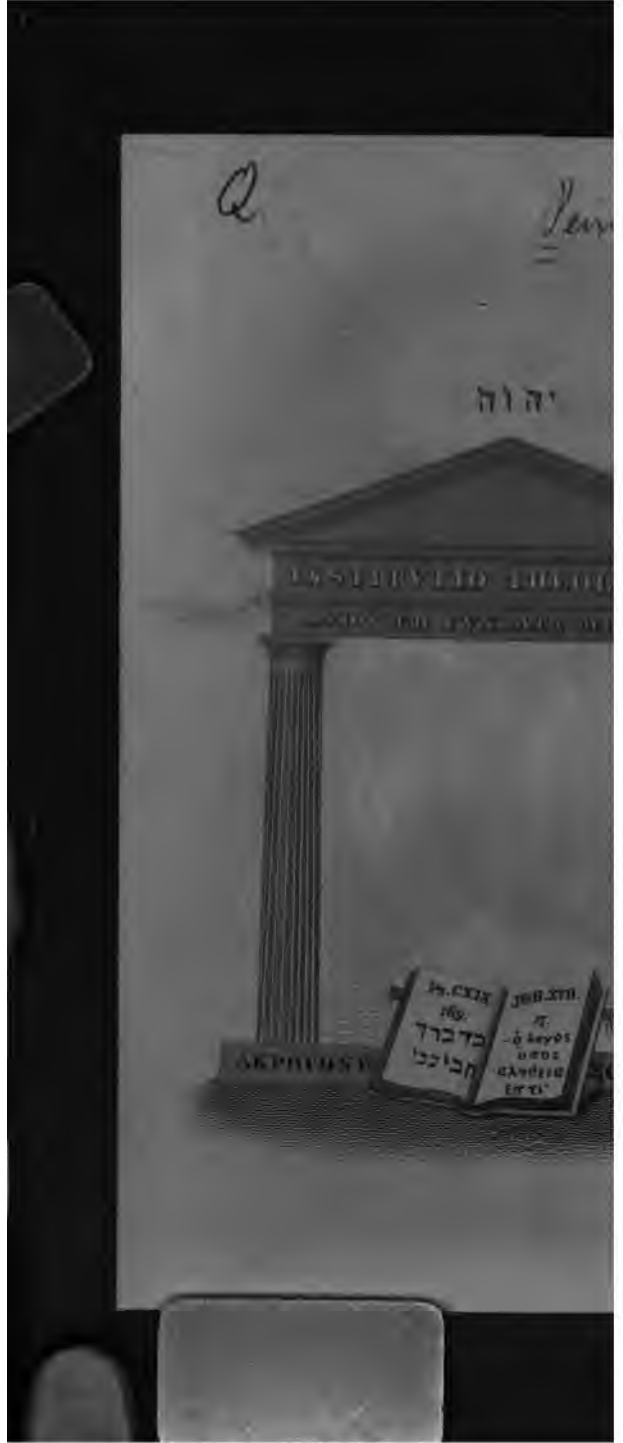
IDEALITY
IN THE
PHYSICAL SCIENCES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IDEALITY

IN THE

PHYSICAL SCIENCES

BY

BENJAMIN PEIRCE

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I Dedicate

THESE LECTURES

TO MY WIFE

WITH MY WHOLE HEART

BENJAMIN PEIRCE

Cambridge, 790320

EDITOR'S PREFACE.

In the winter of 1877–78, Mr. Augustus Lowell proposed to my father to deliver a course of lectures at the Lowell Institute in Boston, and suggested his taking the occasion to express his views on the true attitude of science towards religion, and to discuss other subjects of wide interest, falling within the range of his lifelong thought. My father was already sensible of the weakening and dispiriting influence of ill-health. He was little accustomed to write out his public addresses, or even his communications to scientific societies, and he greatly shrank from that labor; while in this instance he was unwilling to trust, in any considerable degree, to the utterance of the moment. But he could not long hesitate to accept the opportunity — his last, as he expected it to be, and as indeed it was — of appearing before the general public, to advocate that high conception of the functions of science which he always earnestly

maintained, to offer his own contribution to the great theory of evolution, and to testify his unwavering faith in the ultimate advantage to religion of every movement of scientific thought.

He limited himself to a course of six lectures, and devoted his leisure during the year 1878 to preparing the contents of the present volume. The lectures were delivered in February and March, 1879. They were also given, a year later, at the Peabody Institute in Baltimore; and two or three of them were read occasionally in various private circles. It was a great satisfaction to my father to have given this final expression to some long-pondered views, for which he felt, as he used to say, all the anxious tenderness of a parent; and it is pleasant to remember that the kindness of his public towards these children of his brain was a bright source of happiness to him in his last years.

The plan of publishing the lectures was entertained and abandoned at several different times. Shortly before his death, my father thought of printing separately the first, second, and sixth lectures; and he prepared them for the press with that view, so far as any writing is prepared for the press before the actual printing begins. He early concluded not to publish the third, fourth, and fifth lectures till he had worked out more fully the form of the meteoric

theory there broached, and its relation to the nebular theory. He wished also to subject to careful revision his criticism of other writers. But he left the question of the publication after his death of these, as well as of the other, lectures to the discretion of his family; who feel that, — however some details of statement or of argument may have been liable to modification, if a final consideration had been given to the work, — all the lectures have too high an interest in their relation to the mind of their author, too much real value in the way of suggestion to other students of the physical constitution of the universe, and too excellent a quality as popular expositions of the great theories with which they deal, not to be invested with the permanent definiteness of print.

In editing this volume, I have ventured on none but unimportant alterations, chiefly slight verbal changes in the three unrevised lectures. I am responsible for the foot-notes, which undoubtedly, in the main, name the authorities my father had in mind, but perhaps in some instances err by excess or defect. For the appendix, also, I am solely responsible. Throughout, I must ask the indulgence of the reader in view of the difficulty of the questions that can hardly fail to arise in the case of a posthumous publication.

The lectures, as originally delivered, were profusely illustrated by diagrams and familiar explanations at the blackboard. The words used in these parts of the lectures were extemporary; and the manuscript is continuous and complete without them. Nor do I greatly regret my inability to add to the scientific and philosophical discussions here presented matters which, though serviceable in the lecture-room, might have appeared as intrusions in the printed form.

J. M. PEIRCE.

HARVARD UNIVERSITY,
12 May 1881.

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IDEALITY IN THE PHYSICAL SCIENCES.

I.

IDEALITY IN SCIENCE.

Ladies and Gentlemen:

It would not be unjust in you to demand an apology of your lecturer for the seeming inconsistency between his customary labors and the subject of his lectures. Enter his workshop; open either of the worn volumes on his table. It is filled with figures. From the beginning to the end it is a mass of figures. Inspect his manuscript. Figures everywhere! nothing but figures! Where is the ideality in this monotonous repetition of the nine digits? You might as well hope to find it in the lawyer's plea, or in the doctor's prescription, or in the balance sheet of the merchant; or statesmanship in the cobbler's stall; or charity in the miser's pocket; or a

sweet perfume pervading the laboratory of the chemist. Nevertheless, you cannot think that any man, with a man's soul in his body, could devote his life to the drudgery of addition, subtraction, multiplication, and division, for the mere pleasure of the thing. To accumulate coin, men have degraded themselves lower than the beasts. But to accumulate useless figures is a martyrdom which is beneath man's lowest folly.

There are people whose habit it is to count each night up to ten, or twenty, or even to more than a hundred, in order to induce drowsiness, — to quiet the ghosts of the day's unburied cares and secure a healthful sleep. An endless sleep would be the legitimate termination of an incessant, objectless, and fruitless counting. Computation is not barren when it supplies subsistence; it ceases to be an unmitigated evil when it is dignified by ministering to the necessities of material life and comfort. But the computation of the geometer, however tedious it may be, has a loftier aspiration. It provides spiritual nourishment: hence it is life itself, and is the worthy occupation of an immortal soul. The arith-

metical formula, considered as an end, is the embodiment of fact, and isolated fact is as worthless as the idle gossip of the parlor or the club; whereas facts combined into formulæ and formulæ organized into theory penetrate the whole domain of physical science, and ascend to the very throne of ideality.

