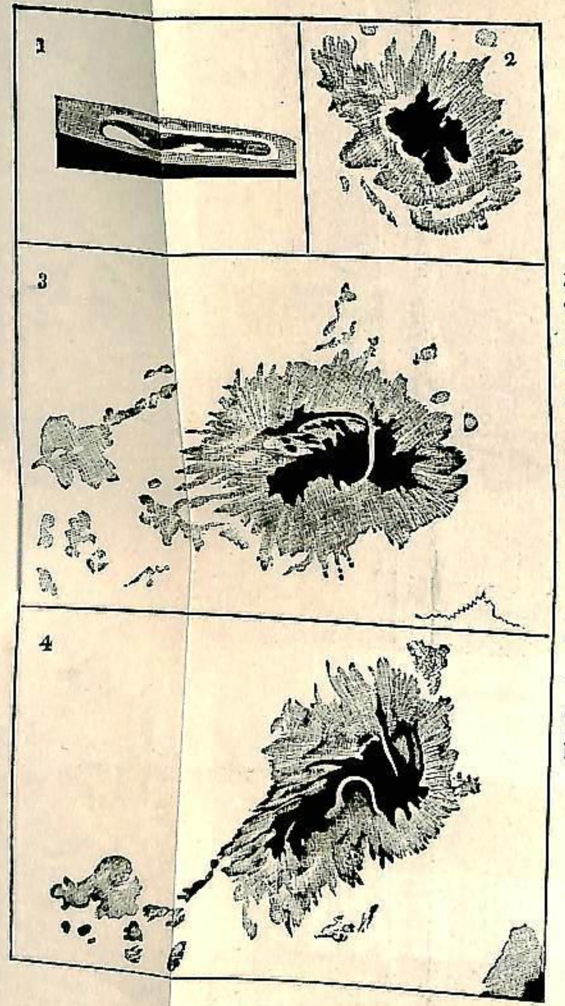

Fig. I.—Sun Spots. The Great Sun Spots of 1865.
1.—The Spot entering on the visible disc, October 7th. 2.—October 10th.
3.—October 14th, showing the formation of a bridge. 4.—October 16th.

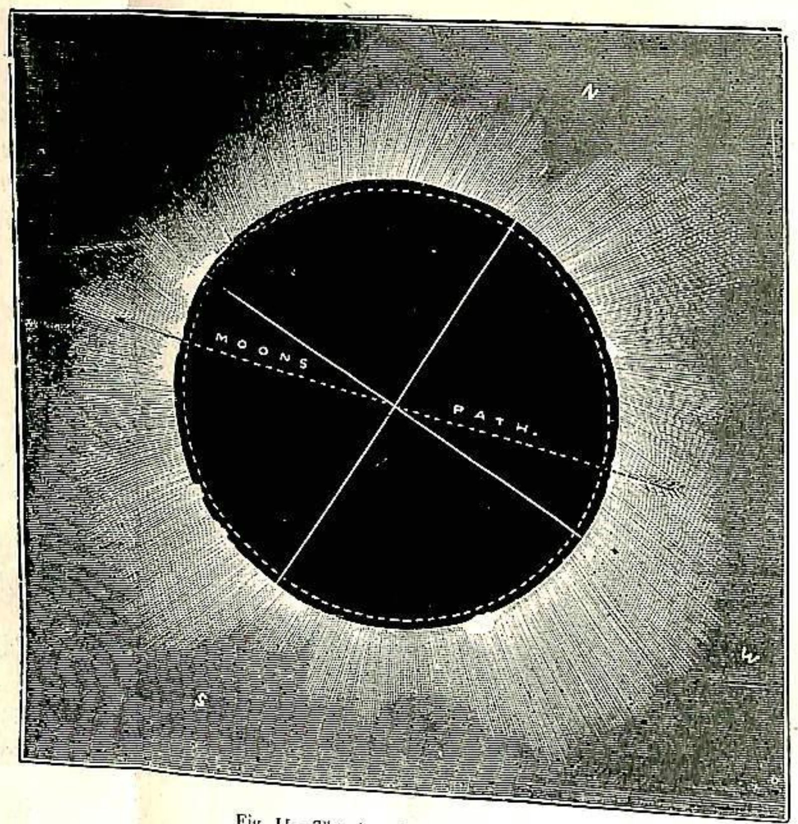

Fig. II.—The American Eclipse, 1869.

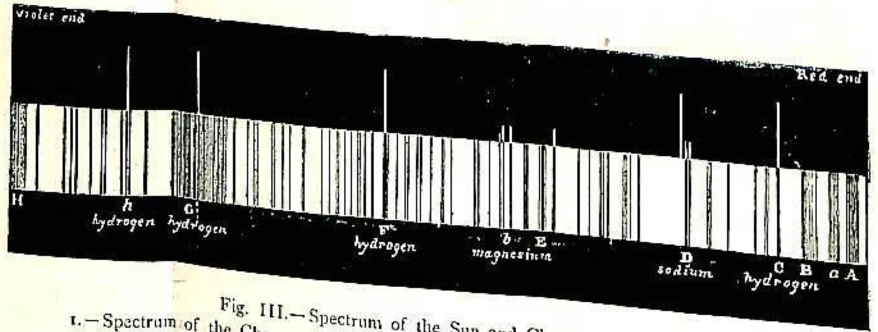

Fig. III.—Spectrum of the Sun and Chromosphere.
1.—Spectrum of the Chromosphere. 2.—Spectrum of the Sun's edge.

ILLUSTRATIONS OF LOCKYER'S LECTURE ON THE SUN.

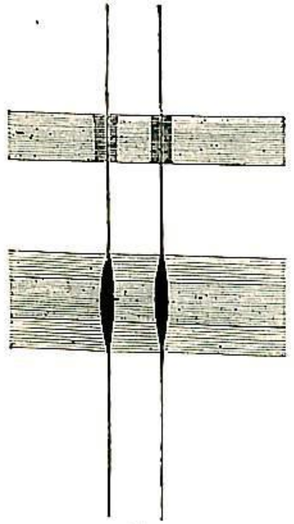

Fig. III A.—The thickening of the D line is the Spectrum Spots.

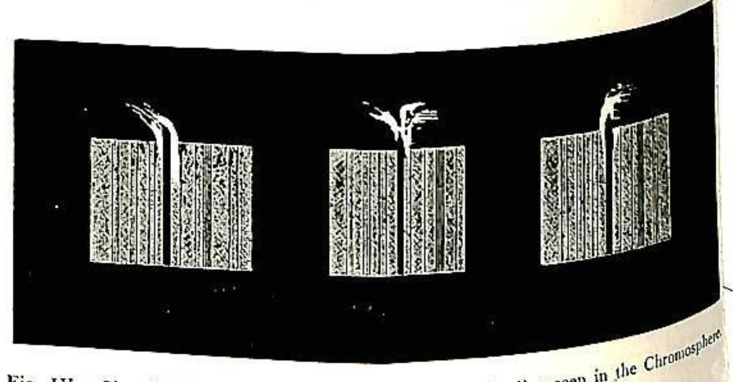

Fig. IV.—Showing changes of wave length in the bright line seen in the Chromosphere.

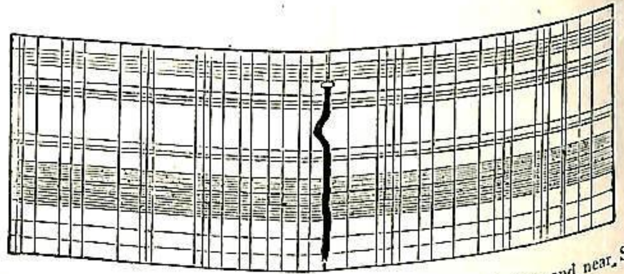

Fig. V.—Showing changes of wave length in the F line on the Sun and near Spots.

No. 7---University Series.

SPECTRUM ANALYSIS:

THREE LECTURES.

BY

PROF. ROSCOE, WILLIAM HUGGINS, AND NORMAN LOCKYER.

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SPECTRUM ANALYSIS:

A LECTURE BY PROFESSOR ROSCOE, F. R. S.

Whilst we all look with admiration at the countless stars which, on a clear night, are seen to be brightly shining, or delight in the blaze of the midsummer sun, there are, perhaps, few amongst us who know that the light of the twinkling stars and that of the bright sun carries along with it some secrets of its nature which it has been the privilege of modern science to unfold. No less strange than true is it that by means of this light we are able to tell something about the composition of these heavenly bodies—we can learn what they are made of. Yet this seems almost incredible—that we should be able to tell what exists in the sun at a distance of ninety-one millions of miles; or still more, that we can say that substances which we know well on this earth, such as iron, sodium, magnesium, calcium, and hydrogen, are present in stars at distances from us so great that the mind utterly fails to conceive of them, for though light travels at the rate of 192,000 miles per second, it may take 1,000 years for the light of some of these stars to reach earth.

I wish to explain to you, as clearly as I can, and using as plain language as may be, how these discoveries have been made, and to show you that this strange discovery is the result of plain and straightforward reasoning upon simple and exact observation and experiment. In endeavoring to do this I shall be very much aided by the fact which I am able to announce, that the continuation of this subject will be taken up by a gentleman who has rendered his name illustrious in connection with spectrum analysis — Dr. Huggins — who will tell you how he has been able to discover the composition of the stars, though they are at such an inconceivable distance.

I shall confine myself to-night to the simpler and introductory portion of the subject, and endeavor to show you the principles upon which this language of the stars has been translated for us, by applying the discoveries in spectrum analysis in the first instance to the earth, and at the close of the lecture to the sun.

In the first place, I must remind you that it is the aim of the study of chemistry to determine of what the earth is made up; and I shall have to show you that spectrum analysis has taught us a great deal concerning the composition of our earth with which we were not formerly acquainted. Chemists have to ascertain the composition of everything that comes within their reach, whether that thing be fetched from the deepest mine, or from the highest point to which man has ascended, even in a balloon, or whether it comes from the north or south pole, or from the tropics. Chemists have discovered that substances can be divided into two great classes — those which have been divided into something different, and those which have not been so divided. The last of these are termed elementary bodies. We

are acquainted with sixty-three of these elementary substances, and it is these that make up the substance of our earth, and therefore constitute the fabric of which the science of chemistry is composed. I need hardly remind you that because a body is invisible there is no reason to suppose that it does not exist. For instance, you know that coal gas is invisible, for if you open a gas tap you do not see anything come out; but if you put your nose to it you will perceive the smell of the gas. So that invisibility is no proof of the sameness of chemical bodies. We have a host of invisible bodies besides air and coal gas. Chemists, by their investigation of nature and her products, have discovered that all bodies can exist in three distinct states, namely, as solids, liquids, and gases. For instances, as solid ice, liquid water, and gaseous steam. All substance may be converted into gases, liquids, or solids, by adding or removing heat. We add heat to solid ice to convert it into water; we add heat to liquid water to make it into gaseous steam; and if we add heat enough to iron we can turn it into vapor. There is no substance which cannot, if we heat it sufficiently, be converted into vapor; and we have reason to believe that there is no substance, which, if we could cool it sufficiently, would not both be liquified and solidified, though this has not yet been in all cases effected. There are many gases which we have not yet been able to condense into a liquid or a solid; but if we were able to apply a sufficient degree of cold, or rather to abstract enough heat, from these bodies, we have every reason to believe that they would be convertible into solids and liquids. These three conditions of matter are what we may term functions of the temperature; that is to say, they depend entirely upon the temperature. For instance, I can show you that we can burn a piece of iron when we have the means, such as I have here, of producing a high temperature, hotter than anything we know, excepting the electric spark. [Professor Roscoe consumed a piece of watch-spring in the heat of the electric lamp as though it were a piece of tinder, the coruscation of the sparks making this a very pretty experiment.] I can actually turn metal into vapor by means of the electric lamp, which gives not only a very bright light but an exceedingly high temperature. [The image of a piece of carbon was thrown upon the screen, and a small bit of silver having been placed between the poles of the lamp, the bright green streak of the silver vapor produced by its volatilization was distinctly visible.] I might go on showing you a great number of illustrations of this sort, to demonstrate that all bodies can be converted by temperature into vapor.

I stated at the beginning that we have by means of this spectrum analysis the means of detecting the composition of the sun and stars; but we have also the means thereby of ascertaining the composition or chemical nature of the earth with a degree of accuracy beyond anything that chemists previously possessed. Allow me to illustrate this to you in another and familiar way, and the commonest illustrations are often the best. Suppose we were to visit the Manchester waterworks at Woodhead, which are so creditable to the corporation of this city and so beneficial to its inhabitants, and were to throw a cartload of salt into the clear water, when that water reached us, after passing through all the ramifications of the supply pipes, I do not think that any one who drank the water would be conscious by

its taste that a cartload of salt had been tumbled into the reservoir. In other words, our palates are not delicate enough to detect the presence of this small quantity of salt; but the chemist has other methods placed at his disposal, far more delicate than the human taste, for detecting the presence of salt. If I take one or two grains of salt, and put it into this large quantity of water, it is quite inappreciable to the tongue or palate; but if I use a more delicate test, I can detect the presence of even a fraction of a grain of salt. I will take a small quantity of nitrate of silver, and add it to the water in which I placed the salt, and you will see by the light of this burning magnesium wire that the salt is made distinctly visible; whereas in the other vessel of water, in which I placed no salt, there is no such evidence when I likewise add nitrate of silver. That serves as a simple and common illustration of this fact, and it seems to be one that you appreciate. Now let me put this case:—Suppose a chemist had so small a quantity of salt present in this bottle that his test with nitrate of silver failed to give him any reaction, he might say there was no salt there; but now spectrum analysis steps in and shows us that all our chemical reactions have hitherto been only rough approximations to the truth, and we can by spectrum analysis show the presence of salt in this bottle. Thus the minutest trace of salt can be made visible in this non-luminous flame composed of a mixture of common gas and air; and there is, probably, a small quantity of salt even now floating in the atmosphere. You notice certain yellow specks in the flame; those specks show that there is salt in the air. If I only rub my hands which have touched the salt, or even shake my coat over the flame, you perceive the yellow color indicating the presence of salt. You must not suppose that I salted my coat beforehand. (A laugh.) Here we have the means of detecting substances by means of the color which they impart to flame.

Now let us follow this out a little further, and for that purpose I must change my point of view, and ask you to accompany me in an examination as to the nature of the light from the sun and other bodies, in order that you may understand what makes the difference in the light of this gas flame when substances are burned in it. For this purpose I will again make use of the electric lamp, the beautiful white light of which is due to the incandescence of pieces of carbon, or gas charcoal. I want to call your attention to the characteristic properties of this white light. It is to Sir Isaac Newton that we owe the discovery of the peculiar arrangement of colors in this white light. Sir Isaac Newton experimented with sunlight; but I cannot command sunlight in this room, and must therefore manufacture a light the nearest to it that I can. If I pass this white light through two triangular pieces of glass, called *prisms*, we shall see that it is built up of different colors. I have now passed the light through the prisms, and you perceive that it makes on the screen a brightly colored band. This is due to the decomposition of the white light; that is to say, the white light is split up into this splendid rainbow, showing that white light is composed of varying tints, ranging from red to yellow, orange, blue, and violet.

I drew your attention at the beginning of the lecture to the fact that all bodies can exist in three states; and we find that those substances which are solids all give off the same kind of light. If I were to take a piece of

metal, gold, silver, or platinum, and make it white hot, as I am now doing with these carbon points, the gold, silver, or platinum would each exhibit all these rainbow colors, and by this means I should therefore not be able to tell whether the substance were gold, silver, platinum, or carbon. This fact that white light consists of a number of different colors, although it was first made known by Sir Isaac Newton, in 1675, yet it is only within the last ten years, or less, that we have been able to make use of this important and interesting fact, by applying it to the discovery of the composition of the earth, and the sun and stars. I should like to show you, by another simple experiment, that all these differently colored rays when brought together again produce the effect of white light. This I can do by reversing the prism. In the first place, let me say that if I use no prism, we get on the wall a bright image of the slit through which the light passes. If I put one prism in, I get on the wall a bright spectrum, though not so extended as that which I obtain when I use two prisms. Now, if I allow the light to pass through the second prism placed in the opposite direction, you will see that I shall be able to get nothing but a bright slit of white light. Here you see the light coming through both prisms, but all the colored lights on the wall are again converted into white light, by the reversal of the second prism. Now, I have again produced all the differently colored rays by turning round the prism, and the effect is to show you that white light is a mixture of all these differently colored rays. That is the conclusion to which Sir Isaac Newton arrived.

Now, let us pass on to the more immediate portion of our subject. I will strew on these carbons a small quantity of common salt. I will take with my knife a small portion of salt, and bring it on to one of these poles; and I think it will not take long to show you a considerable and remarkable change in the nature of the spectrum. You see that I have made a bright yellow line visible. I can show it to you better in another way. I will put a little of the common salt into the hole on the carbon, so that it may be held, and it will be turned into gas, by the heat of the electric arc. There! You see that instead of getting a continuous spectrum, we have a bright yellow band. It is a remarkable fact that sodium has the power of producing this bright yellow line; and what is more remarkable we find that no other substance is capable of producing this yellow line. The metal contained in common salt is the only substance we know of which has this particular power. This peculiar yellow band would be much more distinctly seen if you could all look separately into the instrument called a spectroscope; I am at a great disadvantage in being obliged to show it to you all at once. In the instrument you would observe the yellow flame to be excessively thin, as thin as the thinnest spider's web; and yet it is always visible when any sodium is present.

So delicate is this reaction, that the first experimenters some years ago could not believe that this yellow light was due to the compound of sodium; but some thought it was due to water, whilst others did not know to what it was due. They could not believe that sodium was everywhere present; for you cannot leave a clean platinum wire exposed to the air for a moment without little particles of soda becoming attached to it. We have heard a great deal lately from Professor

Tyndall and Dr. Angus Smith about the dust in the air, and this is a corroboration of the fact.

Sodium or common salt pervades the earth and air universally, it dances in the sunbeam, and we cannot get rid of it, do what we will. Now, the light emitted by sodium is termed a monochromatic light, that is, it contains rays of one kind only; and I will show you that it is so by a very simple experiment. I have here a diagram containing large printed letters in various bright colors, which I am going to illuminate. When I take a little of this soda and burn it, you will see that the diagram, and perhaps my face also, shows no trace of difference of color, but is one uniform grey tint. (A laugh.) That proves that the light which the soda vapor gives off is made up of one kind of ray, and is therefore termed monochromatic.

Now, as all we have to do to be able to detect soda is to bring it into the state of vapor, so we have only to do the same thing when we want to detect the presence of any other metal, namely, bring it into a state of vapor, and examine its spectrum, that is, examine the light which the vapor gives off. You saw just now on the screen a beautiful green light which was caused by the vapor of silver; and if I now bring a small quantity of metal on to the poles of the carbon, you will see that the light consists of particular rays, the spectrum does not exhibit one continuous band, but is a broken one. You will readily perceive that this gives us a delicate means of detecting the presence of substances. Supposing, for instance, I want to detect silver, I have only to make it volatile and examine the silver gas by means of this bright electric spark, by which I can produce a temperature sufficiently hot to volatilize almost any substance. What does this bright spark consist of? Simply of metals brought into a state of gas. If that light from this spark were sufficiently strong, it would enable me to throw upon the screen the bright lines produced by the metals which form the poles from which the spark is passing. I will now show it to you with the electric lamp, first an experiment with zinc, and afterwards with copper and brass. What I want you to understand is that no other substance but zinc has this power of producing these particular bright lines; so that wherever we see these bright lines, we are perfectly sure that zinc must be there present. [The experiment showed first the copper lines, then the zinc lines, and afterwards the lines of both these metals from the volatilization of brass. Having to experimentalize almost in the dark, Professor Roscoe had to ask for patience on the part of the audience for momentary delays in making the arrangements. We may say here that the utmost order, patience, and good humor prevailed throughout the lecture.] You now see how splendidly the red and blue bands of the zinc come out. Of course the effect is momentary, and not continuous, owing to the limiting conditions of the experiment. Now, I will try to show you the effect with copper. You will remember that I must change the copper into gas before I can exhibit the beautiful lines which the copper gives; and as it requires a very high temperature to fuse copper and convert it into vapor, and as I am at a considerable distance from the screen, I shall again have to tax your patience a little. I dare say we shall get it, but we shall have to boil our copper a little longer. (A laugh.) There! Now you see the beautiful green light of the copper, and now we have the lines of both zinc and

copper, as I have now placed a piece of brass on the carbon pole. I will now show you silver. There you see the bright silver lines If I were to go on showing you all the metals, it would be the same, that is, each metal would exhibit special, peculiar, and characteristic bands. By such delicate test experiments as these, chemists have been able to detect no less than four new elementary bodies. They have discovered that one of these substances, lithium, which was thought to be a very rare substance, is really present almost everywhere. Lithium imparts to the flame a remarkably fine crimson tint, which you will see in a moment in the flame of the lamp on the table. This lithium, I repeat, was considered to be a very rare substance; but by means of spectrum analysis it has been found to exist everywhere. If you only hold the ash of a cigar in the flame, you will see this peculiar red line in the spectroscope. I am afraid that the sodium which is present in the flame will rather neutralize the tint, nevertheless you will be able to see it. Why is it that we do not see the red flame more distinctly? It is because the red color due to the lithium is mixed up with the yellow color due to the sodium; but by means of spectrum analysis we can separate the red light from the yellow. The yellow light is more refrangible than the red light, and consequently, by means of the prism, we shall find that the sodium line takes one place, and the lithium line another; and the result is we have a beautiful red line alongside the yellow line. There you see the yellow sodium line; and there, on the right side, you see the red lithium line. You can now understand how the minutest trace — the millionth part or less — of a grain of lithium, can be detected, because the light which it emits is not interfered with by the yellow light, and, as I said, no other substance but lithium gives the splendid red line.

I will next show you a substance which has been newly discovered. It is called *thallium.* It is an elementary body, and was discovered by an Englishman, Mr. Crookes. Two new elementary bodies had previously been discovered in the same way by a great German chemist, named Bunsen, the discoverer of two new alkaline metals resembling potassium, the metal contained in common potashes, and which he would have been unable to detect, had it not been for this wonderful spectrum analysis. I am going to show you the spectrum of thallium. You will see a brilliant green line, from which it takes its name, derived from the Greek word thallus, a green twig. That green line indicates the presence of a new body; it tells us a secret — that of the existence of this new substance to which the name of thallium has been given. No other body gives this green line but thallium, and no other body gives this yellow line but sodium, or this red line but lithium.

Now, you will, I hope, be in a position in some degree to understand how it is that the light of the distant sun can be analyzed, a body so distant that if we had a railway from here to the sun, and we were to travel as passengers at the rate of 40 miles an hour — which railway directors tell us is about as fast as is consistent with safety — it would take us about 300 years to get there! Light travels at the rate of 192,000 miles in a second, and consequently it does not take more than eight and a half minutes for the light of the sun to reach us. You will now readily understand how this spectrum analysis enables us to judge what there is in the sun, because if

I saw this yellow line in the sun's rays, or this green line, I should infer that the substances producing these lines existed in the sun. This would appear to you still more striking if I could show you the lines caused by the vapor of iron and many other metals, all producing lines of different degrees of breadth and luminosity. Spectrum analysis enables us to test in the same way the light of the fixed stars, although they are at such an inconceivably much greater distance than the sun. If I discover the yellow line in the starlight, I infer the presence of soda. It does not matter whether the flame which I analyze is five inches from my eye, or five miles, or five millions of miles, or five millions of millions of millions of millions of miles! If I can by means of the prism perceive certain well-known lines, I am justified in inferring, with scientific certainty, the presence of the corresponding substances. I say I am as certain of my conclusion in this case as I am of any other question in natural science. I apply certain tests to a mineral sent to me from New Zealand, and I come to the conclusion that the mineral is iron; and nobody doubts it. But somebody might say that if other tests had been applied, I should have found that the mineral was not iron. Still, having applied all the means in my power, I find that the effects correspond with those produced by iron, I am scientifically logical in asserting that the substance really is iron, and so for the existence of iron in the sun, all I can say is that if I apply these tests and the result is invariably to show the presence of these lines of light, indicating the existence of iron in the sun, I am as philosophically and scientifically correct in my inference that iron exists in the sun as though I had seen and handled it.

Let me now try to explain to you what we see in the sunlight. This will be the second part of my lecture, and I shall not detain you much longer, because I am simply making this part of my lecture introductory to Mr. Huggins's What do we see in the sunlight? Do we see the same bright uninterrupted band that we have noticed here? No, we do not; we have something different. I cannot show you sunlight now, but I will try to explain what it is we see in the sunlight, when we look at it through an accurate instrument. I have here a picture, or diagram, which will serve to show the kind of thing we see in the sunlight. I use the common means of the magic lantern to show this picture, which is roughly prepared and imperfectly colored, but it will serve you that the solar spectrum is a colored band, from red to blue, as in the electric spectrum, but with this addition — that it is intersected with *dark lines*. These dark lines are always present in the sunlight, though Sir Isaac Newton did not see them. They were first mapped by a German optician, named Fraunhofer, and these lines are known as *Fraunhofer's lines*. Ten years ago nobody knew what Fraunhofer's lines were; they were a kind of sphinx amongst opticians, nobody knew what these black lines in the sunlight denoted. They were always found whether in direct or reflected sunlight, whether in the light of the sun or in the light of the moon, or the planets Venus, Mars, Jupiter, &c., which, you know, reflect the light of the sun. So long ago as 1819 Fraunhofer found that although there are dark lines in starlight, yet they do not exist in the same number and proportion in starlight as in sunlight; the stars shining, as you are aware, by their own light. He therefore came to the conclu-

sion that these dark lines were caused by something which existed in the sun and the stars, and was not due to anything in our air, else why was starlight different from sunlight, both having to pass through our air? I wil: show you a drawing made by Fraunhofer, exhibiting the black lines, of which there are thousands in the sunlight, and they are nothing more than parts of the sunlight where a particular kind of light is wanting, and therefore there is a black space or line; and these lines are so numerous that they appear nearly to fill up the whole space, and are yet so thin that they do not appreciably detract from the total amount of light that comes to us.

What causes these shades in the sunlight? The great discovery of the cause of these dark lines was made by a German, Professor Kirchhoff. In matters of science we have been very much indebted to the Germans, and but for their laborious and intellectual labors we should be wanting in many valuable discoveries. Of late they have been taking the lead in war as they have long done in their knowledge of nature. Professor Kirchhoff, working quietly in his laboratory at Heidelberg, was able to explain this enigma of the dark lines in the sunlight. He discovered this long-kept secret of nature, and told us what these dark lines really mean. Kirchhoff found on examining these dark lines that certain of them correspond exactly with those beautiful bright bands which I have endeavoured to show you on the screen. He observed that every one of the hundreds of bright lines in the iron spectrum had its corresponding dark line in the sunlight. How was this? Why should these lines all exactly coincide. I will endeavor to show you the correspondence between these dark lines in the sun with the bright lines of the iron. There! these are maps of sunlight uncolored, for we only desire to show now the position and breadth of space occupied by these dark lines. Below these you will see a number of smaller lines which indicate the position of the bright iron lines. I was fortunate enough myself some years ago to see this thing with my own eyes. I am privileged to reckon Kirchhoff and Bunsen among my intimate friends, and I was visiting them when they were making these interesting discoveries. When they showed this thing to me it flashed upon my mind at once — there is iron in the sun! — because for every one of the bright iron lines there was a corresponding dark one seen in the solar spectrum. Understanding this remarkable coincidence, the only question we need now to ask is — How is it that if there is iron in the sun we do not see these lines *bright* but *dark?* How is that? That is the only point which now remains to be answered. I will endeavor to show you an experiment to prove to you that we can make these bright lines dark, and I will try to show you that I can make artificial sunlight so far as regards the formation of one black line, and that I can get in place of the bright yellow sodium line a black line. I can only show this in the case of sodium, but the same thing holds good for all the other metals. I am going to burn a little sodium, and I want you to notice that on the part of the screen where you saw the yellow line you will see in its place a black one. By that experiment I have, in a rude and imperfect way, manufactured sunlight. There you see the black line between the two yellow ones. There is a black line where the sodium ought to be, and as that absorbs the sodium, it is that black band which appears in the sunlight. The

same thing takes place in the sun. It seems very singular that the sodium vapor, which gives off a yellow light, should absorb yellow light; and yet nothing in reality is more true, or more likely, from being in accordance with many other facts in science.

Now, we know from astronomical and other observations that the temperature of the sun is exceedingly high. Things which on the earth are solid and liquid are in the sun gases. Therefore, we do not need to wonder at finding iron in the sun in a state of gas, for the temperature of the sun is far higher than the temperature of this electric spark, or of the oxy-hydrogen flame in which I burned iron just now. It is this iron and sodium and other elements in a state of vapor which have the power of absorbing the exact kind of light which they give off; and the consequence is that instead of showing bright lines in the sun you see dark ones. As if to render this explanation still more easy of our acceptance, science has helped us again by a recent discovery in regard to the appearance of the sun during a total eclipse. Some very extraordinary appearances present themselves when the sun is totally eclipsed, and I hope that after Christmas I shall be able to announce to you that we shall have a lecture on the forthcoming eclipse of the sun from Mr. Lockyer. The extraordinary red flames or prominences which shoot out from the sun are only visible during an eclipse, and many of us are going to Sicily shortly to see that phenomenon. These red prominences are due to the ignition of hydrogen gas, and they give bright lines, instead of dark ones, exactly like those you saw on the screen. These red flames shoot up some 80,000 or 90,000 miles above the surface of the sun, and they are due to the presence of glowing hydrogen. I am going to show you some glowing hydrogen. I have here in this glass tube hydrogen gas, and when I heat it by an electric current, you will see the beautiful colors due to the glowing hydrogen, and identical with those of the red solar prominences. That beautiful red color on my right is the color we see in a total eclipse when the red prominences shoot out. These red prominences then consist of glowing hydrogen.

And now, suppose you ask me — What of all this? How much better shall we be for knowing that there are these new elements in the earth, or that lithium is present everywhere, or that iron and hydrogen are contained in the sun and stars? What am I to say to you? Why, I will begin by telling you the story of that good old American philosopher, Benjamin Franklin, who, like the fabled Prometheus of old, first brought lightning down to the earth by the string of his kite. He was asked this question of his discovery, and he answered, "Tell me the use of an infant." "Make it of use." So in science, the infant truths must be made useful. Neither you nor I perhaps can see the *how* or the *when*, but that the time may come at any moment when the most obscure of nature's secrets shall at once be employed for the benefit of mankind, no one who knows anything of science can for one instant doubt. Who could have foretold that the discovery that a dead frog's legs jump when they are touched by two different metals should have led in a few short years to the discovery of the electric telegraph? Who could have imagined that a chemical compound, a few years ago scarcely known but to a few scientific chemists, should turn out the greatest boon ever bestowed by science

upon suffering humanity? We all now know the value and uses of chloroform. So I might go on through all the different branches of science, unfolding to you, in endless variety and number, instances of the direct benefit of scientific discovery. Enough, surely, has been said to satisfy you of the national importance of science and of scientific research.

But apart from the *usefulness* of science in the sense which I have here employed — by which I mean its application to raising the material welfare of mankind — there is another and a higher part for science to play, namely, to enlarge the understanding and to purify the hearts of men. To the study of nature men may always look as a source of pure, unalloyed enjoyment, a spring which is never dry, a food which never satiates. What gives zest and spirit to that poor weaver's life, who walks for miles after his hard day's work — as many do — to secure a rare fern, or find a new coal fossil? Does he earn a farthing more? Will his master pay him more wages? Or can he thereby "turn an honest penny," as it is termed? Not he. His aims are loftier and nobler. His prize and payment is a far higher one — that of an enlarged mind and a peaceful heart. His thoughts are raised above the mere struggle for wealth and position. He lives quietly and contentedly, and finds in the pursuit and study of nature that peace and happiness which alone such studies can give.

It is with the hope that some few may be induced to take up scientific pursuits that these lectures have been arranged. We all know how in England political power is gradually being transferred to the masses of the people. Whether that transference proves a blessing or a curse, depends on the people themselves. A people whose masses are without knowledge and without tastes for higher things than the mere struggle for existence can come to no good. The education bill passed last session will, let us hope, secure for every child the rudiments of education; but to elevate the tastes of the people, to show men how debasing are the habits to which many of them are chained, and to point out the direction in which they must tread in order to be true and happy men — this is even a more difficult and tedious task.

If this course of science lectures to the people helps even in the slightest degree to advance this, perhaps the greatest necessity of our land and of our time, the labors of those who are engaged in giving them will not have been bestowed in vain.

SPECTRUM ANALYSIS, IN ITS APPLICATION TO THE HEAVENLY BODIES.

A LECTURE BY WILLIAM HUGGINS, LL.D., D.C.L., F.R.S.

I have to describe, this evening, some of the most important of the recent additions to our knowledge of that vast array of luminous orbs which have been in all ages a beauty and a mystery to mankind. Last week, my distinguished friend, Professor Roscoe, gave in this room an account of the principles of the new method of investigation, spectrum analysis, which may be said, with but little exaggeration, to have given to man a new sense. But great as is the value of the searching power of this method of analysis, as applied to terrestrial substances, by which there have been revealed to us four entirely new kinds of matter, the metals rubidium, cœsium, thallium, and indium, it is in its application to the heavenly bodies that this method of research has produced the most remarkable results. This new mode of investigation is peculiarly adapted to the needs of the astronomer, since the only requisite is light; and it matters not how great the distance that light has come, nor how long it has been upon its way; the spectroscope places within his reach certain knowledge on many points on which before all we could hope for was a mere probability of conjecture.

The chemical nature, the physical constitution, and, within certain limits, the temperature, and the density, and the motion of the line of sight of the most distant parts of the visible universe can now be investigated in the observatory; and in respect of some of the heavenly bodies, considerable information has been obtaiained on these points.