A celebrated philosopher has advanced the theory that every science has its three successive stages, which he designates as the theological stage, the metaphysical, and the positive. In the theological stage, each phenomenon is referred to the direct agency of divinity; in the metaphysical stage, abstraction takes the place of deity in the development of phenomena; but in the positive stage, facts constitute the whole of science, without regard to any question of theological creation or of abstract generation. The theological stage becomes perfect when all the gods are reduced to one God; the metaphysical stage is perfect when all the abstractions are comprehended in the one abstraction of Nature; the positive stage will be perfect when all facts are resolved into one fact.

Our philosopher regarded the positive stage as the only one entitled to a profound and philosophic study; and such seems to be the final verdict of physical science. We must recognize the initial attraction to the human mind of the theological form. Mind irresistibly seeks in mind the primitive source of power. Hence arise the gods created by men, which are finally recognized as shadows. Earth-born, their images of clay are broken, and they are at last dethroned. Their places are occupied for a time by the equally shadowy and inefficient, though it may be high-sounding, nomenclature of metaphysics. But the inevitable end of science is pure fact, with its indisputable generalizations and irresistible laws. Where then is the ideality?

What is this which we call fact? It is not a sound; it is not a star. It is sound heard by the ear; it is a star seen by the eye. In the simplest case, it is the spiritual recognition of material existence. One moiety of it may be of the earth, earthy; but the other moiety is essentially mental and dependent upon the constitution of mind. There are

even physical facts of which the knowledge is wholly mental, and of which there is no direct evidence to the senses. They are directly known only to the few who have the logical training to follow the argument by which they are demonstrated; and indirectly to those other few who have the loyal faith to trust the testimony of the geometers. It is undoubted that there are sounds which are inaudible to some ears, and colors which are invisible to certain eyes. It is equally undoubted that there are innumerable vibrations, coursing through space, which make no sensible impression on any auditory or visual organ or on any human nerve. Such facts, known through our powers of reasoning, are to us non-existent, except as pictures on the imagination.

You remember that soul of Laura Bridgman, almost hermetically sealed from external impressions and the recognition of other minds. You remember with what incredible patience, untiring skill, and loving assiduity of the great-hearted philosopher she was educated into humanity. Observe the peculiarity of her perceptions. They scarcely

extend to the direct observation of outer Nature, and are mostly restricted to the artificial signs addressed her by others. Yet such is the constitution of her mind, so harmonious is it with all our minds, that through these narrow avenues intellectual intercourse is possible. How different from that of the dog, whose intelligence you applaud! How immeasurably superior to the horse, who perceives and obeys the intention of your finger! or to the bird, who imitates your voice! Their restricted brains exclude imaginative speculation and consecutive discussion, and include no foundation for rational conversation. The brute endowed with perfect senses is alive to all physical impressions, but is subject to the monotonous limitations incident to its want of ideality; whereas the poor girl, confined to the minimum of sensation, and awakened from her solitude by the friendly taps which bring the only light to her perpetual dungeon, can expand in a spiritual universe as full of thought and knowledge and poetry and religion as our own.

Independent of this ideal element, which

we see to be inseparable from fact, and additional to it, the classification and generalization of facts, their combination and reduction to fewer facts, and their arrangement in series are processes which are not performed automatically in the laboratory of Nature. They are the intellectual result of profound thought, enduring research, and fruitful imagination. To translate a great poem demands months and years of earnest devotion, coupled with poetic inspiration. But to read the book of Nature is the province and privilege of consummate genius, submissive to unremitting discipline.

When Kepler undertook the investigation of the motions and order of the planets, he was under the influence of a species of superstition, which may have been a remnant of the theological romance of the ancient science; and he expected to find a reproduction or image of some innate ideas in his own mind. While this expectation partly emanated from the gross astrology by which he computed his almanacs and sought to read the story of individual life and of national events in the aspects of the stars, it also partook of an exalted faith, anterior and superior to all

science, in the existence of intimate relations between the constitution of man's mind and that of God's firmament. The study of the geometric solids had fascinated him, and especially the doctrine of the spheres circumscribed and inscribed to polyhedrons. He hoped to find in them indications of the arrangements of the planets. His search was vain. He found rude approximations to the numerical ratios of the solar system. They were such as might perchance have satisfied the arithmetic aspirations of the weak enthusiasts who are ever pestering science with their delusive ciphers and visionary hypotheses. But he honestly rejected them, as giving no solid foundation for substantial theory. His researches in the geometry of cycles and epicycles were equally fruitless. But when he turned to the conic sections, and applied them to the astronomical measurements, they immediately fitted the observations. He could have no doubt that the true key was found, and that the rhythmic door of the firmament was at length opened. His faith and zeal had met their due reward. He was enabled to reduce all the facts of planet-

ary motion to the three great facts which are familiar to men as THE LAWS OF KEPLER. This grand discovery required his unique imagination.

But the task was not completed; the three facts were to be reduced to one, and the reduction was accomplished by an imagination not less unique than his own, but as different as intuition from prophecy. The one fact is NEWTON'S LAW OF UNIVERSAL GRAVITATION; and it may never be equalled as a sublime embodiment of all-embracing thought.

The whole domain of physical science is equally permeated with ideality. You cannot escape from it if you would. It illumines the remotest star and the first-born of the nebulæ. There is no obscurity which it does not penetrate, no resistance which it does not overcome, and no magnitude which it does not embrace. Call it by whatever name you will, the spiritual eye recognizes its omnipresence. "If you ascend up into heaven, it is there; if you make your bed in hell, behold it is there. If you take the wings of the morning and dwell in the uttermost parts of the sea, even there shall its hand lead you,

and its right hand shall hold you. If you say, 'Surely, the darkness shall cover me,' even the night shall be light about you." Yea, spirit of ideality, "the darkness hideth not from thee, but the night shineth as the day; and the darkness and the light are both alike to thee." By what more satisfactory name can we approach thee than by the awful name of Jehovah?

There is nothing the eye can perceive which is so small as not to contain a rich mine of speculation. The drop of water represents infinite power, with its load of electricity, — enough to charge a thunder-cloud; it is the type of infinite beauty, as it transforms sunlight into rainbow; it is the embodiment of infinite love, in its gentle descent upon the grateful flower; and by its curious constitution it represents and stimulates an inexhaustible knowledge. Is it not worthy to be the vehicle of a divine baptism?

Ascend from the infinitesimal to the infinite; pass from the elementary particle to the universal cosmos. With the increased grandeur of dimension, the intellectual utterance is not enfeebled. There is everywhere in Nature a

voice audible to human ears, and a speech intelligible to human understanding. It is the truth of science, the beauty of poetry, the logic of philosophy, and the faith of religion. Ignorance cannot hide it, nor deformity degrade it, nor superstition corrupt it, nor scepticism conceal it. It vibrates in every soul; it is the consolation of the slave, and the conscience of the king. It is the corner-stone upon which sound government is built, and the fulcrum by which eloquent speech moves the world.

Mythology herself, however she may be clothed in barbaric mystery, however she may have been born of the dread of the powers of Nature and of the ignorance of law, attests the all-pervading ideality. The gods of Egypt, whether worshipped as light or sun, whether incarnated in bull, or hawk, or cat, or beetle, or vulture, or ibis, or crocodile, declare the presence, in the first source and in every form of life, of a Nature imbued with intelligible thought. The Chaldean, Babylonian, and Arabian gods of the sun, moon, and stars; of the planets, and the months with their presiding triad; of him

who rules the day, and of him in whose hand is the flaming sword, and who dispenses abundance and wealth, — are the definite representation of a real philosophy of Nature. The gods of Greece and Rome, — Uranus and Saturn, Jupiter and Juno; Neptune, with his amphitrites, his tritons, sirens, nereids, and naiads, his Scylla and Charybdis; Apollo and Minerva, with the Muses; Pan and Flora, with the fauns and nymphs; Venus, with the graces and the satyrs; Terminus and Vertumnus, with the lares and penates; Pluto and Proserpine, — what are they all but human recognitions of the universal ideality? And what was the perpetual intercourse between gods and men but the perception by vivid minds of the amazing intellectuality inwrought into the unconscious material world?