Before describing the results obtained when spectrum analysis is applied to the heavenly bodies, I would recall to your recollection, in as few words as possible, the principles of this method of analysis, as explained in this room last week. The prism, or the spectroscope, enables us to see, in succession, and so to discriminate the different kinds of light which may exist together in the radiations of a luminous body, and which without the intervention of the prism would fall simultaneously upon the eye, and so be lost in a common impression. These different kinds of light, existing together in the radiation of a luminous body, when they are thus separated by the prism, so that the eye can discriminate them, form the spectrum of that light. All the different kinds of spectra which are observed from different luminous bodies may be very conveniently arranged in three classes. I shall now exhibit to you a spectrum representing each one of these three classes; but before exhibiting upon the screen the first spectrum, I wish to show upon the screen the luminous source from which the light has come. That is of importance. In this case the luminous source will be two pieces of carbon rendered incandescent by means of electricity. Part of the electricity is converted into heat by the resistance of the carbon. The carbon is not burning; it is merely rendered white hot. We now see upon the screen

the images of two small pieces of carbon rendered white hot by the electric current. At the present time there are upon that screen all the gorgeous colors of the rainbow, but you cannot see them. Why? Because they all fall together exactly upon the same spot; they all enter the eye together; and the impression that we receive is that of all the colors together at the same moment, and such a compound impression we call "white." Now the same light which is falling upon that screen will be thrown upon this screen after having passed through two prisms. You there see this beautiful object, and you would see it much better if we could have the room darker. [The gas was lowered still further, and the beautiful effect of the colors thereby heightened.] There are not more colors on this screen than on the other; the only difference is that the prism has separated the colors, so that they fall on different parts of the screen, and the eye can view them in succession, thus discriminating the different kinds of light. You perceive that in that spectrum the colors are complete from the red to the blue, and it is therefore called a "continuous spectrum," and such a spectrum indicates that the light is derived from incandescent solid or liquid bodies, as you saw was the case when the source of the light was thrown on the other screen. We will now throw upon the other screen the same points of carbon as before, but before allowing the electricity to pass through them, we will place a small quantity of chloride of lithium on one of them, and you now see that the points can be separated, because the chloride of lithium is decomposed, and the lithium volatilized, and you have a beautiful arc of red luminous vapor between the two points. The lithium is not burning; it is simply converted into vapor, and the vapor become so hot as to be luminous. In this case nearly the whole of the light comes from the luminous vapor. There will now be thrown upon the other screen the spectrum of this light from the luminous vapor of lithium, and you will see that we shall have an entirely different form of spectrum. There will be a little of the continuous spectrum that you saw before, because the carbon points are also present, and though less intensely luminous, still they are adding a certain amount of light. You see that nearly the whole of the light now consists of three bright bands, two in the red, one in the green, and one in the extreme blue. These colors represent the light which together entered the eye from the red vapor that was seen upon the other screen. In this case the spectrum is not continuous; the colors are separated; and when we have such a spectrum it is called a spectrum of bright lines, because the width of the colored bands depends upon the narrowness of the slit in the apparatus. With the best arrangements the bright lines would be still narrower. When we have such a spectrum of bright lines, we know that the source of the light is luminous vapor or gas. As you were informed last week, each terrestrial substance gives a set of these bright lines peculiar to itself; so that when we see these particular lines upon the screen, we know for certain that the source of the light is the incandescent vapor of this metal lithium. In this way, when certain bright lines are seen in the spectra of the heavenly bodies, if these bright lines coincide with the set of bright lines given out by any terrestrial substance, we then know that this terrestrial substance is really present in those distant bodies. The third class of

spectra are spectra which have been modified, or altered and changed, in some respect, on their way to us. The light at its origin would be from an incandescent solid, and would give continuous light; but the light on its way to us has passed through a certain vapor, say sodium, and that vapor stops out a certain portion of the light, and the part of the light which it stops out is of a particular color, is precisely of the same part of the spectrum which sodium would emit if sufficiently heated. To show this, there will be thrown upon the screen the continuous spectrum of the carbon points; and Professor Roscoe will kindly convert a small piece of sodium into vapor, and cause the vapor of the sodium to come upon the screen, and the result will be a black line where the yellow point would have been if the luminous vapor of sodium had been employed. The spectrum containing these dark lines shows that the light has been modified on its way to us, and has suffered absorption by passing through a certain vapor. As this dark line corresponds in position to the bright line from sodium, it is easy, by comparing the set of dark lines as seen in the spectrum of the sun or stars with the set of bright lines given out by any terrestrial substance, to determine whether that substance is one of the vapors or gases through which the light has passed. If the dark lines coincide with the bright lines, we then know that the absorbing gas is the vapor of the terrestrial substance which we have under examination. Kirchhoff applied this investigation to the sun; and he gave us the first certain knowledge of the constitution of that body, showing that it consists of matter similar to that which exists upon the earth, and that at so high a temperature that such metals as iron, nickel, magnesium, and zinc exist there in a state of gas or vapor.

This was the state of this newly-born science of spectroscopy when in 1861, in conjunction with my late distinguished friend, Dr. William Allen Miller, I endeavored to extend this analysis to the other heavenly bodies. And here some formidable difficulties presented themselves. Though the stars appear to shine very brightly in the sky, yet the amount of light which enters the eye from a star is exceedingly small. It was therefore necessary by some means to increase the amount of light which enters the eye from the stars. This was accomplished by the use of a large telescope, so that the whole of the light which falls upon the object-glass, eight inches in diameter, is gathered up and concentrated into a bright point, and is thus enabled to enter into the eye. It may be well to state that a telescope has not the same light-gathering power, in respect of an object of sensible size, as a nebula or planet, because the image of the nebula or planet is as much larger than the image formed by the unarmed eye, as the instrument gathers more light; but as stars remain in the telescope as minute points of light, it is possible, by means of a large mirror or a large lens, to increase their brightness many thousand times.

Another difficulty presented itself in the apparent motion of the heavenly bodies. When we look up to the sky, the stars appear to be standing still; but it is for the same reason that the hands of a watch appear to be stationary. A few seconds suffice to show that the hands of the watch have moved; and a few minutes will be sufficient to show to any careful observer who has taken the precaution to notice the particular direction of a star to a fixed object — as the edge of a wall

or the point of a steeple — that the stars also move rapidly from east to west. This motion is not real but apparent, and it arises from the rotation of the earth, which is sweeping us round towards the east, and thus causing the stars to appear to move towards the west. Hence it is obvious that if the telescope be fixed to an axis, and the axis be placed parallel to the axis of the rotation of the earth, and then that this axis be made to move round by a clock motion with a speed exactly the same as that with which the axis of the earth turns, that the telescope will be moved towards the west with the same speed with which the earth is moving towards the east, and in this way a star may be made to appear stationary in the telescope for hours together.

There will now be thrown upon the screen a view of the interior of my observatory. There you see the telescope; here is the axis parallel to the rotation of the axis of the earth; and there the clock motion by which the telescope is moved. Those wires are connected with a powerful conducting coil, and this again with batteries, for the purpose of obtaining a sufficiently high heating power for converting metals into vapor; and thus the bright lines produced by the vapors of iron, nickel, &c., could be directly compared with the lines as seen in the stars. The most convenient way of converting these metals into vapor is by the apparatus I have here — an induction coil. Between one of the poles is placed some lithium, and between the other some of the metal thallium. I will cause the sparks to pass, and you will see that they are beautifully green. It is green because a portion of the metal thallium has been converted into vapor; the light emitted is from the vapor of thallium. I have here another, which is arranged with a portion of lithium between, and in that case the light is red, that being the color of the vapor of lithium. [These and all the preceding and subsequent experiments, superintended by Professor Roscoe, were very successful, and it was often impossible to suppress the applause of the audience.]

In the picture of my observatory, still on the screen, you see the observing chair, whence the observer, by touching a small button, could at any moment, by means of the apparatus, bring into view with the spectrum of a star the spectrum of iron, magnesium, or any other terrestrial substance, and see the two simultaneously side by side. In this way it was easy to determine with accuracy whether a group of bright lines as are produced by magnesium were coincident or not with a similar set of bright or dark lines as seen in the spectrum of the heavenly bodies.

When we look up to the heavens on successive nights we do not fail to observe that some two or three of the brighter stars are found to be moving amongst the vast host of stars. Such stars were noticed by the ancients, and were called by them "wandering stars." We have adopted the term, and call them "planets;" and we now know that together with the earth they revolve about the sun, and shine only as they reflect his light. The spectrum, therefore, of a planet or of the moon would be the same as that of the sun; it would, indeed, be a spectrum of solar light reflected from a planet or from the moon. Therefore all the information we could expect to obtain by examining the spectrum of the moon or of a planet would be the modification or alteration which had been produced in the solar light by the absorption of atmospheres which might exist about

those bodies. Now the atmosphere of a planet is capable of producing such an absorption. We have certain evidence of this in the effect produced upon the solar light by the atmosphere of the earth. You now see upon the screen a spectrum showing a number of dark lines, which are added to the solar spectrum by the absorbent action of our atmosphere. When the sun is near the horizon, so that his light passes through a greater extent of the earth's atmosphere, and especially through the vapor near the earth's surface, we get these additional dark lines; but as the sun rises higher in the heavens, these lines become fainter and fainter, until at last they nearly disappear.

There will now be thrown upon the screen, in succession, telescopic views of two or three of the planets. You have now upon the screen an appearance of Jupiter, as seen in a large telescope. There you see those strange belts across, which may be masses of clouds, dependent upon fixed currents of air similar to our trade winds. When the spectrum of Jupiter was viewed I saw three or four strong lines, one of them coincident with a strong line produced by the earth's atmosphere, showing that this planet has an atmosphere similar to that of the earth, but not identical with it.

There you have the telescopic appearance of the planet Mars. Here again we have great similarity to the earth. You see that white spot at the top of the diagram. We have certain evidence that that is an accumulation of ice, because it is seen to diminish and increase as that portion of Mars is more or less illuminated by the sun. The spectrum of Mars shows also that this planet has an atmosphere similar to that of the earth.

There is now thrown upon the screen a view of the most beautiful of all the planets — Saturn — with its rings. This planet also gives lines, and similar lines are noticed in the rings of the planet, so that it is obvious that both the ball and the ring are surrounded with an atmosphere.

We must now pass from these near bodies, the moon and the planets, into the remoteness of space, to the true stars, which are self-luminous bodies, and which are so far off that we are quite unable to form a proper conception of the distance which separates them from us. Sir John Herschel has suggested the following illustration of the size of the solar system:— If you place a globe, two feet in diameter, in the centre of a large plain, to represent the sun, then the earth could be represented by a pea placed at a distance of 215 feet from it, Jupiter by an orange placed at a distance of a quarter of a mile; and Neptune, the most distant of the planets, by a plum at a distance of a mile and a quarter. But Sirius, one of the brightest of the stars, would, upon the same scale, have to be removed to a distance of forty thousand miles, or five times the diameter of the earth. So that the earth is not one-fifth part big enough to hold even a model to represent the distance of the stars, on a scale the same as that on which the earth itself would be represented by a pea. And yet the power of this new method of analysis can bridge this enormous gulf of space, and we can analyze these distant bodies with almost as great a certainty as we can the vapor of any metal on the laboratory table.

There will now be thrown upon the screen the spectra of two stars which we examined with very great care, the stars Aldebaran and Betelgeux now visible in the

southeast. The spectra resemble in general character the solar spectrum. You observe a number of dark lines, which are not the same in both spectra. They are grouped differently, and underneath each spectrum you will see a number of white bright lines. Those white lines represent the bright lines of the terrestrial substances which I compared directly with the spectra of the stars by the method which I have described; and in the case of many of the metals complete coincidence was established. For example, in the case of this double line of sodium. Sodium gives a double bright line; and there was seen to be a double dark line in the spectrum of that star coincident exactly with the double bright line of sodium. So again the triple green line of magnesium was found to coincide, line for line, with the triple dark line in these two stars. Five bright lines of iron were found coincident with the same number of dark lines. The lines of hydrogen in one of the stars were found coincident with two dark lines in one of the stars. In this way the presence of seven or eight terrestrial substances were ascertained to exist in these distant bodies. We thus learn that the stars have a community of matter with the earth; that the matter of which they are composed is of the same order as that of the earth; that it is subjected to the same force — the force of heat; and that it emits light in the same way as terrestrial substances. It should not be forgotten that before these investigations we had no certain knowledge of the true nature of the stars; it was merely as a matter of analogy that they had come to be considered as suns similar to our own sun. In this way some fifty of the stars were examined, and they were found to differ one from the other, but were all formed upon the same type; all contained some terrestrial substances, but apparently in different proportions; and containing, it may be, many other new bodies. Many of these lines which are not found to be coincident with terrestrial lines may be indicative of some forms of matter entirely new to us; but at present it is impossible to recognize these substances so as to know what they are. It may be worthy of remark, that the elements which are essential to life, as we know it upon the earth, and which would be most easily recognized in the spectroscope — such as hydrogen, magnesium, iron, and sodium — these were, with possibly one or two exceptions, found to be present in the spectra of all the stars which we examined. Now, many of the stars are seen to differ very greatly in color, and especially is this the case when the telescope is employed. Many stars which to the naked eye appear single, when the telescope is directed to them are seen to be composed of two stars, beautifully contrasted in color. There is now thrown upon the screen, and I hope visible to the greater part of the audience, the appearance which the star Beta in the Swan exhibits when viewed through a large telescope. The orange star has a very beautiful bluish purple companion. Now, it seemed probable that as the spectra of the stars are crossed by these dark bands, that if they were found to exist in groups and were not scattered evenly over the whole spectrum, but crowded together in some places more than others, then those parts of the spectrum where the strongest lines occurred, or where the lines were most numerous, would become dim, and these colors would be darkened relatively to the parts of the spectrum where few lines occur; and hence these latter colors would tinge the

stars with their own tints. And this speculation was found to agree with observation. We now throw upon the screen the spectra of the two stars which you have just seen. The dark lines, you will observe, occur for the most part in the blue and red ends of the spectrum, leaving the orange part of the light almost undimmed; hence the orange light predominates in the star, and the star instead of being white becomes tinged with orange. In the lower spectrum a number of absorbent lines occur across the orange part of the spectrum; hence the red and the blue predominate; and the result is that beautiful bluish purple color which you saw upon the screen. I will give one more illustration. The brightest of the two stars forming Alpha in the constellation Hercules is a double star, and the brighter of the two component colors has an orange tint. In this exceedingly beautiful spectrum you see that the orange part is comparatively free from dark lines of absorption; therefore that color predominates in the light of the star.

A phenomenon observed among the stars of great interest is the periodical waxing and waning of their light. Many of the stars have shorter or longer periods, through which their light increases or diminishes. This phenomenon, which has been studied with great success by your distinguished townsman, Mr. Baxendell, is one upon which spectrum analysis will probably throw much light. Up to the present time we have not gained much information; but I will throw upon the screen the spectrum of one of the variable stars, representing an appearance which is seen in many of these objects. The spectrum now upon the screen is that of the star named by the Greek letter μ in the constellation of the

Whale. It is not known at present whether these variable stars are related to a phenomenon of very rare occurrence — namely, the sudden outburst in the sky of bright stars. Such a phenomenon has been seen occasionally, but it is only a few generations of mankind who are fortunate enough to be witnesses of this rare sight. Most fortunately a grand example of this class of stars burst into sudden splendor in the year 1866. I think it is probable that these are not new stars, but that they are small stars which have burst into sudden splendor; and though their splendor has been temporary, and has soon dwindled down into insignificance, it is probable that they have not become entirely extinguished, but still exist in the sky, and perhaps at some future period they may again burst forth into unwonted splendor.

In 1866 such a star shone out with great brilliancy — a star, I believe, of the first magnitude, in the constellation of the Northern Crown. It was first observed by Mr. Birmingham, in Ireland. He kindly wrote to me, and I was enabled to examine its spectrum before it had much diminished. The spectrum of that star is now thrown upon the screen. I think without a word from myself you will see that the spectrum presents one peculiarity entirely different from the spectra you have already seen. In addition to the continuous spectrum and the dark lines, you see that there is a group of bright lines. Now this shows that the light which comes to us from this star has had a double origin; that part of it has come from an incandescent solid, and has passed through absorbent vapors, just as the light of the stars and sun: but that, in addition to this light, there is a light that has come to us directly from

some luminous gas, and which forms the spectrum of bright lines. I found by direct comparison that two of these bright lines, and probably a third, coincided exactly with the bright lines of hydrogen, and we therefore know that this star must have been surrounded by an atmosphere of hydrogen so intensely hot as to be luminous. This phenomenon becomes of more interest from the results of recent observations, to which I shall presently refer. We now know that the sun is surrounded by luminous hydrogen, that the red prominences seen in a total eclipse of the sun consist for the most part of this intensely heated hydrogen; therefore, bright lines similar to these are always present in the solar spectrum, but we do not see them. Why? Because the luminous hydrogen round the sun is very faint as compared with the great intensity of the photosphere, or that part of the sun which gives a white light. Consequently, all these lines can do is to render rather less dark the lines of the sun which coincide in position with them. But when we look at that part of the sun where there is no bright photosphere to overpower the hydrogen — as, for instance, the dark part of the solar spots — then these bright lines become visible. Hence we learn that in this star the atmosphere of hydrogen must have had a very great intensity relatively to the brightness of the photosphere. And there have since been discovered two or three other stars in which this state of things appears to be permanent, at least of no very temporary character. In what way this atmosphere of intensely heated hydrogen has got round these stars we do not know — whether it was an outburst from the center of the star, which we must suppose is hotter than the surface — whether it was thus a mass of much hotter hydrogen burst from the sun, or whether, which is far less probable, in some way a combustion had been set up, and in this way the hydrogen become heated, we cannot say.

Now we will leave the stars for some other objects seen in the heavens — objects less familiar to you, because they are not to be seen by the common gaze, but a telescope is necessary to discover them. When a telescope is directed to the sky there are seen to be amongst the stars a number of patches of luminous matter, faintly shining clouds, with small wisps of light, sometimes of fantastic forms. These have great interest for us, because they are not similar to any parts of the solar system; and, therefore, from analogy we have no clue to their nature. What are they? Are they great companies of suns so distant that their individuality is lost in the common blaze? Or are they portions of the original and unformed material of the universe? Are they some of the bricks and mortar out of which the heavens and the earth have been made? How much light could be thrown upon these bodies if only we could examine their spectra. This has been accomplished. In 1864 I was successful in examining the spectrum of one of these objects. I have now thrown upon the screen the telescopic appearance of one of these objects. You have there a very good representation of the appearance presented by the nebula called the "dumb bell nebula," as it appeared in the telescope of Lord Rosse. There will now be thrown upon the screen the appearance presented when the light of one of these objects was analyzed by the prism. You see now something perfectly unlike the spectrum of a star — no continuous spectrum from red to blue, with a number of

dark lines; but in place of that three brilliant lines in the middle of the spectrum, a green line and then two lines further towards the blue. This showed at once that the nebula was not a group of suns, was not made up of stars, but that it was a mass of luminous gas. The next thing was to examine the position of these lines, and the result of that examination will be shown in the next diagram. One of these bright lines was found to be coincident with the brightest lines of the gas hydrogen; another line, the brightest of the three, was found to be coincident with the brightest lines of the gas nitrogen; the third line was not coincident with any substance which was compared with it, though it was very near the bright line of thallium. We thus learn that these nebulæ consist for the most part of two gases, hydrogen and nitrogen; and that these are so hot as to emit light — to be luminous. If you ask how it was there was only one line of each gas — since hydrogen and nitrogen give spectra of several lines — we cannot answer that question with certainty. I may state, however, that I found that when the light of hydrogen and nitrogen was diminished in any way by moving the spark from the gas to a greater distance from the slit, or by the interposition of a neutral tint gas, then all the bright lines of these gases became extinguished, with the exception of just one line; and the one line in each gas which remained was precisely the one line coincident respectively with two of the lines of the spectrum of this nebula.

I will now call your attention to that nebula which we have upon the screen. This is a very remarkable one, as it shows that wonderful spiral structure which is so characteristic of some of these bodies, a sort of double spiral. In the spectrum of this object I was enabled to detect a fourth line, and that fourth line — which extends further into the blue part of the spectrum — is probably coincident with another of the lines of hydrogen.

You have now upon the screen one of the most interesting of the nebulæ — the Ring nebulæ in the constellation of Lyra. This nebula looks very much like an oval bird's-nest. I found that the faint light in the interior of the Ring gave the same spectrum as the brighter portions of the margin of the object.

There is another of these remarkable objects. That gave also a spectrum of three bright lines. Here you have another resembling very much the planet Saturn, seen edgeways; that gave also three bright lines. These are given as illustrations of the various forms presented by the nebulæ.

It was interesting to observe the spectrum of the nebulæ which had been resolved by the telescope into discrete points of light; and in this case it was found that the spectrum was continuous. There are some few nebulæ which have not been resolved by the telescope, but which have given a continuous spectrum. One of these is now upon the screen — the great nebula in Andromeda. This may be seen as a small cometary object with the naked eye. It is favorably situated for observation now at ten o'clock at night, if you look exactly in the zenith, just south of two small stars. This gives a continuous spectrum, and upon comparing the results of some sixty or seventy of these bodies with telescopic observations on the same nebulæ by the late Lord Rosse, it was found that as a rule the nebulæ which had been resolved by the telescope gave a con-

tinuous spectrum, while the nebulæ which had not been resolved by the telescope gave a gaseous spectrum.

We must now pass again to another order of the heavenly bodies, objects which appear suddenly, possess strange and rapidly changing forms, and which in all ages and amongst all peoples have been regarded as signs and portents of war and common calamities. Up to the present time, only five comets have been examined with the spectroscope. In 1861, I was enabled to observe a telescopic comet in this way, and I found that the nucleus was distinct from the light of the sun; that it was not merely reflected solar light, but gave one or more bright lines. In 1868, a more complete examination of one or two comets could be made; these comets, however, were telescopic, invisible to the naked eye. The appearance presented by one of these in the telescope will now be thrown upon the screen. The slit of the spectroscope was placed across the head of the comet, so as to examine the light of the nucleus. The central part of the head is called the "nucleus;" around it is the "coma," or hair of the comet; and behind is its "tail," always in a direction turned from the sun. There will now be thrown upon the screen the spectrum of this comet, and also the spectrum of another comet observed about the same time. This was the periodical comet of Brorsen, and the other was a small comet discovered by Dr. Winnecke. The spectra of both are similar. Both consist of three shaded bands of light, but the positions of the bands are not identical in the two comets. This was the light from the head of the comet. The tail of the comet gave apparently a continuous spectrum, and may have been merely reflected solar light. Now, on the evening

I made that observation, I suspected that the spectrum resembled very closely the spectrum of carbon, as I had observed it some two or three years before. The next evening I compared directly the spectrum of carbon with the spectrum of this comet. The spectrum of carbon is represented in the two upper spectra. Both these are identical as regards the green bands; they differ only in one point, namely, in one of the spectra the bands of light can be resolved into distinct lines; in the other spectra the light fades gradually. Now in the light of the comet no such lines were seen, and when the electric spark is taken in a gas containing carbon — olefiant gas for example — such a spectrum is obtained. On the second evening, therefore, I made some olefiant gas, and fitted up an apparatus so that I could take the electric spark in this gas, and that light was reflected into the spectroscope when fixed to the end of the telescope; and in this way I could see at the same moment the spectrum of the comet and of the olefiant gas, and the appearance presented was exactly the same as you have it on the diagram. You will see that the bands of the second spectrum coincide exactly in position with the bands in the spectrum of the comet; they begin and end at the same part, and the coincidence in every respect seems to be complete between the light of that comet and the light obtained by passing a spark in olefiant gas. It seems almost certain that this spectrum is that of carbon, because a similar spectrum is obtained when a gas is viewed in which no hydrogen is present. Now the obvious conclusion would be that this comet consisted of luminous vapor of carbon. This, however, is an exceedingly difficult supposition. There are many reasons

why we can hardly conceive such to be the case, unless carbon exists there in some other form or allotropic state to that in which we know it upon the earth.

In the next diagram you have the appearance presented when the head of the large comet of 1858 was viewed in the telescope. And this is of great interest in connection with the point upon which I am now speaking. That is the head of the great comet of 1858. It shows an exceedingly bright envelope, then a dark envelope, then a bright one, and then comes the tail; and the *modus operandi* seems to be that as the comet approaches the sun, the nucleus throws out a certain amount of luminous matter, which becomes dark and then luminous again, and then forms the tail. It may be that if the nucleus is self luminous that it throws out some luminous gas; then that it becomes so far cool that it cannot emit light, but still being gas it reflects but little light, and when it gets further from the nucleus it becomes condensed, and then as solid particles it is capable of reflecting light. The whole question of comets is one upon which no doubt great light will be thrown when a brilliant comet can be examined in the spectroscope.

I have now to pass for a few moments to an application of spectrum analysis in an entirely new direction. I stated that it was possible by means of this method of analysis to determine the motion of a luminous object in the line of sight; that it was possible by spectrum analysis to tell whether a star was coming towards the earth, or going from the earth; and also of determining approximately the velocity with which stars approach or recede from the earth. The importance of obtaining information upon this point will be obvious when it is remembered that the so-called "proper motion of the stars" relates to that part of their true motion only which is at right angles with or transverse to the line of sight; because any motion that a star has in the line of sight directly towards the earth or from the earth would not cause any visible displacement in a star relatively to the stars near it; and therefore it could not be detected by the ordinary method of observation.

Now, I wish to endeavor to explain to you, in a few words, in what way it is that by spectrum analysis we may be able to determine the approach or recession of a luminous body. You all know, I think, that the color of light depends upon the number of vibrations or impulses which reach the retina of the eye in a given time; just as the pitch of a note depends upon the number of pulsations of air which reach the ear in a given time. It is, therefore, obvious that if by any circumstance we can increase the number of impulses which fall upon the eye in a given time, say a second, then that light will no longer appear of the same color. It is further obvious, that if a luminous body is coming near to us, or we are going towards it, that a greater number of these impulses will enter the eye in a second of time than would be the case if the luminous body and the observer were at rest relatively to each other. Just in the same way a swimmer striking out from the shore will pass through a greater number of waves in a given time than would wash upon his feet if he stood upon the shore; and each wave appears to him shorter, because he is passing through them, instead of allowing them merely to pass over his feet. Or if you imagine soldiers marching in single file, and that the distance

between any two of the soldiers would represent the length of a wave of light, then it is obvious that if you are meeting the soldiers by walking in an opposite direction, you will pass a greater number of soldiers in a minute than you would do if you stood still and merely allowed them to pass you. Now, the velocity of light is so enormous that it is not possible for me to give you any experimental illustration of the change of color produced in this way by the motion of a luminous body. If I could make a luminous body move at the rate of 20 miles, not in a minute, but in a second, that would be almost rest — it would be merely like a little snail crawling along a bank when the express train passes by — compared with the velocity of light. Even if I could make a luminous body move with a velocity of 120 miles in a second, the change of color would be so exceedingly minute that it could not be seen by the eye; and it could only be detected in the spectroscope by showing that the light had shifted its position a little. It was the German physicist, Dopler, who, in 1841, first suggested that a change of color might be produced in light in this way; he also suggested that a change of pitch or tone could be produced in sound in an analogous way. I dare say every one in this room is familiar — at least all those who have musical ears, which in the north of England means everybody — I suppose all of you will have noticed the change of pitch which occurs in a railway whistle. If you are standing in a railway station when an express train is approaching, the tone of the whistle will be very different after the train has past you, to what it was when approaching. I have here an apparatus by which I will endeavor to make this fact audible. I can only hope the difference of pitch will be heard by those whose ears have been cultivated by musical education to discriminate minute differences of tone. I have at the top of this long rod an organ reed, which is connected by a tube with an air bag below, and when this air is allowed to pass through the tube, the reed will sound. While the reed is sounding I shall move this rod rapidly towards you and then as suddenly backwards, and I think you will notice that during the fraction of a second that it is approaching you the pitch of the reed will be higher; while during the fraction of a second that the reed is coming from you the tone of the reed will be lower. I hope the difference of tone is perceived. [The experiment was quite successful.] Nevertheless, it is true that, notwithstanding this, the color of a star would not be altered though the star might be approaching or receding from us with great rapidity. Why? For this reason. The light of a star which we can perceive is not all the light that there is; that is to say, the stars send us impulses of force which the eye cannot perceive, because these impulses succeed each other too slowly, like sounds which are too bass for the ear to hear; and the stars also send us other waves of light of which the impulses succeed each other so rapidly that they are like sounds which are too shrill for the ear to catch. And if that part of the impulses from a star's light which the eye can perceive were moved either upwards or downwards in the spectrum, that is, towards the blue or towards the red, by the approach or recession of a star, then these invisible waves would be at the same time degraded or exalted into visibility, and would take the place of the light which had been shifted either upwards or downwards. Hence

no change of color would occur in the light of the star until the whole of these waves had been exalted or degraded into visibility, which would require a velocity far greater than could be conceived to take place in a star. In order, therefore, to apply this method of illustration to the stars, it was necessary that we should be able to pick out some one part of the star's light, and then be able to recognize that particular part of the star's light again in its altered position in the spectrum. Therefore it was not sufficient that we should be able to pick it out by its color, because how should we know it again when it had changed its color? But by means of spectrum analysis it can be done. We see in the spectrum of a star a bright line which we know to be coincident with the line in some terrestrial substance; say the line of hydrogen; then when once we find out that that line belongs to hydrogen, if it altered in the star, we can see exactly how much it has altered by comparing it with the bright line of terrestrial hydrogen. The star which I found most suited to this method of investigation was the bright star Sirius. There will now be thrown upon the screen a representation of the star Sirius. I will explain the diagram. [There was first shown upon the screen a diagram of a part of the heavens, by Mr. Procter, with the proper motion of each star marked with an arrow.] To each star is placed a small arrow, and the arrows represent the direction of the proper motion of these stars relatively to the motion of the earth. You will see that they are all up and down, in different directions. Now, if all these motions merely arose from the proper motion of the sun in space, then all these proper motions of the stars would be in one direction; but you see they are in different directions. This shows the great importance of obtaining information of that part of their motion which is either towards or from the earth. I will now pass to the star Sirius, upon which the experiment was made. This star is remarkable for having in its spectrum three very strong lines, which have been found to be coïncident with hydrogen — one in the blue, one in the green, and one in the red. It is necessary to say how it is that one knows that these lines are coincident with hydrogen. These lines were compared directly with the bright lines of hydrogen; and, in a spectroscope of considerable power, these lines appeared to be exactly coincident with the lines of hydrogen. But when a very powerful spectroscope was obtained, it was found that this green line, which was the only one which was bright enough to allow examination to be made, that this bright line was not absolutely coincident with the line of hydrogen, the probability therefore was that it had been slowly moved by the motion of the star. In the next view we shall have the comparison of this line with the line of hydrogen. Now you see that this bright line in Sirius is not exactly in the position of the one in the solar spectrum and in the spectrum of hydrogen. Then it might be said that this broader line had expanded in one direction rather than in the other, and that this was no proof that the line had actually been displaced by the movement of the stars. Now you will see above the upper spectrum a faint haze of light just in the position of the bright line of rarified hydrogen, that represents the appearance which the same line has when hydrogen is subject to a pressure of air around us. The line being broad in Sirius showed that the hydrogen there is of rather greater density than it is in the sun, or than it

was in this rarified gas. I then made a series of experiments by which I found that as this narrow line is converted into this broad line, by alteration in pressure of the hydrogen, it rose symmetrically — that is, equally on both sides; therefore we had a right to say that the want of coincidence really indicated that the line of the star had been shifted to a small degree by the motion of the star. The next point, therefore, was to determine what velocity in the star would be required to cause this. It was found that about 40 miles in a second would be required. But at that time the earth was moving in its orbit from the star with a velocity of about 11 miles per second, leaving, therefore, 29 miles per second as indicating the velocity of the recession of the star. There would also have to be deducted about four miles per second, as due to the motion of the sun, leaving about 25 miles per second as the rate of the recession of the star from us. It had been found before, by ordinary observation, that the motion of a star at right angles to the line of sight was from 30 to 35 miles per second. The true motion of a star would therefore be compounded of these two parts. At present this method has not been applied to any of the other stars, for it involves extreme difficulty, a very fine state of the atmosphere, and powerful instruments. I hope that after a time we shall be able to apply it to other stars.

I will now just, in conclusion, for a few moments, as I have not time to go into it properly, show the application of this method to the visibility of the red flames about the sun at the time of a solar eclipse. You have now upon the screen a representation of a solar eclipse, one of the grandest phenomena of nature. At such a time we discover that the sun, as viewed by us on ordinary occasions, is not the whole of that body, that there is something more about the sun than we see.

At the time of an eclipse the moon covers the sun, and at the time this picture was taken, the moon appeared a little larger than the sun, which was overlapped and entirely concealed; but there were visible at the bottom and at the top, large red flames, consisting of great columns of luminous hydrogen, extending in one case to a distance of 80,000 miles from the sun. Now why is it that these appearances can be seen only at the time of a solar eclipse? They are not rendered invisible by the glare of the sun itself; for it would be possible to hold a screen between the eye and the sun, and so make a sort of temporary eclipse. They are prevented from being seen in consequence of the imperfect transparency of our atmosphere, for our atmosphere scatters a large quantity of the light that comes upon it. You always notice that the sky is very bright close to the sun. Now the light scattered from our atmosphere is greater than the light of these appendages of the sun. Our atmosphere forms a bright screen, which conceals them; but at the time of a solar eclipse the light is cut off by the moon on the other side of our atmosphere, and no light falls upon our atmosphere, which is not illuminated, and then it is that these objects become visible. Mr. Lockyer first published a suggestion that by spectrum analysis these objects might possibly be examined; and the same idea occurred also, quite independently, about the same time, to Mr. Stone, of Greenwich, and to myself. However, from various causes, the experiments made at that time were not successful. The principle upon which the conjecture is based is this—it seemed probable, especially from the specu-

lations of Mr. Stoney—that these flames consisted of gas. Now, if they consisted of gas, they would give a spectrum of bright lines. But the light coming to us from our atmosphere was reflected solar light, and we know that solar light consists of all colors; therefore, if we applied the spectroscope, the prism would spread out the light from the atmosphere and diminish it perhaps a hundred fold; while if the light of the prominences consisted of bright lines, it would only separate that light into bright lines, and each line would be perhaps only one third or one fourth as bright as the prominences; while the light of our atmosphere, or what is the same thing, that part of the light, of the same color as the lines of the prominences, would be reduced perhaps one hundred fold; and in this way we should diminish the brightness of the interposed air in a much greater degree than we should diminish the brightness of the objects which lie beyond it. This method was applied at the eclipse of 1858 in India, and it was found during the eclipse that these prominences gave bright lines. The next day Mr. Janssen applied his spectroscope to the edge of the sun, and saw the lines of these objects distinctly in the full glare of the sun. About a month later Mr. Lockyer, having a more powerful spectroscope, also succeeded; and others, when they have looked at the sun with a knowledge of the position of these lines, were able at once to see them. Mr. Lockyer has since investigated these lines with very great success, and it is found that at certain times these prominences, these masses of gas about the sun, contain other substances besides hydrogen, the vapors of substances which we know to be present in the sun, such as iron, magnesium, and sodium. It was also found that these gases shoot up at certain times in the form of circular storms, with the gases whirling around at the same time that they are shooting upwards. However, up to this time the form of these objects had not been seen directly, only the bright lines of their spectra, and the forms of them were inferred by causing the slit to traverse over these objects, and then, by noticing the different lengths of the line, as the slit went over the different parts of the prominences, to guess at the forms of the objects. The diagram represents the bright lines of these prominences compared with the lines of hydrogen. Those are the bright lines which are almost always seen in these masses of gas about the sun, but at certain times other lines are also present. I was saying that the form of these objects had not been seen. After several trials I succeeded, by means of a wide slit, in being able to see directly the shape of one of these objects; and you now have upon the screen the representation of the first of these objects ever seen directly, excepting at the time of a solar eclipse. This method of reviewing the forms of these objects has been applied very successfully abroad by Zöllner, in Germany, and by Respighi, in Italy. You have here a representation of these objects as seen at intervals of a few months, by Zöllner, showing how rapidly they change. The first has the appearance of a short tree; in a quarter of an hour it had shot up into a long peak. At the same time that many of these objects changed thus in a few minutes, others seemed to be very persistent for some days. The Italian observer, Respighi, has mapped these objects, and placed them as they appear on successive days under the other, so as to compare the appearances of these flames at different times. Besides these objects

to which I have referred, at the time of a solar eclipse there is also seen about the sun a large mass of light, which has been called the "corona." And this apparently consists of two portions, the light immediately about the sun and those large beams which are sometimes seen to extend outward in different directions. The question has long agitated astronomers as to the nature of these appearances. Is it the result of some luminous atmosphere about the sun — some atmosphere exterior to the atmosphere of hydrogen? Is it some meteoric matter revolving round the sun? or is it caused by anything about the moon or in our own atmosphere? The more observations have been made upon these objects, the more puzzling the phenomena appear, and the less light seems to be thrown upon them. During the eclipse in India in 1868 this light was carefully observed by the polariscope, to show whether the light was original or reflected. By this instrument observers were enabled to show that the light of the corona was not original light, but that it was reflected light, and that it was the sun's light reflected from something. But at the total eclipse of the sun which occurred in America last year, a quite different account was given. There it was stated that this light, for the most part at least, was not reflected, but that it was self-originated light, and that it gave not a continuous spectrum, but one in which bright lines appeared. Then again there is the extraordinary circumstance that these outer portions of the corona have not been seen by different observers in exactly the same position. It is therefore doubtful how far these outer beams are realities, or whether they may not be optical phenomena. The investigation of this coronal is the great object to be attempted at the approaching eclipse. A large number of observers are going out to Spain and Sicily, where it will be visible, for the purpose especially of endeavoring to obtain a knowledge of what the corona is. Our own countrymen, unfortunately, will not be able to take so good a share in this work as we had hoped. Application was made to the government by the scientific bodies as far back as June last for a ship and assistance to go out; but we received from Mr. Childers a flat refusal to give a ship, and in consequence great delay has occurred. However, at last the government have agreed to assist us, and I am happy to say that they have now granted a ship to go to Spain, and a sum of money not exceeding £2,000 to assist observers to go to Sicily, and for providing apparatus; but it will now be scarcely possible to provide the apparatus, or to organize the expedition as might have been done at an earlier time. We can, without grudge or envy, I think, share in the delight of our American friends who have been exceedingly energetic in this matter. It seems that they concluded that we should immediately get the aid from our government that we asked for, and they applied to their government, and at once a vote of £6,000 was made to send a thoroughly equipped expedition all across the Atlantic, in order to observe the eclipse in Spain and Sicily. I recently had the pleasure of meeting several of these American astronomers. No doubt a good many of our countrymen will still go out, and it is not improbable that from some one you may hear of the results of the expedition; and I hope that then we shall get some light as to the true nature of this mysterious corona.