Remove the plurality of the deities, and the absurdities vanish; the myth is transformed into a glorious truth, and inestimable is the gain to philosophy. The dragon no longer guards the sacred fruit; nor does the serpent distribute it to the tempted sinner. No Cerberus is in the path to the inner mys-

teries; there is no danger in accepting the invitations of Minerva, lest you may incur the anger of Venus and Juno. In undertaking the problems of the Sphinx, you need not fear the ambiguities of a deceitful oracle nor the inconsistent responses of rival gods and capricious goddesses. The light of Nature is henceforth single, and her heart purified from all malice and duplicity. However strange the forms of phenomena may be, and however complicated the combinations, there remains no dark corner of hopeless obscurity. Everywhere it is written, "Knock, and it shall be opened unto you; seek, and ye shall find." Undertake the most intricate and profound investigation which can be presented to you; pursue it with ardor, intrepidity, and unswerving faith: you will surely secure the prize, and accomplish the miracle promised to the faithful. It is the universal story of invention and discovery, from Cadmus and Pythagoras to Edison and Sylvester.

It is undeniable that some portion of the ideality attributed to Nature has been the product of man's fancy; and its human aspect is to that extent a subjective phenomenon.

The images seen by the soothsayer in the burning coals, in the lines of the hand, in the flight of birds, in the configuration of the stars, and in the dreams of imperfect sleep are the weeds and spawn of a teeming superstition. Look at yonder cloud. It is backed like a weasel, it is very like a whale, it is in the shape of a camel, — in accordance with the suggestions of frivolity and delusion. Go where you will among the mountains — giants, men, and animals present themselves to you in the contours of all the hills; but they are the offspring of your own childish conceit, and no thinking child regards them as truly earth-born. How different is their insignificant tale from that of the lovely shadows; of the changing foliage; of the grasshoppers, the butterflies, and the humming-birds; of the lightning, the rainbow, and the shooting star! The brilliant and majestic firmament is studded with stars, distributed under no order which can be deciphered, and with an irregularity greater than that of the spots of water on a floor, dashed from a dripping brush. Nevertheless, the inventive imagination of the ancients combined them into

constellations which have been a perennial reservoir of beautiful poetry. The ideality in this case is altogether a human artifice, however real and divine may be the poesy; and it exhibits the cunning of man, where Nature had declined to manifest any corresponding intellectuality.

I have seen an ingenious artist who permitted me to mark arbitrarily on a paper the positions of the hands, feet, and head of some proposed man; and however impossible the mutual relations might seem to be, it was curious how he always contrived to design a natural figure engaged in some occupation which admitted of the proposed positions. In one case the positions were given for many figures, scattered in the most bewildering confusion. His corresponding picture was that of a ship assaulted by pirates, in which the limbs of the sailors were cut off and thrown about in the required places. With our unrestricted play of fancy, how can we be sure that our intellectual picture of the external world is not a human creation, and the fabric of a vision?

We will return to the starry heavens. Amidst the constellations is a group of stars

which cannot escape observation. The sweet influence of the Pleiades may be rejected as a baseless poetic myth, their supposed position at the centre of the stellar world may be a scientific error, the beauty of the constellation may be set aside as having slight intellectual significance; but the reality of the combination of at least five hundred stars into one close family is indisputable and absolutely independent of human recognition. There is also the attractive cluster of the Hyades, and that of the Coma Berenices. The telescope has revealed a multitude of such clusters, and the story which they compel us to accept is irresistibly rich in ideality, and of infinite comprehension. It reveals a history of the sidereal universe which transcends all possibility of human invention.

There is visible to every eye, whatever may be the constitution of the mind of the observer, a beautiful zone of small stars, circling the whole heavens, and which we call the Milky Way. Even the brighter stars have an evident connection with it, and it again contributes an incontestible chapter to the stellar history.

There are some stars which move among the others, distinguished at times by their superior brilliancy. They are the planets; by their motions they have revealed the chain of universal gravitation, and by their harmonious system have a third time carried us back to the origin of the stars. Even here, then, where there has been through the ages the most extraordinary accumulation of fanciful suggestion; where no strange meteor can appear, but the nations are threatened with war; where the eclipse and the comet are associated with the lightning and the tempest as dragons of destruction, — in the very stronghold of astrology, — we find the quiet and indubitable evidence of the dominion of intellectual order.

The conclusion in every department of science is essentially the same. Whatever may have been the play of fancy, or the delusion of superstition, or the allurement of profit, at the outset, the end has ever been a congregation of facts, organized under law, and disciplined by geometry. With the transformation of astrology into astronomy and of alchemy into chemistry, the planets,

which were the lords of human fate, have become the slaves of gravity; the sublime developments of celestial mechanics have replaced the puerile predictions of wealth and prosperity, of war and famine; and instead of the philosopher's stone and the elixir of life, we are blessed with the golden laws of chemical affinity and the profound philosophy of physiology. The records of each science justify its claim to the inheritance of ideality. The wisest physical philosophers have ever been the most rigid observers; they have penetrated through fact to the inmost soul of Nature; and their proudest discoveries have invariably been vast intellectual conceptions exhumed from the recesses of the material world. When the sculptor develops his Apollo or his Venus from the quarried marble, it is his own creation, and has his image stamped upon it; but the truth which the man of science extracts has an absolute character of its own, which no power of genius can transform, and which is neither attributable to accident nor born of human parentage. It pervades the meanest chips of stone, which the artist rejects as superfluous.

When we read the great poems and orations of former times and distant peoples, we may often differ as to the intention of the authors; but we all agree that the works of Homer and Virgil, of Dante, Voltaire, and Goethe, of Æschylus and Sophocles, Aristophanes, Molière, and Shakspeare, the sermons of Massillon and Bossuet, of Taylor and Channing, and the Vedas, and the Cid, and Job, and the Psalms of David, and the Song of Solomon, and the wise sayings of Confucius and of Emerson are unmistakable productions of minds constituted like our own, however surpassing they may be in their beauty and sublimity. Is it otherwise with the "books in the running brooks, the sermons in stones, and the good in everything"? If there be any validity in logical inference, if there be any soundness in the argument from analogy, we must accept the unanimous testimony of experience and observation. There is no physical manifestation which has not its ideal representation in the mind of man. The humanity of Nature is its clearest utterance and its surest reality.

There is a grand phenomenon in the history of science, by which the coincidence is drawn still closer. Wild as are the flights of unchained fancy, extravagant and even monstrous as are the conceptions of unbridled imagination, we have reason to believe that there is no human thought, capable of physical manifestation and consistent with the stability of the material world, which cannot be found incarnated in Nature. The dreams of Pythagoras and Plato upon the mysteries of number have been surpassed in the numerical relations discovered by modern science. The doctrine of the polyhedrons, which Kepler did not find in the system of the planets, has as real a relation to Nature as it had to his generous mind. It is found to be an essential feature of the modern theory of crystallization, just as he recognized in the paths of the planets and comets, marked out by the Creator, the same conic sections which were but ideal existences with Euclid and Apollonius. The imaginary square root of algebra, from which the puzzled analyst could not escape, has become the simplest reality of Quaternions, which is the

true algebra of space, and clearly elucidates some of the darkest intricacies of mechanical and physical philosophy. The highest researches undertaken by the mathematicians of each successive age have been especially transcendental, in that they have passed the actual bounds of contemporaneous physical inquiry. But the time has ever arrived, sooner or later, when the progress of observation has justified the prophetic inspiration of the geometers, and identified their curious speculations with the actual workings of Nature. Geometry had been projected forward and onward into the free regions of ideality by a force of imagination which could not be restrained, although it always submissively obeyed the logic of which it was born; just as the jet of hydrogen which is ejected from the surface of the sun hundreds of thousands of miles into space never escapes from the solar attraction, and in the course of time returns to its controlling luminary.

Identity of law, structure, or material is indicative of community of origin. Such is the nature of the evidence for the common

origin of the sun and the stars, of the sun and the planets, of the planets and the earth, and all the other components of the solar system, whether satellites, comets, or meteors. A few lines of the spectrum, seen in the gas thrown from the sun, prove it to be hydrogen, because the same lines are found in the hydrogen upon the earth. In the same way, the identity between the laws of mind and matter may justly be urged as an evidence of their common origin. But is this a sufficiently solid basis for the hypothesis that either of the two has originated the other? The speculation that the mind of man first constructed the world with its great harmonies, and then shrank to its present stature, may excite a derisive smile. But is it not as worthy of serious consideration as the opposite fable, that the mind has grown out of this brute matter, which is now utterly unconscious and incapable of intellectual argument or spiritual emotion?

I have read an attempted explanation of the process by which consciousness could be evoked out of the unconscious. It might have been written in some prehistoric San-

skrit, or in lunar hieroglyphics, for all my capacity to understand it. I cannot, therefore, presume to criticise it. But it seems to be a gross violation of the principle of the necessity of an adequate cause for the production of an effect. Without some more lucid exposition, notwithstanding my sincere respect for the high authority from which it emanated, I must place it in the same category with demonstrations which I have in vain striven to understand, of the possibility of perpetual motion, and of the falsity of the law of gravitation, or of the earth's curvature. It leaves us at the mercy of vague speculation, and deprives philosophy of its soundest instrument of research.

If the common origin of mind and matter is conceded to reside in the decree of a Creator, the identity ceases to be a mystery. The divine image, photographed upon the soul of man from the centre of light, is everywhere reflected from the works of creation. The origin is as distinctly imprinted upon the records of philosophy and the laws of Nature as are the lines of the sun upon every solar spectrum. How could it be otherwise? Is

it not a vagary of philosophy which erects one part of creation, and that the least, into the authorship of the whole? — which ignores the Deity, because he is materially invisible except in his works, wherein is his only possible mode of material manifestation? We might better assert that the star, which is only known by its light, consists of mere rays; that the picture is a product of self-controlled color, and the anthem the offspring of unconscious sound.

That the perfection of theology requires that all the gods should be reduced to one God, will be admitted. But let us consider where the proposition lands us, that all science can be reduced to one fact. Among the facts to be embodied, are the facts of omnipresent ideality, the intelligible cosmos, and the all-comprehending intellect. The law of universal gravitation must be incorporated in it, and the laws of rest and motion, of chemistry and heat and electricity, of sound and light, and of all vibrations audible and inaudible, visible and invisible, and of all forms of sensation actual or possible. All the laws of the material world must be included, and they will

constitute its least part. The mind of man must be in it, with its philosophy, its emotions, and its infinite capacity of development. It must contain the law of love, the Sermon on the Mount, and the Lord's Prayer. What can this mighty fact be but God himself? Where is the man who will not accept this fact, as the one fact which comprehends all others? And where is he who will accept less than this?

But will science receive this doctrine? Physical science has long outgrown its theological stage. The manufacture of human gods is a lost art, which superstition and priestcraft cannot revive, even with the aid of animal magnetism, legerdemain, and spiritualism. Science is rapidly emerging, if it has not already emerged, from its metaphysical stage. Nature no longer abhors a vacuum; abstract and final causes have lost their power; grass does not grow, trees do not bear fruit, fish do not swim, birds do not fly, beasts do not walk the earth, for the purpose of supplying food to man. Events and beings are because they cannot help it; they obey a law which they cannot resist. The struggle

for existence is an instinctive battle, which has no more volition or sentiment in it than the fall of the forest pine struck by the thunderbolt; than the frosts of winter, or the showers of spring, or the heats of summer, or the autumn's harvest moon. The primitive nebulosity has condensed into definite nebulæ; the nebula has concentrated into stars; each star has surrounded itself with its solar system; each planet has cooled from a gaseous to a liquid form, and thence to solidity, till it became a fit residence for plants and animals and man, warmed and nourished by the heat and light of the central sun; and every step in the progress of evolution has been the unconscious yielding to irresistible force.

In the midst of this vast series of transformations, science has humbly submitted to the task of observation. It has devoted itself to bringing together and co-ordinating facts; it has collected museums, founded laboratories, and built observatories. It has invented microscopes and telescopes, polariscopes and spectroscopes, and all forms of instruments for enlarging the realm of the

senses. It has ascended mountains, risen in balloons, sounded the depths of the sea; it has gone to the uttermost parts of the earth to watch the eclipse and the transit; and it has faithfully and humbly recorded its watchings. But is there no tinge of condescending pretension under its humility? It has nowhere seen the divine hand, and therefore it does not recognize deity. It sees evolution and the magnificent harmonies everywhere evolved. Is there not reason to apprehend that it is placing this very evolution upon the throne which can be occupied by no created power or any metaphysical abstraction? The force of evolution is as brute and unconscious as that of fire; there is no more royalty in it than in the log which Jupiter threw down to the frogs. In its descent it has made a frightful splash in the pool of science; but the world will recover from it, as it did from the dangerous doctrine of the earth's motion.

Science, in its positive stage, devoted to rigid observation, has nowhere seen the divine hand. With all its power of prediction, with all its keen capacity to penetrate the past and

the future, we are as far from the end of the world as is science from the one final fact, which must also be the primal fact, — the first and the last, the alpha and the omega of fact. But notwithstanding the short-sightedness of scientists, we may not forget that there have been wise philosophers, who in the beginning have seen the end. Call it wisdom, call it inspiration, call it what you will; it was divine truth which the great lawgiver of Judea uttered, when he dethroned all the heathen gods with the declaration that "In the beginning God created the heavens and the earth." Without this treasure of faith, the omnipresent ideality of science terminates in an impoverished and powerless pantheism. With it, the observed ideality is the divine thought, and the book of Nature is the divine record. At the turning of each new leaf the page may seem dark; but if you will persevere in its perusal with the docility, faith, and patience of the child, it will become luminous.

Men of science! do not forget the lessons of piety and reverence taught to youth. Your logic of induction may be as pellucid as ice; but beware lest you be bound in its

frigid and rigid bonds, till you become as immovable and incapable of progress as those who were seen by the Florentine prophet, condemned to the lowest depths of Tartarus. Retrace your steps upwards, through the narrow avenue of ideality, out of this threatened darkness, to the grateful warmth and light of the surface, where you can see the stars again. Your science will recover the perception of the central luminary, which is the unfailing fountain of pure knowledge, and will be restored to the praise and worship of the almighty, omniscient, and all-loving God.

II.

COSMOGONY.

How came we here, in this physical world, so curiously adapted to our material and spiritual nourishment? This is one of the first questions proposed by thinking man, as soon as he begins to reason. The inquiry into the origin of the world is, almost instinctively, the beginning of scientific speculation; whereas the complete solution of the question can be achieved only at the very close. So long as a scientific doubt remains, the story of cosmogony is partially untold.

At the commencement, the short-sighted observer has nothing to guide him but the obvious phenomena in his immediate vicinity. He cannot see the distant path, with its difficulties and dangers. But, fortunately, Nature is God's messenger; and her clew, faithfully followed, will, after innumerable turnings and

windings, lead out of the labyrinth. Each observer starts from his own peculiar position, which may be far removed from others. In the dim and uncertain light, he pursues crude theories, imbued with the minimum of fact and the maximum of fancy. He is easily diverted from his course by some delusive *ignis fatuus* or some glittering generality. When the causes are obscure and the visible agents fail, he constructs fairies and genii, demons and gods, to work out the mysteries which he perceives, but cannot understand.

He whose home is in the plains, where the strata of the earth are nearly horizontal and have an almost uniform thickness, finds in the evaporation of aqueous solutions a natural and sufficient explanation of the phenomena of geology. He, on the contrary, who lives in mountainous countries, where the evidences of volcanic action are apparent to the most superficial observation, is impelled to adopt fire as the primary earth-building agent. The various observers, justly confiding in the soundness of their own observations, unjustly oppose the apparently inconsistent views emanating from other localities. Human pas-

sions, swift to vindicate opinion, are aroused on either side.

Under the banners of Neptune and Vulcan, scientific armies were arrayed against each other about a century ago, and a bitter war was waged for many years. So long as victory, and not truth, was the leading incentive, the contest endured, with virulent onslaught of words and impassioned demolition of reputations. The excited combatants accumulated immense stores of fact to sustain their respective hypotheses of the formation of strata and the origin of the successive terrestrial inequalities. The collected facts had in themselves a mighty power of instruction; when warmed into life, their teachings were irresistible, and the warlike attitude of those who marshalled them yielded before their enlightening influence. The controversy had done its work in stimulating study; and the field was left to the legitimate operations of the searchers after truth. Without formal surrender or articles of treaty, the strongholds of faithful record were abandoned by their partisan garrisons, and became the common property of the science of the world.