THE SUN.

A LECTURE BY J. NORMAN LOCKYER, ESQ., F.R.S.

Dr. Roscoe, in introducing Mr. Lockyer, said there was no man living who knew more about the physical constitution of the sun than their distinguished lecturer, to whom he felt much indebted for taking the trouble to make a special journey from London to deliver this lecture. Dr. Roscoe also expressed his indebtedness to Mr. Harrison for placing the whole of his apparatus at their disposal, and superintending its use himself.

Mr. Lockyer said:—It is a great satisfaction to me to know that in coming before you to-night to say a few words (for, after all, in an hour or so, one can only say a few words) about the sun, my way has been made smooth for me by that altogether admirable discourse which has recently been delivered to you by Professor Roscoe. He told you how Newton, arranging the facts which he had inherited from those who had gone before him, touching the action of a little piece of glass called a "prism," discovered that white light, including the light which we get from the sun, consists of different colors; and Professor Roscoe also told you how Wollaston, Fraunhofer, and especially Kirchhoff and Bunsen, took up the wondrous tale, until, at last, nearly the whole story which is to be read, by those who are cunning enough to read it, in that glorious cypher-band which is called the solar spectrum, was placed before man's view, and the secret of the sun, to a very large extent, might be said to have been revealed. This, then, is my starting point to-night. I take it for granted, not only that all of you who were privileged to hear it have recollected that important lecture, but also that the size of the sun, its distance from us, and how the planet on which we dwell is but a little atom, so to speak, travelling diligently round that sun, year after year—I say I take it for granted that what we may call the "Sun's place in Nature" and the most important solar discoveries of Kirchhoff and Bunsen are, to a certain extent, familiar to you.

Now, you will have understood, from what has already been placed before you, that the work which was done by Kirchhoff dealt with the sun, to a very large extent, as if it were a star. It is quite true that the sun is a star; but it is the nearest star; and it is on this account that we have been enabled recently to make some advances, probably of some importance to science. You know that the stars are so very far away from us that, even with the largest telescopes which we can command, we can never get anything more out of them than a small point, the brilliancy of that point in the telescope de-

pending upon the size of the telescope; we can never make a star look as large as the sun; nor can we make it look as large as even the smallest of our fellow planets. But with the sun you all know the case is different. Not only is the sun obviously very much larger than a star appears to be because it is so much nearer to us, but it is so large that sometimes wonderful things called "spots," are even visible on the sun to the naked eye. Now, the use of even a small telescope enables us to observe the different parts of the sun's face, and so you see we are in a position to learn very much more about the sun than we can about the stars. I should like, before I go further, therefore, to give you, as it were, a general view of the sun, and explain some of those phenomena which have been long known to those interested in the subject. Now here, on this screen, we have a small portion of the sun represented. It is not the whole of the sun, as you see, but it includes a part very near the sun's edge, or as astronomers prefer to call it, the sun's "limb;" and you see that on the general surface, which is represented by the brighter portion of the diagram, there are here and there darker portions, these are the "spots." There is one very obvious spot there, and another there; and there is another one here, nearer the sun's edge.

Now I hope I shall have time to explain a few hard words I shall have to use as I go on; so that I may as well tell you at once that the brighter portion of the sun which you see here is called the "photosphere;" that is to say, the "light sphere;" because most of the light which we get from the sun comes from that portion. The meaning of the term "sun spot" speaks for itself. Here and there, in addition to the spots, you see some portions which are brighter than the rest of the surface of the sun, or the photosphere, and these are called "faculæ." Now, "faculæ" simply means "torches," *facula* being the Latin for a torch; and the people who first gave names to these things called these brighter portions "faculæ," and these dimmer portions "maculæ;" the one meaning torches, and the other meaning spots. Now I will show you next one of these spots on a larger scale, and then you will see that a sun spot is a very wonderful thing indeed. This spot was one drawn years ago by a distinguished astronomer living in Rome, where the sky is much clearer than it is here, and therefore he was able to observe it better than we generally can, even when we have large telescopes at our disposal. Here you see is the general surface of the sun, the photosphere, and here is the spot, and you see at once that in the spot itself are different regions having different shades. I beg you to bear that in mind, because as I go on I hope I shall be able to explain to you what these shades mean. For a long time men have been endeavoring to get at the secret of these spots; and here is a drawing more than two hundred years old, which will show you that people at that time had got a very definite notion, as they thought, as to what a sun spot was. Here you see are blazing fires—torches—presenting the brighter portions of the sun; you see at once why they called them "torches;" it was because each of these flame-like portions represents a torch, and here, in these other portions of the sun's surface are darker bits, which if you were nearer you would see are intended to represent smoke; the smoke of course dimming the light of the sun which was below it.

The first great fact which was got from the study of

these spots (it is a fact I am anxious to set before you, although it does not come within my lecture, properly speaking) was this—that this great sun is very much like our own earth, in so far as it rotates on an axis in exactly the same way that our earth does. Not only do the spots change their position on the face of the sun, in consequence of the sun's rotation on its axis, but they change very much from day to day and even from hour to hour; so that we have evidence not only that the sun is rotating like our earth, but that the atmosphere of the sun is subjected to most tremendous storms; storms so tremendous, in fact, that the storms on our own earth are not for one moment to be compared with them. The fact that the spots do really move with the sun, and are really indentations, saucer-like hollows (that is the next point I wish to impress upon you) in the photosphere—in that brighter portion which I have brought under your notice—is shown by the appearance which is always presented by a spot when it is near the edge of the sun. You know if you take a dinner plate and look it full in the face it is round; but if you look at it edgeways it is not round. Here are two different views of the same spot; there you look the sun spot straight in the face, and you see into it and can learn all about it; but here, where it has nearly gone round the corner and is disappearing on the sun's edge, you see it in the same way that you would see a plate looked at edgeways.

The limited time at my disposal has made my few words about the general appearance of the sun very hurried ones; but some of you will already have suggested to yourselves that I have not yet finished about the actual appearances touching the sun. You are quite right. Up to the present moment we have been dealing with what we may call the "workaday" sun, the sun as he generally appears—the sun as we know him best. But sometimes, as many of you know, the moon comes between us and the sun, and then we get what we call a "partial" eclipse of the sun; and you also know that if the moon comes right between us and the sun, all the sunlight is cut away from us, and we get what is called a "total" eclipse of the sun. Now I will show you a photograph of the sun taken by the astronomers in America, when it was partially eclipsed in the year 1869, and you will see that the only difference between no eclipse at all and a partial eclipse of the sun is that we do not see so much of the sun as we otherwise should do. Here you see is the general surface of the sun; there is its outside edge, and here is a spot. I do not know whether all of you can see that spot—it is rather a small one—close to the edge of the sun, but you can all see that the edge is just as we usually see it. But when we get the sun totally eclipsed—when all the sun is cut away from us—then we see certain things which we do not see when the sun is not eclipsed and when the sun is only partially eclipsed. The importance of observing these things, and of learning all we can in the precious moments of a total eclipse, is the reason why civilized governments, whenever there is an eclipse of the sun, send out expeditions to those places where the eclipse will be seen as total. For instance, there has recently been an eclipse of the sun visible as a total one in Spain, North Africa, and Sicily, and consequently civilized governments sent out expeditions to observe the sun in those places. I will now show you exactly what I mean. On this diagram you will see parts of Spain, Africa, Italy, and Greece, and the curved lines

show the regions in which the eclipse was to be seen as a total one in other places. The moon only partly covered the sun, as it did at Manchester, as you will remember, consequently we had parties in Spain, Africa, and Italy, observing the eclipse. Now let me give you some idea of what those parties saw. You see on this picture indications here and there (round the black moon, which hides the sun) of little bits of light; and at first you may wonder what they mean. Allow me to tell you. The workaday sun, when this picture was taken, was entirely covered by the moon, but strange to say, in those regions just outside the sun, where generally we see nothing whatever, are here and there, as you see, bright points of light; and here and there a sort of hazy light, which reveal to us something new. Here, in the next picture, in the same eclipse of 1869, the moon has moved a little over the sun, and those bright things that we referred to before have now changed, simply because the moon has changed her place, and because the regions near the sun which were covered before are now uncovered, so that these strange things can be revealed to us. So that you see even from these diagrams which I have already shown to you—diagrams, let me tell you, printed and warranted by the sun, for the hand of man has never touched them—these pictures, I say, show you that in those regions round the sun where the naked eye, with the uneclipsed sun, sees nothing whatever, there are all sorts of strange and wonderful things. Next I must tell you that these wonderful things have been seen for a very long time. And I may tell you that these wonders to which I have referred have only been half shown to you. You saw that close to the moon, where the dark moon was covering up the sun, you had here and there points of light. The reason that you had only those points of light revealed to you was not because they are not the only things which are seen round the sun during an eclipse, but because they are the brightest things,and so the photographic plate registered them sooner than it would register other fainter things outside the sun. Mr. Harrison will now show you some pictures taken in different eclipses, in which you will see that outside these brighter portions, you get other and fainter appearances further away from the sun. And I may tell you that the understanding of these things is at present almost beyond the best of us, so much do people who try to find out all about them vary, not only in the accounts they give of the things they see, but also in their explanations of what they mean. Now here is a very remarkable series of drawings, made by a very distinguished astronomer during the eclipse which happened a few years ago. Here you see, close to the body of the moon, we get a perfectly distinct ring; outside that ring we get another ring somewhat less distinct; and then, in addition to those two rings of different brightnesses, we get five rays, as seen in one picture, in one particular portion of the sun's limb or edge. Now the middle picture represents the same eclipse after the moon had traveled a little more on to the sun; and there you see that those five rays have almost disappeared, and you get some new ones in different places. Here is another picture of the same eclipse taken by the same observer when the moon had traveled still further over the sun. There you see the rays which we first observed have almost disappeared, and a new lot of rays altogether is developed on the other side of the sun. Astronomers for a long time past have agreed to call those brighter

portions which I showed you in the first diagram the solar "prominences," or "red flames;" and they form part of an envelope round the sun called the chromosphere—that is, colorsphere—as it is in this region that the various colors are seen in eclipses, the outer rings and rays, and other strange looking things, which have been observed, have been called collectively the "corona;" so that over the workaday sun, the sun as we see it every day, we have bright spots and dark spots to account for; and in an eclipse of the sun we have those brighter portions close to the sun, called the "prominences," and the "chromosphere," to account for and also the irregular ring of light and those rays extending further outside than the chromosphere itself does.

Now what I have to do to-night is to tell you just as much as I can of the manner in which spectroscopists have attempted to attack these questions, and to give you as fairly and as honestly as I can what I believe to be the conclusions they have arrived at. Now you will see in a moment that to do anything at all with the sun, separating a spot, say, from the faculæ, or separating the outside part of the sun from the middle of the sun, or the region outside the sun from the body of the sun itself, we really must no longer be satisfied with the method adopted by Kirchhoff and Bunsen, or Wollaston, and the rest of them, of dealing merely with a solar beam, but we must, literally, take the sun to bits; we must deal with here a little and there a little; we must use this magnificent instrument, the spectroscope, which, in the hands of Kirchhoff, as Professor Roscoe told you so truly and so well, has worked wonders, which has given us the largest crop of facts that we have got during this century; we must, I say, take this spectroscope, and, instead of dealing with all the light from a star, or all the light from the sun, we must take the sun to bits, and work at it little by little. The smaller the portion of the sun we deal with, the better will be the result that we shall get. Now you will see how this is to be done. Nothing is so simple. When Kirchhoff and Bunsen wished to observe the sun, they immersed their spectroscope in a beam of sunlight, in the same way as Newton did, and that gave them the light of the sun, so to speak, upon the average, as we get it when viewing the sun or a bright cloud in open daylight, making no difference between the light which comes from the outside of the sun, and the light which comes from a spot, or from a bright portion. But this method will not suffice if we wish to examine a part of the sun by means of the spectroscope. In this case we must first get a telescope to form an image of the sun, and then we must so arrange matters that the light which comes from that particular part of the sun we wish to examine shall alone enter the instrument.

We now come to the first great facts revealed to us by both these methods. The use of facts in astronomy, as in anything else, is to test our notions of things, and to help us on in the path of knowledge. Now, it so happened that our knowledge of the sun, obtained by the telescope, was tremendously upset by the discovery of Kirchhoff's, to which Professor Roscoe alluded. Up to the time that Kirchhoff made that wonderful experiment by means of a little sodium flame, which showed us that the sun was an incandescent, that is, a terribly hot body, surrounded by a cooler atmosphere—up to that moment, I say, the opinion of a very large number of astronomers was—as Sir William Herschel had an-

nounced in the last century—that the sun itself might be a cool, habitable globe, in which people like ourselves might live and move and have their being; that there might be beautiful fields, high mountains, cloudy skies, and the like, exactly as we have here; but Kirchhoff, with his spectroscope, said that it was nothing of the kind, that there must be a state of intense heat in the sun, and that, therefore, the sun could not be habitable. Sir William Herschel accounted for the spots, those dark regions of the sun which I have spoken to you about, by supposing that the brighter part of the sun was an atmosphere of cloud which here and there was broken open, allowing the cool, dark body of the sun itself to be seen. I need not go into details showing how he explained that that envelope which gives us all our light and heat should have been rendered rather a pleasant thing than otherwise to the people who were living below it. That is not necessary on the present occasion. But I wish to show you one important consideration connected with Kirchhoff's theory, who, by the way, held that sun spots were clouds floating in an atmosphere above the photosphere. He, as you know, wanted something solid or liquid, giving a continuous spectrum—I quote Professor Roscoe's words—and outside that he wanted an atmosphere, absorbing here a little and there a little light in the spectrum, so that the Fraunhofer lines—those dark lines which you see in the solar spectrum—should be accounted for. Now I think I am not going beyond the mark when I say that Kirchhoff himself, and all those who followed him, came to the conclusion that the real atmosphere of the sun was the corona which I have just shown you on the screen, as revealed to us during an eclipse. You know that it must have been a comparatively cool atmosphere because it was essential that the atmosphere should be cooler than the underlying substance, or else you would not have the Fraunhofer lines at all. All that has been thoroughly explained, and I need not go into it.

But let me now show you how admirably the new method of taking the sun to bits enables us to settle the question once and for all by a single observation. As I told you, Sir William Herschel came to the conclusion that a sun spot was really a hole in the sun's clouds, which enabled us to see the dark body of the sun. Now that was entirely exploded by Kirchhoff's discovery. But after Kirchhoff's discovery there were two reasons given to account for a sun spot which you will see do not at all agree with each other, or with the explanation given by Kirchhoff himself. A distinguished Frenchman, Monsieur Faye, said that a sun spot was seen by us as a sun spot because there we lost the light from the outer envelope of the sun, and got but a feeble radiation from the intensely glowing interior gases of the sun; whereas English observers, and among them Dr. Stewart, a townsman of yours, gave very good reasons why this could not be so, and held that a sun spot was black because the light and heat, which the sun must be giving out there, as everywhere else, had been gobbled up, so to speak, before it got to us, so that it came with a balance on the wrong side of the account. Now let me show you on the screen the sort of thing which we have as the representative of the new language of the spectroscope as applied to taking the sun to bits. In this case we are looking at the orange portion of the spectrum of a sun spot. I am afraid that this will require some little explanation, but if you will bear with me one moment I

think I shall be able to make it clear to you. You all know what that wonderful double line D means; it is the absorption line of sodium seen in the solar spectrum. Now here is the double line D, as seen in a spot spectrum; and I beg you to observe that along the spectrum we have a shade, showing that the spectrum there is enfeebled all along its length; and if the screen were large enough for me to have a diagram giving you the spectrum as seen from the red to the extreme violet, you would find that you would get that general enfeeblement all along. In addition to the general enfeeblement of the light, you get a wonderful thickening out of this classical double line D. There, you see, it widens out gradually; there it widens out suddenly.

Now what does all this mean? Allow me to recapitulate what has been told you before, that solid, liquid, and densely gaseous or vaporous bodies give us a *continuous* spectrum. Let me show you what I mean by a continuous spectrum. Mr. Harrison will now be good enough to throw on the screen a spectrum, which I am sure most of you will recognize as the beautiful spectrum which you have seen before in the rainbow. I may tell you that the great point I wish to bring before your notice, in the first instance, is that the spectrum is complete from red to the extreme limit of the violet. As you see it on the screen, nothing could be more beautiful I am sure you will all acknowledge. Here, then, we have what is called the "continuous" spectrum; that is to say, there is no leaving off of the light; there are no gaps. Now that is the sort of light we get from a solid, or a liquid, or a densely gaseous or vapory substance, whatever it is; whether it is a match; whether it is the interior of the sun; whether it is coal, iron, steel, mercury—anything—we get that same sort of spectrum; and as long as we have that sort of spectrum, we do not know what the particular substance is that gives it, we only know that it is a solid, or a liquid, or a densely gaseous or vaporous substance. But if we deal with a gas or a vapor we get something perfectly different. You see at once that the moment the slit is narrowed, and we begin to deal with the gases and vapors which are in that lamp, that we alter the continuous spectrum entirely, and get a discontinuous or broken one.

Now I want you to be kind enough to allow me to define four important things. The giving out of light by such an arrangement as Mr. Harrison has in that lamp, is called the *radiation* of light. I want you to allow me to call that *general* giving out of light "general radiation;" and I want you to let me call that giving out of light such as you see now *discontinuous*, and I thank Mr. Harrison for enabling us to see these things so well. I say I will call that "selective radiation." So that the giving out of light may be of two kinds, general in the case of solids, liquids, or dense gases or vapors; and selective if we are dealing with gases or vapors which are not dense. So much for the giving out of light, or radiation—all this by way of reminder. Now I want to deal not only with the giving out of light, but by the stopping of light; and I will tell you exactly what Mr. Harrison has done. He has been good enough to smoke a piece of glass, and he will stop the light as well as he can by means of that piece of smoked glass. Now I think all of you can see that wherever that glass has been smoked, we get the light passing through it eaten out all along the spectrum. In fact, the stopping of the light here is as general as the

giving out of light was in the first case, so that we match general radiation by general absorption. Now if Mr. Harrison would be good enough, instead of using smoked glass, to give us such a substance as red glass, or any similar substance which we know has a peculiar action upon light, you will see something very different at once. There is red glass. You see that now we have not to deal with what we had to deal with before in the case of smoked glass, we have not to deal with something which stops out all the light equally, but we have to deal with something which stops out all the light except the red, exactly as in radiation we had to deal with things which gave out a line here and there, and did not give us light all over the spectrum. This not only shows why red glass is red glass, because it allows the red kind of light to pass, but it shows that we have general and selective radiation balanced by general and selective absorption. Here again you see absorption due, not to red glass, as before, but to a different substance altogether—to chlorophyll. And now it is the green part of the spectrum which is alone left, and not the red. So that when we send light through bodies we have a kind of action which is exactly similar to the kind of action which we get when we have light coming to us from brilliantly incandescent bodies. Now you will see, in the first place, in this picture of the spectrum of a spot, that we have no indication, first of all, of bright lines. This is a faithful copy of nature, and you see there are no bright lines at all. Here, then, is a single observation, disposing for ever of the French idea that a spot was due to the radiation from an intensely heated interior solar gas. I do not know whether I have made myself quite clear. But now let us see how it bears on Dr. Stewart's idea. These horizontal bands which you see here are, as you will understand in a moment, indications of general absorption. The general absorption is, no doubt, due to dense gases or dense vapors, which, as I have just told you, if they were intensely radiating, would give us a continuous spectrum. Get a dense gas, make it incandescent, and its radiation is continuous. Get a dense gas as you have it on the screen, and instead of radiating make it absorb the light, put it between you and a substance which is radiating, and its absorption will be continuous. So that so far as these horizontal bands go, they show you we have to deal with absorption due to dense gases or vapors. There is some dense gas or vapor which is cutting off from us the sun's light where a spot is, and that is one reason that the spot is dark. That is the plain English of the thing. But that is not all. I will now draw your attention to that thickening of the sodium lines. I shall show you, by and by, that that thickening of the sodium lines not only enables us to say that the sun spot is dark because there is some dense vapors there, but it enables us further to say that the sun spot is dark because among those vapors is sodium vapor. I might parallel that in the case of other lines in the solar spectrum, but I have taken the case of sodium as sufficient for my purpose for the present. Now there is another very curious fact which I beg your attention to in connection with what I have said; and I hope have been clear, because it is important that you should get this thoroughly into your minds. If we observe the spectrum of the faculæ, instead of observing the spectrum of the spots—that is to say, if we observe the spectrum of the brightest bit of sun that we can find, instead of

the blackest bit of sun we can find, we shall discover that that bit of sun is brighter, for two reasons; first, there is no absorption at all of the general kind, no absorption stretching along the spectrum in that horizontal way which you see there; and secondly, all the lines which are thickened in a spot are thinner in a facula.

And now I come to a part of my subject which probably may startle you, if you are not already familiar with it. I have shown you that there are a good many things round the sun which we do not see except the sun is eclipsed; and you will take it for granted, I dare say, that the new method of taking the sun to bits, as I have called it for simplicity's sake, has nothing whatever to do with those things which we see outside the sun during an eclipse. Nothing of the kind. The spectroscope has a good deal to say to those things, too; and you will say how? Well, I will tell you. What is the reason that we don't see these things except during an eclipse? Because the region of our atmosphere near the sun's place is lighted up by the sun so brightly that we cannot see them, any more than we can see the stars, but we know that the stars are there, and we know that these things round the sun are there, for night comes and we see the stars, and now and then the kind moon comes and cuts off the sunlight, and then we can see the things round the sun. But the spectroscope very fortunately does come to our assistance, if, for one moment, we are willing to agree that those things round the sun are not liquid, solid, or densely gaseous, but are built up of gases or vapors, which are so little dense that they can give us bright lines. And for this reason. If we get the spectrum of a solid, that continuous spectrum which you have already seen most beautifully represented to you upon the screen, we can, by adding prism after prism, prism after prism, make that spectrum so dim that you can hardly see it at all. We might say that, in the case of the continuous spectrum, nature is prodigal of her light, she spreads it all over the place, and by spreading, weakens it. But now, mark what happens if, instead of a continuous spectrum, we have what I have ventured to call the selective spectrum, the spectrum, for instance, of which all the light consists of one, two, or three lines. Then, in that case, by adding on prisms, we do not spread that light—it is still one, two, or three lines, however many prisms we use, and it is not spread all over the place in the same way that the continuous spectrum is, which you saw was complete along the spectrum from red to the extreme limits of the violet. So that you see in an eclipse we have the moon cutting off the light which hides these solar appendages from us except during an eclipse, and we have the spectroscope, armed with a large number of prisms, doing exactly the same thing; it kills the atmospheric light in one case, and the moon does not allow the atmosphere to be lit up in the other. So that in either case, whether the sun is eclipsed, or whether we use a powerful spectroscope, we should see these things round the sun if we assume that they are built up of gases or vapors. I will show you the instrument by which it has been attempted to artificially eclipse the sun in this way, and I think you will see in a moment how the thing works. Here you see is such a system of prisms as I have just mentioned to you. Here is the slit of the spectroscope, and through this aperture in the eye end of the telescope the image of the sun is thrown into the slit. The light is taken up

by that instrument which you see there, and it is brought round and turned, and twisted through all these seven prisms, till it ties a true lover's knot, and comes back again crossing its own path, and is driven down to the eye of the observer. So that instead of having one or two prisms, as Mr. Harrison has in his arrangement, we have no less than seven prisms to disperse the atmospheric light. And as a matter of fact, I can tell you that the action of the prisms is so satisfactory that no atmospheric light whatever gets through that instrument to the eye when the sky is perfectly clear. Well, then, you will ask, How about the things round the sun? Well, the things round the sun are easily visible in that instrument. Let me show you how they appear to us. I must, however, tell you that this observation of the prominences without an eclipse was first made by Dr. Janssen the day after the eclipse which was observed in India, in the year 1868. Let me show you now the sort of thing that we get by this new method, and by using this large dispersion. You must imagine that here is the slit of the spectroscope, so arranged that half the sun's image falls on the slit, and half of the slit falls off the image. (See Fig. III.) So that here we have the spectrum of the extreme edge of the sun; and here we have whatever we can get outside the sun. Now what have we got? There is one of the lines which we always see round the sun by this new method of taking the sun to bits; and I need not tell you that it is one of the lines due to hydrogen; because in what has been told you about the solar spectrum you have heard that the line C (and this is nothing but the line C in the solar spectrum—in the red end of the spectrum) is due to the absorption of the hydrogen. Nothing you see could be more beautiful than the absolute proof afforded by this accuracy of everything which Kirchhoff and others had predicted with regard to the reasons for the lines. It was impossible in the then state of science for them to put the sun and the hydrogen absolutely in the same instrument in the way it is done here; but here you see the hydrogen of the sun absolutely where there is no hot sun behind it, or, I should say, a hotter sun behind it, giving you a dark line.

If I had time I could show you the other hydrogen lines which are seen by this new method. I think, however, you will now at once appreciate with what justice those who first named those strange things round the sun "red prominences" and "red flames," came to their conclusions with regard to color; although that is not so easy as it seems, seeing that prominences have been seen of almost every color of the rainbow; and that is a fact which I hope I shall be able to explain to you, if time does not run away too quickly. I want now to show you the red tinge of the gas in this tube. I do not know whether you can see it plainly, but if it were possible to show this gas under proper conditions, you would see not only that the gas in the tube is itself red, but that the spectrum which we get from the hydrogen in this tube is exactly the same as the spectrum which we get from the hydrogen in the sun. I do not know that it would be possible to have a more convincing proof of the truth of what Kirchhoff has told us with regard to the sun on this point. Assuming, then, that we have hydrogen generally round the sun, and that it is always present, let me tell you what next happens. Into this hydrogen are ejected in the most beautiful order, whenever there is a storm, underlying vapors, the

bright lines of which vapors we generally see thickened in the spots. I hope you follow that. We take for granted, on telescopic evidence, that the spot is a cavity. We assume, then, that the spot is a place filled with these denser vapors which I showed you on the screen were indicated, in the first instance, by that general absorption, and then again by that selective absorption in the case of sodium vapor; and I told you that it was possible to multiply these cases in the matter of other things besides sodium; and then you see going up outside the sun, when there is any great state of disturbance, exactly these substances the lines of which are thickened in the spot spectrum; only when these substances come up, then these lines are thin. Now, what does all this mean—this thickening out of the line in some cases, and the thinning out of the line in others. I dare say it may seem to some of you a ridiculous distinction to draw. Surely, having got the Fraunhofer lines, and having settled to a very large extent what they all mean, it is rather hard upon them to chide them when they are thick and chide them when they are thin. If you will bear with me for one moment I shall be able to show that we were completely justified in not resting content with these thickenings and these thinnings without trying, if possible, to understand something about them. And I may tell you that I think if anybody had time, and would, for the next ten or twenty years, employ that time in observing the spectra, and determining the different thickening and thinning of these lines, he would do as much for science as any man could do in that period. You know what an immense thing was done when it was determined that by showing a line here and a line there in the spectrum you could determine the existence of a much smaller portion of the substance that was indicated by that line than you could by any other method. Now, in addition to the fact of these constant lines being given out by the same substance, it has long been known to those who have studied the question more deeply that the same substance is competent to give us different kinds of spectra; that is to say, that although the spectra in some cases have a general likeness here and there, you do get a very marked distinction between the spectrum which you get of the same thing as seen under one condition and as seen under another. You may ask me to tell you what that condition is. Well, I must tell you that up to a little time ago, if even not at the present moment, doctors differ. These gases are observed in tubes something like this which you see on the table. What we do is to get the electric spark, as we have here; we then make it pass through a gas enclosed in tubes, as you see here, and then we observe the spectra entitled light. If we get a change in the spectrum of the gas or vapor, it is difficult first of all to find out to what that change is due, whether it is due to increased temperature—as we have power to vary the temperature—or whether it is due to difference of pressure. Some people think one thing; some people think another; but two workers in England have lately come to the conclusion that temperature *per se* has very little indeed to do with these changes of spectra, except to render the spectra, when they exist, more visible, and enable us to observe them better; but that pressure, which is tied up with the density of the gas or vapor, has really very much indeed to do with it. Now some of you may have said to yourselves, I wonder whether this pressure has anything to

do with the thickening and thinning of these lines? Well, it has everything to do with it. Fortunately in the spectrum of hydrogen, which I have told you exists in these prominences; in the spectrum of sodium which you all know exists in the sun; and in the spectrum of magnesium, we have lines which really seem to have been placed in those spectra by nature, that we might study these rings round the sun to better advantage than we should have been able to do without those lines. There is a line in each of these spectra which thickens out in a most remarkable and beautiful way; and we have shown, I think, beyond all doubt, that the widening out of these lines is really due to pressure. Now I do not know whether I shall be able to show you this on the screen. I will try; but you must bear with us if we do not succeed; it is a very difficult thing to do; but if I succeed I think you will say it is worth while to make the trial. Now there is one way, a very delicate way, in which it is possible you may see it; but more wise than some people, we have our reserves, and if this first experiment does not succeed we will bring up our reserves, which I think will help us. Let me tell you exactly what Mr. Harrison is good enough to attempt to do for us. We have some metallic sodium enclosed in that lamp, and we are going, first of all, if possible, to give its spectrum by means of a strong current due to forty of these electric elements which are in this part of the room. Now with a given amount of temperature you will get a certain thickness of line. What I want you to see is, that with a varying temperature you will get a varying thickness. I think you see now that you get a much thicker double line than before. [Dr. Roscoe asked for the experiment to be repeated.] We will repeat that experiment once more, as it has succeeded. You see that the line thickens. Now you may think that this is a proof that I was wrong; that it is not pressure, that it is not destiny at all, but that it is temperature. We have an arrangement here which I think will put that beyond question. Let me explain what that arrangement is. We have some metallic sodium in this case—not the source of radiation; we do not use the sodium in the lamp, and examine the radiation from its vapor; but we deal now with the absorption of the vapor. Now, as according to the change of pressure we get a thickening of the bright sodium line; we ought equally to get a thickening of the sodium line, when instead of sending us its light radiating to us, it really is absorbing that light: because, as you have heard in the previous lecture, according to the theory of exchanges, the absorption and radiation are always equal. What we shall do in this case will be to heat the metallic sodium very slightly in that tube, and as we heat it you will see that the vapor will be perpetually given off by the metallic sodium, so that near the lump of sodium, at the bottom, the cloud, so to speak, of sodium vapor will be denser than higher up away from the metallic sodium. I must tell you that as we have the lens there, the line will appear to be upside down on the screen. What I expect we shall get will be a dark line, somewhere near where you see that yellow line at present; and I hope you will see that the thickness of the line will be greater at bottom than it is at the top; and you have the appearance of things reversed by the lens. We have now the radiation of sodium as you saw indicated by that yellow line. We shall hope to exchange the radiation from the sodium, which still exists in the

lamp, for the absorption of the sodium vapor which Professor Roscoe is so good as to heat in that tube; and if we succeed, you will see a dark line in the place: thick where the sodium cloud is thick, thin where it is thin, although the temperature is the same. Hence, then, it is not temperature which causes the variation. But whether the experiment succeeds or not, observations made upon the sun itself, put the question, I think, beyond all doubt. You will acknowledge that if it were a question of temperature merely, the hot prominences that gave bright lines on the sun should give us thicker lines than the cool absorbing clouds. Therefore, if we get sodium prominences on the sun, we ought to have the sodium lines thicker than we have them in a spot. Now here is a case in which over the very thick lines of sodium, as seen in a spot, (I think you will recognize these horizontal lines again, and this thickening of the sodium line), we actually have an extremely bright and very thin sodium line, showing, according to our idea, that at a high region in the sun's atmosphere you had a cloud of sodium vapor hotter than anything behind it, giving you an indication of the prominence over the region where below it the cooler sodium vapor is indicated by extremely thick absorption lines. So that we have this new method settling for us what a spot is, and what a facula is. We have this new method settling for us what are those strange red flames seen round the sun during an eclipse, and we have it telling us something about the pressure at work in the chromosphere. I might go on and tell you more about what the spectroscope enables us to determine with regard to these outer envelopes of the sun which are only seen during eclipses. I refer to the corona, which your townsman, Mr. Brothers, has been so extremely fortunate in photographing in Sicily during the last eclipse. But I reserve what I have to say about that for the extreme end of my lecture. I hope you are not tired. I have not quite finished. I should like to tell you that by this new method the forms of the prominences are seen as well as those cypher bands, those hieroglyphics by which we can determine their nature; so that by means of a prism, or a combination of prisms, we may first turn our instrument on to the prominences, or on to a part of the sun even outside the prominences, and first say what they are made of, and then, after that, by a certain arrangement of oscillating or revolving slits, &c., or even by means of opening the slit, without the use of any absorbing medium whatever, it is perfectly easy, after we have found out what the sun is made of, to look at it, and see exactly what it is like. I am sorry to say that in coming from London part of our apparatus got broken, which would have shown this. Mr. Heywood will now be good enough to throw upon the screen two pictures of some prominences seen by this new method of merely opening the slit. It shows you the enormous changes which go on in these prominences. Of course, as long as we are dealing with merely their chemical nature, we cannot examine much into their form; and therefore, it is somewhat difficult, although it is not impossible, to determine the amount of change. But, when we have settled the chemical nature of any particular prominence on the sun, we can not only determine its form, but we can determine its rate of change. Mr. Harrison will show you the changes that take place in the prominences nearly 27,000 miles high, in the space of 10 minutes, and I think you will acknowledge that, in the changes

indicated by that picture on the screen, we get an idea of force and a conception of vastness which it is impossible to become acquainted with by anything that we can study on this earth. And this brings me to another part of my story altogether, one that would have required considerable time to enlarge upon, had I not been able to refer you to Mr. Huggins's lecture, as I was able to refer to Prof. Roscoe's lecture for the basis of solar chemistry. Mr. Huggins showed you that by means of alterations in wave length, he was enabled to say that a certain star was receding from the earth at a certain rate; and, if I recollect, he instanced the case of a swimmer who is swimming with the waves, as against a swimmer who is swimming against the waves. When a man is swimming against the waves he meets and has to surmount very many more waves than he would have to do if he was swimming with the waves. You may imagine the earth to be a swimmer, and you may imagine the different heavenly bodies to be the source of different waves which come to the earth, the swimmer, and which the earth has to make the most of. If those waves (in our case they are waves of light) are receding, if the body which is paying out those waves, as a telegraph ship pays out a cable, is going away from us, then you will see at once that it will be equivalent to stretching those waves, that those waves will be longer; but if we meet those waves and have to breast them, you at once see that they must be shortened. That, if I recollect, was the line of Mr. Huggins's argument, and the result was that he explained to you with considerable clearness that in the case of a planet, or of any celestial body which gives light, if it is approaching the earth, on which we dwell, with any considerable velocity, there will be an alteration in the length of the light waves, and that alteration in those waves will be determined and determinable only if in the spectroscope the spectrum of that body gives us lines. Now you know that in the case of the solar spectrum it is full of dark lines from one end to the other; and in the same way sometimes round the sun the spectrum of bright lines which we see, instead of the spectrum of hydrogen simply, is more or less complete from one end of the gamut to the other.