In earlier times, to which the light of history has scarcely penetrated, but where human nature was the same as to-day and yesterday, and as it will be to-morrow, there must have been going on the same unconscious induction from the processes of Nature. The muddy deposits of the Nile, laden with untold fertility of production, must have suggested a primitive formless chaos to the Egyptian sage. The association of the overflowing of the great river with the rising of Sirius, the most brilliant star of the firmament, was nearly as inevitable as the association of the sun with the light and heat of the day; and the absence of this alliance from the cosmogony of Egypt would not be less strange than that of the solar influence itself, or than the failure of the Egyptian astronomer to associate the pole-star with the pole. On the other hand, it would have been far from creditable to northern philosophers, if the annual concurrent effects of the winter frosts and the summer heats, in tearing the rocks to pieces and converting them into fruitful soil, had not become a fundamental principle in their speculations

upon the earth's origin. May it not also have induced them to recognize the beneficial influence of the battles of the gods?

All nations capable of making profound and thoughtful observation, wherever situated, whether in Phœnicia or Egypt, in India or China, in Polynesia or Finland, must have perceived in the egg the primitive idea of an incipient world. The egg was not more certain to be transformed into a bird, whether buzzard or eagle, — or into a reptile, whether tortoise or crocodile, — than this universal fact to be developed into some theory of evolution. Manifold must have been the forms through which theory groped its way during the long centuries which preceded the definite records of history. At the outset they must have been as gross and deformed as the early residences of man, and, like his temples and divinities, overlaid with superstition and mythological monstrosity. But intellect has its laws, which are as undeviating as those of the physical world. Man's conceit, stupidity, and obstinacy cannot resist them; and in the end they will prevail. He cannot escape the constant observation of

phenomena, succeeding each other by invariable laws. He is forced to the discovery of regions of the universe whence the arbitrary is banished, and where there remains no evidence of choice, or consciousness associated with power. The quiet and silent force here manifested is all the more permanent that it is not subject to the caprices of will; and its unchangeableness may have extended back to the very beginning. There are everywhere opposing forces, violent action, and vigorous resistance; but the result of the struggle seems to be uniformly harmonious with some preconceived plan. The furious hurricane and the roaring and destroying tempest rage for a day and a night; and, in the morning, the ocean and the atmosphere subside to the serenity and rest of the peaceful and well-rounded spheroid.

There have recently been uncovered at Nineveh tablets four thousand years old, containing an account of the Babylonian cosmogony. In the first tablet are placed, side by side, the two primitive sources of creation, — Chaos and Ideality. They stand silent and immovable, — imperturbable med-

itation and inactive mass, — like the sphinx by the pyramid. There they might have remained eternally unproductive. But the tablet's next record is the birth of Motion. Motion is the divine energy of creation; it signifies change and phenomena, and the genesis of the powers of evolution, with the controlling, planning, and warring gods. How this creative energy could itself have been born is of all mysteries the most incomprehensible. It is the inevitable impossibility inherent in any speculation which would develop everything out of nothing.

The subsequent tablets coincide quite well with the Mosaic cosmogony. There is the birth of Thoth, the god of light, previous to the sun; and there is the conspiration of the divinities of the sun, moon, and stars in the establishment of the measures of time; and the order of events is nearly the same as that of the first chapter of Genesis. But it seems not to be the accepted doctrine of the learned Biblical archæologists that the Mosaic account was derived from the Babylonian speculations. It is maintained, on the contrary, that the Mosaic simplicity indicates a greater

antiquity, or at least a more archaic source, but that each may have been the spontaneous growth of human thought.

The Mosaic record is delivered from the grossness and superstition of the pagan tablets. The finite gods — finite in time, power, and wisdom — are annihilated in the presence of the one God, who is eternal, almighty, and omniscient. He can himself declare that the light which he has created is good.

The coincidences of the successive steps of this creation with the established theories of evolution do not indicate the previous knowledge of those theories, but are the conclusions of a sound philosophy, which is ever consistent with itself and with undying truth. The preservation of the cosmological form of science is evidence of the antiquity of this account. Its brevity is accordant with the wisdom which restricted the creative action by no finite limitations. The long periods of time requisite for the action of finite gods, or of laws of development, would have been unpardonable restrictions of almighty power. The creator of time requires no time for his grandest work. The least

measured interval, the single day, is the equivalent of myriads of centuries with him who, like science itself, has neither beginning nor end. The first chapter of Genesis is the sublime termination of the most magnificent example of evolution which the history of mind has exhibited. It was the inevitable outgrowth of free and untrammelled philosophy.

As a cosmogony, the Mosaic account does not undertake to manufacture the details of a fanciful record, and supersede that which man, with labor and study and faith, must read where the Creator himself has written it. It is the simple declaration that no finite agent can accomplish an infinite production; and that the King of kings has placed between himself and his children no other god, to whom the work of creation has been entrusted, and to whom we are to bend the knee.

The cosmogony is the least portion of the wonderful entrance to the book of our religion. It is the mere frame of the door-way. Above it is written the name of Jehovah, the only true king of the Jew first and also of

the Gentile, the source of all power, and the object of all obedience and of all worship. Upon the panels of the door are inscribed the powers of Nature, each of which might seem to claim independent homage; and each is declared to be no god, but a created thing, without proper title to the worship of mankind. The abolition of the heathen polytheism and the charter of the king of Israel to sovereign power are proclaimed with a simplicity and sublimity of language worthy of the great law-giver and statesman to whom they are attributed.

The Mosaic philosophy deserves to be studied as a classification of power. It is complete without redundancy. No source of power is omitted, and each in succession is declared to be a created agent and a servant of the sovereign ruler. First of all, physical force is typified, under the name of light. And God said, "Let there be light," and light was. The work of the day was one instant of thought. What grander type of power has modern science discovered? Next comes the heavenly firmament, the home of Jupiter, the council

chamber of the gods of the Gentiles, the central residence of the regulating spiritual forces, separating the infinite below from the infinite above. God made this firmament, and called it Heaven. Worship him, and not his creatures! And then comes the gathering together of the infinite below into dry land, with its inherent capacity for the production of grass, herb, and tree. God created the earth, and endowed it with its exhaustless power of development. Shall we, scientists of to-day, erect this created evolution into an original divine power, and honor it as a god? We might as well go back to the worship of light and the sun. The infinite above was also concentrated into sun, moon, and stars, which illumined the earth and gave it the divisions of time. The beneficence of Nature, here typified, is not its own intention: God was the author, and he saw that it was good. And whence arise the monsters of the deep, and the winged fowl that fly above the earth in the open firmament of heaven? Whale has been born of whale, and eagle of eagle, back to the very beginning of observation: it is an end-

less birth of like from like, as if it were the manifestation of an eternal, independent power. But the record declares that it was an act of God's volition, and was marked upon its front by his blessing. And so it is with the origin of every living creature on the earth, whether beast, or cattle, or creeping thing, and even of man himself. Let not man boast that he is in the image of the Creator, and that the ideality of the universe is fully represented in his intellect and imagination; let him not wonder at the infinity of his own capacity, nor contemplate his likeness to the Father, until he at length persuades himself that he is a god, and becomes his own worshipper. Like the atom of dust, he was created out of dust, and the divine image was stamped upon him, that he might humbly study and wisely understand the works of creation, and contribute to God's glory, while growing to the measure of the vast cosmos and of the divine plan.

The Mosaic record is, finally, the consummation of the philosophical study of the phenomena of thought, design, and harmony,

everywhere manifested. An all-pervading unity is discovered, of which the only satisfactory explanation is one God. We are not now to consider the importance of this doctrine to every human soul. It is the foundation and hope of science as well as of religion. It assures us that facts and laws are born of God; that in all fact there is law, and that the law is ascertained by the study of the fact. The facts of to-day reveal the law; and the law, applied to the remote facts, completes the imperfect and obscure history of the past, and predicts the future. In this sense, the first chapter of Genesis is a profound cosmogony. It may not be the revelation of an actual past, but it teaches where that revelation is to be found; that it is engraved on stone by the all-wise Author; that it is written in the sun, moon, and planets; that it is inscribed on the sidereal universe, and that every star is an oracle of God. Such is the Mosaic doctrine, rightly interpreted. The most sublime production of human language is the grandest embodiment of human thought. The lips of man, through the soul's craving for ideality, have

involuntarily given voice to God's inspiration.

We may now undertake the consideration of the latest form to which cosmogony has grown, under the sunshine of modern science. The trunk of the tree is the NEBULAR THEORY; and upon its soundness depend the vigor, height, spread, and endurance of the subsequent development. Astronomers are frequently asked whether they believe the nebular theory. The question is logically preposterous. An hypothesis may be believed or disbelieved; but a theory is an organized system of observed phenomena, which may be accepted as good and complete, or discarded on account of its defects, but of which belief or disbelief cannot properly be predicated.

The nebular theory is, pre-eminently, a grand ideal organization of all the phenomena of the celestial universe, and embraces a complete ideal history of the inorganic world. The universe, according to that theory, commences with an all-pervading substance, in which there is no apparent structure nor division into parts, but the same monotonous

uniformity throughout. Passing through innumerable transformations, it terminates in a system, whence disorganization has been wholly eliminated, and where vast multitudes of individuals, each a perfect organism in itself, are combined in indestructible harmony. In the beginning, it has the unity of monotony; in the end, it has the unity of complete organization. In the beginning, it is crude material, without form, and void; in the end, it displays the wonderful plan of an unbounded imagination.

No grander conception of the physical universe has ever been presented to philosophical discussion. While there is nothing vaster in the wide realm of physical science, there is no theory which is more plentifully fraught with rich and varied suggestion. The more the great masters of thought have been penetrated by it, the more searching and profound have been their investigations, and the more exalted and harmonious have been their conclusions. It has proved a curious and unfailing guide amidst the mazes of Nature, and it seemingly stretches throughout the labyrinthic windings of intricate

investigation. It enables the magi of science to read the stars, to decipher the lines on Nature's palm, and to divine the past and future history of worlds and races. From time to time, it must be submitted to rigid scrutiny and analysis, so as to extend its comprehension, enlarge its domain, correct its doctrine, and prepare it for the researches of the next age. It must be liberated from needless hypothesis, which may unguardedly have been allowed to enter it, be closer fitted to fact, and become more and more the incorporation of ideality with strict and exact observation.

Certain wise and good men, jealous of their religious faith, have feared that the nebular theory is liable to the reproach of being an invention to relieve the Almighty from the incessant care of his creation. We cannot deny that some eyes have been dazzled by it, so as to become insensible to the more needed light of spiritual faith. But how could there be such brilliancy, except in an emanation from divine light? The intellectual force of the conception is consequent upon its verity. Any harm which it

may have done is due, not to the impurity or dimness of the light, but to the weakness or disease of the eye.

An undeviating succession of events has been observed. Such a phenomenon is inseparable from uniformity of law and plan, and is the only possible expression of an unchangeable will, which is subject to no caprice. It is the mode of growth adopted by the Creator to accomplish the plan of creation. The universe is a book written for man's reading. If it were destitute of strict logical connection, it would fail of its purpose, and be unintelligible. The luminous order of the pages and the successive introduction of new and strange truths are marvellously adapted to the development and expansion of the created intellect. It is a glorious manifestation of the all-pervading affection and of the fostering care of divine wisdom. Facility of execution was no motive to the Omnipotent, nor transparency of conception to the Omniscient. Our weakness has been consulted in the spiritual food presented to our nutriment.

The divine presence only at the beginning,

and the seeming absence of Deity from the actual course of natural events, is a human misconception not easy to be eradicated, for it is one which is incident to our finite nature. Man lives in time and space. It is only through media that he is cognizant of the near and the remote, of the past and the future. Standing on the earth, he sees the distant star by the light which strikes his eye; and, by the aid of the telescope, can see one still more remote. Guided by the law of cause and effect, he traces back events into the past and prophesies the future.

This is man's mode of seeing; but it cannot be God's. The Omniscient and Omnipresent needs neither created light nor human telescope to penetrate space, nor our logic to connect events. With him there is nothing distant; all objects, celestial and terrestrial, are in immediate proximity, and the past and the future are forever present. Deity does not exist in time and space; but they are in him, — they are his inward conceptions, his created conditions, to which man by his will is subject.

This wonderful riddle is at present be-

yond human conception; it is faintly represented in the mystery of the dream. But it is vain for the finite to strive to comprehend the infinite. We are permitted to know all that we require. The universal plan is apparent to every mind which yields itself to logical induction. The links of the all-embracing chain are in open sight. We need not search the obscure past to find out God. It is not in the first appearance of animal life or of man himself that he need be sought, any more than in the whirlwind or the earthquake. His dwelling is not where the law of continuity is broken. There would be the proper home of some heathen deity, who rejoiced in lawlessness. But our God proclaims himself in the silent law of universal gravitation; he is forever present in the quiet grandeur and intellectual simplicity of the processes of the nebular theory, and in the soul of man, which is fitted to understand the divine harmony. The Creator is not ruled out of the universe by our theory of evolution. That which we call evolution is but the mode in which he is present on whom mortal cannot look

with physical eyes and live. It is the manifestation of his paternity. He becomes through it, more legibly than ever, the beginning and the end, the Alpha and the Omega, the eternal I AM, the omnipresent Father, the breath of whose nostrils is wisdom and power and love.

The Nebular Theory.

Naturalists sometimes divide the history of the animal organism into the successive periods of *germ*, *youth*, *maturity*, and *old age*. Similarly, the nebular history can be divided into the periods of *Chaos*, *Nebula*, *Star*, and *Planet*. The division has the advantage of promoting precision and distinctness of discussion. The successive stages of actual progress are not well defined, nor bounded by clearly marked outlines. This is a significant fact in the history; it shows the existence of those imperceptible gradations of transformation to which forms of growth are necessarily subject.

We begin with *Chaos*. If we venture back to the primeval chaos, we are to regard it as

presenting the uniformly monotonous appearance already indicated. But the uniformity must be an illusion. Complete monotony can be its own only offspring. Where there is a perfectly uniform distribution of material and force, there is no internal cause which could introduce variety. Whatever dissimilitude may have become subsequently visible must have had its corresponding existence in the chaos from which it originated. However dormant and concealed in the outset, its presence in the inscrutable darkness is revealed by the occurrence of the subsequent changes. The plan of the coming universe must have resided in the initial chaos, as surely as the eagle is in the egg, or the leviathan in its primitive germ. The musical instruments of Nature must have included in their structure the psalm of life and the music of the spheres. The organ must have been tuned, the machinery contrived, and the stops arranged, before the descending weight could evolve the symphony.

Subsequent to the original chaos, innumerable chaotic periods may have intervened, some of which may have been par-

tial, while others were universal. These periods involve an enlargement of the idea of chaos. It no longer necessarily implies an exceedingly attenuate matter, universally diffused. Inactivity of condition is now the only essential attribute. The chaotic type is as truly found in the sand of the desert or the slag of the furnace as in the isolated particles of a gas. A perfect chaos could not be visible even as nebulosity; for luminousness, however feeble, is the result of active force. It may be that wholly inert matter is nowhere to be found. Its actual non-existence does not invalidate the ideal theory, to which it is essential as a conception. The masses of chaos may even include the exhausted remains of a previous universe; so that they might then retain the systems of motion which they had already acquired. A harmony of motion, once introduced, would thus be perpetuated through successively alternated periods of chaos and cosmos, through world after world, to countless ages.

The light of the *Nebula* is the first visible signal that the creative power has begun to

act. The uniform distribution of heat is inseparable from the quiescent condition of chaos. But as soon as motion starts, and material atoms begin to aggregate and press upon each other, or to strike each other in their paths, heat and light are developed, and the morning of creation has dawned.

That great astronomer and philosopher, Sir William Herschel, devoted his life to the study of the sidereal universe. He attempted to apply to celestial objects the methods of classification which naturalists had found most instructive in the study of the animal and vegetable kingdoms. He undertook to arrange the nebulæ and stars into groups; and, if we will consent to follow him in his essays and inquiries, we shall appreciate the rich harvest of truth which he gathered into the stores of science. The principal divisions which we shall adopt are: *Nebulosity*, *Nebula proper*, *Cluster*, *Milky Way*, *Magellanic Cloud*, *Annular Nebula*, and *Spiral Nebula*. Very many subdivisions, considered by Herschel and suggested by his immensely extended observations, may be omitted from our dis-

cussion, with the statement that they concur in the same mighty testimony.