But you will say, it is all very well for Mr. Huggins to measure the velocity of a star with reference to the earth's motion by saying that a particular alteration of wave length has taken place in any particular part of the spectrum; but how are you going to work that in connection with the sun? Well, allow me to show you. You see we are in presence of a new thing altogether, and this new thing would be explained if you accept the fact that on the sun there are these different gases and vapors that I have spoken to you about, which in the case of the prominences change tremendously in the space of ten minutes, and in the case of spots change from hour to hour; I say you will understand it if you recollect that tremendous changes are taking place on the sun, changes so enormous in fact that they are comparable to the velocity of light, and that we get just as clearly an alteration of wave length due to these changes on the sun as we do from the actual translation of a star from one region of space to another. Now let me explain to you this diagram. (See Fig. V.) This line which you see is the dark line C in some cases, and in other cases, as here, the dark line F in the solar spectrum; it is, therefore, an old friend of yours; you

are quite familiar with it. But you will see at once that the moment we get off the sun itself, we get something perfectly new; the line instead of being an upright fellow, as it is there, is twisted and turned in all sorts of ways. Now the explanation which has been given of these very strange contortions is that, in this case, the line indicating hydrogen is thrown out of its proper place in the spectrum, and has got into the region of longer waves; that the wave, as it were, is stretched, and, therefore, that it appears in a part of the spectrum, where the longer waves generally live; and here where you see it twisted, not to the left, as in that case, but to the right, it has traveled towards the region of shorter waves because its wave has been shortened. Now what do these two assertions mean? They mean that in that case, which I have indicated, that part of the solar prominence is lengthening out its waves; in other words, that it is going away from us; and that in this part of the prominence, in consequence probably of a sort of spiral motion, it is rapidly coming to us, as rapidly as that is retreating from us; and by carefully measuring the distance to which these various changes and contortions go (you see that they vary in every one of these diagrams) we can determine not only the fact that a portion of the prominence is coming to us or going away from us, but we can actually determine the velocity with which it is going away from us or coming towards us, because the Fraunhofer lines can be really used as so many milestones. In this way we have been able to determine the existence of tremendous cyclones on the sun, or wind-storms you may call them if you like, exceeding anything that we can imagine here. We can watch the wind traveling along the sun at the rate of

120 miles a second; we can watch the different portions of the solar envelope torn up and carried high into the solar air at the rate of 40 miles a second—40 miles a second, not 40 miles an hour—and in this way we have been enabled to show not only that there are tremendous storms and wind currents there, but that they are the same sort of currents which you get in a tea-kettle, going far down into the sun—much further down into the sun than we know anything about—and right to the outer portions where in our spectroscopes we can study all about them, and measure with considerable accuracy their velocity and their change by this new method of taking the sun to bits. Here are five patches of light which at first look extremely strange, but I am certain that a large portion of my audience know exactly what these five points of light mean; but, all the same, a little explanation may be of value. This is the F line of the sun. Here we have not only indications of general absorption—which means that we are dealing with dense vapors—but we have a wonderful shading off of the dark absorption line towards the red end of the spectrum; in other words, the hydrogen represented here by the F line was traveling rapidly towards the region of long waves, and therefore away from us—in fact, it was going down, down, down into the spot; while here we see the hydrogen, intensely bright and hot, coming up, and you see that that lies to the right of the F line, towards the region of the violet—the region of shorter waves—and therefore we know that in this spot we have hydrogen coming up at the rate of something like 30 miles a second, quite hot, incandescent to the last degree; and a little way off there was a current of a cooler hydrogen going down, so as to

keep up the balance in that region of the sun. Now here you have a small spot in which you get an up-rush of heated hydrogen as is indicated by that patch of white, and by it lying, moreover, to the right hand of the spectrum. But here, instead of going down, as it did there, what does it do? It heats the neighboring hydrogen, renders the hydrogen in that region not hotter than the sun underneath, but just as hot; it parts with all its spare heat; and you see that the Fraunhofer line, which we thought such a constant thing, has disappeared altogether; and the reason you get no indication of hydrogen there, either as absorbing or radiating, is that the hydrogen is of exactly the same temperature as the things below it, and that, therefore, it both radiates and absorbs; and, therefore, so far as we were concerned, if we knew nothing else, it would be just as non-existent as it is in those stars where the spectrum of hydrogen is not visible, although we know pretty surely that hydrogen must be there.

So much, then, for the outcome of this new method of taking the sun to bits. We have observed the spots; we have observed the region outside the sun; we can not only determine what it is made of, but we can determine what it is like; we can observe its changes, and we can measure the velocity with which the different currents are moving there almost as accurately as we can observe the currents on the earth.

Now I had a great deal more to say, but I am sorry to say that my time is altogether gone; and if you will allow me, I will conclude my discourse by showing you two photographs taken by Mr. Brothers, your townsman, at the recent solar eclipse in Sicily. I am particularly anxious to show you these pictures which have been taken by Mr. Brothers, because they are certainly the most important contribution which we have had for some time with reference to our knowledge of the outer part of the solar envelope, as a region is photographed in them which has not been photographed before. Recollect that at present our knowledge with regard to the sun may be stated to be as follows :—We know a little about the spots; we know a little about the outer rim, that outer bright portion which is called the photosphere, or light-sphere, which I very early introduced to your notice. Underneath that I think we know absolutely nothing whatever; and the more a man talks to you about what is inside the sun, if you will take my advice, the less you will believe in him. Also with regard to the outer portions of the sun, what lies outside, what is the exact meaning of those strange rings which I showed you, I beg you even in that case not to place too much reliance upon very certain statements. I do not think the thing is certain either one way or the other; but the man of science, the man who is anxious for truth can always afford to wait; and I think we can afford to wait in this case; and I hope that you won't go away from this hall to-night imagining that either you or anybody else knows all about the sun. We don't; we only know very little about it, and that little is confined to a very limited region. We don't know exactly what is outside the sun; we don't know what is inside; but if we fix upon the outside of the sun, as we see it generally, and work gradually, (it may be a work of years, of decades, of centuries, perhaps), first looking outside, then a little lower in, and so on, in the long run we shall obtain a sure and certain knowledge. But these photographs of Mr. Brothers's will certainly have to be taken into consideration by those who are certain

about these matters, either one one way or the other. I may tell you that this outer portion of the sun, which you see here, is undoubtedly a portion of the gases or vapors which lie outside the photosphere, and outside the prominences, which are too faint to be picked up by this new method of taking the sun to bits. Here the light which we lose by our great dispersion is so great that it is greater than the special light which is emitted by this portion of the sun; and, therefore, we can only see it during eclipses. But there is no doubt whatever about a portion of what you see there absolutely belonging to the sun, and I do not suppose that anybody who has ever studied the sun at all, or has even read anything about the sun, and about what has been done with respect to solar matters for the last 50 years, can doubt the thing for a moment. But here Mr. Brothers, you see, in these very exquisite photographs, makes the sun altogether bigger, than what we had before, now the question is—a question which I shall not attempt to decide either one way or the other—does all that belong to the sun, or does it not? About the inner portion there can be no doubt whatever. About the outer portion, however, there is still some doubt. But I think we may fairly be content, after all, not to attempt to settle this thing in too great a hurry. We have waited, now, I don't know how many thousand years, before we knew so much about the corona as we learned on a certain day the month before last; and it is not well for us to hope to settle the enormous field of research in a few seconds. But whether we have longer to wait or not, I think you will all agree with me that anything which increases our knowledge of the sun—which increases our knowledge of that luminary which gives us light, which gives us heat, which gives us, we may say, our life; which is the center of all our force; which is the origin of all our work, either by the bottled-up energy of the sun, as represented by coal, or by the bottled-up energy in our veins, is a thing entirely to be desired, and I think you must acknowledge that, although astronomers have been twitted for going in, as it has been said, too much for that hydrogen in the sun business, still I think that it can do nothing worse than ennoble us, and make us lift our minds from our workaday matters to higher things, when we attempt to solve those riddles which the united work of all the men who have preceded us has been powerless to effect.

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THE EARTH A GREAT MAGNET:

A LECTURE

DELIVERED BEFORE THE

YALE SCIENTIFIC CLUB,

February 14, 1872.

BY

ALFRED MARSHALL MAYER, PH.D.,

PROFESSOR OF PHYSICS IN THE STEVENS INSTITUTE OF TECHNOLOGY.

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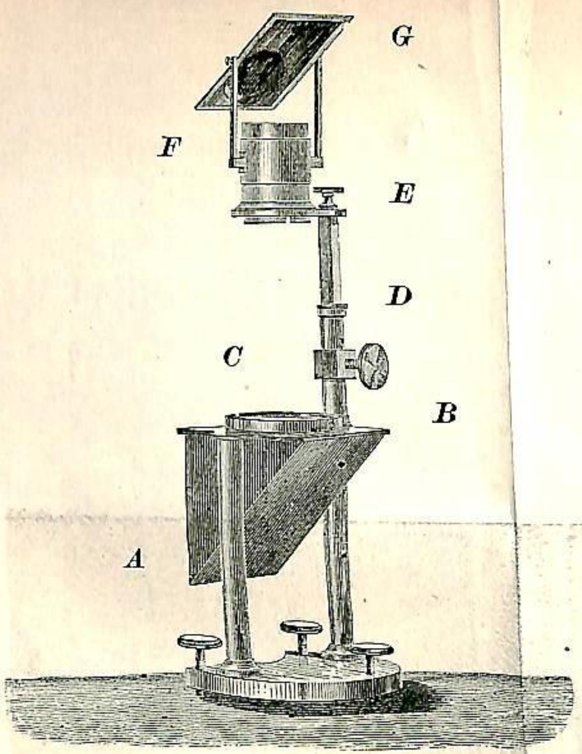
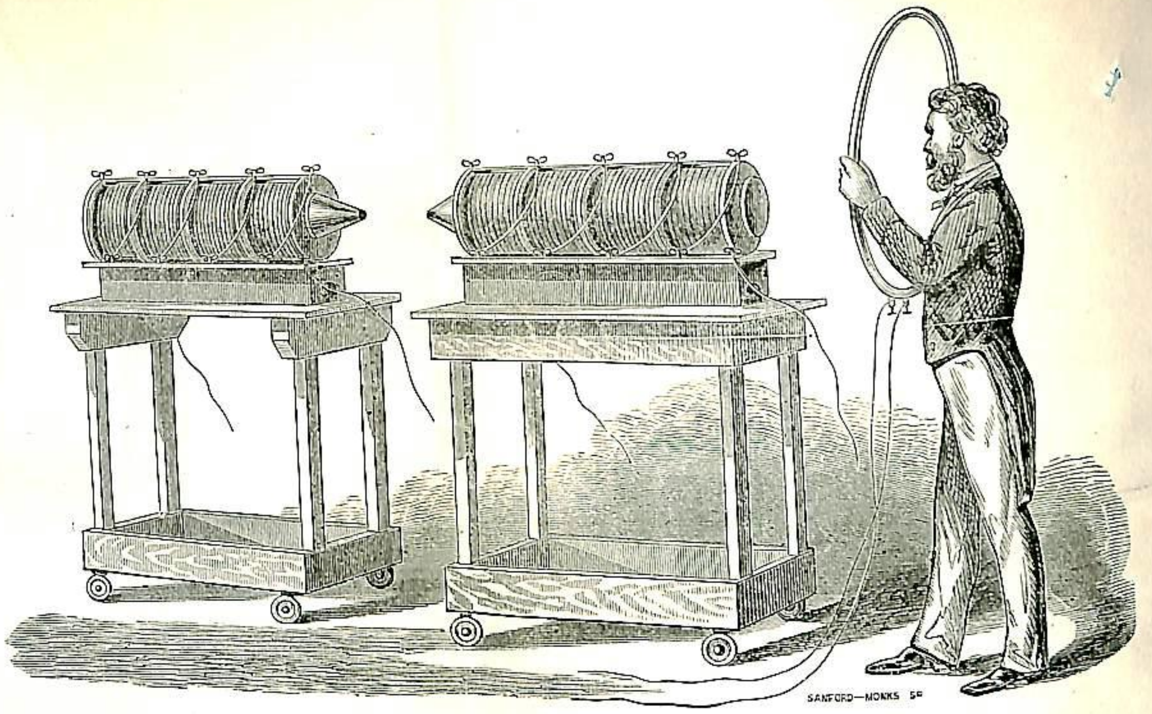


Fig. I.



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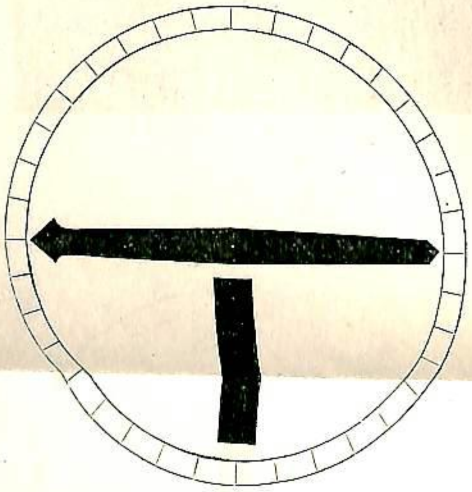

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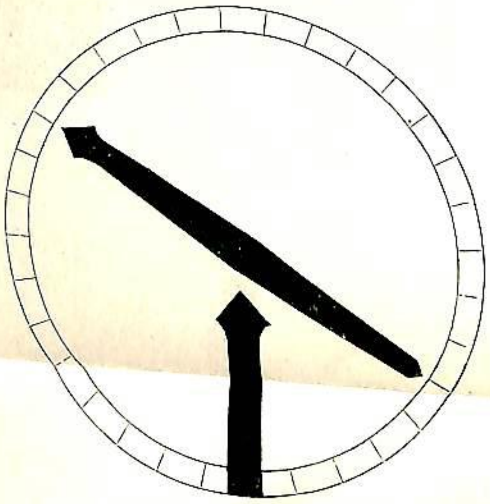

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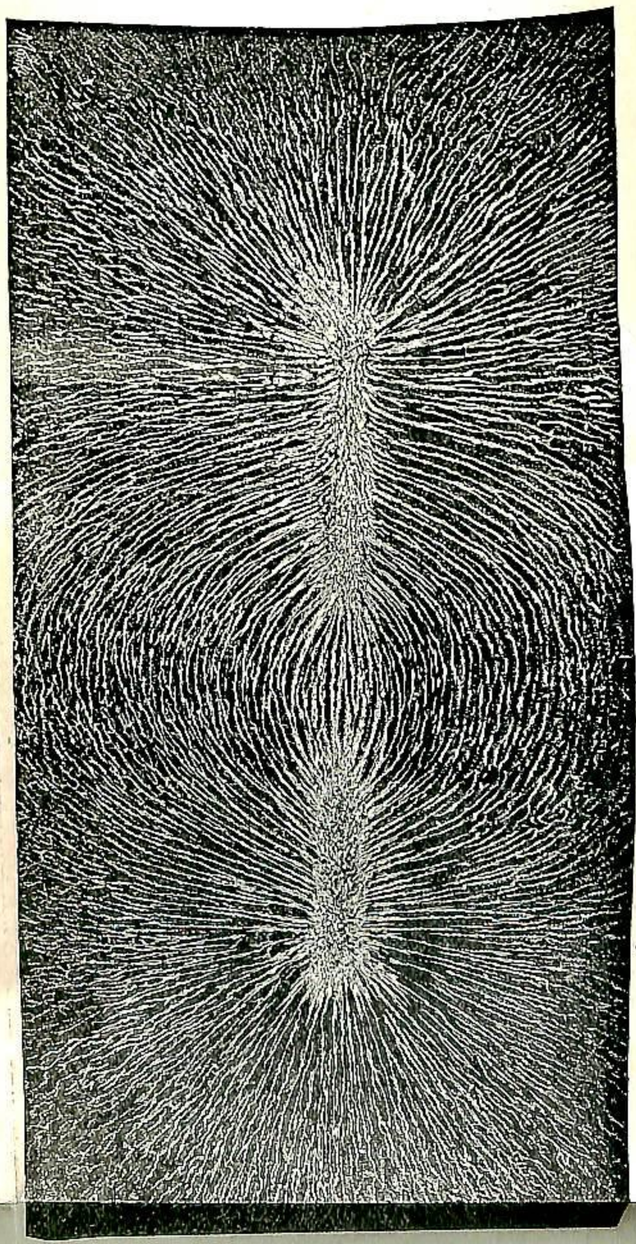

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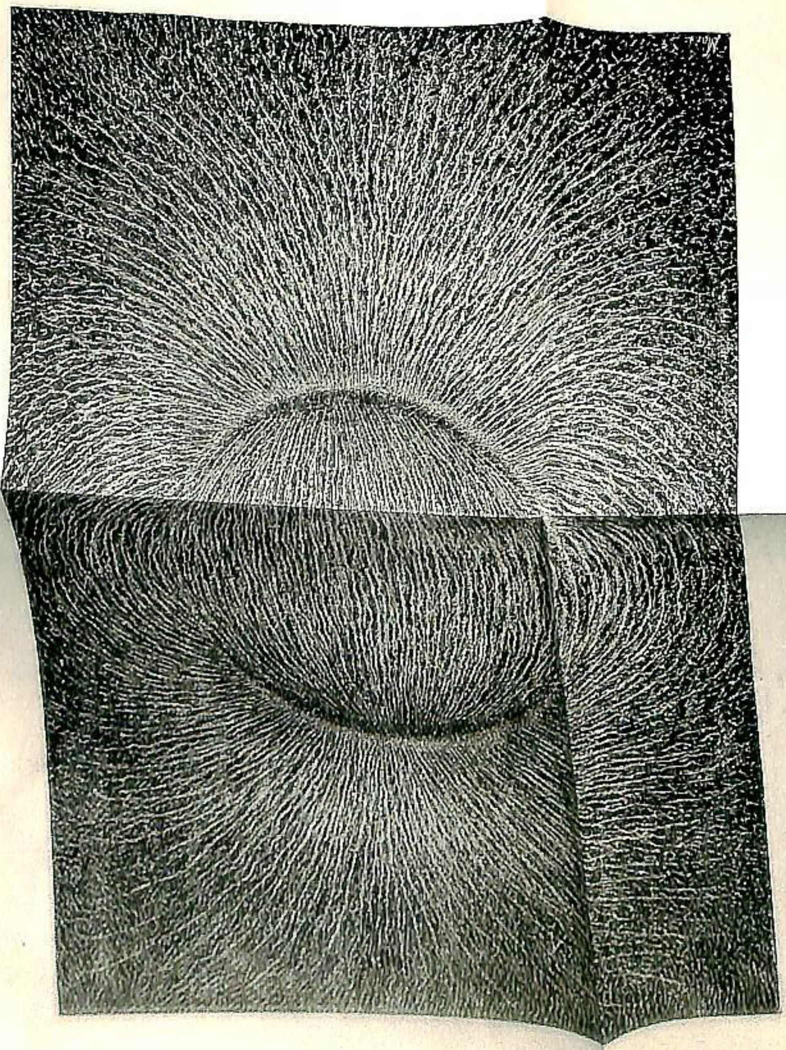

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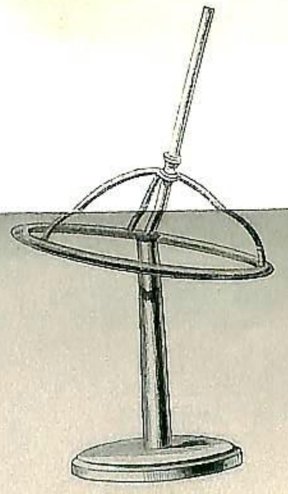

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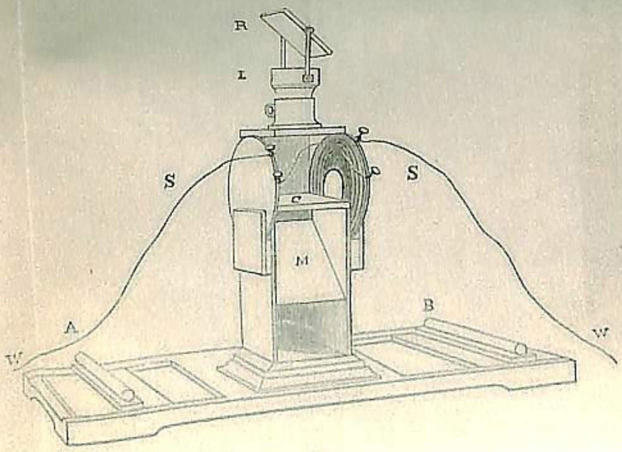

Fig. VIII.

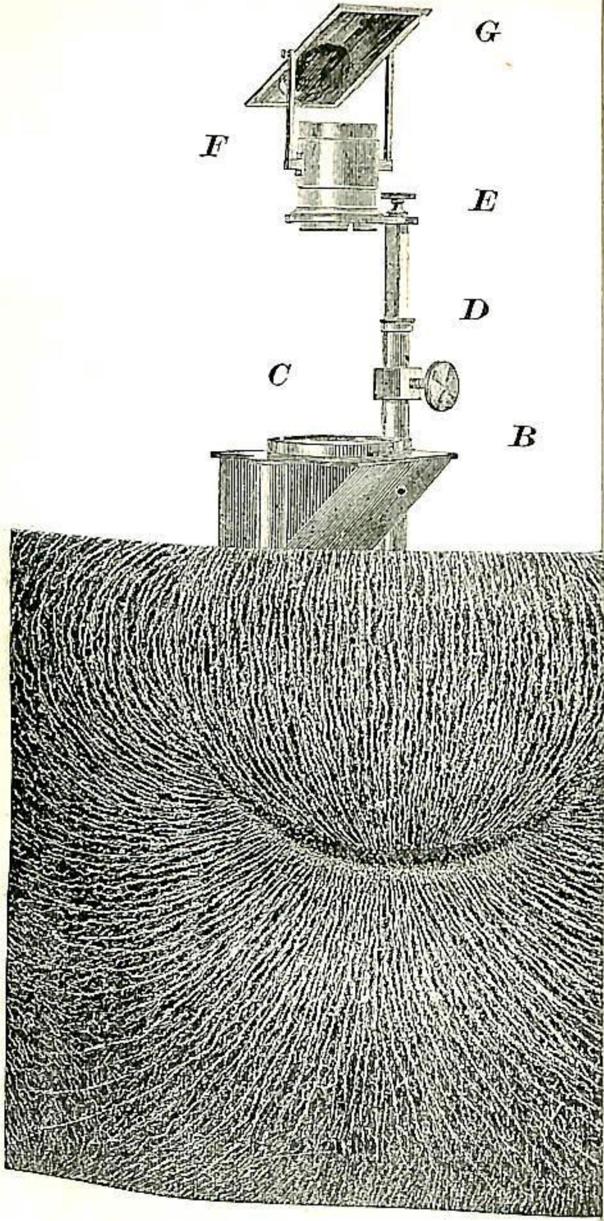

Fig. VI.

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NEW HAVEN, CONN.:
THE COLLEGE COURANT PRINT.

"Il faut se renfermer, le plus qu'il est possible, dans le simple naturel; ne pas faire grand ce qui est petit, ni petit ce qui est grand. Ce n'est pas assez qu'une chose soit belle, if faut qu'elle soit propre au subject; qu'il n'y ait rien de trop, ni rien de manque."

PASCAL, 1650.

THE EARTH A GREAT MAGNET.

A LECTURE BY PROF. A. M. MAYER, Ph.D.

At the invitation of the Yale Scientific Club, I have the honor to appear before you to deliver a lecture on Magnetism—a subject to which I have given several years of devoted study.

Confused by the multiplicity of the facts of this science, and embarrassed by the grandeur of its generalizations, I have resolved to do, what every public lecturer must do who would confer on his hearers any greater benefit than mere temporary amusement; and that is, to select from this subject *one prominent truth*, and to present this to you in simple and striking experiments; *but*, so to describe and logically connect these experiments as clearly and forcibly to bring the truth before your minds and fix it there.

That this method of procedure is necessary, will be evident when you consider that over one hundred men of the highest ability, as original investigators, have toiled, on an average of ten years each, at these problems of magnetism; thus making an aggregate of one thousand years of successful search in the rich mine of natural truth.

From this vast accumulation of fact and of theory I select as my text words given to the world over 270 years ago by Dr. William Gilbert, the physician to Queen Elizabeth. In the year 1600 Gilbert published a work entitled "De Magnete," or, "on the Magnet" (1). In this book I found my text, and thus it reads:

"Magnus magnes ipse est globus terrestris,"

which being interpreted is, "the earth itself is a great magnet."

Those who will examine this remarkable book of science cannot fail to observe how skillfully Gilbert handles the experimental or inductive method of research in arriving at the facts and the laws of magnetism; and if he cannot be styled "the Father of Inductive Philosophy," he can, at least, lay claim to our most hearty admiration for the brilliant manner in which he (with Galileo) first, *by his discoveries*, demonstrated the practical value of this injunction of Bacon—that by observation and experiment alone can the mind of man arrive at a knowledge of the laws which rule the universe.

That the earth itself is a great magnet, I propose as the problem to be solved before we separate, but the short duration of a single lecture will permit me to attack this problem only in the most general manner; and having proved that the earth is a magnet, it will not be allowed me the pleasure to examine with any minuteness the characteristics of this huge lodestone, such as the position of its poles, the path of its equator, and those mysterious variations in the direction and intensity of its force, which latter seem to be in subjection to emanations from the sun—changing with the apparent daily and yearly revolutions of that orb and pulsating in sympathy with the huge waves of fire which sweep over its surface; for, it seems probable, that on any sudden agi-

tation of the sun's surface, the magnetism of the earth receives a profound disturbance in its equilibrium, causing fitful tremors in the magnets of our observatories and producing those grand outbursts of the polar lights, whose lambent flames dance in rhythm to the quivering needle.

The earth itself is a great magnet. Of the earth, you know; but what is a magnet? I hold one in my hand as given us by nature. This is the *lodestone* (2), or leading stone (from the Saxon læden, to lead), so called because it causes iron to follow it. Our forefathers sometimes called it *love-stone*, just as the French now term it *l'aimant*, the affectionate, because it has a strong affection for iron, and draws it to itself. We call it *magnet* from the province of Magnesia in Lydia, whence the ancient Greeks obtained it and thence gave it the name of the *Magnesian stone*.

So much for the name; but yet, what *is* a magnet? Define it. "A definition is the resolution of a complex idea into the simple elements which compose it;" but, in this case, the complexity of the idea conveyed by this name *magnet*, so increases with our knowledge of its properties, and the simple elements of its characteristics are so far removed from ordinary observation that I will be forced not to answer the question I have called up, but allow the magnet to speak for itself in its own "writing on the wall" [pointing to the screen], while I will stand by and be its interpreter.

Over the horizontal condensing lens (C) of this vertical lantern (3), I place this glass plate, and, on allowing the lime light to fall upon it, you observe on the screen a bright circle of over 15 ft. in diameter. Fig 1, I now place on the plate a few tacks, and there they are in the bright circle, each appearing over two feet long. That huge black mass which you see slowly entering the circle is the lodestone—see! as it progresses, how the tacks rush towards it, and observe also how they cling to one another until now they form a train and follow the stone, as it disappears from view. Surely it is "the affectionate."

The lodestone however attracts steel as well as iron, as you see, now that I have substituted these steel needles for the iron tacks. Apparently, the lodestone acts alike on both, but let us examine into this. I have here a piece of copper wire which I am wrapping around one end of this short piece of soft iron. I now have made a handle of wire by which I can draw the other end of the iron through these iron-filings, which you observe as huge grains on the screen. The iron has ploughed a clean track through them. I again draw it through the same line, but you see that I have placed against its other end the lodestone, and you see the filings crowding in towards the iron from outside the bright track, and now the iron has actually taken off the plate a considerable breadth of them. I have placed aside the lodestone and again I draw the end of the iron across this plate, in another direction; see, again it leaves behind it the bright clean line and not a particle of iron adheres to it in its progress. I now substitute for the soft iron a piece of stout darning-needle; it also leaves behind it a clear line and not a grain of iron attaches itself to it; and drawing it again through this line with the stone at the other end you see that it, like the soft iron, draws to itself the filings. But now observe *the difference* when I lay aside the lodestone and draw alone the steel needle through the filings; see the iron brush which has formed

on its end. I pull off the iron filaments; again they form as I draw it across another diameter of the circle. Thus we find that *iron is only temporarily, but steel is permanently magnetized by contact with the lodestone.* Indeed, we find, on furth'r examination, that the lodestone has endowed the steel with *all* of its magnetic properties, and therefore we can now set aside the stone and use in its stead these various steel bars and suspended needles, of more convenient forms, which we will suppose have derived their magnetism from contact with the lodestone.

Thus from the magnetism furnished us by nature in this stone I have permanently affected this piece of steel with extraordinary properties; but there are other means of obtaining them in a far more exalted degree; the most powerful yet reached has been accomplished by means of this instrument—the great electro-magnet of the Stevens Institute of Technology. Fig. 2.

Here on each of these two strong tables rest four large brass spools, each wrapped with nine layers of stout copper wire. Thus we have eight spools containing in all 2,000 feet of 2-10 inch insulated wire. Four of these hollow spools are placed in a line on each table, and into them is introduced a hollow cylinder of very soft iron, 3 ft. 3 in. long, of 6 inches outside diameter, and with an interior diameter of 3½ inches (3a). The two cylinders are terminated with these conical caps, and by rolling the tables they can be placed at various distances apart. On the shelves under these tables are twelve large battery-cells containing a solution of bichromate of potassium in dilute sulphuric acid. By turning these handles those large plates (ten pair to each cell) of zinc and carbon can be lowered into the solution and a powerful development of electricity instantly follows, and by means of these wire ropes it is lead in one direction through all the wire on the eight spools. The electricity thus flows (as we say) around the two iron cores, and whenever this takes place they are instantly endowed with magnetic properties of the greatest intensity, as you will soon see (4).

The plates are out of the solution, and I place against the core these iron spikes. On ceasing to support them with my hands they fall to the ground, for the iron cores have no power to hold them up. Now I lower the plates into the solution, the electricity courses through the spools, and see, how the spikes are jerked out of my hand as I bring them near the magnet, and it takes all my strength to detach even one of them. I now throw a score of these spikes at the cores, which you will observe are about 18 inches apart. How they clash against the iron! My assistants will now lift a whole keg of those 8 inch spikes above the magnet, and turning it upside down they rush to the iron cores, and not one of them has fallen to the ground. Another keg of spikes is now thrown on the magnet, and again another, and now we have an iron arch formed between the poles, on which my assistant, as you see, can stand with perfect security. He will now descend, and I will detach from the magnet one of these wire ropes leading from the battery—the iron bridge breaks and falls with a crash to the floor—and an intensely brilliant flash occurs at the point where I detached the battery-wire. And now observe; the iron cores are as powerless to hold this spike as they were before the electric current enveloped them.

As yet we have only experimented with fixed magnets.

Let us now see what will happen to a magnet when I support it, so that it can move freely around its centre of figure. I have here two hard steel plates; one end of each is terminated in a spear, and in the middle of its length is a little agate cup. I place on the horizontal lens of the lantern this circular plate of glass whose border, as you observe on the screen, is divided into degrees. In the centre of this graduated circle I stand this little needle, and on it I rest one of these steel plates. See, it turns freely round on its agate cup when I tap it with my finger; and now I place its spear-end to any division of the circle, and you see it remains there, and you observe that it has no tendency, in itself, to point to one division in preference to any another. I now replace it with this other similar plate or needle; it behaves precisely like the former one. I am now going to make these needles magnets. What you see on the screen is the end of a steel magnet which is slowly stroking the supported needle from heel to spear-end, and observe, I only pass the magnet over it in that direction. I now have made several passes, and I lay aside the magnet and allow the needle to take care of itself; see, how it is swinging forwards and backwards, and, at last, its spear-end has come to rest at 35° of the circle. I push it away from this position, but you see, it persists in returning to it. It *now* evidently has a preference to remain in this diameter of the circle to any other, and we find on examination that this diameter lies nearly in the N. and S. line of the horizon. I now replace this by the other magnetized needle, and you observe that it also remains pointing to any division to which I direct it. I will also magnetize this needle by drawing over it in the same direction, from heel to spear-point, the same end of the magnet used in the previous experiment. I now remove my fingers from the needle, and observe, it also is swinging to and fro, and gradually it comes to rest and now its spear-end is also pointing to 35° of the dial, and it returns to this division as often as I deflect it from it. Thus, these experiments have clearly shown us that when any magnetized bar of steel can freely turn on its centre, it will (here at New Haven) place its length in a northerly and southerly line.

We will now reverse our first experiments, and instead of allowing a fixed magnet to act on moveable masses of iron, we will see what takes place when a fixed mass of iron acts upon a moveable magnet. I take this short piece of soft iron and point it towards the *spear-end* of the needle; you see that that the spear moves towards it. I now bring it opposite the other end of the needle and it also moves towards the iron. The iron pulls to itself, indifferently, either end of the needle. Hence, *if a rod of iron be placed at right angles to the length of a magnetic needle, and point towards its centre, the needle will not rotate.* You see this deduction is correct, for there, in the bright circle, you see the iron rod pointing towards the centre of the needle and the spear end remains steady at 35°*. Fig. 3.

Let us now see what action this other magnetic needle will have on the similar one in the lantern. We have seen that the spear-end of each pointed in the same direc-

* The pointing of the needle to this particular division means nothing, for the graduated plate was placed on the lantern without thought as to *the direction* of its zero point, and it merely happened that the needle pointed to 35°, when it came into the magnetic meridian, which latter is 8½° W. of true N. at New Haven.

tion. I bring these two ends opposite each other. How remarkable! the *spear-end* of the lantern needle is *repelled.* Heretofore all of our phenomena were facts of attraction, here we first meet with repulsion. The swinging needle is now rapidly coming back to its 35° point, and I will again bring the same end of the needle close to it; see, although it was coming back to its position of preference with a rush, yet the repulsive action between the similar ends of these magnets is such that the swing of the needle was not only arrested but its motion was reversed. See, again, how it shys away as I again bring the spears near each other. But *attraction* also exists between these magnets, as you perceive, as I bring the other end of this needle to point towards the spear end of the lantern needle. Rapidly it swings towards it, and I had to be very quick in my movements or the unlike ends would have struck together. To bring forcibly before you the differences in the action of the iron and of the magnet on the same needle, I now, as I did with the iron, place the magnet at right angles to the length of the magnetic needle and pointing towards its centre. The needle now, however, does not remain steady at 35°, it rotates; the spear end of the stationary magnet draws to itself the other end of the needle. Fig. 4. I reverse the position of the magnet and the direction of rotation of the needle is also reversed. We hence deduce a general rule of the mutual action of magnets. viz.: *Like ends. or poles, repel; unlike poles attract.*

In the course of the solution of our proposed problem we will have frequent occasion to use the guidance of the following experimental tests:

Place the length of the bar you would test at right angles to the length of the needle, and pointing towards its *center. If the needle remain at rest the bar is devoid of magnetism. If it rotate, the bar is a magnet; and if the N. end of the needle approach the bar, then the S. end of the latter is near the needle. If the S. end of the needle approach the bar, then the N. magnetic end of the bar is nearest the needle.*

We have seen that both the lodestone and the great magnet conferred their magnetic properties on masses of iron which *touched* them; but contact with the magnet is not necessary for calling into existence attractive properties in iron; as you will clearly apprehend from the experiments I am about to make. I again bring over the lens of the lantern a glass plate strewn with iron filings, and I draw through them the end of this short iron rod, while *near* to the other extremity I hold this lodestone. You observe on the screen the considerable distance that separates them; yet you see the filings adhering to the iron, just as they did when the stone was in contact with it.