A *Nebulosity* is a faint, indistinct luminousness, without definite boundaries. It is doubtful whether there be any portion of the firmament free from nebulosity, and whether in the darkest spaces there be not a luminous background. If the visible sidereal universe is unlimited, there must be luminousness in every direction, equal to the average intensity of the light of the celestial objects visible in that direction; and there can be no such phenomenon as absolute darkness. The disturbance which such a condition would introduce into the classification of the fainter nebulæ and stars has not been demonstrated; and it may be safer, for the present, to regard the celestial world as having a limited extent.

The *Nebula proper* is a stellar mist, with greater or less distinctness of outline, irregularity of shape, and brightness of light, and even not without resolvability into stars upon the application of sufficient telescopic power. On the one side, it is hard to define where nebulosity ends and nebula begins;

and, on the other side, the limits between nebula and cluster are equally uncertain, and there is no intermediate line of distinct demarcation. The shape is in some cases exceedingly irregular, while in others it is a well-drawn oval; and there are instances of an almost exact circle. The variety far exceeds that of the pebbles on the seashore; and there is scarcely a conceivable form which has not its representative. Sometimes the light is uniform over the entire surface, while in other cases it is concentrated into regular or irregular patches. Here, it is collected at the centre of a regular figure; and, there, it is dispersed without regard to symmetry. The accumulation of light is often limited to a single bright spot, and as often, perhaps, there are many luminous centres. There are sometimes two or three nebulæ distinctly separated from each other, but whose proximity and constellation indicate that they belong to the same nebulous aggregation, and constitute a *double*, *triple*, or even *quadruple* nebula.

The *Cluster* has the same variety in shape, brightness, and mode of concentration as

the nebula, and is sometimes so filled with nebulous matter that it is doubtful where it should be classed. With a little more concentration, the nebula is transformed to cluster; and, with a little less, the cluster reverts to nebula. For many a cluster you can select a nebula to which it corresponds, as a child to its parent; there can be no doubt as to the closeness of the relationship.

A powerful telescope frequently illustrates the effect of concentration, and brings out a cluster, where an inferior telescope had seen only a nebula. Sir William Herschel at one time thought that there were peculiarities by which he could distinguish the resolvable nebulæ, and that all the *nebulæ proper* are really clusters. But after some errors of judgment he frankly acknowledged his mistake, and became convinced of the actual existence of irresolvable, and of partly irresolvable, nebulæ. The discovery of the spectroscope is held to have established this view, and to have furnished a test for distinguishing the genuine from the apparent nebulæ. It is found that the spectrum of a star is continuous, like that of the sun; while that of

the luminous mist is discontinuous, and consists of a few isolated lines, like that of a gas. It is even possible to identify the gas of the true nebula. But this remarkable observation does not wholly separate the two forms of matter. They are often found united in the same nebulous star or cluster. There seems to be a series of these doubly constituted bodies, differing in the proportion of their constituents from one extreme to the other, and offering little opportunity for sharp and definite classification.

The *Milky Way*, or *Galaxy*, is familiar to all. To the naked eye it bears a nebulous aspect; but the slightest telescopic power resolves it into a cluster. It girdles the whole sphere of the firmament; and "this remarkable belt," says Sir John Herschel, "has maintained from the earliest ages the same relative situation among the stars; and, when examined through powerful telescopes, is found — wonderful to relate! — to consist *entirely of stars scattered by millions*, like glittering dust, on the black ground of the general heavens." The constitution of the galaxy has been subjected to special investigation by

the two Herschels; it has been gauged in every direction and mapped with extreme care. It is a stratum of stars, of which the thickness is small, as compared with its other dimensions. But it is thick enough to include all the stars visible to the naked eye; and their apparent removal from the common zone of the Milky Way is a simple visual consequence of their proximity. The distance of the farthest star is not greater than light traverses in two or three thousand years; and the thickness of the stratum is not far from one thirtieth of its longest diagonal. Its bifurcation and its branching and diverging streams afford opportunity for curious speculation, and correspond to the structure of many of the nebulæ and clusters. It is concentrated symmetrically above and below its central plane, which is that of the greatest density. It presents an embodiment of the historic idea which pervades the celestial universe. But it has advanced to such a period that the regular oval nebulæ and the globular clusters have disappeared from its inner structure. The cosmical spring-time and summer, with their nebular buds and flow-

ers, have passed away; and the ripe harvest of suns and planets is maturing.

The two *Magellanic Clouds* are conspicuous displays of stellar light, which are unseen by the northern astronomer. They resemble portions of the Milky Way in their general aspect and brightness. When examined through the telescope, their constitution is found to be astonishingly complex. According to Sir John Herschel, they combine patches of nebulosity of every degree of resolvability "nebulæ in abundance, both regular and irregular; globular clusters in every state of condensation; and objects of a nebulous character quite peculiar, and which have no analogue in any other region of the heavens." They are celestial museums, in which examples of all sidereal forms are collected. Not only do they contain every variety of nebula and cluster, but even the monsters have their representatives.

The *Annular Nebulæ* are sidereal rings, which exhibit a peculiar mode of development. Unlike the ordinary nebulæ, they manifest a centrifugal rather than a centri-

petal class of aggregation; they do not indicate statical, but dynamic, equilibrium. They suggest an approach to organic constitution.

The ring furnishes an ideal connection between the most immense and the minutest phenomena of the physical world. It is found among the stars and planets, as well as with the nebulæ. It adorns Saturn, making it the most beautiful of the stars; and Laplace saw in it the remnant of the process by which the solar system was developed. It is quite probable, as indicated by Mr. Charles S. Peirce of the Coast Survey, that our galaxy should be classed as a stellar ring. The ring is conspicuous among the typical forms of the animal kingdom, and is essential to the elemental vortex theory. In the intellectual world it is not restricted to geometry; it has wound its way into art as the type of infinity, into law as the symbol of authority, and into religion as the pledge of faith. The geometric idea does not expand with the magnitude of the circle, nor dwindle with its contraction. It is equally perfect in the molecule and in the sidereal cluster; and no

complication of appearance can obscure the simplicity of the conception.

The annular nebula demands careful study on account of the variety of aspect under which it may be presented. Its circular form may be foreshortened into an ellipse, or an elliptical form into a circle. When viewed from the side, it may be undistinguishable from a dumb-bell nebula; and since it cannot be taken in the hand, and turned around for inspection, the actual figure can be recognized only by refined and thoughtful observation.

The *Spiral Nebula*, first exhibited by the telescope of Lord Rosse, is the visible representative of a peculiar process of evolution. It tells of mighty explosions, of a rotating mass, and of a resisting medium. Behold it, and wonder if geometry will ever penetrate its mystery and explore the secret of its formation! Its suggestions are obvious to the simplest understanding; but the profoundest philosopher may exhaust his wisdom in exploring its ideality. There is evidence of similar action in the streaming outskirts of a large number of nebulæ and of the galaxy itself.

I have attempted to give a simple description of the various classes of nebulæ. Typical forms can be selected, but they are never sharply isolated from other forms. We have always a continuous series, and an uninterrupted succession of apparent transformations. There are not distinct species and genera and families and classes, as in the organic world; but each division seems to be a temporary and transitional stage.

When you enter a grove of oak, and see trees of every size surrounding you, you do not hesitate to arrange them in a mental series, according to their seeming age; and you read, in the succession, the history of each individual, as correctly as if you had seen it grow. When the botanist inspects his herbarium, with its specimens of seed, germ, early shoot, and plant in flower, in fruit, and in seed, he is enabled to study each growth, without awaiting the long course of development. In the same spirit of philosophy, Sir William Herschel interpreted the unbroken law of succession in the celestial forms. They constitute an illustrated history. If he could have prolonged his

life for the immense period necessary to watch the change of a nebula from nebulosity to cluster, he would have found the forms intermediate to those which he actually observed. But what was his magnificent discussion of his observations but a prolongation of life? In becoming penetrated with the truth of Nature, he had drunk the veritable *elixir*.

We can see the changes of these lower clouds which give us rain and hail and snow, and are laden with thunder and lightning, and associated with wind and rainbow. We can study them as thunder-storm, or water-spout, or cyclone, and trace their path across the continent. But their history is not more clearly legible than that of the sidereal clouds with their innumerable varieties and modes of transformation.

O ye of little faith! Accept the divine record of the sidereal universe, or ye would not believe in God if his name were written in letters of fire upon the firmament! To reject the ideal history is to strengthen the stronghold of scepticism. It is to deny the celestial doctrine written upon the heavens

and the earth. It is to reject the law of the Lord, which is perfect, converting the soul. Let the children be faithful to the Father, and loyally receive the declaration that he made the light with which he shines through the stars, and that it is good.