A similar experiment I will now perform with the great magnet. My assistants have unscrewed its conical caps, and have brought the two iron cores and the two sets of spools in close contact. Thus we have made out of the two cores one magnetic bar of seven feet in length. I now lower the battery plates, and the iron is powerfully magnetized. My assistant will stand against one of its ends, and I place against his chest this iron rod over four feet long; the bar is thus separated from the magnet by the thickness of his body, yet on bringing these rings to its free end they cling to it and to each other and swing like a chain from its extremity; the bar is magnetized through the body of a man.

Again, another experiment I will make. I take this

bar of soft iron, 14 inches long and 2 inches in diameter, and ascending these steps I hold it aloft, a foot or more above the end of the great magnet. My assistant will now hand me those iron rings each weighing three pounds; I bring one to the end of the bar nearest the magnet; the ring firmly adheres to it; to this ring I suspend another; and lifting the iron rod yet higher I have attached another; and another; and now, I have six rings suspended from this stout iron rod; yet, none of this mass of suspended iron *touches* the magnet. The battery wire is now detached and the rings fall to the floor. (5)

There is, however, another condition, besides mere proximity to the magnet, which is necessary for magnetization at a distance, and that is *the part of the magnet towards which the iron bar points.* Only with the great power of this huge magnet can I clearly show you this important truth, and without it a link in the chain of my reasoning towards the solution of our problem would be wanting. I hold in my hands a bar of soft iron, four feet long; I bring this towards the centre of the great magnet and point it at right angles to its length. Observe, it is powerless to hold up even a nail. Holding the bar at the same distance I now point it towards one end of the magnet, and see the difference; how the spike and rings adhere to it; for as long as the bar points towards the end of the magnet it is magnetized; but observe as I slowly rotate the bar around the end nearest the magnet,—spike and ring are falling to the floor, and now that it points again towards the center of the magnet it is powerless. Therefore direction as well as proximity is necessary for the magnetization of a bar by induction.

With the knowledge of the method I have given you to distinguished between a mere *magnetic substance* which is attracted indifferently by either pole of a magnet, and a *magnet*, which is rotated in one direction by one pole and in the opposite direction by the other, we have the means of still further exploring this curious action of a magnet on a distant bar of iron or steel, and I ask your special attention while I make the following experiments, which give additional evidence of the power of this noble instrument, for it alone can accomplish what I now proceed to show you.

In my hands I hold a piece of gas pipe, which I have carefully freed from any trace of magnetism, by a process which you will presently appreciate. You see that it is really devoid of magnetism, for you observe that when it is brought close to and pointing towards the center of the lantern-needle that it does not produce in it the slightest rotation. I now set in action the great magnet, and carefully carry this pipe to a distance of about twelve feet from one of its ends, and I point the tube in an east and west line towards its pole; I now bring the tube again opposite the lantern-needle, but, as before, no rotation takes place. I again place myself at the same distance, but, while the tube is pointing towards the pole, and in the same direction as before, I strike it with this hammer; the tube rings at the blow, and all of its particles are powerfully agitated. I now present the tube to the lantern needle, and see! how it swings around. The large magnet really magnetized this tube when I previously pointed it towards its pole; but only temporarily, its magnetism disappearing as I receded from the magnet; but, when the bar in exactly the same position was vibrated by the blow, it received a permanent charge. Thence we deduce another important fact, namely, that *to produce at a distance from a magnet a permanent magnetic*

charge in a bar of iron (or steel) this must not only point towards its pole, but also, its particles must be violently shaken.

By these conclusive experiments, we see that it is not necessary for an iron or steel bar to touch a magnet to derive from it either a temporary or a permanent magnetic charge, for, at a distance of twelve feet, we have shown that the magnet *influences* the iron, or *induces* it to become a magnet like itself; hence, this action of a magnet on a distant mass of iron or steel is called *induction.*

It now only remains to examine how the poles of these *induced* magnets are situate when referred to the positions of the poles of the *inducing* magnet. In the last experiment you observed that I pointed towards the great magnet, the *red* end of this iron tube and that on presenting this end to the centre of the lantern-needle, you saw its spear or N. end rotate towards it. I again repeat the experiment—you see it is as I say. Therefore this direction of rotation tells us that this red end of the bar is a S. magnetic pole, and you observe that the other, or white end, is a N. pole, because, as you see, it produces in the needle a rotation in the opposite direction. Now we will examine the magnetic condition of the end of the great magnet towards which the bar pointed, and then we can deduce another of those general rules, or laws, which are to serve us in our demonstration.

Here, on this wooden column is a magnetic bar, over two feet long, which you observe turns freely on a hard steel point. It, therefore, has placed its length in the magnetic meridian, and on this end, which points towards the N., I have tied this ball of red cotton-wool. I will now carry this column near that end of the great magnet, towards which we pointed the iron tube, and placing on the steel point the magnetic bar you all observe that the cotton-wool moves away from the magnet; therefore, this end of the magnet is its N. pole. From these facts we can deduce this general rule: *When a bar of iron or of steel is magnetized by induction, the end of the bar nearest the inducing magnet is of the opposite polarity to that end of the magnet towards which it points.* In the experiment just made, the end of the magnet was its N. pole, and the red end of the bar nearest it has S. polarity given it by induction.

With labor on my part, encouraged by patience on yours, I have at last put you in full possession of those tests which can determine for us whether any given bar has magnetic properties or is devoid of them; and I have also experimentally shown you those conditions necessary for a distant magnet to produce either temporary or permanent magnetism in bars of iron or steel. The process of the experimental establishment of these elementary principles, preparative to our actual work with the earth as a magnet, has been tedious to you and to me; some, thoughtlessly, may say *puerile;* yet as well say "every one knows that," and erase from your geometry its axioms as omit from our demonstration those elementary facts and principles which constitute its very foundation, for

* * "To tell by which of nature's laws,
The stone called magnet by the Greeks—since first
'Mong the Magnesians found—can iron draw.
* * * * * *
Here many principles we must first lay down
And slow approach by long preparative,
Rightly to solve the rare phenomenon."

Lucretius, Book VI., Trans. of C. F. Johnson.

"The earth itself is a great magnet;" if so, it also will confer on this iron bar temporary magnetism when its length points towards the earth's magnetic pole; and, if vibrated while in this position it will also receive permanent magnetic properties. But here difficulties at once meet us. Are we not begging the question when we talk of drawing a line towards the earth's magnetic pole? That the earth has magnetic poles is just the problem to be solved. True, but we can do this; we know from experiment that *if* the earth be a magnet, then this point of concentration of the magnetic effect, called the pole, is situate somewhere in the depth of the earth, and this depth we can, (as has, indeed, been done), approximately determine by experiments on a magnetic sphere of steel. Then, we can furthermore *assume* that these polar points exist somewhere on or near the earth's axis of rotation, for a freely suspended magnetic needle places itself, here in New Haven, approximately in a plane passing through this axis. Also, as the spear end of the magnetic needle points towards the geographic north, then either that part of the earth is of south magnetic polarity, or it is of north polarity and the spear end of the needle of south polarity. It matters not much which nomenclature you adopt, but we will call the spear end of the needle its north pole, and the geographic north the south magnetic pole.

If after assuming these circumstances our experiments conform to such hypotheses, we have an honest reason for thinking that, in the main, their existence is highly probable; and this much established we can, from this knowledge, devise other and more searching observations and experiments, whose agreement or non-agreement with our hypothesis will carry more conclusive evidence as to the truth or falsity of our suppositions; and so, step by step, we ascend to the widest and surest generalizations of physical science. This, indeed, is the method of arriving at all the fundamental laws of natural philosophy, and if not satisfactory to the strict scholastic logician, we only say that this is all that we can do, and show its value by pointing to *the results* obtained by such methods of inquiry. We start with imagining existences, and banish these dreams one after the other until one is called up which conforms to the actual experiences of observation and experiment. The fault of the ancients was not that they wanted vivid imaginations—quite otherwise —but that they were satisfied that their imaginings should remain "of such stuff as dreams are made of," and never endeavored to find their realities in the material world, and give them embodiment in those entities which exist all around us. The search for these entities is the pursuit of science, and the finding of them is its object.

Thus we will proceed in our work. These parallel white cords, which you observe stretched above the floor, lead to the point in the earth where, in our imagination, we have placed its magnetic pole. We will soon see that there are other methods of very accurately determining the direction of these lines, and we will also find that our ideas have to be somewhat modified as to their paths, for we shall see that instead of being straight lines they really lead to the pole in curves. But remember that we are indulging in our first reverie, and this can but be a vague image of the truth. But all of the conditions necessary for the realization of our reverie are already clearly in your mental vision, and we can at once proceed to seek if any resemblance to it in nature really exists.

I take this bar of soft iron, and holding it horizontally, I bring one end of it near the centre of the lantern-needle. You now see in the circle the end of the magnified rod, and you observe that the needle does not rotate. The bar is entirely devoid of magnetism. But those conditions necessary for the earth to act on it, do not yet exist, for the bar must point towards the assumed position of its magnetic pole. I will, therefore, presently slowly raise this bar until its length is parallel to those stretched lines, and then, if the earth be a magnet,the needle should not only rotate but the spear-end of it should go away from the lower end of the bar; and also if the rod, retaining its direction, should be lowered in the direction of its length, until the centre of the bar has come opposite the needle, then the latter should return to the position it had when the bar was away; and furthermore, on lowering yet more the bar until its upper end comes opposite the needle we should see it again rotate, but this time its spear-end should approach the iron bar. I am now slowly elevating this white end of the bar, while the other, or red end, remains near the needle; see, it really is turning on its centre, and the spear-end, as we imagined, is moving away from the rod. I have now brought the length of the rod parallel to the stretched cords, and observe how powerfully the needle is deflected, the spear-end turned away from the rod. I will now lower the rod along the line of its length; you observe the needle slowly moving to the position it had before the iron bar was brought near it, and now it is steady at that position, and the centre of the rod is opposite the needle. I lower it yet further and the needle is now turning in the other direction, the spear-end is approaching the bar, and now it has come quite close to it and the upper, or white end of the bar, is opposite the centre of the needle. I now reverse the position of the bar and place the red end up: the white end is now close to the needle, and see, how the latter is swinging away from it. This white end has now north polarity, the same as the red end had when it was similarly placed. On lowering the bar in the line of its length, you see that its centre is again devoid of action on the needle, and now, that its upper or red end is opposite the needle you observe the spear-end of the needle quite close to it, showing that again the upper end is of south magnetic polarity. I now remove the rod, and placing it in a horizontal position, I bring either end near the needle's centre; you see that its magnetism has left it. From all of these experiments what are we to infer? *That the magnetism of a bar of soft iron depends alone on its position, and is therefore due to some action outside of itself.* When placed in a horizontal east and west line it is devoid of all magnetic properties; when placed parallel to these cords it is powerfully magnetic, and also, whichever end is downwards that end has north magnetism. Thus have we found really existing in nature every one of those surmises which, before experiments were made, we only knew as the creatures of the imagination called up by logical inference.

This first success flushes us with the consciousness of our power and our vision involuntarily expands from this room out over the great earth itself, and we picture to our minds what would happen to this bar of soft iron if it were carried from here southward, across the equator into the southern hemisphere, and as we progressed on our voyage we should frequently hold the bar in a vertical line and test its magnetic condition.

Here, in the northern hemisphere, we know from the experiments just made, that the lower end of the bar is of north magnetism; but if, when we had reached the equatorial region of the earth we should test the bar, should not the experiment show that it was devoid of magnetism? for did not our experiments on the great magnet teach us that when the bar was placed at right angles to the axis of the magnet and pointed towards its centre, the bar remained unmagnetized? and those conditions would seem to be exactly repeated with the earth, supposing it a magnet, if we held the bar upright on or near the earth's equator. Pursuing our voyage yet more to the south we enter the southern hemisphere and approach nearer the point where we supposed the earth's north magnetic pole to exist. Here this nearer pole should induce its opposite magnetism in the lower end of the bar which should now be of south magnetism, which is opposite to that which it had when on the other side of the equator. We cannot travel so far together and test all this for ourselves, but I find that another man has also had this same vision, and actually sailed with a bar of iron into the South Atlantic, there to seek its reality; for, fortunately for the completeness of my argument, I made a note of a curious paper on this point, which I once found while studying the history of magnetic research, as contained in the *Transactions of the Royal Society of London.* This paper is entitled "*On the Tendency of the Needle to a piece of Iron, held perpendicular, in several climates. By a master of a ship, crossing the Equinoctial Line, Anno* 1684." Let the mariner give his own evidence: "All the way from England to 10° north latitude, the north end of the needle tended to the upper end of the iron, and the south point to the lower end, very strongly. * * * In latitude 8° 17′ south, and meridian distance from the Lizard 17° 35′ west, the north point the needle would not respect the upper end of the iron: but the south point would still somewhat respect the lower end. * * * In latitude 29° 25′ south and 13° 10′ west, from the meridian of the Lizard, the south point of the needle respected the upper end of the iron, and the north point, the lower end strongly." The sailor's evidence is completely in our favor, and especially will it so appear when you refer to any physical chart of the globe, when you will find that latitude 8° 17′ south and longitude 17° 35′ west of the Lizard, is almost exactly on that line laid down as the *magnetic equator*, on which the inductive actions of the north and south poles neutralize each other.

The first series of experiments we made on the distant action of the great electro magnet, suggested these which we have so successfully repeated with the earth; but you will recall other experiments, in which a bar of rather hard iron pointing towards the pole of that magnet *was permanently magnetized* when, in that position, I made it ring with the blow of a hammer; whereas when gently removed from that position, without having been agitated, it was found to be unmagnetized. Let us repeat these experiments, for all the conditions of their manifestation are known and can readily be obtained with the earth. Holding this bar horizontally with either end, near the centre of the lantern-needle, you see that it is free of magnetism, for the needle does not move. I now place its length parallel to the direction of those stretched cords; this condition seems exactly

to correspond to our previous experiment, when at a distance of twelve feet we pointed a bar towards the pole of the large magnet. I now bring it into a horizontal position and again place its end near the centre of the needle; you see it is still unmagnetized, exactly as when, after pointing a bar towards the magnet, we brought it near this needle. But we found that it was permanently magnetized when, in that position, its molecules were powerfully vibrated. This condition we can readily fulfil. Observe, I place the red end of the bar down, with its length parallel to those stretched cords, and now I strike down on its upper end with this hammer. We will hold it in the same position until its ring has died away. Now it has ceased to tremble; and placing it again in a horizontal position, I bring its red end near the needle. You all see how violently the needle swings around, its spear, or north end, rushing away from the bar, showing that the red or lower end has received a charge of north magnetism. The upper, or white end, is now opposite the centre of the needle, and you see that it is as powerfully charged with south magnetism. The experiment is a beautiful one, but we have not yet seen all of its excellence. Let us again muse over our work and see if we cannot gain further mastery over these actions. You remember that the red or lower end of the bar is of north magnetism. Suppose, however, I place this end up and the white end down. Will this white end then have *north* magnetism? Let us try. No, it is evidently weaker in its action on the needle, but is yet of south magnetism—*but weaker*. This weakening evidently comes from the action of the earth on the reversed bar. Therefore, suppose while holding the bar in this position, I strike it again with the hammer what will happen? Will merely a blow be sufficient to take the south magnetism out of that end of the bar and to leave the bar neutral, or, will it do even more and replace the south by north magnetism? In other words, will it reverse the magnetism of the bar? I will test it. Look steadily at the needle and observe its fixed position, while the end of the bar is near it, and keep your eye on the needle, and when you hear the blow of the hammer and ring of the bar, observe what takes place. I have struck the bar, and look, how the needle swings, and now its spear-end is away from the bar, thus showing that its magnetism has indeed been reversed. Thus can we cause the magnetism of the ends to change places as often as we wish; but can we not do something else? Can we not, by a properly regulated blow, shake (allowing such a crude expression) the magnetism entirely out of the bar? I think we can. You know that the lower or white end is of *north* polarity. I now reverse the position of the bar and the white end is up. I strike a blow. I now test the bar, but you see that I struck it with too much force, for the magnetism of the white end is now *south*; but feebly so, for the needle is only slightly deflected. Now I will show you a pretty experiment. I again reverse the bar, and the white or south magnetic end is down, and I strike the upper end with the palm of my hand. I place the bar in a horizontal position and test it; it has evidently been weakened. I again bring my hand down on it. Its magnetism has, you see, almost disappeared. I again bring the bar into the upright position and tap it with my fingers. See, it is entirely freed of magnetism. I stated, when I began working on these bars, that they had all been demagnetized by a process which you would soon appreciate. I hope you now appreciate it.

How satisfactory is such work; we here repose on the decision of an upright judge. We bring our doubts and differences to the bar of nature, and the verdict is convincing to all. It is truth, which is the soul of science.

I think we can say that the experiments we have made with these magnets have well directed us in the progress of our experimental solution of the problem of the earth's magnetism; and this encourages me to examine more minutely the manner in which these curious attractive and repulsive effects, which we call magnetism, are distributed over the surface of these magnetic bars. We can only thus hope to secure more light to illumine our further progress which seems here almost brought to a termination. But from experience we know that it is generally only by the most searching look into known phenomena that we can obtain that dim view of the path which leads to the hidden truths beyond, and thus, therefore, we will endeavor to find an opening into further research.

We have, as yet, only examined roughly the effects of the ends and of the central portions of a magnet on bars of iron; but, we can instead of using these large bars and needles make use of quite minute and very short bars in the form of iron filings, and by this process give many points for the magnetic radiation to act on; and by distributing these points over the whole surface of the magnet we may arrive at some highly suggestive results. The idea is worth following up and we will proceed to test its value.

I strew this glass plate with finely sifted filings made from the softest Norway iron, which has been repeatedly annealed; I lay the plate on the horizontal lens of the vertical-lantern, and I place this small bar magnet on the filings. You observe how they arrange themselves about its ends. I now roll the bar over and over, and you see more evidently than before that *the attraction is localized.* The middle of the bar has no filings adhering to it, but observe from the ends of the magnet these radiating iron filaments, and remark how their gradually declining contour actually shows how the magnetic hold on the iron gradually diminishes from near the ends of the magnet towards its centre.

I now modify this method of exploring the distribution of the magnetic force. I place this same bar magnet on the condensing lens of the lantern, and down on it I lower this glass plate on which has been sifted iron filings. They do not appear in the least affected by the magnet beneath them; but, observe when I let fall vertically on the plate this piece of light copper wire; see the curious lines that are growing around the magnet. Fig 5. These proceeding outwards from the ends appearing to radiate like rays of light from points within which we call *the poles*, while these, originating nearer its centre, bend over the magnet, and in graceful curves embrace it. Let me try if I can give you some insight into their significance. The plate sprinkled with iron dust was placed upon the magnet and nothing remarkable appeared. Why? Simply because *all phenomena, without exception, are either motions or the results of motion;* and no motions of the iron particles could take place until the plate was vibrated; then they sprung into the air and the magnet, from its proximity, rendered every iron grain magnetic by induction, while the same directing principle joined their north and south poles. Thus, while in the air or when gliding over the plate they were deflected into those curious curves which is the figure of their dance. These lines

thus show the directions in which act the combined magnetic radiations from the two poles. They are the lines of magnetic force. They indicate far more than this; but for the present what I have shown you will suffice. Now, if these curves are actually formed of iron filings whose greatest lengths lie in these lines, and whose contiguous ends are north and south poles, and if these lines truly mark out the resultants of the combined actions of the two poles, then this tiny magnetic needle which I have by a silk fibre suspended from this thin wire, will, if brought any where in this field of curves, always place its length in the direction of a line; moreover, when the centre of the needle is moved along one of these lines the length of the needle will always come into the line. I now bring all this to the test of experiment. You see all happens just as I predicted.

To lead the mind from the small to the great, from our puny experiments to the action of the great earth itself, I have magnetized this disc of steel; therefore, this metallic circle has magnetic poles, like the bar we have just experimented with. Hence, if "the earth is a great magnet," this disc gives an ideal section of its magnetism, and should produce in a small scale what the earth does on a grand one. Voyagers and philosophers have stated that the earth has two magnetic poles or points in its mass towards which the magnetic lines converge. When the little exploring needle was carried around one end of the bar magnet, you will remember that it always kept pointing towards one point, which we called the magnetic pole of the bar. So, in the case of this disc, will the exploring needle, when brought near the region of its poles, always point in lines which converge to these inner centres of force; hence it necessarily follows that there must be two points on the circumference of this disc at which the needle points towards its centre. Also, it is said that the earth has two such points, and when in June, 1831, the celebrated Sir James Ross reached the western coast of Boothia, and found the magnetic needle pointing almost directly towards the centre of the earth, he inferred that he stood on the termination of a line drawn from the earth's centre through its magnetic pole to his feet. Thus rewarded for his hardihood, this bold mariner undertook another voyage of discovery in search of a similar point in the southern hemisphere, and in 1841 succeeded in reaching south latitude 76°.12′, on Victoria Land, where the needle made an angle of 88 40′ with the horizon, and he conluded from this and other observations that the position where the needle would be vertical was about 160 nautical miles distant. From these and other discoveries made in the Antarctic seas, it is supposed that the pole of the southern hemisphere must be somewhere about south latitude 70° and near the meridian of 125° E. of Greenwich, which would bring it somewhere on the territory discovered by our countryman Wilkes. The exact position of this point, however, is not known, for no explorer has yet reached it. Now, if you will mark on a terrestrial globe the position of these two points, as I have here done, you will see that they are not exactly opposite each other, but are, however, nearer to that relation than is generally taught, and we might be led to infer from an examination of a physical chart of the world. This is another example of the great importance of using the globe whenever it is possible to do so, and never being satisfied with the information and impression given by a distorted map of the world. Placing the pole of the northern hemisphere at latitude 70° and long.

W. 85°; and the other pole at south latitude 70° and long. 125° east, one of these points will be removed from the end of a diameter drawn from the other by only 30° in longitude; which, on a parallel of 70°, only equals about 600 miles, so that if the southern pole should be moved by this quantity to the west, it would be exactly opposite the pole on the Isthmus of Boothia. But even this want of geographic symmetry has been reproduced on this disc, for I have made its poles distant from each other by the same arc of a sphere's circumference as separates the magnetic poles of the earth. This I accomplished in the following manner. Having calculated the angular distance of the terrestrial poles, I marked this opening by two points on the circumference of the disc, and at these points I placed the conical terminations of the cores of two very powerful electro-magnets. On passing the electric current around these cores, the disc was magnetized and its poles coincided with the points of contact of the cores. Thus this little disc of two and a quarter inches in diameter gives us an approximate representation of a section of the earth's magnestism, passing through the two magnetic poles. (6)

We will now experiment with this disc as we did with the bar magnet, and in the same manner examine its magnetic curves; for if the earth be a magnet, they must give us an idea of the lines in which it also exerts on the needle its directing influence, and greatly aid in giving clear conceptions of the magnetic actions which have been observed by navigators and explorers. I now place the disc upon the horizontal condenser of this lantern, and down upon it I lower this plate on whose upper surface iron filings have been uniformly sifted. I now gently tap the plate. How beautifully these lines

form around the disc! Here are its poles, for you observe
the lines all leading to these points within the dark
circle of the magnet, and directly over these points the
lines tend directly to the centre of the disc. Here,
however, at positions on the circumference midway be-
tween the poles you observe that the course of the lines
for a short distance is parallel to the surface of the
magnet, and places so situate determine points of its
magnetic equator. Fig 6.

With this tiny magnetic needle, suspended by a delicate
silk fibre, I will explore the magnetic condition of this
bright space covered with lines, which you observe sur-
rounding the black circle of the magnet. Wherever I
place the needle, you see that it always stands with its length
in the direction of a curve, and now that I move its point
of suspension over one of these lines you see it swing-
ing round with the bend of the curve, just as a car curves
on a railroad track; and you will remark that this takes
place when it is moved over any line, whether near to or
far from the disc. Now follow me as I move the needle
around the circumference of the magnet, while at the
same time I describe what takes place to a needle freely
moving on its centre when placed over the earth at
points corresponding in latitude to those marked on this
disc. The needle is now over the magnetic pole of the
disc, for you see it points towards its centre; thus stood
the needle of Sir James Ross on the west coast of
Boothia (8). I now progress southward, and observe how
the end near the disc is gradually moving away from it;
thus acts the needle on the earth when carried south
from its position of verticality. Now the little needle is
at a point of the disc marked with the latitude of New
Haven, and you see it making an angle of about 75°

witth the periphery of the circle. In like manner be-
haves the needle in this room, as I will presently show
you. Here we have progressed so far south that the
needle sets its length parallel to the circumference of
the circle, thus the needle rests when moved about 90°
from the magnetic pole of the earth. We are now trav-
elling over the other side of the magnetic equator, and you
observe that the end of the needle which in the former
semi-circumference pointed towards the disc, now points
away from it; this also represents exactly what occurs
when the needle is carried to the south of the terrestrial
magnetic equator. As I proceed around the circle, the
needle points more and more towards it; now it stands at
right angles to its surface and is directly over the other
magnetic pole: likewise points the needle when carried
towards the magnetic pole of the southern hemisphere.

It is only possible for us to examine together the dip
here at New Haven; all the rest we have to take
on faith from the trustworthy travellers and voyagers
who have reported in a minute manner on what I have
given in a very general way. But, desirous that my work
before you this evening should leave a permanent impress
of that repose which always follows a thorough demon-
stration, I will at least show you the earth's directive
action in this room in a very satisfactory manner. I
have in my hand a disc of glass on whose margin is
photographed a graduated circle, and at its centre is a
freely moving axis which passes through the centre of
gravity of this unmagnetized needle; thus supported, the
needle will remain indifferently at any division of the
circle to which I may direct it. I now place it in front of
the condensing lens of this ordinary lantern, and the axis
of the needle is horizontal, while the needle itself can

move in a vertical east and west plane. I now place the needle at various angles of the circle, and you observe it remains immovable at all of them. Now its ends point to the zeros of the circle, which shows that its length is in a horizontal line. I will now magnetize it, and you will observe immediately that it is then endowed with a decided preference for a certain angular division of the circle. You now see on the screen end of the magnetic bar passing over the needle from heel to point. Now I have drawn it over several times, and I will take away my fingers which have held it in a horizontal position; see how it is swinging; no longer indifferent to its position in reference to the horizon, its spear or north end shows a decided preference for the lower part of the circle, and now, after several oscillations, it has finally come to rest with its spear end 74½° below the horizontal line. This deflection of the needle below the horizontal plane is called its "dip" (7), and we see that at New Haven it is 74½°, about what we observed with our exploring needle when it was placed at a similar (magnetic) latitude on the edge of the magnetic disc.

We have now in our possession a most valuable instrument for exploring the magnetic condition of the earth, and with similar needles, explorers have, travelled over all the accessible regions of the earth and have carefully noted how its inclination to the horizon changed with various stations. At New York the north end of the needle dips 73°. Carrying it up the Hudson, we find that at Catskill it has increased to 74°; and at Saratoga it is 75°. Proceeding north and west we find the needle dipping more and more, until we reach latitude 70° and a longitude that brings us in the centre of

the North American continent, where the needle points in the direction of the plumb line. Retracing our path to the south, we see the needle continuously lifting its north end, until we again have it at New York dipping 73°. At Philadelphia it points a little below 72°, and when we reach Washington it is at 71°. Its north end gradually rising, we pass over the end of Florida, where it dips about 55°. At the mouth of the Amazon, directly on the equator, it is yet 25° below the horizontal line; but when we have reached latitude 17° south of the equator, and are about 12° in longitude west of the coast of Brazil, we see the dipping needle with its length parallel to the horizon. Here we have reached a point of the earth's magnetic equator corresponding to the point midway between the poles on the magnetic disc. But does the position we have reached correspond to such a position in reference to the earth's magnetic poles? I again take the terrestrial globe, and on it I draw a circumference of the sphere, which I pass from this point west of Brazil through the North American magnetic pole, and extending this circle beyond, I pass it round on the other side, until it has girdled the sphere. It very nearly cuts through the other pole, whose position we marked on Wilkes' Land. I now take a string and stretch it along the line from the Boothia pole to the point off the coast of Brazil where the dipping needle is horizontal. I then apply this same length from the southern pole towards the same point off Brazil, and I find that this point is only 1° too far south to be exactly midway between the two terrestrial magnetic poles. The coincidence is as near as we can expect with a sphere composed, like our earth, of such varying materials. We will now transport ourselves to the other side of the earth, on the line which we drew around the globe, and we find that the needle takes a horizontal position about latitude 6° north: again stretching the string from northern and southern magnetic poles to this point, we find that it is 6° too far south to be exactly midway between these poles. Here is a discrepancy, but yet a sufficient approximation to serve in the broad argument we are making.

Standing on the east coast of Brazil, at Porto Seguro, in south latitude 16°, the dipping needle is horizontal. Let us now travel eastward from this point around the world, and in our progress keep such a direction that the needle always remains horizontal. The line of our course will have marked out what is called the earth's magnetic equator. This line, starting from the coast of Brazil, tends north towards the coast of Africa, cutting the geographic equator at about east longitude 2°, and then enters the African continent at the Bight of Benin; hence, leading slightly north, it strikes the parallel of 10° N., and keeps this line directly east to Cochin, on the western coast of Hindostan; now gradually bending south, it again cuts the equator in west longitude 170°, and thence trends southerly to South America, and meets that continent at about south latitude 7°, on the west coast of Peru, and from this point it bends southerly to reach the place of our departure at Porto Seguro. Such is the sinuous path of the earth's magnetic equator.

We have only roughly tracked this one line and have approximately given the position of its poles, but the necessities of navigation require a minute knowledge of the magnetic condition of the earth, and charts have been prepared from the observations of magnetic observatories and from the results of voyages and travels

of discovery that, by means of similar lines (9), exhibit at a glance its action on a magnetic needle placed anywhere on its surface. This action manifests itself in giving to the needle (1) a direction in a horizontal plane; (2) a direction in a vertical plane; and (3) by causing the needle to persist in these planes with intensities (10) increasing from the magnetic equator towards its poles.

These charts, however, show only the earth's superficial magnetic action. But did not the experiments with our magnetic disc show that wherever in that bright circle we brought our tiny needle, it there placed its length in the direction of a curve emanating from the magnet? And does not this fact show us where to "let the imagination go, guarding it by judgment and principle, but holding it in and directing it by experiment?" [Faraday.] You see the disc on the screen with a diameter of about six feet; imagine this the 8,000 miles of the earth's diameter. Observe that the illuminated circle, containing the disc, has a diameter of eighteen feet; let this suggest to us a portion of celestial space extending everywhere 8,000 miles from the earth's surface. Now contemplate those curves surrounding the magnet, and then lift up your minds and behold the lines of terrestrial magnetic force! Only imagine this circle 24,000 miles in diameter instead of eighteen feet, and then these curves, stretching thousands, yea, tens of thousands of miles from the earth, plot out for you in celestial space the earth's magnetic influence! Thus by a legitimate effort of the imagination, we rise from the visible and tangible toward the invisible and unapproachable; yet, in this case not altogether invisible, for these very curves you have all seen traced in space by the light of the aurora's beautiful beams. That these luminous columns of the Aurora Polaris lie in the curves of the earth's magnetic force, and therefore have their lengths in the directions of the dipping-needle, at the points over which they appear, is a well established fact deduced from many observations and measures made on them. Thus "the well remembered aurora of September 2, 1859, formed a belt of light encircling the northern hemisphere, extending southward in North America to latitude 22½°, and reaching to an unknown distance on the north; and it pervaded the entire interval between the elevation of 50 and 500 miles above the earth's suface. This illumination consisted chiefly of luminous beams or columns, everywhere nearly parallel to the direction of a magnetic needle when freely suspended; that is, in the United States, these beams were nearly vertical—their upper extremities being inclined southward at angles varying from 15° to 30°. These beams were, therefore, about 500 miles in length; and their diameters varied from five to ten and twenty miles, and perhaps sometimes they were still greater" (11).

The discovery that the auroral columns coincide with the curves of the magnetic force was a noble one, and I have ever loved to dwell upon the very words in which such truths are given to the world; for thus the inspiration of the discoverer infuses itself insensibly into the soul of the reader, and leaves ineffaceable impressions of the simplicity, the dignity, and the comprehensiveness of science. This discovery, from its very nature, is the result of many accurate measures made on these beams; and only when it had been clearly shown that these measures agreed with the hypothesis that the aurora is subject to the directive influence of the earth's

magnetism, was it that the discovery was really made. This work is due to John Dalton, the illustrious founder of the numerical laws of Chemistry, and his beautiful revelation affords another argument in the demonstration that the earth itself is a great magnet. Seventy-seven years before him, I find, Dr. Edmund Halley, of England, had *imagined* very clearly the same relation; but with Halley it only remained in the region of the imagination, for he never really found its embodiment in the material world. Dr. Dalton's discovery is found in his "*Meteorological Observations and Essays, Manchester,* 1793," from which I give these few lines of his simple language:

"A very moderate skill in optics was sufficient to convince him, that as the luminous beams at all places appear to tend towards one point, about the zenith, they must, in reality, be straight beams, parallel to each other, and nearly perpendicular to the horizon; and from the appearance of their breadth they must be cylindrical."

* * * "The length of the beams bore a very great proportion to their distance from the earth, even so as to equal, or perhaps, surpass the said distance."

"Thus stood the author's knowledge and ideas upon the subject in the autumn of 1792. The very grand *aurora* in the evening of the 13th of October, was that which first suggested and led to the discovery of the relation betwixt the phenomenon and the earth's magnetism. When the theodolite was adjusted without doors, and the needle at rest, it was next to impossible not to notice the exactitude with which the needle pointed to the middle of the northern concentric arches. Soon after, the grand dome being formed, it was divided so evidently into two similar parts, by the plane of the magnetic meridian, that the circumstances seemed extremely improbable to be fortuitous; and a line drawn to the vertex of the dome, being in direction of the *dipping-needle*, it followed, from what had been done before, *that the luminous beams at that time were all parallel to the dipping needle.* It was easily and readily recollected at the same time, that former appearances had been similar to the present in this respect, that the beams to the east and west had always appeared to decline considerably from the perpendicular towards the south, whilst those to the north and south pointed directly upwards; the influence was therefore unavoidable, that the beams were guided, not by gravity, but by the earth's *magnetism*, and the disturbance of the needle that had been heretofore observed during the time of an *aurora*, seems to put the conclusion past doubt. It was proper, however, to observe whether future appearances corresponded thereto, and this has been found invariably the case, as related in the observations."

We now give the previous surmises of Dr. Halley, contained in these extracts from his very ingenious and suggestive paper, which I found in the Transactions of the Royal Society, entitled "*An Account of the late surprising Appearances of the Lights seen in the Air, on the 6th of March last; with an Attempt to explain their Principal Phænomena. Anno* 1716."

"But without inquiring how sufficient the Cartesian hypothesis may be for answering the several phenomena of the magnet: that the fact may be the better comprehended, we shall endeavor to exhibit the manner of the circulation of the atoms concerned therein, as they are exposed to view, by placing the poles of a terella or spherical magnet on a plane, as the globe on the horizon

of a right sphere; then, strewing fine steel dust, or filings, very thin on the plane all round it, the particles of steel on a continued gentle knocking on the under side of the plane, will by degrees, conform themselves to the figures in which the circulation is performed. Thus, * * * by doing as prescribed, it will be found that the filings will lie in a right line perpendicular to the surface of the ball, when in the line of the magnetical axis continued. But, for about 45 degrees, on either side, they form themselves into curves, more and more crooked as they are remoted from the poles; and more and more oblique to the surface of the stone: as the figure truly represents, and as may readily be shown by the terella and apparatus for that purpose, in the repository of the Royal Society.

"Now, by many and very evident arguments it appears that our globe of earth is no other than one great magnet. * * * It suffices, that we may suppose the same sort of circulation of such an exceedingly fine matter to be perpetually performed in the earth, as we observe in the terella; which subtile matter freely pervading the pores of the earth, and entering into it near its southern pole, may pass out again into the ether, at the same distance from the northern, and with a like force, its direction being still more and more oblique, as the distance from the poles is greater. To this we beg leave to suppose, that this subtile matter, no otherwise discovering itself but by its effects on the magnetic needle, wholly imperceptible, and at other times invisible, may now and then, by the concourse of several causes very rarely coincident, and to us as yet unknown, be capable of producing a small degree of light; perhaps from the greater density of the matter, or the greater velocity of its motion: after the same manner as we see the effluvia of electric bodies, by a strong and quick friction, emit light in the dark: to which sort of light this seems to have a great affinity.

"This being allowed, I think we may readily assign a cause for several of the strange appearances we have been treating of, and for some of the most difficult to account for otherwise; as, why these lights are rarely seen anywhere else but in the north, and never, that we hear of, near the equator: as also, why they are more frequently seen in Iceland and Greenland, than in Norway, though nearer the pole of the world. For, the magnetical poles, in this age, are to the westward of our meridian, and more so of that of Norway, and not far from Greenland; as appears by the variation of the needle this year observed, full 12 degrees at London to the west.

* * * "And whereas in this appearance (and perhaps in all others of the kind), those beams which arose near the east and west, were farthest from the perpendicular, on both sides inclining towards the south, while those in the north were directly upright: the cause of which may well be explained by the obliquity of the magnetical curves, making still obtuser angles, with the meridian of the terella, as they are father from the poles.

* * * "But whatever may be the cause of it, if this be not, I have followed the old axiom of the schools, Entia non esse temere neque absque necessitate multiplicanda."

The fact that the earth's magnetic and geographic poles do not coincide, at once leads us to suspect that the needle cannot on the meridian point directly north

and south. Its departure from this direction actually exists and was no doubt the earliest experience of those who first made the great discovery of the directive property of a suspended magnet. The first recorded use of this most valuable discovery appears among the Chinese, where we find that "an apparatus of this kind (called *fse-nan*, indicator of the south), was presented during the dynasty of the Tscheu, 1,100 years before our era, to the ambassadors of Tonquin and Cochin-China, to guide them over the vast plains, which they would have to cross in their homeward journey. * * From its use on land the compass was finally adapted to maritime purposes, and under the dynasty of Tsin, in the 4th century of our era, Chinese vessels under the guidance of the compass visited Indian ports and the eastern coast of Africa." (12).

The mariner's compass was certainly known to Europeans in the 12th century, for in the great library at Paris is a manuscript poem called *La Bible Guyot*, written by Guyot, of Provins, about 1190, in which he speaks of it as well known. In this curious poem we find, in quaint old French, these lines:

"Un art font qui mentir ne peut,
Par la vertue de la marinière,
Une pierre laide et brunière
Où le fers volontiers se joint,
Ont, si gardent le droict point."

Guyot now tells how a needle which has been rubbed by the *mariniere* will point to the pole-star, and in the dark nights, without star or moon, will guide the mariner on his course.

"Quant il nuit est ténèbre et brune,
Quant ne voit estoile ne lune,
Lor font a l'aiguille allumer,

Puiz ne peut ils assorer,
Contre l'estoile va le pointe,
Par se sont il mariner cointe,
De la droit voie tems :
C'est un art qui ne peut mentir."

To one who loves his science it is pleasant to see the objects of his thoughts considered worthy of the poet's song, and I cannot here resist giving another extract, though neither it nor that of Guyot—to which it bears some resemblance—can really be said to form steps in the logic of my argument. Many years ago I cut these lines from the N. Y. *Tribune;* they are signed Ch. R. Clarke, Rochester, N. Y.:

"Ho, burnish well, ye cunning hands !
A palace home for me,
For I would ride in regal state
Across the briny sea.
Bring ivory from the Indian main
To pave my mystic floor,
And make my dome of crystal sheen,
My walls of shining ore.

Now mount the wave, ye fearful ones
Though raging storms assail,
My sparry lance o'ercometh all—
My strength will never fail.
The storm fiend wraps his murky clouds
Around your trembling sight,
But I can pierce that gloomy veil,
And soar beyond the night.

The lone enchantress of the deep,
I rule its boist'rous realm ;
Watch ye my lithe and quiv'ring wand
To guide your straining helm.
Aye, bend your anxious gaze on me ;
The polar star is dim,
And driven darkness is awake
With ocean's awful hymn !

For I commune with spirit forms,
Within my wizard cell,
And mantling midnight melts before
The magic of my spell.
By many long, enduring links
I clasp the northern star—
And on the wiry-shadowed chain
I visit her afar.

And sapient eyes have watched me long,
And science has grown gray,
And still ye dream not how nor why,
I keep my wondrous way.
Ye know me as ye know the storm
That heaps your heaving path,
Ye love me though, since mine is not
The mystery of wrath !"

The fact that the needle does not point at all places to the true north, was early known, but the discovery that it changed its direction with a change of place is generally attributed to Columbus (13); but this is incorrect, for the needle's departure from the geographic meridian (called its *variation*, or *declination*), is marked down for different points of the sea, on the atlas of Andrea Bianco, which was made in the year 1436; but what Columbus really did discover was a line of no variation 2½° east of the Island of Corvo, in the Azores, on the 13th of September, 1492 (14).

Some time after this, about 1620 (15), it was found that the needle did not keep one line of direction even in the same place, but slowly moved year after year. Thus it was found that in the year 1580 the north end of the needle at London pointed 11° 15′ east. In 1622 only 6° east; while in 1660 the needlo pointed due north and south. Then in 1730 it pointed 13° west; in 1765, 20° west; in 1818, 24° 41′ west; in 1850, 22° 30′ west, and in 1865, 21° 6′ west. Here we see in the needle a most remarkable motion, governed by some cause acting regularly through a long period of time, which after having given it a swing from the meridian to its extreme westerly position, in 158 years, is now slowly, year after year, throwing it to the meridian on its easterly swing. Thus, in about 320 years, it makes one oscillation; and what is yet more remarkable is this—*it follows the same kind of motion as a pendulum*; for from the figures, you see that it moves faster and faster, until it gains the meridian; then it slacks its velocity and gradually comes to rest at its extreme easterly or westerly position.

Surely this is a most noteworthy fact and well worthy of being studied and remembered. To impress this on your minds I have devised an experiment which shows this phenomenon in all the peculiarity of its varying velocity. It is shown to you not only to exhibit this great law, but also to illustrate to you the extreme mobility, the constant fluctuation, the regular ebb and flow of some mysterious unknown action which we *call* magnetism. I have here a heavy brass ring of 18 inches in diameter and weighing ten pounds. Fig. 7. Springing up from this are two metal semicircles which meet exactly over its centre. Through this point of meeting passes a steel axis, pointed at its lower end, which rests in a cup of agate placed in the top of this wooden column. This axis is a powerful magnet, and I place it on the column, near this lantern, so that its pole and the centre of the needle of the verticle lantern are in the magnetic meridian. You observe that the needle is at rest in this position, while the axis of the ring is vertical. I now set the ring in rapid rotation, and inclining its axis, I let it take care of itself. See how majestically it slowly

tilts its ring around the horizon, always keeping the same angle to it, while at the same time its magnetic axis revolves and swings around a vertical line. Thus the magnetic pole of this axis, revolving in a circle, is now to the east and now to the west of the undisturbed position of the needle, and you behold on the screen the lantern-needle, slowly swaying backwards and forwards, in subjection to the guidance of the revolving pole. And observe how completely it represents in a few minutes, what takes place only through centuries in the grand cycle of the needle's variation. The axis, in revolving around the vertical, has now gained its extreme easterly position, and the motion is nearly in a line with the length of the needle, and therefore the latter is at rest; but now the magnetic axis is moving westerly and the needle keeps pointing towards its pole, and is moving faster and faster, until now the axis is sweeping directly across the needle's natural position. The needle is with a gradually diminishing velocity approaching the end of its western swing, and now is again momentarily at rest, for the revolving pole is running on the western bend of its orbit. Thus every swing of the needle follows the same law of motion as rules the vibration of a pendulum, which is also the motion of the magnetic needle, as through 320 years it moves from one extreme side of the meridian to the other.

Various hypotheses have been formed to account for this wonderful phenomenon. As far as observations extend, they seem to show that the very magnetic pole of the northern hemisphere is revolving, in a direction opposite to that of the hands of a watch, around a fixed geographic point, just as you have in like manner seen the pole of this magnetic axis rotating around a fixed a vertical line;

and with this polar revolution the magnetic equator is supposed to tilt its plane around the terrestrial equator (17). Thus the change of position of the magnetic poles and equator (16), causes constant movements in the lines of the earth's magnetic force, and the needle, as we know, ever keeps its length in these curves. But the object of this lecture is not to prove, to support, or to discuss magnetic hypotheses, and I do not give this experiment as defining my opinion as to the cause of the needle's variation; but I do give it as showing in the most complete manner this *fact*—the constant fluctuation, the ebb and flow of the earth's directive influence. For picture to yourselves the magnetic curves of this axis as it sways around its circle; they move with it, and stretching beyond and enveloping yonder lantern-needle, it obeys their bends and flexures, and thus, as a matter of fact, the magnetic lines on the earth's surface sway and bend, though we may be ignorant of the present cause and future manner of such action.

If an elastic rod is clamped at one end and bent from its natural position, its free end will vibrate with a regular motion like a swinging pendulum; but it is also found that this free end may at the same time have shorter and quicker swings and carry these along in its main vibration. Thus, likewise, vibrates the magnetic needle; for this, in its 320 years swing, does not steadily move year after year or even day after day, but as Graham found, in 1722, makes in its grand vibration many minor trembles and deflections. Some of these follow regular laws, others follow no law, and are called *perturbations*. Among the former is the regular march of the daily vibration. This depends upon the apparent position of the sun, and therefore follows the

time of the meridian of the place at which the needle is observed. In the northern hemisphere, the northern end of the needle has its extreme easterly position 4 to 5 hours before midday; hence it begins to swing with an increasing velocity, which attains its maximum nearly at the moment when the sun crosses the magnetic meridian of the station. One or two hours afterward the needle comes to rest and soon after begins its eastward swing, and comes, with a slight secondary vibration, to its first position, about sunrise. The arc of the daily oscillation is small, only from 5′ to 25′; and its extent changes with the seasons, being nearly proportional to the diurnal arc described by the sun. Thus, from Dr. Bache's observations at Philadelphia, the mean daily arc of vibration for the year, is 7½′; for summer it is 10½′, and for winter it is 5½′. This daily vibration also increases from the magnetic equator to its poles. On the equator it is only 3′, while Dr. Kane found over 60′ at Rensselaer Harbor, north latitude 78° 37′.

Yet another cause, apparently removed from the earth itself, affects the magnitude of the needle's daily swing; which strange to say seems to depend upon the condition of the sun's surface. We owe this astonishing discovery to the labors of three men (18). First, Counsellor Schwabe, of Dessau, Germany, began in 1826, daily observations on the number, size, and position of the spots which are nearly always visible on the solar disc. With an admirable perseverance, worthy of his nation, he has kept these up for 46 years. This long siege at last made the sun reveal the order of his changing appearance; and in 1850, Schwabe announced that the amount of spotted surface which yearly appears on the sun, follows a regular law, going through a cycle in about 10 years. Thus in 1860 the number of spots visible was remarkable; but in 1865 very few were to be seen; after this they become more and more frequent, until in 1870 they again appeared in profusion. About the same time that Schwabe gave this discovery to the world, Professor Lamont, of Munich, announced that the daily range of the needle's vibration went through a similar cycle. Very soon afterwards Gen. Sabine, of England, discovered independently the same fact, which he deduced from magnetic observations made at places so far removed from each other as Toronto in Canada, and Hobarton in Van Diemens Land, and was thus led to refer the cycle to some cause exterior to the earth, and then pointed out the coincidence of the 10 year solar spot cycle and that of the magnet's daily range of deflection; which latter, at Göttingen, for example, is 4′ more during the year of the greatest number of spots than during the year of the least.

But we have said that the needle is subject to unruly vibrations, coming at unexpected times, and affecting simultaneously, magnets suspended at great distances from each other. These disturbances are often, though not always, accompanied by outbursts of the aurora polaris (19), and it has been observed that the regular flashes and lateral movements of the auroral columns are always accompanied by simultaneous deflections of the suspended magnet, (20)while the examination of extended series of observations on Auroras has evolved the remarkable fact, that they obey periods of maximum and minimum frequency, coinciding with the cycles of the solar spots and of the mean daily range of the magnet's vibration.

The direction of present research in these interesting

problems is to find a relation of concurrence between the sudden changes on the sun, now visible by the aid of the spectroscope, and sudden deflections of magnets suspended at many points on the earth's surface. This problem, however, is yet far from being solved, and I will therefore merely make this hint as to its attractiveness and importance (22).

Again let us return to the contemplation of our magnetic curves, whose paths have already conducted us to some very important truths. So valuable, indeed, is their guidance in nearly all precise and delicate research in magnetism, that their attentive study has become necessary to the further advancement of the science. Thinking, therefore, that a method by which they can be firmly fixed on glass plates, so that they may be securely kept for study and measurement, and also serve for lantern slides and photographic negatives, would be welcome to students of physics, I devised the following process (21). A clean plate of thin glass is coated with a firm film of shellac, by flowing over it a solution of this substance in alcohol, in the same manner as a photographer coats a plate with collodion. After the shellac film is hard, the plate is placed over the magnet, or magnets, with its ends resting on slips of wood, so that the under surface of the plate just touches the magnet. Iron filings, made from very soft Norway iron, are now uniformly sifted over the plate by means of a very fine sieve, and the magnetic curves are developed by letting fall, at different points on the plate, a light copper wire. The glass is now lifted off the magnet and placed on the end of a cylinder of pasteboard, which serves as a support in bringing it near the under surface of a hot metal plate. Thus the shellac is uniformly heated and the iron filings, absorbing the radiation, sink into the surface and are fixed. The plates can now serve (1) for the most accurate measures upon the magnetic field; (2) for a photographic negative, which in the printing-frame will produce the lines in white upon a dark ground, giving most beautiful and distinct impressions; or, (3) they can be used as "slides" for the lantern, and plates can thus be secured for exhibition to the largest audiences, and this is important, for it is not easy to obtain the best results in the quick experimentation required in a public lecture.

My assistant will now place in the lantern a plate which has fixed on it the curves of a straight bar magnet. Some of you will recognize this as the original plate of the engraving which illustrates Professor Tyndall's recent work, "Fragments of Science." From a photographic print from this plate Dr. Tyndall made his engraving. Fig 5.

Many philosophers have studied long and attentively these graceful, sweeping curves (23). You may ask, what can one arrive at by brooding over these forms? Let us see. As you know, a magnetic needle carried along a curve will always point in its direction, therefore these curves indicate the lines in which the directive force of the magnet acts, or, as philosophers are pleased to state it, they are the lines of resultants of the actions of the magnet; for the iron filings which trace them were when under the inductive action of the magnet, little magnets, and therefore trace these lines exactly as the tiny needle did in our previous experiments, when you saw it always placing its length in the direction of a curve. But they indicate more, far more, than this. That wonder of experimental fertility, Fara-

day, in 1831 (24), made this remarkable discovery, probably, the most subtile and far-reaching insight yet made into the mysteries of nature. He found that when a wire was closed on itself, forming what we call a circuit—that is, a metallic path along which electricity can pass—he found that when such a wire was passed along these curves, that is, without cutting any of them, that nothing happened, no electricity flowed through the wire; *but* when this wire cut across any of these curves, then a current of electricity traversed the wire going round and round as long as the wire was moved so as to cut these lines. Also, when the wire was moved, only in one and the same direction, then the electricity went in one direction through the wire, but, when the motion was reversed, the direction of the current was reversed also.

By this wonderful discovery—the production of a current of electricity from a magnet—the name of Faraday will ever remain illustrious. He did many good things, but this excelled them all! With a master's hand he traced the strong broad outlines of the truth, and for forty years philosophers have pondered on these facts and have made thousands of experiments, yet have failed to fathom their full significance.

Faraday termed these curves "the lines of magnetic force," and wrote much of them. Their contemplation constantly suggested and directed his researches, and one of his last papers was devoted to calling the attention of philosophers to the deep insight which their study would give into the manner of action of other radiant forces.

Let us consider them with more minuteness. You observe that this is the axis, or the centre line of the magnet; those lines run off in its direction; these appear to radiate or spread out, fan-shape, from its end, and when traced back they all converge to a point on its centre line called its pole. While these, which are further removed from the axis curve slightly in their upward or downward paths. Those nearer the centre are yet more curved, and following their direction, they lead us to points on the other end of the magnet, corresponding to those from which they emanated. But they all are curved and have their origin in the axis of the magnet and return to points on the other side of its centre symmetrically placed with those from which they emanated.

Viewing these lines, we are immediately struck with their analogy to the rays of light radiating from a luminous point, and would therefore naturally infer that the force expands itself in like manner, and produces less and less effect on one and the same surface as we recede from the magnetic pole. Experiment shows the truth of this conclusion, for we find that when we quickly cut across these lines, always making one and the same sweep, that the force of the electric current in the wire diminishes as we recede from the pole, just as the brightness of a light diminishes as we recede from it. But, in the case of light, if the rays are parallel the brightness remains the same whether we are at one foot, a thousand feet or several miles from the point of origin; so, in the case of the magnetic lines, if they are parallel, the magnetic intensity, as evinced in the electric current, remains the same at all distances. Also, if the rays of light converge, the brightness increases as we approach their point of confluence; so with the magnetic rays, their magnetic effect on one and the same body increases as we near the point of their convergence. Moreover, if a

beam of light of parallel rays have twice the diameter of another (from the same source), then the quantity light in the first will be four times that in the second beam; likewise is this the case with a bundle of parallel rays emanating from the magnet; a beam of twice the diameter of another giving a fourfold quantity of electricity. Thus is completely established an analogy, in intensity of action, between these magnetic lines and the rays of light, a fact easy to remember, and of great significance in all reasonings and researches on magnetism. But the main facts I have given we can establish for ourselves, and this I now purpose to do by experiment.

However, before we can attempt these experiments, it is necessary that we should clearly understand the experimental method by which we detect the presence of a current of electricity in a wire, determine what we call its direction, and ascertain its strength. All of these facts, of such fundamental importance for our further progress, are obtained by observing the deflections which a magnetic needle experiences whenever a wire carrying an electric current is brought in its vicinity. This most important discovery was made by Œrsted, of Copenhagen, in 1819, and since then many instruments called *galvanometers*, that is, measurers, of galvanic currents, have been devised by applying the following facts.

You observe on the screen the magnetic needle, supported on its steel point, around which it turns with the greatest ease. I will now bring quite close over it this copper wire, and stretch it in the direction of the needle, north and south. You now see on the screen the wire, one end only of which is at present connected with this small galvanic battery; when the other end is likewise connected, an electric current will pass, as we say, through the wire, and the needle will move. I now join the other end of the wire to the battery; look how the needle swings around tending to place itself athwart the wire. If I place the wire below the needle,—observe it swings in the opposite direction. Also, if the wire remains either above or below the needle, and I reverse the current, then the direction of rotation of the needle is reversed also. Therefore, if we pass a wire *around* a magnetic needle,—enclosing it in many coils—we have a most precious instrument, in which *the direction of the needle's deflection shows the direction of the current, and the amount of the deflection shows the intensity of the current.*

But, as you have observed in these experiments, the wire is either above or below the needle, and to render the latter sufficiently responsive to an electric current, the wire has to envelope it with many coils; but such an arrangement will completely hide from sight the motions of our lantern-needle. How then, can we show its motions to so large an audience? The idea of using a galvanometer in this lecture weighed heavily upon me after I had decided to work before you, for heretofore the usual method of exhibiting the motions of a galvanometer needle consisted in attaching to it a light mirror and observing the motions of a beam of light reflected from it; thus producing a faint patch, or brighter band of light, on the screen. On the inadvertent approach of somebody's jack-knife, however, or the handling of some distant magnet, in an experiment, and this patch of light is thrown off the screen, and is brought again to subject itself to our service, only after your patience and my lecture's continuity are lost. It

was thus evidently imperative that a new method of exhibition should be devised, and the result of the investigation is this galvanometer (25), which keeps the image of the needle itself always in full view, and exhibits and measures its smallest swings as its ends course round the divided circle you now see on the screen.

The plan of this instrument can be explained in a few words. You here see another vertical lantern, Fig 8. whose sides are made of thin mahogany boards so that the circumference of this horizontal condensing lens, *c*, over which is placed the graduated circle and the magnetic needle, may come as near as possible to the two vertica spirals, S and S, each formed of about 50 feet of $\frac{1}{10}$ inch copper wire. The two spirals, you observe, are so connected by a short copper wire, that a current of electricity revolves through both in the same direction. Whenever this takes place, the needle which swings between them instantly turns on its centre and from the direction and amount of its rotation, we have the direction and intensity of the electric current. Under the needle is this inclined mirror, M, which sends the rays from this lime-light up through the graduated circle to the lens, L, whence they issue to be reflected from the swing-mirror, R, on to the screen, where you now see the enlarged image of the needle enclosed in the graduated circle. But a magnetic needle kept in its meridian by the entire directive power of the earth would require a strong current of electricity to move it, and hence the usefulness of this lantern-galvanometer would be very much restricted. To render its needle more sensitive, we neutralize the earth's directive action on it by means of these two large bar magnets, A and B, which you observe on this board which forms the base of the lantern. The poles of these magnets point in the same directions as the similar poles of the needle, and thus they oppose the earth's directive action on the needle. By approching the magnets to the lantern the needle is rendered more sensitive to the current, and by rotating one or both of these magnets in a horizontal plane, we can immediately balance the magnetic disturbances inevitably produced in the coures of the experiments; such, for example, as happen whenever we bring into action our great electro-magnet; and thus, we have both the sensitiveness and the direction of the needle entirely under our control. Without the aid of this instrument the experiments which I will shortly make could not have been exhibited to you, and I therefore need hardly remark that this is the first time they have been evolved in a public lecture.

You will notice that the two iron cores of our great magnet are placed but to but, thus forming one bar of 7½ feet in length; its ends are terminated with these iron cones, which you observe projecting beyond the spools of wire which envelope all the rest of the bar. Close behind the magnet is this large screen. I now place in another ordinary lantern this glass plate, on which I have fixed the curves of a small magnet, whose form was exactly proportioned to the length and diameter of that long iron core of the electro-magnet. You now see the the greatly magnified image of these lines, appear to me actually as if formed by that electro-magnet, on filings which have been spread over the screen, but to those at a greater distance they seem to emanate from the core of the magnet, for the axis of the image of the lines and the axis of the magnet coincide. These lines, therefore, can serve as guides in working with the magnet's actual influence at a distance.

I hold in my hand a light wooden rod, attached to whose end is a ring of eighteen inches in diameter, formed of thick copper wire. Part of a long wire was bent into this ring and the remaining lengths were carrried down the sides of the rod and firmly tied to it. On the ends of the wire I fasten these binding-screws, from which wires can be led to the galvanometer-lantern. Thus I have made an electric wand, as wonderful as that of Prospero, for with it I also can catch the stuff that lightning is made of, and send it where I will. We will now begin work on these lines, or rather on what they so clearly map out—the rays of directive influence surrounding this huge magnet.

There are two ways in which I can cut through these "lines of force." First, we can, as you see, do so by moving this ring's centre over the line which is the prolongation of the axis of the magnet, thus; or secondly, by rotating this ring around an axis, thus;—and I have cut the lines fore and aft. By rotating this ring around *any* axis I can cut these lines as well; but I beg you to remark that during the following experiments, in which I will explore the magnetic condition of the space surrounding this bar, I will only rotate the rings I use around a *vertical* axis. The reason of this will soon be made evident to you. The plane of the ring now stands at right angles with the length of the magnet, and you observe the lines appearing to go through it. My assistant will now connect the ends of my wire-wand with the conductors leading to the galvanometer. I will now move the plane of the ring towards the pole of the magnet. See how the galvanometer-needle responds; its marked end moving upwards. The needle has now come to rest at its first position, though the magnet is active and the ring is, as it was during its motion, connected with the galvanometer; I wish you to remember this fact. I now move the ring away from the magnet; and you observe how the needle moves as I recede, and it now rotates in the opposite direction to what it did when I approached the magnet. I will now rotate the ring around a vertical axis, in the direction in which move the hands of a watch. The needle at the same time moves its spear end towards the ceiling. I reverse the motion of the ring's rotation and the direction of the needle's deflection is reversed also. Thus we have found that whenever the ring moves so as to cut the magnetic lines, an electric current is driven through it; and on the direction of translation or of rotation of the ring depends the direction of the current.

We will now gradually recede from the magnet, moving in the direction of its axis, and rotate the ring at various points of our progress. Here the needle, you observe, is not swung over so many divisions of the circle as when we revolved the ring at our previous station; therefore the magnetic influence is diminishing. I remove yet further and the needle swings less than before. I do not know that I shall get any deflection whatever at this distance; yes, but very little; the needle just nodded. Here, however, the needle responds to no motion that I give the ring. So far, then, extends the magnetism outward from that iron bar, but no farther. But may it not be that it is really here also, and that our means of detecting it only extend thus far in their indications. To test this supposition I will lay aside this ring of one turn of wire, and take up another, which is really a coil of nine turns of wire, and has a diameter of about 18 inches. Nine wires will now cut

twice the area of magnetic rays. Yes! the needle is deflected, and it replies even here—and here—but at this distance it barely moves; and here, the needle again refuses to notice the ring's rotation. But have we yet reached the boundary of the magnetic envelope of that bar? I will try again. I replace this coil by another, two and a half feet in diameter, and containing 40 turns of 300 feet of $\frac{1}{10}$th inch wire. I now hold this in a vertical position, with its plane perpendicular to the axis of the magnet. The ends of its wire are now connected with the galvanometer, and I rotate it about a vertical axis. Look! the needle moves. I recede to this position; even here the needle vibrates. I retreat to the extreme end of the stage, and even here the needle swings with the swing of the coil. But I can exalt the sensitiveness of the galvanometer a hundred fold by wrapping a coil of thick wire quite close around the needle; and then I can go to the farthest corner of this room, I can descend into the cellar, or place myself upon the roof, and yet in all of these positions the needle will swing to the revolution of the coil. The whole space enclosed by the walls of this house contains—is permeated with—something. It goes through your clothes, it penetrates your bodies and saturates your brains. It *must* do so; something must be all around us and within us, for surely out of *nothing* I cannot evolve *something*—a current of electricity; and a current of electricity is surely something; *it is everything*, physically considered; for it is a force, and will do work; it is a power, the product of the motion of the wire; for, without its motion the current will not be produced, and whenever the current is produced a break is placed on the motion of the wire —it requiring more force to turn the ring when the current traverses it than when it does not. In other words, part of the force which urges the rotation of the wire disappears but only to reappear in the motion of that needle, and in the electric wave which traverses the galvanometer and these conducting wires. "But," as Faraday observes, in speaking of these phenomena, "mere motion would not generate a relation which had not a foundation in the existence of some previous state; and therefore the *quiescent* metal [the ring] must be in some relation to the active centre of force" (26), [the magnet]. "He here," says Tyndall (27), "touches the core of the whole question, and when we can state the condition into which the conducting wire is thrown *before* it is moved, we shall then be in a position to understand the physical constitution of the electric current generated by its motion." Yet, is there not *something* existing in and around the wire "before it is moved," and through which, in moving, the wire experiences a resistance And does not the magnet either send out this something, or exerts on something previously existing around it, a peculiar action, which action constitutes the propagation of its distant effects? Surely, in the language of Newton, "that one body may act upon another at a distance through *a vacuum* and without the mediation of anything else, by and through which this action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be caused by an agent acting constantly, according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers." Yes, the whole of this building and the neighboring streets are permeated with

something—immaterial or material, I know not—emanating from this magnet or acted on by it. The street cars have run through it while I have been lecturing, and pedestrians have cut it with their legs in walking. What it is I know not: we *call* it Magnetism.

But if "the earth itself is a great magnet," it also must affect surrounding space—stretching thousands of miles from its surface—with this magnetic influence. The dipping-needle has shown us its lines of force. These lines, stretched above this stage, show as truly the direction in which its magnetism acts, as this plumb-line shows the direction in which gravity acts. If a dipping needle were carried all over the area of this city it would be found everywhere to point parallel to these lines. Let your imagination lead your minds along their paths into their heights above us, just as we have seen the long streamers of the polar lights tracking them out for us.

But if all this be so, then why can we not evolve a current of electricity from the earth's magnetism as we did from yonder magnet. That, indeed, would be a grand experiment! Let us hasten to try it. Here I have a coil of 300 feet of copper wire wrapped in a circle of 2½ feet in diameter. I place it thus, so that the earth's magnetic lines pass through its circle. You observe that its plane is at right angles to the direction of these stretched cords. The conditions, therefore, are absolutely those which we had when experimenting with the electro-magnet. Now, how will I cut these terrestrial lines? By rotating the ring around a north and south axis, just as we rotated this same coil around a vertical axis, when we obtained an electric current from the large magnet. The ends of the coil are connected with the galvanometer, and now look at the needle on the screen while I turn this ring. See, it moves! a current of electricity has passed round the coil and out of it into the galvanometer (28). Consider the simplicity of the apparatus which has given us the astonishing result. Nothing but a coil of wire and a galvanometer. No battery used, as in the experiments which explained the galvanometer to you. No magnet near, as when we got a current from that one. Yes, no magnet near—*but the earth* For now I can boldly say, "the earth itself is a great magnet," and not only a *great* magnet, but a *strong* magnet. Let us pit it against our magnet. How far shall we be obliged to remove ourselves from *it* to obtain the exact degree of deflection in that needle which the earth has just given? Then we can compare them; for, at the distance of so many feet from the poles of our electro-magnet, (the coil being, in reference to its poles, similarly placed with reference to the earth's), the force *it* sets in motion in this coil exactly equals the force which *the earth*, at some thousands of miles from its poles, sets in motion in the same coil. Let us make the calculation. Suppose we find from experiment that the force decreases in its action, as the squares of the distances we recede to, from the magnetic poles (29); that is, at a distance of 10 feet, say the force is one; then at 20 feet it will be $\frac{1}{4}$ of what it was at 10 feet; and at 30 feet it will be $\frac{1}{9}$th, and so on. Hence, the strength of our large magnet is to the strength of the earth's magnetism as the square of the distance of the coil from the poles of the electro-magnet is to the square of the distance of the coil from the poles of the earth. By such a rough measure we shall gain some idea of the enormous magnetic effect with which the earth influences surrounding space. Gauss, the illustrious German astronomer

and natural philosopher, calculated this quantity and taking as the unit of his measure a magnet of the size of this I hold in my hand—which is 14 inches long, one inch wide and $\frac{1}{4}$ inch thick, and weighs one pound —he found that the earth's magnetism is equal to 8,464,000,000,000,000,000,000 such magnets; that is, to this number of the hardest steel magnets, each weighing one pound, and made as strongly magnetic as possible. Gauss then states that if this amount of magnetism were equably distributed, throughout the mass of the earth, the magnetic intensity of each cubic yard would be equal to six of these one pound steel magnets.

But if the earth contains all this magnetism, from which we have obtained a current of electricity, is it not likely that some of our previous experiments with the electro-magnet were vitiated by this earth-current coming into our coil? This supposition explains why I always rotated the coil around a vertical axis; for, look, when I do so, I do not deflect the galvanometer needle, for I do not cut the magnetic lines in such a manner as to develop a current that can flow out of the coil, because the current in one-half of the circle of the coil is opposed to that generated in the other half, and they therefore neutralize each other.

In the experiments you have just witnessed, the electric current from the earth's magnetism produced a deflection of only 15° to 20° in the lantern-needle; but if I connect this coil with the delicate galvanometer in my laboratory, I cannot lift one side of it 6 inches above the table, thus, without giving the needle a deflection of 20°, and if I place the coil in a vertical plane and tilt it 8 inches towards the horizon, the needle swings through a quarter of its circle. With this coil and a sensitive galvanometer, the difficulty is not to produce these currents from the earth, but it is to prevent them from continually mingling with the other effects of your experiments.

The earth is indeed a powerful magnet. Then why not use the electric current we have evolved from it? Let us put it in harness and make it work for us! But to swing this coil is laborious, and to facilitate this I will strap it on this large wooden ring, and now we literally have it in harness. Let not this simple mechanical intervention between the coil and the galvanometer perplex you; in fact, it is only here to enable me to give a continuous revolution to the coil, and, by means of this brass circle and these metal bands to which its ends are connected, to cause the current evolved in it, always to issue from the same end of the coil. This current of electricity continuously evolved, can do many things: it can give out heat and light, and rend the elements of matter asunder; but the grandest application of electricity is to convey thought; and why not, then, convert our apparatus into a telegraph? Here, in this ring, is the generator, which produces an electric current directly from the earth's magnetism; here is the wire leading to the distant galvanometer. Here I separate the wire and reconnect it through a telegraph key, and behold "a needle telegraph." This wheel is now turned, and look! the needle goes from 0° up to 90°, and now it stands steady at 80°. We can easily make an alphabet: let one deflection to the left mean A; two, B; three, C; one to the right, followed by one to the left, D; one to the left, then one to the right, followed by one to the left, E; and so on. Thus we can form a series of signals that will spell out whatever we desire, and the galvanometer can speak for us through the deflection of the

needle produced by the magneto-electric currents of the earth. Now I will bring the needle from 0° to the left; it is coming 0°, and now I hold it there by rotating the coil, and thus opposing its motion. I now deflect it, one to the right, then one to the left, and so on. You see we have actually telegraphed with a current of electricity evolved from this great magnet, the earth.

Now we have finished our experiments, and what have they shown? I have temporarily magnetized a bar of soft iron by pointing it towards a pole of our large magnet. I did the same with the bar and the earth. I permanently magnetized an iron bar by directing its length towards the pole of the magnet, and vibrating it with a blow of a hammer. I did the same with a bar, struck when pointed towards the earth's magnetic pole. I have shown you the action of a small magnetic disc on iron filings, placed above and around it. You saw that the earth produced the same action on the beams of the aurora. I showed you the action of this disc on a freely suspended magnetic needle; and pointed out to you the earth's similar action on a dipping needle carried over its surface. I have evolved a current of electricity from a magnet by cutting with a closed conductor across those lines in which a magnetic needle freely suspended places its length. I did the same with the earth by cutting across those lines which are marked out by the pointing of the dipping needle. Therefore, what am I authorized to infer? When the effects are the same, the causes must be the same; for, according to all the principles of philosophy, and conformably to that universal experience which we call common sense, like causes produce like effects.

Have I not shown you that the earth is indeed a great magnet? But I hope I have shown you more—much more than this—for I trust I have given you an insight into those methods by which men of science work out great truths; and *Truth*, is of all value *in itself*, simply because it is truth; irrespective of any practical application it may contain. Yet the process by which we have been led to such grand results, teaches even more than I can express, and I retire behind the true eloquence of our great master of experiment, and leave you with these words of the good Faraday. "We learn by such results as these, what is the kind of education that science offers to man. It teaches us to be neglectful of nothing, not to despse the *small* beginnings; they precede of necessity *all great things*. Vesicles make clouds; they are trifles light as air; but then they make drops, and drops make showers, rain makes torrents and rivers, and these can alter the face of a country, and even keep the ocean to its proper fullness and use. It teaches a continued comparison of the *small and great*, under differences almost approaching the infinite, for the small as often contains the great in principle, as the great does the small; and thus the mind becomes comprehensive. It teaches to deduce principles carefully, to hold them firmly, or to suspend the judgment, to discover and obey *law*, and by it be to bold in applying to the greatest what we know of the smallest. It teaches us first by tutors and books, to learn that which is already known to others, and then by the light and methods which belong to science to learn for ourselves and for others; so making a fruitful return to man in the future for that which we haveo btained from the men of the past. Bacon, in his instruction, tells us that the scientific student ought not to be as the ant, who gathers merely, nor as the spider who spins from her own bowels, but rather as the bee who both gathers and produces." (30).

NOTES AND REFERENCES.

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(1) The full title of the folio edition of this work is "*Guilielmi Gilberti Colcestrensis, Medici Londinensis, De Magnete, Magneticisque Corporibus et de Magno magnete tellure; Physologia nova, plurimis et argumentis, et experimentis demonstrata. Londini Excudebat Petrus Short Anno MDC.*" "About the close of the 16th century, William Gilbert, a man who excited the admiration of Galileo [who said of him, "great to a degree that might be envied," *Cosmos* vol. 1, p. 170], although his merits were wholly unappreciated by Bacon, first laid down comprehensive views of the magnetic force of the earth. * * * Like other men of genius, he had obtained many happy results from feeble analogies, and the clear views which he had taken of terrestial magnetism, (de magno magnete tellure), led him to ascribe the magnetism of the vertical iron rods on the steeples of old church towers to the effect of this force. He, too, was the first in Europe who showed that iron might be rendered magnetic by being touched with a magnet, although the Chinese had been aware of the fact nearly 500 years before him. Even then, Gilbert gave steel the preference over soft iron."—Humboldt's Cosmos, vol. 5, p. 57.

"It is not saying too much of this work of Dr. Gilbert's to affirm that it contains almost everything we know about magnetism. His unwearied diligence in searching every writing on the subject, and in getting information from navigators, and his incessant occupation in experiments, have left very few facts unknown to him. We meet with many things in the writings of posterior inquirers, some of them of high reputation, and of the present day, which are published and received as notable discoveries, but are contained in the rich collection of Dr. Gilbert. Dr. Gilbert's book, although one of those which does the highest honor to our country, is less known in Britain than on the continent. Indeed, we know of but two British editions of it, which are both in Latin; and we have seen five editions published in Germany and Holland before 1628. We earnestly recommend it to the perusal of the curious reader."—Prof. John Robison—A System of Natural Philosophy. London, 1822: p. 209. Also, refer to Dr. Young's Lectures on Natural Philosophy, 1845: p. 583—to Sir D. Brewster, *Treatise on Magnetism*, Edin. 1851: p. 9. Whewell, *History of the Inductive Sciences*, vol. iii, p. 37; *et seq.*

(1) The lodestone is an oxide of iron ($FeO+Fe_2O_3$). We must not, however, infer that all specimens of *magnetic oxide of iron* are magnetic. The lodestone is black or deep brown; sometimes, however, it is of a lighter color. It is often cystalized in octahedra, more or less modified, or in rhomboidal dodecahedra. The best are homogeneous, with a fine-grained fracture, and susceptible of a beautiful polish. Their density varies, but is about 1.24. The magnetic ore generally occurs in primary mountains of gneiss; chlorite slate in primitive limestone, and sometimes in considerable masses in serpentine, and in trap. It is found in great quantity and purity at Rosslay, in Sweden, in Corsica, on the island of Elba, in Norway, Saxony, and in Bohemia. A hill in Swedish Lapland, and Mount Pumachanche, in Chili, are said to consist almost entirely of magnetic ore. Extensive beds of magnetic ore occur in various places in the United States, and at some of them are found masses of the mineral possessing polarity; such as those at Marshall's Island, Maine; at Magnet's Cove, Arkansas; at Goshen, Chester County, Pennsylvania; and at Franklin, New Jersey. "The most powerful native magnets are found in Siberia, and in the Hartz; they are also obtained on the Island of Elba." [Dana].

"Wolf mentions examples of natural magnets which could support, by means of an armature, from 16 to 40 times, and even 320 times their own weight. Dufay had in his possession a magnet of 9 lbs. in weight, which could hold 76 pounds. As a general rule, smaller magnets can support comparatively more than larger ones. Such, for example, as weigh from 20 to 30 grains will sometimes support 50 times their weight, whilst magnets weighing two pounds scarcely ever sustain 10 times their own weight. According to Dr. Martin, Sir Isaac Newton had a magnet which was set in a finger-

ring, and which, though only of 3 grains in weight, could hold 746 grains. In the philosophical cabinet of the University of Dorpat there is a magnet weighing 40 pounds, including the armature and the copper case, which is able to sustain 87 pounds. A still larger one is found in Tyler's Museum, which weighs 307 pounds, the armature inclusive, and holds more than 230 pounds. Not less considerable was the magnet which John [V], King of Portugal, received as a present from the Emperor of China, which weighed a little over 38 pounds, and was able [Feb. 1781], to support 202 pounds." Smith, Rept., 1863, p. 288.

(3) "The original plan and general idea of this instrument is due to Prof. J. P. Cooke, of Cambridge," who placed in front of the condensing lenses of an ordinary lantern, a mirror A, B, inclined 45°, as shown in the figure 1, which reflected the cone of rays to the object placed horizontally above it at C, whence the rays proceeded through the converging lens F, and were then reflected by the swing-mirror G to the screen on which the image of the object was formed. This arrangement was shown by Professor Cooke to Professor Morton during the summer of 1870. Subsequently the optical plan and general mechanical action of this instrument were greatly improved by President Morton, of the Stevens Institute of Technology, who separated the lenses of the condensers, placing the two back ones in the front of an ordinary lantern, with the lime light about two inches behind them. The curves of these lenses were such that a beam of nearly parallel rays issued from them to be reflected from the inclined mirror, A, B, to the front lens of the condenser, placed above it at C. Directly over C and quite close to it is placed the object to be thus illuminated. This separation of the lenses is of prime importance; for otherwise the field on the screen is contracted, unevenly illuminated and colored, whereas with Prof. Morton's arrangement we obtain a large colorless field, uniformly illuminated. See *American Gas Light Journ.*, April 3, 1871; *Amer. Journ. Sci.*, July, 1871, p. 71; *Quar. Journ.*, Oct. 1871, p. 561.

(3a) A. M. Mayer, Researches in Electro-Magnetism. *Amer. Journ. Sci.*, Sept., 1870.

(4) This most remarkable magnetizing power of an electric current was discovered by Arago in 1820, who found that as long as the current encircled an iron wire, the latter remained magnet-

ized, and that in similar circumstances a needle of steel received a permanent magnetic charge. The full development, however, of this discovery of Arago we owe to the genius of Professor Joseph Henry, who subsequently, in 1831, discovered the conditions necessary to obtain the greatest magnetic effect from any given bar of iron with any given battery; and guided by these discoveries he constructed a magnet which supported nearly three tons. Thus, to our countryman belongs the honor of being the first to present *freely to the world*, the knowledge of these fundamental facts—*absolutely essential for the subsequent invention of the electro-magnetic telegraph;* which invention, in all its essential principles, is also due to Henry, who, in 1832 at Albany, and during the following years at Princeton, exhibited his apparatus for transmitting electro-magnetic signals to a distance. Subsequently, Morse, backing his mechanical genius by an undaunted perseverence, succeeded in embodying the discoveries of Henry in his efficient invention which has given to American ingenuity such world-wide renown. The powerful magnet which I used in this lecture is essentially Henry's magnet of 1832. It differs from it only in having had removed from its iron cores their inactive central portions, and in the trivial difference of these cores being placed—merely for convenience—in a horizontal position. See Rept. of Regents, Smith. Inst., 1857, p. 85; *et seq.*

(5) This experiment, which appears to have all the beauty or simplicity and completeness, is due to Mr. W. E. Geyer, of Hoboken.

(6) *Amer. Jourl. Sci.*, April 1871, on Magnetic Spectra, by A. M. Mayer.

(7) Gilbert, in his *De Magnete*, Lib. i, ch. 1, says: "This is that Robert Norman (a good seamen and an ingenious artificer), who first discovered the *dip* of magnetic iron." Norman made this very important observation in 1576.

Gilbert Lib. v. ch. ix, gives an account and a wood-cut of a very ingenious experiment of his to show *the dip*. He perforates a cork-ball with a steel needle of such weight that the cork-ball and its transfixed needle will remain indifferently in any position in a vessel of water. He then magnetizes the needle, without removing it from the cork, and replacing it in the water it swings into the magnetic meridian and *dips*.

(8) On the remarkable chart of the New Continent, which was added to the Latin edition of 1508 of the Geography of Ptolemy, we find that north of Greenland (Gruentlant), which is represented as belonging to the eastern portion of Asia, the north magnetic pole is depicted as an insular mountain. Its position was gradually marked as being farther south in the *Breve Compendio de la Sphera*, by Martin Cortez, 1545, as well as in the *Geographia di Tolomeo* of Liveo Sanuto, 1588. The attainment of this point, called *el calamitico*, was associated with great expectations, since it was supposed, in accordance with a delusion which was not dissipated till long afterwards, that some *miraculoso stupendo effetto* would be experienced by those who reached it. *Humboldt*, Cosmos, vol. v, p. 55.

(9) The cosmographer Alonso de Santa Cruz, teacher of mathematics to the young Emperor Charles V., in 1530, and therefore 150 years before Halley, drew up the first variation chart, although it was certainly based upon very imperfect materials. Halley's attempts to combine graphically together by lines different points of equal variation was a very happy one, since it has given us a comprehensive and clear insight into the connection of the results already accumulated. My isotheral lines (that is to say lines of equal heat or mean, annual summer and winter temperature), which were early received with much favor by physicists, have been formed on a simlar plan to Halley's isogonic curves. Humboldt, Cosmos, vol. v. p. 59.

(10) *Humboldt, Cosmos*, vol. i., p. 179, note; vol. v. p., 90.

(11) *The Aurora Borealis, or Polar Light, its Phenomena ana Laws*, by Elias Loomis. Smith. Rept., 1865, p. 220.

(12) *Humboldt, Cosmos*, vol., v, pp. 50, 52.

(13) Robertson, *Hist. Amer.*, bk. II A. D. 1492. Irving, Life of Columbus bk. III ch. 2.

(14) *Humboldt, Cosmos*, vol. v, p. 54; p. 118, note.

(15) Dr. Thos. Young's Nat. Phil., 1845; p. 583. *Robison, Mech. Phil.*, vol. iv, p. 356.

(16) *Observations on the Magnetic Orbit;* by the Rev. H. Grover, Lond., 1850.

(17) See Sabine's Chart for years 1825 and 1837, in his *Contributions to Terrestrial Magnetism*. 1840. *Humboldt, Cosmos*, vol. i. p. 178.

(18) *Humboldt*, *Cosmos*, vol. v. p. 84.

(19) *Olav Hiörter* and *Celsius* at Upsala were the first who, in the year 1741, and therefore before Halley's death, confirmed by a long series of measurements and determinations the connection, which he had merely conjectured to exist between the appearance of the aurora borealis and a disturbance in the normal course of the needle. *Humboldt*, Cosmos, vol. v., p. 132.

(20) *Observations of the Variation of the Magnetic Declination* in connection with the *Aurora of Oct.* 14, 1870; *with remarks on the physical connection between changes in area of disturbed solar surface and Magnetic Perturbations*; by Alfred M. Mayer. *Amer. Jourl. Sci.*, Feb., 1871.

(21) *On a method of fixing, photographing and exhibiting the Magnetic Spectra*, by A. M. M.; *Amer. Jourl. Sci.*, April, 1871; *Phil. Mag.*, 4th series, vol. 41, p. 476.

(22) *Explosion on the Sun*, C. A. Young, Ph.D.; *Amer. Jourl. Sci.*, Dec., 1871, 3d series, vol. ii, p. 468. Compare this with *Magnetometer Indications on September 7th*, by C. A. Young, Ph.D.; *Amer. Jourl. Sci.*, 3d series, vol. iii., p. 69. Also refer to *Spectroscopic Notes* by John H. Leach, Jourl. Frank. Inst. June, 1872; *Nature*, June 13, 1872. *The Sun and the Phenomena of its Atmosphere*, Charles C. Chatfield & Co., New Haven, Conn., 1872, p. liv; and *on the Solar Corona*; *Amer. Jourl. Sci.*, May, 1871, by Prof. C. A. Young.

Professor W. A. Norton's theory of the Sun's Corona and its relations to the Magnetic action of the Sun is briefly this: the corona consists of matter in the same essential condition as the substance of cometary envelopes, and like this is in the act of streaming off to an indefinite distance into space, under the operation of a force of solar repulsion. As to the probable origin of the coronal matter, it is conceived that a portion of the sun's photosphere may be in the habitual condition of auroral magnetic columns, and that by electric discharges along these columns their substance becomes dispersed, and when thus dispersed becomes subject to the sun's repulsive

action. The initial velocities communicated by the electric discharges are chiefly in the directions of the prolongations of the original magnetic columns. In fact, by the process, these columns become indefinitely prolonged into space. They are seen at great distances from the Sun in the Zodiacal light, which owes its lenticular form to their convergence toward the plane of the Sun's equator. A portion of this auroral matter streaming away from the sun, falls upon the earth's atmosphere, and may furnish the substance of terrestrial auroras, for which no terrestrial origin has yet been detected. It is also conceived that by its impact it developes electric currents in the upper atmosphere (the region traversed by the electric currents of auroras), which are the principal cause of the *irregular* perturbations of the magnetic needle. Electric discharges along terrestrial auroral columns are another cause of these paroxysmal disturbances of the needle. The diverse phenomena of "Magnetic Storms" are thus to be ascribed to the descent into the earth's atmosphere of copious showers of the solar emanations of auroral matter. The more uniform magnetic action of the sun, by which the periodic disturbances of the magnetic needle are produced, may be attributed to the wave propagation of the impulsive actions on the ether of space, of the electric or eruptive discharges occurring at the sun's surface, and originating the material emanations.

This theory of the origin of the diverse perturbations of terrestrial magnetism has been elaborated and followed out into a detailed discussion of the variations of the different magnetic elements (see *American Journal of Science, March and July*, 1855.) It may be added that Prof. Norton's views are strikingly sustained by the general results arrived at by Professor Chambers, in his discussion of the "*Nature of the Sun's Magnetic Action*," viz., that "the mode in which forces originating in the sun, influences the magnetic condition of the earth, is not analagous to the action of a magnet upon a mass of soft iron placed at a great distance from it, but that these forces proceed from the sun in a form different from that of magnetic force, and are converted into this latter form of force probably by their action upon the matter of the earth or its atmosphere."

In his discussion of Terrestrial Magnetism and the Magnetic condition of the sun, in his paper on Molecular Physics, published in the Journal of Science, and republished in the London Philosophical Magazine, Prof. Norton endeavors to show that the earth and sun may derive their normal magnetic condition from electric currents developed in the mass of these bodies, having simultaneous motions of translation and rotation, by the impact of the electric molecular atmospheres against the ether of space; and maintains that the periodical variations of the magnetic elements at any locality, are partly due to the new electric currents that are thus being perpetually excited.

Read also, *On the origin of the Earth's Magnetism, and the Magnetic Relations of the Heavenly Bodies, by F. Zöllner, L. E. and D. Philosophical Magazine, May and July*, 1872.

(23) Gilbert, *Physiologia Nova de Magnete*, 1600. Muschenbroek, *Essais de Physique*. Fuss, *Coment, Petropolit.* Lambert; *Hist. de l Acad. Roy. Sci.*, Berlin, 1776. Playfair. Robison's *Mech. Phil.*, vol. iv., p. 350. Leslie, *Geometrical Analysis*, Edin., 1821, p. 399. Dr. Roget, *Jourl. Roy. Inst.*, vol. i., p. 311, 1831, and in *Nat. Phil.* of *Lib. Us. Know.*, vol. ii., article *Magnetism*, p. 19. Cellerier, *in De la Rive's Traité d'Electriaté*, vol. i., p. 592. Faraday, *Phil. Trans.*, 1852, p. 1. *Pro. Roya'. Inst.*, Jan., 1852.

(24) Faraday, *Exp. Resear. in Electr.*, London, 1849; vol. i., p. *Royal Society, Trans.*, 1832. *Phil. Trans.*, 1852.

(25) *On a new form of Lantern—Galvanometer. Amer. Jourl. Science*, by A. M. M., June, 1872.

(26) Exp. Resear. in Electr., vol. iii., p. 367. See also, *On the Physical Condition of a closed circuit contiguous to a permanent and constant voltaic current; or, on the Electro Tonic state.* By Alfred M. Mayer. *Amer. Jourl. Sci.*, Jan., 1871.

(27) *Faraday as a Discoverer.* Amer. edit., p. 132.

(28) Faraday, *Exp. Resear. in Electr.*, vol. i. p. 42 *et seq.*

(29) Tobias Mayer—in an important unpublished paper, read before the Roy. Soc. Göttingen, referred to by Lambert—showed in 1760 that the law of variation of the magnetic attraction corresponds to that of gravity. Lambert, *Hist. Acad. Roy. Sci., Berlin*, 1776; "a memoir," says Robison, which "would have done credit to Newton himself." Coulombe, *Roy. Acad. Sci., Paris*, 1786 and 1787.

(30) *The Life and Letters of Faraday*, by Dr. Bence Jones; Lond., 1870, vol. ii., pp. 403 and 404.

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BY

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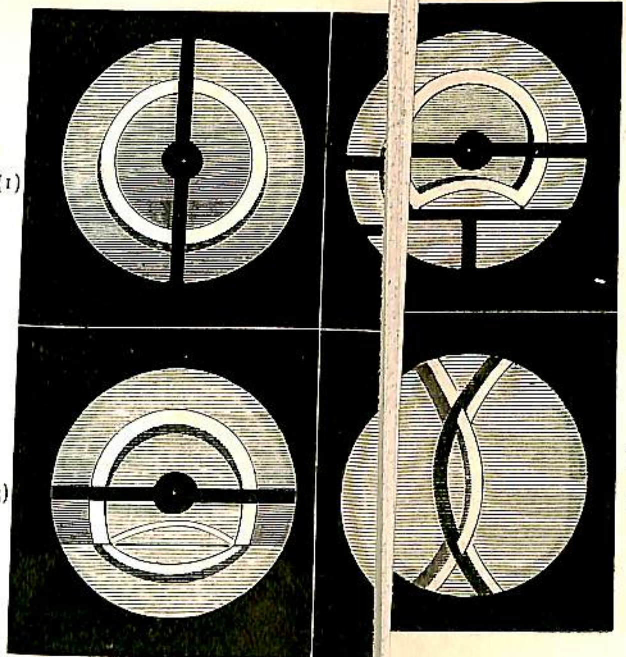
1873.

Sound Wave. (1)

Reflexion of a Sound Wave. (2)



Refraction of Sound Waves. (3)

Interference of two Sound Waves. (4)

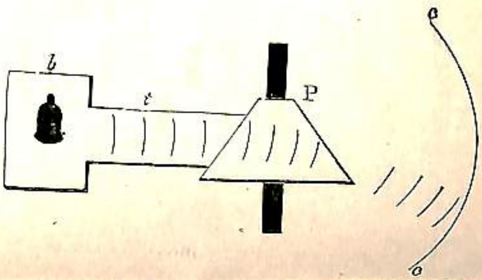


Fig. I.—About Refraction of Sound.

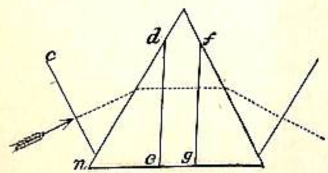


Fig. II —About Soldiers and Ploughed Field.

Fig. III.—About the Interference of Two Sound Waves.

Fig. 4.

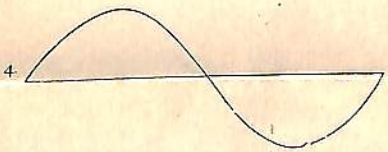


Fig. 5.

Fig. 6.

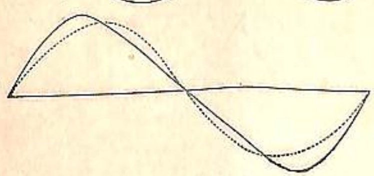


Fig. IV.—About the Combination of Waves of diff. lengths.

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Mysteries of the Voice and Ear.

Probably every person who is present to-night has at some time stood on a sea beach, and watched the long lines of advancing waves as they swept inward, only to be followed by others, in a perpetual, monotonous succession, so that it seemed as though the ocean was actually sending towards the coast vast masses of water from its inexhaustible magazines. But this beautiful appearance, like so much else in our world, is partly illusory; the water is not transported towards the coast, and if the tide happens to be ebbing, it may have a real, though slow, motion away from it. The waves are produced merely by a momentary heaping up of the drops of water, along a great line parallel to the shore—an instant afterwards the drops fall to their old level, and you say the wave has passed that spot.

Can, then, a mere up and down motion produce the appearance of an advancing wave? Yes, if that motion be executed in suitable time, as I will show in an instant; but let me first add, that the motion we are considering can also be reversed—the wave, after it has struck on a precipitous rock, is driven back from the shore, travels outward to the regions that gave it birth, its drops of water meanwhile remaining near their original positions, moving for the most part only upward and downward. (1.)
When this reversal of the wave's motion occurs, we say

that the wave of water has been reflected, just as the infinitely smaller waves we call light are reflected from a mirror.

Now this transmission and reflection of a wave I can easily show you, under circumstances which forbid the idea of any motion of transportation. I have here a very elastic cord or rope, made of brass wire, wound in a long, thin spiral, and when I strike it with my hand vertically, you see the wave which runs along its whole length, and then, meeting an obstacle in the hand of my assistant, who holds the other end of it, is reflected, returns to me, is again reflected, and so on, a number of times. But the particles of brass in this experiment are moved neither forward nor backward, they simply rise and fall. (2.)

Perhaps this idea may be made still more evident with a little apparatus I devised years ago. It consists of two pieces of window glass painted on one side with black varnish; from one of the glasses some of the varnish has been removed in vertical lines, while on the other a wave line has been traced by the same means. Placing one of these glass slides over the other, and then holding the combination in the magic lantern, it constitutes a convenient apparatus for exhibiting the nature of wave movement to a large audience, and as you see, we now have on the screen a row of small bright spots, intended to represent a line of material particles at rest. I can communicate to them a wave-like motion by moving one of the slides, so that we now have distinct waves advancing along their whole length, and although these waves are so plain, pray notice that each particle merely rises and falls, in suitable time. Hence to sum up: in the case of a wave of water, it is the

motion which advances, not the material, and this advance of the motion may be brought about as we have seen, by a movement of the material particles at right angles to the direction of the advancing wave.

Strangely enough there is another kind of motion, which can be communicated to a row of material particles, which also will generate along them, waves, but waves of a different character. In these new waves, which will give us so much occupation to-night, the particles are not pushed aside out of line, as in waves of water or light, but at one instant are crowded together, and afterwards fly apart, remaining, however, always in the same original line. I have contrived a little piece of apparatus which will make the nature of this singular action evident. We have upon the screen a row of spots of light, representing material particles, and you readily see how this alternate condensation and expansion affects them, and it is plain that they are transmitting a series of wave-like impulses. If you select any individual particle for observation, you easily notice, that at one instant it presses nearer its neighbors, and the next retreats from them, each particle beginning and ending this swaying motion in such time that the general effect is that of a wave in motion. I gave an experimental illustration of the first-class of waves with the brass cord, and will now add, that its spirals will just as easily transmit the waves we are now considering, though of course you could not see them. If you should hold the end of the cord, you would, however, be able to feel them, for when they struck your hand they would give it a little push and a pull. This thin elastic box will answer our purpose. I attach the end of the cord to it, and send along it one of these waves; as it strikes the box a sharp distinct sound is produced, in fact a series, owing to repeated reflections of the wave, which I generated merely bo pulling back with my finger nail for an instant, one of the spirals.

The air with which we are surrounded is capable of transmitting such waves as these, and when they strike upon our ears we say we hear a sound. I cannot at all to-night even indicate the experiments and reasoning which many years ago forced physicists to believe in the existence of these sound-waves, which they had never seen and never hoped to see; but perhaps we may do better than thus to consume our time. Let us ask ourselves, what ought to be the appearance of one of these sound-waves out in the free air, and we will suppose, for simplicity, that it is produced by a single impulse. You know that when a stone is thrown into a quiet pool of water, the wave which is generated is circular; it expands itself over more and more surface, but always retains the form of a circle; and analogy tells us that our sound-wave ought also to expand in a circle; that this circle should exist not only horizontally but upward, downward, in all directions, or that our wave ought to be bounded by a great many such circles. Now, bodies which are thus bounded we call spheres; the sound-wave ought then, to be round like a globe, and we must think of it as a kind of hollow bubble, which is swiftly growing larger. So much, theory would indicate.

Wonderful as it may seem, the recent advances of science have actually placed in our hands the means of rendering visible these waves of sound, and although it would be quite out of place for me on this occasion to enter into a detailed account of the method by which

this magical triumph was achieved, still you may be interested in a few hints with regard to the general line of thought followed by Prof. Toepler, to whom we owe these beautiful observations. (3).

A sound-wave consists, as we have seen of a layer of air which is more, and of another which is less compressed than the surrounding atmosphere—in fact, of a layer of denser and rarer air. Now, when light which is traveling through the atmosphere meets with a denser or a rarer layer, it is usually turned a little out of its straight path—a very little, but enough sometimes to render the layer actually visible, if proper optical means are employed. Let me give a rough experimental illustration of this: All the lenses of the magic lantern have been removed, and the screen is illuminated by rays of light which emanate from the ignited lime—that is, which come from one point. The jar in my hand contains a few drops of sulphuric ether, and the upper part of it is filled with its vapor, which, as you know, looks just like the air—that is, it is invisible—is, in fact, a kind of air itself, but denser than our atmosphere. When the jar is uncorked I can pour out this dense air, and you notice on the screen how the divergent beams of light render it visible: we see it streaming out, floating away, and can follow the wavy fluctuations it is subjected to by currents of air. If I had used the hot, rarer air which streams up from a candle flame, it would have been equally visible at a distance of many inches above the flame itself.

In our experiment we plainly saw the layers, which were denser than the atmosphere, by the aid of the deviation of the light which they caused, and it is very evident that if we could only isolate just the particular rays concerned, getting thus rid of the overpowering glare of the unaffected light, the whole phenomenon would have been far more distinct. Toepler contrived to do this very thing by the aid of a peculiar screen, and thus was able to deal with the far more subtle variations in density, involved in the case of a sound-wave.

But a steady light, like the one we have employed, would have been of no use in such an experiment; the sound wave travels as fast as a cannon ball, and a light of this character would render visible neither one nor the other. It should be illuminated by an instantaneous flash of light, so that the wave would not have a chance to move perceptibly while lighted up, and for this purpose the electric spark was just what was wanted. Let me make an experiment to illustrate this point: We have before us a disc six feet in diameter, which is being turned so rapidly that you cannot see the design painted on it; the disc looks merely gray. The gas-lights having been turned down, I illuminate our swiftly-spinning disc, from time to time, with the electric spark; it seems to stand still, and you readily see that it actually is painted in great black and white sectors. This talented young German physicist used then the electric spark to illuminate his sound-waves, and the snap of a second electric spark to generate them.

We have now upon the screen the greatly enlarged representation of one of these waves as seen by Toepler's method; it is spherical, as we expected, and beautifully shaded. (See frontispiece, Fig. 1).

But though the sound-waves move so rapidly it is not very difficult to measure their velocity, if they are allowed to run over the distance of a few miles. As is well known, this was accomplished in 1822 by some

members of the French Academy, using for signals the discharge of cannon in the night time, the difference of time between seeing the flash and hearing the report furnishing the desired information. Among the observers were Humboldt, Gay Lussac and Arago, though it is, perhaps, a little remarkable that to this important experiment, only two nights were devoted. (4). Besides this we have the more careful determinations made by the Dutch shortly afterwards, (5), and finally the experiments of Bravais and Martins, (6), who measured the velocity of sound in a slanting direction, from the Lake of Brienz upward to a station on the Faulhorn.

These last two observers proved that it travels with the same velocity in an upward direction as on a level, just as is required by the celebrated formula of Laplace. The result of these experiments is, that sound travels through our atmosphere at the rate of about 1,090 ft. per second, if the thermometer stands at 0° Centigrade, or at the freezing point of water; and that its velocity is quickened about 2 feet per second for each additional degree of heat. Recently several pieces of apparatus have been devised by which the velocity of sound can be measured, where the distance traveled over is only a very few feet, so that it is now possible to make this measurement in a very small room.

Suppose that we generate a sharp, short sound, at the open extremity of a tube, the other end being closed by a membrane; the sound impulse reaching the closed end of the tube would announce its arrival by giving the membrane a little push outward, and if we had fastened to it a pencil, this would be caused to make a mark on a sheet of paper at the same instant. Let us now imagine that we had, side by side, *two* such tubes, the second one being longer than the first, but bent so that both still terminated side by side, each with its membrane and pencil, and that finally our sheet of paper instead of being stationary were in motion. Then, under these circumstances, the sound-wave traveling through the shorter tube would make its mark first, and the paper would have a chance to move a few inches before receiving the pencil mark due to the companion wave, and if we knew the rate of the paper's motion, it is evident that we could easily calculate the velocity with which the sound had traveled through the longer tube. This explanation will give an idea of the general principle of a number of new contrivances, with some of which it is even possible to experiment at various temperatures, and on other gases than our atmosphere. A simple and cheap apparatus of this kind was, in 1866, devised by Dr. Ernst Neumann, (7), a school-teacher in Dresden; the difference in the paths of the sound-waves was about twenty feet, although the length of the apparatus was only three; the sound itself was generated by the discharge of a child's brass cannon. The paper was attached to a circular disc arranged like a common grindstone, with a handle which enabled the observer to rotate it. The disc was moved with a velocity of only one turn per second, which was rudely accomplished by watching a seconds pendulum, consisting merely of a ball or weight attached to a string and having a length such as to cause it to vibrate seconds. The mean of a number of observations gave a result far more accurate than could have been expected. I mention this apparatus partly because it illustrates so well the idea I wish to convey, and partly because of its simplicity and cheapness, which offer no obstacles to its introduction into

every country school, where any attempt is made to give instruction in physicis. Of course by causing the disc to revolve by clock work, it would be possible to greatly reduce the size of the apparatus, while at the same time increasing its accuracy.

Using the same general idea, but causing the sound-waves to act on little gas burners connected with the two membranes, in the same year Ivan Zoch (8) in Erlangen, contrived a far more delicate apparatus, with which he obtained results rivaling those of the French Academy in 1822, although in his case the difference in the paths was only three or four feet. With it he measured the velocity in various gases, and by driving a current of air through during the experiment, was actually able to ascertain the change due to this cause.

A somewhat similar idea was used in the same year by Prof. Quincke,(9) of Berlin in a very beautiful contrivance, where unlike the two preceding, the signal was given not to the eye but to the ear; the two sounds were made to destroy each other, producing silence, in a way which I shall presently explain experimentally. With this apparatus, Dr. Seebeck(10) has proved that in small tubes sound travels slower than in the open air, partly as it would seem owing to friction, and partly to loss of the heat developed by the sound wave itself, through conduction by the walls of the tube. He has also shown that in small tubes the velocity is less in the case of deep notes, than with those that are higher.

May I trespass on your patience to mention one more extraordinary set of measurements of sound-velocity, which recently were obtained by a scholar(11) of Professor Magnus in Berlin, who by indirect methods which I cannot now indicate, actually measured the swiftness with which the sound waves traverse as unlikely substances as stearine, parafine, wax and tallow! finding for example, that the velocity in wax was almost three times as great as in our atmosphere, the result differing but little from that previously obtained by Stefan, another German scientist.

Waves of light, we know can be reflected, and Toepler with his delicate apparatus was actually able to watch the *sound waves* in the act of reflexion; my copy of his drawing is now on the screen, and you notice that the reflected portion is spherical like the original wave. (See frontispiece 2.)

In still another matter the sound waves are found to obey the same law with the waves of light or heat. When I place this triangular glass prisms in the path of the rays of light issuing from the lantern, you notice that they are bent out of their original direction and now fall near the edge of the screen, an experiment so simple that a child could easily repeat it. Not so with the sound waves; owing to their greater length it is far more difficult to experiment on their refraction by a prism, though recently this has been successfully accomplished by an Italian physicist (12). Prof. C. Hajech generated sound waves in the interior of a box b by the aid af a bell which was struck by clock work; traveling along the tube t they reached the prism p, and were refracted by it as indicated in fig. 1. The amount by which they were bent out of their path was ascertained by moving the ear over the graduated circle c c which was in an adjoining room, till the position of maximum intensity had been ascertained. The sides of the prism were made of thin membrane, or paper, or finally of

sheets of mica. Experiments were performed on hydrogen, ammonia, illuminating gas, carbonic acid and on sulphurous acid gas. Besides these gases two liquids were also employed, ordinary drinking water and water which was saturated with common salt. Amongst other results it was found that the same prism refracted waves of different lengths, (or different tones,) alike. This is not the case with waves of light, for as you must have noticed in the experiment made a moment ago the blue rays were bent more than the red. Hajech farthermore by his measurements ascertained, that the sound refraction, in each case, took place in harmony with the well known velocities of sound in the different gases. Let me explain this; going back to first principles let us ask ourselves the question, why in general should waves of light or sound be refracted by a prism at all? Taking the most familiar illustration, we will suppose the line C N, fig. 2, represents a column of soldiers marching over hard ground in the direction indicated by the arrow and that they reach in a slanting manner a triangular ploughed field. It is evident that the soldier at N will be the first to reach the softer ground, and as he and his companions successively enter it, owing to its yielding nature their progress will be retarded, so that the men at C will all the while gain upon them, and by the time the whole column has entered the field, it will have been turned around somewhat and will occupy the position D E; while in the the ploughed field the column will advance parallel to itself; but on leaving it the soldier at F will now be the first to set foot on hard soil, so that he and his nearest companions will gain on those at G, and finally when the whole column is once more on hard ground, it will be found that it has been turned still farther around as indicated in the diagram. Substitute for the column an advancing wave of light or sound, and you have the explanation of their refraction by a retarding medium. To make the matter complete it is only necessary to remember that the forward motion of light or sound is always squarely in front of, or at right angles to the direction of the wave itself, a point which all of you have seen exemplified with the waves of water on a sea beach.

From this explanation it is very evident that the extent to which a wave of sound is refracted by a prism of glass depends on the retardation experienced in the prism, and knowing the velocity of the wave in the air and in the prism, and the angle of the latter, we ought to be able to predict the amount of its retardations and consequently refraction. As I have said, Hajech found that the calculated and observed results agreed remarkably well.

Toepler in his beautiful observations, also, after many attempts, was able actually to see the passage of a sound wave leaving the air and entering carbonic acid gas, and you notice the evident retardation which the wave is experiencing. (See frontispiece 3.)

I wish now to say a few words in regard to the inflexion of waves, or their ability to travel around corners. Waves of water as you all know, quite readily sweep around isolated rocks, the rocks unless quite large affording but little protection from their fury, casting let us say but little shadow, while in your ordinary experience you have noticed that waves of light do not seem to have any such tendency, a circumstance indeed which

was urged by Newton against the undulatory theory of light. But the waves of light are very minute, and to make a fair comparison we should also let them strike on small obstacles; when this is done, it is found that they readily sweep around them, and reuniting aftewards pursue their path unimpeded. But in the case of our sound waves all obstacles which we can conveniently employ are relatively speaking small, so that these waves experience not the least difficulty in passing around them, the obstacle itself casting almost no acoustic shadow, unless it has large dimensions.

Thus far we have occupied ourselves with single sets of waves, and have supposed the particles of air to be acted on by only one wave at a time—it will however more commonly happen that it is necessary to deal with particles which are at the same instant being acted upon by more than a single wave. Let us take the simplest case and suppose our particles acted on by two equal and similar sound waves: now it may happen under these circumstances that the two waves agree in their action, any particular layer of air being at the same moment subjected to a condensation or rarefaction from both these sources; when this happens the motion of its particles will be twice as great and we shall hear a louder sound. But something else is equally likely to occur: it may happen that just at the moment when the layer ought to be condensed by one wave, its companion attempts to rarify or expand it; these two motions will then neutralize each other, and instead of sound we shall have silence—a case where two sounds generate silence! I can illustrate this with these two similar organ-pipes which give exactly the same note; sounding them both together gives us a louder tone than either would furnish alone, and now after one or two attempts we have them both in action but furnishing only a faint sound; the silence is not quite perfect, but removing my finger from either of the keys you notice how much louder the tone becomes when we have only one set of waves. We can combine both these experiments into a single one, which though so well known always remains beautiful. I slightly alter the length of the waves furnished by one of the pipes: if now I start both sets of waves fairly together, the condensations and rarefactions being in harmony, this state of things cannot long remain, owing to the inequality in their length, as is shown in Fig. 3, where condensation is marked heavily, rarefaction lightly; already at 1 the condensation coincides with the rarefaction, farther on at 2, the old state of things has again returned, and the condition at 3 is the same with that at 1. Hence in our experiment we must expect to have alternations of sound and silence, the tone rising and swelling to a maximum, then dying away again to repeat itself, &c., and you notice how by slightly varying the length of the waves, I can cause this "beating," as it is called, to take place slowly or rapidly. When it happens slowly, we know that the waves are almost of the same length or the tones almost identical, while a greater difference in the notes instantly calls forth more rapid beats. These beats furnish even to the unmusical ear a most admirable and accurate means of judging of the identity of musical tones, and we shall have occasion to employ them later in some of the demonstrations I wish to make. Let me here introduce an experiment spoken of a few moments ago and which is calculated to de-

monstrate the *reflexion* of sound by the aid of interferences. Holding at arm's length this Ut3 tuning fork, I direct it towards the wall in front of me, and advancing cautiously soon find a position where the waves of sound reflected from the wall interfere with those which come to me directly from the fork, producing for my ear silence; going a step nearer the sound becomes louder, then fainter, etc., and I have found it possible to render these changes of intensity evident to six or eight persons at a time, they being arranged in line perpendicular to the wall and directly behind each other, their individual distances from the wall determining whether at any moment sound or silence was perceived.

Having advanced thus far, let us draw some comparisons between some of these matters common to light and sound. In the first place then, although sound travels so much more slowly than light, yet the extreme ease with which its velocity can be directly measured is not a little remarkable; the *direct* determination of the velocity of light on the other hand is one of the most difficult of physical problems, and its recent solution by Fizeau and Foucault, one of the most splendid triumphs of physical science. Again, to measure *directly* the refraction of sound is a troublesome work, and the results thus far gained, hardly equal in accuracy those which an intelligent child could easily obtain with a glass prism and a beam of sun light; the same may be said of the reflexion of sound, its study is laborious and difficult, and I think our intelligent boy with his bit of looking glass and beam of sunlight, would in a few minutes outstrip in results the work painfully accomplished by many eminent philosophers with the waves of sound. Then the inflexion of sound waves is something we cannot escape from, they are perpetually traveling around corners, but to make corresponding experiments on light requires some knowledge and experience, and there can be no doubt but that the very nature of our civilization has been remarkably influenced by this difference. Suppose that it were always possible to see a human being from any position in which you could hear his voice! And lastly in the matter of interference alone, perhaps light and sound stand more nearly on the same level. It is tolerably easy to observe this property with both kinds of waves.

Let us pass to another point. Waves of water as you well know, differ much in length, the great ocean waves stretching themselves out a hundred feet and more, while the tiny wavelets in quiet water often measure less than an inch. So it is with sound. The deepest tones of the organ, which are almost felt rather than heard, are produced by waves many feet in length, while the shrill sounds emitted by a child's whistle are due to waves only an inch or two long. The pitch of the note depends on the length of the wave; low notes are given by long waves, high notes by those which are short. I have here a couple of flute-organ pipes, which are so contrived as to furnish ærial waves of about twice their own length; this two-foot pipe is now sending through the house waves that are about four feet long, and when we compare them with the waves furnished by the shorter pipe, we notice that the latter note is just an octave higher than the first.

As we lengthen the waves, then, the pitch of the note sinks; when they do not attain a length greater than

about 28 feet, they can still produce the sensation due to musical sounds, but with a greater length the separate waves begin to be perceived as such and the height of the tone can no longer be estimated by the ear, and finally with waves about 70 feet, long the sensation of sound altogether ceases. In the other direction we have also a limit, and when the waves are as short as three or four tenths of an inch, they also cease to affect the nerves of hearing.

The long and short waves travel, however, with the same velocity, and when I sound the two pipes together both notes reach your ears at the same instant, and this would happen if you were a hundred times more distant from me. But in order to do this the short wave must take twice as many steps as its longer companion; it must in the same period of time excute twice as many vibrations; hence, finally, when long waves strike on the drum of the ear they cause it to vibrate slowly, while shorter waves compel it to vibrate more rapidly.

This leads us to the remarkabe conclusion, that if, by any means, we cause the drum of the ear to bend inward and outward, or to vibrate slowly, we shall perceive a *low* note, while, if the process be carried on rapidly, the sensation will be that of one which is *high*. I have here a brass wheel, originally contrived by the celebrated Savart, with its rim cut into teeth, and I can cause them to strike, one after the other, on this visiting card; when this is done slowly, the separate taps are distinctly audible over the whole house, but as I quicken the rate, the taps follow so swiftly that the ear fails to recognize them individually, and we have in their place a musical note—not quite pure—which, as you notice, rises and falls as I change the rate of the wheel's rotation. If this alteration in rate is effected rapidly, the sounds may be made, as you hear, to resemble human cries, not unlike those of infantile distress or anger. These sounds are sufficiently ludicrous, I admit, but they have for us an important lesson; they teach us that in this purely mechanical way, out of the taps on a card, it is possible to build up sounds which have some resemblance to those uttered by human beings!

I wish, in the next place, to make an analagous experiment, in which the resemblance to musical notes will be more complete. The little piece of apparatus I have in my hand is so contrived that, when set in operation, it allows the air to pass through it in puffs, like those of a tiny locomotive. With the organ bellows I drive a current of air through it, and now, leaning over it, I hear a succession of these puffs, which, as the current of air is increased, will follow each other more rapidly, and also gain in strength. We have at last a deep musical note issuing from it, which, as you notice, rises regularly in pitch each instant, becoming at last quite shrill and loud. The instrument was contrived by Cagniard de la Tour, and is called a syren, because it is capable of uttering its musical tones under water. It is provided with an attachment by which I could easily count the number of puffs emitted in a second, and thus determine the number of impulses due to a given note, and hence, knowing as we do the velocity of sound in the air, easily measure the length of the wave producing that note.

The circumstance that musical notes can be reproduced by a series of taps or other short quick sounds, has led to the construction of an apparatus which is something like an electric telegraph for sound. The

sound waves issuing from an organ pipe or the human voice, are made to act on a membrane, which by its vibration breaks and re-establishes an electric current, and this latter acting on a rod of iron at a distance of say 300 feet, calls forth from it a corresponding series of taps, and hence reproduces at this distance to some extent the same musical sounds. This is the "Telephon" of Reis, which although still far from perfect, has at least been so much improved recently that it can be used by others besides its inventor, though I do not think that we can hope ever to see it transformed into a true telegraph of sound. (13)

But we must pass on to the consideration of another matter, and will return once more for an illustration to our waves of water. While out at sea, those of you who were able, must have noticed that the large waves of water, which lifted and rolled the ship, were for the most part not simple in form, but covered with minor wavelets which carved their surfaces into ragged and ever changing outlines. They demonstrate for us the possibility of the coexistence of two or more sets of waves, and show us the manifold forms assumed by water acted upon by several independent wave-like impulses. I have in my hand a large tuning-fork which is vibrating in a certain way, and by drawing the fork over this smoked glass, the little wire attached to it renders these vibrations visible, and we have them now delineated on the screen under the form of a straight band, which consists of a multitude of minute waves. But I can also communicate to the fork a second motion, still preserving the first, and you see it has traced on the screen a series of larger waves, whose mountains and valleys are built up of the little undulations. Just so it is with the waves of sound; they are often, indeed almost always, thus broken up, it being seldom that simple sounds produced by smooth, clean cut waves reach the ear. Let me give some experimental examples: I sound this mounted tuning fork; it furnishes us with a pure note, and you can observe its quality. This (flute) organ-pipe gives the same note a little mixed with the higher octave, but this reed organ-pipe, which also gives the same fundamental note with the other two, has an entirely different sound, and one might imagine its note was an octave higher than those of its companions; but the notes are the same as is announced by these beats, which I produce by sounding any two of the instruments together, and then lowering the note, of one of them slightly, by holding my hand near the top of the pipe.

The reason of the difference in the case of the reed-pipe is simple; it generates not only the four-foot waves of its companion, but many other sets which are shorter, waves which give the octave, the next higher duodecime, &c. The fundamental or lowest note of the pipe, being mingled with all these noisy companions, fails of course to produce as decided an impression on the ear as otherwise would be the case. Now these reed pipes, with their train of multitudinous notes, have for us, as speaking human beings, a particular interest, and we must pause for a minute to examine their construction. They consist of a vibrating tongue down at the base, which lets the current of air from the bellows pass through in puffs, and generates a set of tones, after the manner of the syren, except that the tongue remaining of the same length, the set of tones is always the same; whereas the tones of the syren, in my experiment, were always changing.

But can each of these ærial pulses generated by the vibrating tongue really contain a series of waves having different lengths? How is it possible that they all can coexist at the same moment, since the particles of the air certainly cannot actually move at the same instant in two different directions. The experiment with the tuning fork and the smoked glass demonstrates practically the possibility of coexistent motions in a very simple case; there the lengths of the two waves and their heights differed so greatly that you all easily recognized both in the compound curve, which looked like a single wave drawn with a trembling hand. But cases may happen where the resulting curve while it contains two waves of this character, at the same time conceals them. The curves now on the screen are quite definite in character and are known as sine curves; (figures 4 and 5;) figure 6, (the unbroken line,) is produced by combining figures 4 and 5 together; in it we fail to recognize the smaller curve, though it is virtually present and inevitably makes its appearance when we attempt to analyze fig. 6 into two sine curves. The dotted line is the same with figure 4, and shows the degree of variation produced. We might by a process of construction, easily add to fig. 6 a third, a fourth, indeed any number of constituents, each a new sine curve, our resulting curve always assuming a new shape, and a patient analysis of it would finally reveal the presence of all these additions. By the selection of suitable and numerous sine curves even forms can be produced where the likeness to the original shape is quite obliterated and the curvature replaced by straight angular lines. Hence if we should see a wave having a form similar to figure 6, (unbroken line,) we should be justified in saying that it virtually contained the waves in fig. 4 and 5, and that our angular wave also virtually contained a very much larger number of constituents of the same general character. All this applies directly to the first class of waves with which we were occupied to-night, but it is no less true of waves of sound. Here we have also a typical form of wave for our point of departure, where each particle swings backwards and forwards obeying the mathematical law which regulates the swings of a pendulum, and this typical motion we can modify at will by causing the particles to be simultaneously acted on by a second, a third, or any number of other waves having different lengths, and as we shall hereafter see, the unaided ear instantly analyzes the complicated resultant wave into its simple constituents.

It is then by the discontinuous action of the vibrating tongue in the reed pipe that complex waves are produced, consisting virtually of several sets which vary greatly in length, and they are afterwards strengthened or weakened by the pipe; by altering the shape and size of the pipe you can strengthen or weaken particular notes which are present, and thus give the sound a different quality, without necessarily altering the pitch of the proper or fundamental note. I have here three reed-pipes which give exactly the same fundamental note, but the quality, as you notice, is quite different—one of them giving trumpet-like tones, while the others resemble in sound the hautboy and clarionet.

It was remarked that reed-pipes have an interest for us, and it is because the human vocal apparatus is essen-

tially built on the plan of a reed-pipe; the membrane in the throat called the "vocal cords," corresponds to the vibrating tongue, and the cavity of the mouth and nose has the same functions as the pipe. The section of a head on the screen shows the relation of these parts.

Let us make some comparative experiments: I have here the vibrating tongue or reed, without its pipe, and driving the air of the bellows through it, can, by varying the acting size of the tongue, draw from it a series of different notes, which have a quality that is evidently due to complexity; none of the notes sound in the least like that of the tuning fork. Corresponding to this I have in my hand artifical human vocal cords made of sheet india-rubber, and as you hear, can by stretching them more or less, draw from them a series of inharmonious semi-human tones, which break up from time to time into an inarticulate howling. I add to my reed a short conical pipe; the quality of its sound is entirely changed, although the fundamental note is unaltered; and opening and closing it with the hand, I easily cause it to pronounce the words, "Ma, Ma." Next I supply my artifical vocal cords with a short broad pipe or cylinder (slightly conical), and they easily utter sounds like "Pop-par." Removing the cylinder and substituting for it this glass flask, we have it pronouncing the words "Pa, Pa," with a somewhat nasal twang.

All this shows that by varying the shape and size of the pipe, or the cavity and opening of the mouth, without in the least altering the fundamental note, we can strengthen or weaken particular sets of the higher notes which accompany it, and thus entirely alter the quality of the resulting sound.

Many years ago, Willis, in England, found that by mingling certain tones produced by reed-pipes, the vowel sounds could, to some extent, be imitated, but more recently the subject has been examined with great care by Helmholtz, (14), Germany's greatest living physicist.

Let me attempt to convey an idea of the mode in which Helmholtz's analysis of the vowel sounds was performed. You all know that light can be analyzed with a prism of glass and separated into its constituent colors, red, orange, yellow, green, blue and violet. Now, though sound can be refracted by a prisim of gas just like light, it is not possible in this way to analyze a mixed sound into its components; here the prism fails us. But there is another method of analyzing a beam of light and ascertaining its composition: we have now upon the screen a beam of purple light; I hold in my hand a piece of stained glass which will transmit only rays of red light. Let me try to send the purple light through the plate; if *red* rays are present they will easily traverse it, and we shall see them on the screen. Making the experiment then, you see evidently that our purple beam contains red light. Let me now test it with a glass which transmits only green rays, and the result is darkness; evidently green rays are absent; and, now, finally, trying this blue ammonical solution of copper, which stops all rays but the blue and violet, we find that *they* traverse it with ease, and hence conclude that our purple light contains red, blue and violet rays. Now Helmholtz contrived for musical notes pieces of apparatus, which correspond to our plates of stained glass, but vastly surpass them in accuracy of action. These most important instruments he called reasonators; they consist of hollow spheres or cylinders having a definite

capacity, and provided each with a mouth or opening of a certain size, and any one of them has the remarkable property when applied to the ear, of rendering the experimenter comparatively deaf to all notes but one, and of greatly strengthening that particular note so that attention is instantly called to it when sounded. I have often amused myself by observing the recurrence of some particular and unconspicuous note during the performance of a complicated piece of music, indicating by a gesture its presence to the musicians, and I can easily show you that one of these resonators actually strengthens the note to which it is attuned, while paying but little attention to other tones. This tuning fork is in vibration, and the sound is too feeble to be heard beyond a very few feet, but when I bring it near the open side of the resonator, the sound is rendered audible over the whole house; trying forks which give other notes you notice that no such strengthening is produced.

The analysis of the tones of the human voice offers greater difficulty, than other sounds of corresponding complexity, from the circumstance, that from chilhood up we all have been accustomed to regard its tones, each as an independent whole, making no attempt to ascertain the musical components employed in any particular case, and hence for its tones the use of resonators became all important. With the aid of these instruments, Helmholtz proved that the vowel sounds are produced by the presence of a fundamental note, mingled with higher harmonicals in various proportions. He even ascertained that the intensity of the *highest* tones varies somewhat in different individuals, being greater in voices that are shrill, than in those whose sound is softer.

Having gone through this labor the same physicist undertook the artificial reconstruction of the vowel sounds. To accomplish this in a scientific manner it was of course necessary to employ pure tones, and these are most easily obtained by the use of tuning forks. One of these instruments, alone by itself, furnishes, as you notice, a sound which at a little distance is quite inaudible, but by causing it to vibrate directly in front of a hollow metalic cylinder of exactly the right capacity, its sound is greatly strengthened, and can now be heard in all parts of the room. The cylinder is entirely closed, with the exception of a circular opening at the end, near the fork, and in general apppearance resembles a fruit can. When the fork is caused to vibrate thus in connection with a resonator, the sound is instantly extinguished if the aperture be closed, but as it is gradually opened the sound correspondingly gains in intensity, hence it is evidently in the power of the experimentor to regulate the loudness of the tone produced. A tuning-fork, however, soon ceases to vibrate, accordingly it is to be provided with a contrivance to obviate this difficulty. By placing it between the arms of an electro-magnet, having the form of a horse-shoe, it can be caused to vibrate for any period of time, provided the magnetic attraction is intermittent and always exercised at exactly the right moment. This is accomplished by breaking and re-establishing the electric current with the aid of a second tuning fork, which vibrates at exactly the same rate, and the second fork, being also provided with a similar electro-magnet, is able independently to maintain itself in vibration for any length of time, just exactly as is the case with the vibrating attachments so often found on electrical apparatus intended for medical

purposes. If now with this arrangement, we should attempt to sustain in vibration a third fork, whose rate was *a little* faster or slower than that of its two companions, the result would be a lamentable failure; not so, however, if the rate should happen to be exactly twice, three, four times as great, for then the attractive impulses though fewer in number than might be desirable, still would always be rightly timed. It hence is evident that a series of forks whose rates of vibration are as 1, 2, 3, 4, &c., can be kept simultaneously in vibration for a long period by a contrivance of this kind. And this plan was actually employed by Helmholtz in his celebrated apparatus for the reproduction of the vowel sounds out of pure constituents. Keys were connected with the valves of the cylinders, and pressure on them, opening the resonators, produced the proper notes with the desired strength. Helmholtz's apparatus as made by Mr Kœnig of Paris, so celebrated for his acoustic instruments, consists of eight tuning forks with their resonance cylinders, the fork which establishes and regulates the current, being on a separate stand. These forks give the following notes Ut_2, Ut_3, Sol_3, Ut_4, Mi_4, Sol_4, Ut_5, the eigth giving a tone intermediate between the two last. (15.)

When all these tuning forks are caused to vibrate by the electro-magnets, their resonance-cylinders remaining closed, only a low humming sound is heard, but by pressing one or more keys, the corresponding sounds are called forth with any desirable degree of strength.

Thus the German vowel sound U can be imitated either by sounding the ut_2 fork alone, or better by adding in small proportion ut_3 and sol_3. O is obtained, with a weak ut_2 and strong ut_4; ut_3, sol_3, and mi_4; mingling to a small extent.

The German A, with ut_5 and mi_4 strong; ut_3, ut_4, sol_4, being moderate in strength. In the same language the Æ is given by mi_5 and sol_5 strong, with the notes ut_4, ut_5, sol_4 weaker, and finally the E by the aid of sol_5, si_5 flat, and ut_6, strong, ut_3 and ut_4 being weaker. (16.)

Of course, inasmuch as only pure musical notes are employed they can reproduce only the musical constituents of the vowel sounds, hence the effect resembles the sound of the vowels as sung rather than pronounced.

When, then, a human being utters merely a vowel sound, its production requires that the cavity and opening of the mouth should have exactly such a size and shape as strengthens the appropriate notes to the proper degree, so that it is indeed no wonder that an infant requires the practice of a year or two before becoming practically familiar with these delicate operations, the real wonder being that children ever learn to talk at all, for the construction of the consonants is far more complex, and although we know for the most part the manipulation necessary for their formation, their composition, so far baffles all attempts at exact analysis. (16.)

Corresponding with these remarkable experiments, Helmholtz also found it possible to imitate with the same apparatus certain varieties of organ pipes, at least, to reproduce the musical constituents of their tones, though, of course the *noise* with which they are often accompanied was absent; he in addition, imitated the nasal tones of the clarionet, by the use of a portion of the forks, while the joint action of the whole set gave the softer tones of the bugle-horn.

This apparatus of Helmholtz, as would be supposed, is somewhat difficult of manipulation, and an attempt has been made by Appun to replace it by a series of reeds provided with resonators. (17.)

I must here mention the remarkable results, attained in the last century, by Professor V. Kemplen, in Vienna, with his Speaking Machine, which more recently has been greatly perfected by the two Fabers, uncle and nephew. (18.) A few weeks ago the latter kindly exhibited to me this wonderful apparatus, which is capable of uttering, not only syllables, but words and sentences, with great distinctness and a soulless precision, such as we might attribute to the handiwork of a Frankenstein, its laughter being particularly demoniacal—or shall we say idiotic. In it the vocal human organs are directly imitated, and it is remarkable that it is operated on by only fourteen keys or stops, which give the five vowels and the nine consonants, L, R, W, F, S, B, D, G, Sch. The other consonants are produced partly by combinations of the above, and by increasing the strength of the current of air from the bellows. Mr. Faber has, also, after many attempts constructed a singing machine, which, by means of quick changes in the form of the vocal cords can rapidly run through the musical scale.

These illustrations will serve to give some slight idea of the mode in which we speak, and I now pass on to the consideration of that wonderful and mysterious apparatus with which we receive and actually analyze the sounds that are presented to us. We have on the screen a plan of the ear, not a correct drawing, for that would be so complicated as to be of little use. The sound-waves enter the outer ear, and strike on this not tightly-stretched membrane, which we call the drum of the ear, and cause it to vibrate, to bend inward and outward, keeping exact time with the sound vibrations themselves. To this membrane, as you see, are attached three little bones, called, respectively, the hammer, the anvil, and the stirrup. The membrane shakes the hammer, the hammer beats the anvil, the anvil vibrates the stirrup, and the stirrup sets in vibration the water in this strangely-shaped cavity, which is colored blue for distinctness. In this cavity, which is not without its unsolved mysteries, the nerves of hearing terminate, and transmit from it the sensation of sound to the brain. A simple arrangement of the kind indicated would transmit to the brain, merely a general sensation of sound, just as the blind on turning their eyes to the sun, have a general sensation of light; but what is the apparatus which enables us to distinguish between different sounds, high and low notes, and notes of different quality? Let us place this question distinctly before ourselves; but before answering it, allow me to repeat for you a beautiful experiment of Tyndall's which has a bearing on its solution. We have here a tall gas flame issuing from a jet, (which was made and given to me years ago by Prof. Mayer of Hoboken,) and I now arrange the pressure on the gas, so that the flame is almost ready to flare or vibrate, of course at a rate of its own selection, and if I send to it sound vibrations of its own chosen kind, it will instantly acknowledge the relationship—it will shorten itself, flare and roar. It pays, for example, no attention to the sound of this two foot organ pipe, but, as you see, instantly responds to the least sound from the bunch of keys. I pronounce to it the vowel sounds; it is evidently deaf to the German U, does not pay much, attention to O, more to E, I, and much more to the sound Ah. As you see, the least hiss, even from this distance, causes it to roar. So we find in a general way, that a stream of gas can be set in vibration by the sound-waves which it has a tendency itself to generate.

But still more accurately to the point is an experiment with two similar tuning-forks, which I now wish to make. Here are two tuning-forks in all respects alike, mounted on their boxes, and exactly in unison. When I set one of them in action, the feeble sound vibrations, travel through the air, and set the second fork with all its mass of heavy steel also in vibration, simply because it naturally vibrates at exactly the same rate, for owing to this fact, the transmitted vibrations always reach it at the right instant for coöperation, all conflict being avoided. But in this large house the greater number of you would not be able to hear the feeble vibrations of the second fork, and I have contrived this delicately suspended mirror, which, hanging by a hair that is fastened above and below, can be set in motion by the least vibration of the fork in contact with it. The mirror reflects a beam of light on the screen: it is now stationary; but the instant the bow is drawn over its companion, it begins to move, and the motion becomes each moment more violent, till now the spot of light sweeps over the whole screen, and you notice that even at a distance of several feet we have the same result reproduced. By the use of a single silk fibre instead of a hair, the delicacy of the aparatus is so greatly exalted as to render it unfit for a locality like the present. I slightly lower the note of the first fork by loading it with a nickel cent, attaching it with wax, and observe that the second fork with the mirror, now pays no attention to its call; the spot of light remains stationary.

Let us make an application of our experiment. In the ear, in the strangely shaped cavity, we find a multitude of very small elastic rods fastened at one end, just like our tuning-fork, and, like it, capable of vibrating only when the particular notes to which they are tuned are struck. When this happens to one of these rods it is set in vibration, and affects the delicate nerve fibril connected with it, and we have the sensation due to a particular rate of vibration, due to a particular note. A drawing of some of these rods enormously magnified is on the screen. But for the full illustration of this matter, I need yet one more experiment, and must ask you to make it for me when you go home this evening. Open a piano, and while pressing with the foot on the right hand pedal, pronounce in a clear loud voice over the strings, for example, the vowel sounds, and you will find that the strings, which are capable of giving the notes of which they are built up, will be set in vibration, and will echo back in a far off, ghostly way, the sound you have just uttered. So in all probability is it in the ear; for we find there, locked up in its bones in the strangely shaped cavity, an instrument with not less than 3,000 strings, tuned, as we believe, to different notes, and connected with different nerve filaments, ready to transmit to the brain the sensations due to different tones. A drawing of a portion of this wonderful contrivance which has been particularly described by the Marchese Corti, is on the screen, and some of the strings can be seen. Its probable action is as follows: When a sound composed of a number of notes, reaches it, the compound tone is analyzed into its constitutents, the corresponding cords vibrate, as in the piano experiment, and by their action on the nerves, reproduce the appropriate sensations. (19.)

The two contrivances I have described are well fitted to make us sensible of sounds which are sufficiently pro-

longed to allow of the reception of a certain number of vibrations by the sympathetic apparatus in the ear, but in those cases where the vibrations, though powerful, are very few in number, it is probable that the cords and rods would fail to take cognizance of them; that is, they are probably deaf to short, quick sounds, generated by a single blow or impulse, such for example as the electric spark, and yet it is just these sounds which often announce the presence of danger. This case has also been provided for—curiously enough, by introducing into the strangely-shaped cavity, small, rather heavy, solid bodies, which *will not* vibrate readily or easily. In certain parts of the labyrinth, we find particles of calcareous sand imbedded among the delicate nerve filaments, whose office it is to resist their motion, when they tend to vibrate along with the water which fills the cavity, and acting as drags to stretch, and thus stimulate them into activity.

I hold in my hand a long india-rubber string stretched by a weight: if I raise the string slowly, the weight readily follows, and the string is not elongated more than before, but when I attempt suddenly to raise the string the weight resists, the string is greatly lengthened, and it is possible by a quick jerk to cause it, as you see, to separate from the weight. The last form of hearing apparatus is the simplest, the least elaborate of the three, and we find it among the lower animals, where the more complex contrivances are to a greater or less extent absent.

Thus it would seem that nature has provided man with a most elaborate and complicated piece of apparatus, with which it is practicable to perceive and distinguish several thousand simple tones, and the number of their possible combinations is, of course, infinite. Think of the delicate care required to keep such an instrument in order, its strings properly weighted and stretched, its rods all in tune, day after day, during the process of growth and waste, to which it, like the rest of the body, is constantly subjected! It gives us no care, we never think of it as in our random way we supply ourselves with such food as we fancy, some of which is sure to be required for its use, and to become eventually incorporated into its tissues—by the aid of an unseen, unfelt hand, whose delicacy of operation surpasses our thought. And with what may seem to us a certain prodigality, we must reflect that the Creator has also bestowed this same beautiful and complicated apparatus, not only on the wildest of savage men, but likewise on many of the higher animals—"brutes that perish"—and with the same fond, all-embracing care, preserves it for them in order during their lives.

The pictures produced on the retina of the eye are evanescent, vanishing with the light which generated them, and the vibrations in the ear which give us the sensations of particular sounds die away with their cause, leaving behind absolutely no record, for that which we retain in the brain, is the recollection of a *sensation*, not of the vibrations which gave it birth. Hence, we must regard with interest and curiosty the beautiful apparatus of Scott and Kœning, with which it is possible to register these vibrations, even when produced by rather complicated sounds; Scott, indeed, hoped at one time, thus to obtain the autographs of sounds uttered by the human voice, though this has been found practicable to some extent *only* with the simple vowel sounds, for which the

celebrated Donders obtained definite curves, and more recently determined the actual *duration* of one of the vowel-sounds in certain words. (20). We must, perhaps, the less regret our inability to record all sound-vibrations, from the circumstance that the curves thus produced, would by their great complexity defy analysis, by anything short of angellic intelligence.

If you were to tell a thoughtful man who happened to be quite ignorant of the mechanism and action of the voice, that there were living beings who endeavored to express their wishes, thoughts, and feelings, merely by the aid of mechanical vibrations, thus causing the particles of the air to swing like invisible pendulums, backward and forward in certain ways, your listner would be impressed by the poverty of the device, and would too hastily conclude, that only a few of the simplest and rudest ideas could possibly find expression by the aid of a contrivance so clumsy. He would tell you it was conceivable, perhaps, that by appropriate vibrations the idea of joy, or rage, or fear, or possibly of hunger, might be imperfectly expressed, with a few others of like character, but that to expect more would be visionary. He would urge that all vibrations were necessarily so similar in general character, that it would be impossible to communicate to them the stamp of thought or feeling. And yet how wonderfully each one of us employs just such vibrations, and with a skill which seems truly superhuman impresses upon and commits to them an infinite variety of thoughts, feelings, and ideas which at times we pour forth in torrents that seem inexhaustible; the vastness of the result attained, the poverty of the means are utterly overwhelming!

Think, also, for a moment of that gift by which we read the stories written on the invisible waves of the air, how we instantly interpret and disentangle their complexities, as they roll in towards us, thousands in a second, with the velocity of rifle-bullets. The power to hear and speak are gifts, which, from purely physical and mathematical standpoints, are absolutely magnificent! And we the possessors of such powers? Is it conceivable that they have been bestowed on us only to be used as at present? Do they not point to a future for our race when they will be employed in a manner which better accords with their inexpressible richness and grandeur?

Notes and References.

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(1) The constitution of waves of water was carefully examined by the brothers Weber, and their remarkable investigation while adding greatly to our knowledge of the subject, at the same time has shown that here, as elsewhere in nature, complexity is the rule, simplicity only apparent. Troughs provided with glass sides, and about six feet in length were employed, the wave being generated at one end by means of a tube containing a column of water of a certain height. The sudden fall of this liquid gave the required impulse with accuracy; the wave was then observed through the glass sides by the naked eye or with a low-power microscope, which was provided with a simple micrometric attachment. In order to facilitate the study of layers below the surface, the water held in supension small fragments of amber, which made visible the motions of the liquid.

In this manner they found that the particles of water when traversed by waves do not merely rise and fall, but at the same time have a motion backwards and forwards, which would assign these waves a position intermediate between those of sound and light. In point of fact they described ellipses, when the waves were perfectly regular in form; when however this regularity was absent, other curves not returning into themselves were generated. In these experiments the mountain was always in advance, unless the wave was generated not by the fall of a column of water, but by effecting with a little pump its sudden *rise*; in this latter case the valley formed the advancing front of the wave. Finally it was ascertained that the surface-waves affected the particles of water under them, to a depth of not less than 350 times the height of a wave. Many of the phenomena are beautifully illustrated by an ingenious apparatus which a few years ago was contrived by Prof. Lyman of New Haven. American Journal of Science and Arts, Vol, xlv., p. 384.

(2) This simple and beautiful apparatus which never fails to excite admiration, and which may be used for many other experiments besides those here described, seems first to have been contrived by Prof. Kirchoff. The one used by me was made and placed in our physical cabinet by Prof. Eli W. Blake.

(3) Poggendorff's Annalen der Physik and Chemie, 1867. Bd. cxxxi, S. 180.

(4) Ann. de chim. et de phys. T. xx, p. 210. Their result was $331\frac{2}{10}$ metres, at a temperature of 0° cent.

(5) Pogg. Ann. Bd. v, S. 351, 469. The result was $332\frac{26}{100}$ meters at a temperature of 0° cent.

(6) Pogg. Ann. Bd. lxvi, S. 351. The result was $332\frac{37}{100}$ meters at 0° cent.

(7) Pogg. Ann. cxxviii, S. 307.

(8) Pogg, Ann. cxxviii, S. 497.

(9) Pogg. Ann. cxxviii, S. 177.

(10) Pogg. Ann. cxxxix, S. 104. Compare also the experiments of Regnault on this subject. Comp. Rend, t. lxvi, p. 209, also those of Kundt, Pogg. Ann. cxxx, S. 337, and finally those of H. Schneebeli, Pogg. Ann. cxxxvi, S. 296.

(11) Emil Warburg, Pogg. Ann. cxxxvi, S. 285. Placing the velocity of sound in glass=1, it was found in Stearine=0.265, in Parafine 0.251, in Wax 0,168, and in a mixture of wax and turpentine 0,111, and in tallow 0,075. The velocity in the glass employed was 15.65 times that of sound in the air.

(12) Pogg. Ann. ciii, S. 163.

(13) For an account of this apparatus, see "Die neueren apparte der Akustik," by Prof. Fr. Jos. Pisko, page 94. This work is quite indispensable to those who wish to be acquainted with modern progress in the department of sound.

(14) Die Lehre von den Tonempfindungen, by H. Helmholtz, p. 163.

(15) Rudolph Kœnig, No. 30 Rue Hautefeuille, Paris. Ut_2, gives 128 double vibrations and corresponds to litlte c or c°.

(16) These combinations are token from the work of Pisko, already referred to (p 27), and merely transposed half a note, so as to suit the apparatus, made by Kœnig.

(17) The morning after the delivery of this lecture I received a work by Dr. Oskar Wolk, entitled "Sprache and Ohr," which contains the results of an elaborate attempt at acoustic analysis of the consonants, directed particularly to the determination of the pitch of their predominating notes.

(18) See Dr. Wolf book, page 11.

(19) "Der Mechanismus der menschlichen Sprache nebest Beschreibung einer sprechenden Machine von Wolfgang v. Kempelen, Vienna, 1791.

(20) Hensen was able was with the microsope to observe this action in the external auditory apparatus of certain Crustaceans. V. Hensen, Studien über das Gehoerorgan der Dekapoden. V. Siebold u. Kölliker, Z. S. J. wissench. Zool. xlll.

(21) F. C. Donders with the phonautograph of Keonig not only found that each vowel sound gives a particular curve, but determined the duration of A in the words, daag=42, dagen=37, dag=16 vibrations, each single vibration cousuming $\frac{1}{216}$ of a second; so that the actual durations are 0.16, 0.142, 0.061 of a second of time. Nederl. arch. voor Genees—en Natuurkunde ii. 466.

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