III.

FROM NEBULA TO STAR.

In the last lecture, the nebulæ were discussed. Plain description was offered, with no varnish of hypothesis. There was an attempt at classification, which was only roughly successful, because no definite lines of demarcation could be found from one end of the series of forms to the other. But there was spontaneously developed a profound history, an extraordinary tale of continuous transformation, indicative of growth and evolution. The changes testified to the forces by which they were accomplished. We may now proceed to investigate the nature of these forces, and their modes of action.

Force, regarded as cause, is an ideal phenomenon, suggested to recognition by the effort which we make to perform work. Invisible as the mind of man, it can be known

only by its effects. The mechanical philosopher can discover nothing in it but a phenomenon of motion and a transfer of action from one mass of matter to another. Even when a man performs a work, there is no external evidence that any exertion of the power of mind was involved. All the physical effects are fully accounted for by the known consumption of muscular material. The mind, undoubtedly, has a controlling influence, just as the engineer controls the steam engine, or the sovereign his subjects; but the work which is done is the exact equivalent of the expenditure of material. How it is that the controlling power of the mind is exerted, cannot be explained. When philosophy strives to give an account of the inexplicable, she finds herself hemmed in, on all sides, with impenetrable mystery. But when she is content with the legitimate search for the laws of operation, the mystery vanishes, like the cloud before the rising sun. When work is done, the requisite amount of physical strength is manifestly consumed. Less is not sufficient, and more is not required, whatever may be the mode of operation. This is the law of

power; it is so simple that it is almost an axiom, and it cannot be explained by other independent laws.

Again, when a man wills, his brain is heated, and his arms and feet obey the intention of his will; they have no innate power of resistance. This is the law of harmonious action. It is sufficient to itself and to all the demands of healthy work and inquiry. The laws of power and of harmony are both pre-established, and I am not aware that the boldest evolutionist has ever regarded them as the results of evolution.

In almost every natural phenomenon, there is a combination of two or more forces incessantly occurring, and indispensable to any variety of appearance. The mode of combination, at each instant of time, is exceedingly simple. A mass to which a force is applied must, in consequence of its inertia, yield unresistingly. To decline to receive the offered force would be an evidence of volition, and directly antagonistic to inertia. The mass, if it starts from the state of rest, moves in the first instant in the direction of the force, and in a straight line, to a distance propor-

tioned to the magnitude of the force. The body to which the force has thus been applied, and in which it may be considered as deposited, continues to move uniformly in its initial direction and with its initial velocity, until some new force is applied to it. Upon the application of a new force, the body moves in a second straight line, with the velocity corresponding to this second force, while at the same time it preserves the velocity previously imparted to it. The combined effect is one which might have been produced by a single force, called the resultant. If, instead of acting at successive instants, the forces act simultaneously, the resultant is the same. The components being represented by two straight lines starting from a point, the resultant is the geometric sum of these lines; it is the diagonal of the parallelogram constructed upon the component lines; it is the third side of the triangle of which the components are, successively, the other two sides. This proposition admits of generalization: any number of forces may be added together by the construction of a polygon, of which each side, in succession, represents one of the

forces; and the closing side of the polygon, drawn from the initial to the final point, expresses the resultant of the given forces. This mode of combining forces constitutes the fundamental idea of Analytic Mechanics and the substance of the doctrine of that science.

If, instead of one body, there is a system of bodies, connected by however complicated relations, the mathematical conditions of the problem are susceptible of simple algebraic expression. An equation, first written by the illustrious Lagrange, consisting of only six symbols,

$$\Sigma P \delta p = 0,$$

is the universal type by which every problem of mechanics is subjected to analytic discussion. All that remains is for the mathematician to pass the equation through his ideal alembics, and give it the just interpretation. All physical forces and phenomena, possible as well as actual, ideal as well as real, are condensed into this formula and subject to its magical power. It embraces the complete history of the material universe from the beginning to the end. Man has been permitted to write it. What a marvellous proof of his ideality! Could

he read all that is contained in it, he would be greater than one made in the image of his Creator; he would himself be omniscient.

The system of which the forces balance each other is in equilibrium. There are two forms of equilibrium, — the stable and the unstable. The stable equilibrium is spontaneously maintained; and when it is disturbed the system tends to revert to its original position, and oscillates within narrow limits about its normal state of rest. A system in unstable equilibrium, on the contrary, not only yields to a slight effort of displacement, but constantly tends away from the state of rest, from which it may recede to some very great amount. The simplest example is that of the rod which hangs down from a point of support, and is then in stable equilibrium; whereas, when it is skilfuly balanced in the reversed position, above the supporting point, it is in unstable equilibrium.

The only possible position in which an inorganic system can remain at rest, is that of stable equilibrium. But positions of unstable equilibrium are essential to organic structures. Where there is life, there must

be motion as well as rest; and those are the conditions best adapted to life in which there is the greatest facility both for rest and for motion. Perhaps the most striking characteristic of an organism is its power of maintaining unstable equilibrium, either in its elements or in its whole mass. The philosophy of instability is profoundly connected with the variety of organic condition and the preservation and development of its ideality. All the chemical compounds essential to vitality are unstable, as is evident from their ready decomposition when life ceases. Men walk, birds fly, fishes swim, through a constantly recurring series of unstable positions of equilibrium. Instability is a necessary element of spontaneous action, and intimately connected with the universal pre-established harmony. Without it, the germs of being could not be developed, the egg could not begin to grow, nor chaos take its first step towards cosmos. The equilibrium of chaos must be the unstable equilibrium of organic life; and its legitimate type is, — where the slightest motion of heat may originate action, and where all philosophy has sought it, through Plato and Aris-

totle, from the most ancient Egyptian, Chaldean, and Judaic speculations, — in the egg.

In most of the processes of art, instability is the habitual and necessary resort of the engineer. When the sexton goes to toll the church bell, he finds it hanging by its wheel, in a stable position, with its weight below the axis of suspension, and not at all disposed to move at an imbecile bidding. He is not strong enough nor heavy enough to reverse it immediately. He skilfully vibrates it from side to side, gradually increasing the height of oscillation; until he brings it up to rest, and "sets" it, above the axis, in the unstable position of equilibrium. Happy is the bell-ringer who can accomplish his feat in fewer vibrations than his fellow; the bell itself rings out the story of his triumph, and all the village, which understands his art, applauds him! Have you not seen the grim smile with which he contemplates his achievement? The bell is now placed so that the gentlest impulse will start it off upon the complete circuit of a maximum oscillation, and the sexton's artful touch readily carries it up on the other side, and restores it to its unstable rest.

Were there no friction, no resistance of the air, and no impediment of any kind to the motion of the wheel, an infinitesimal disturbance would suffice to give the initial start. But if only such a disturbance were applied, an infinite time would be required to start the bell sensibly from its place of rest, or to communicate to it a finite and visible motion. The sexton would have been buried and forgotten, although his force would remain alive. The interval of the visible vibration, when it came at length, would endure a few instants; and after another infinity, the perfect equilibrium would be again attained. We will not be diverted to discuss the philosophical significance of this ideal geometric infinity. But as we know that for any phase of oscillation of the bell and the wheel there is a definite velocity of easy computation, which belongs to this infinite duration of vibration, we claim that it cannot be rejected as a baseless vagary. In the constant approach to the unstable equilibrium, which is never reached, and the constant diminution of velocity, which never vanishes, we may struggle in vain to form a distinct

conception. It is one of the problems with which the sphinx delights to feast on man's intelligence. It is a hieroglyph, which no power of figures can enable the mathematician to decipher, so long as he is no less rigidly subject to the trammels of time than the unpretending ignoramus.

We will resume the consideration of the nebular theory, within the due limits of scientific research. The active forces of the nebulæ may be considered, relatively to their effects, as concentrative or diffusive. In most nebulæ there are regions of concentration, and indeed every visible nebula is a concentrating mass. The purely gaseous nebula would be diffused, if it were not held together by a sufficient attraction towards its interior. It would gradually grow faint and disappear, if it were not constantly giving out light and heat by compression and condensation. It must, then, be that the attraction is more powerful than the internal elasticity. It would be extraordinary if this were not the case, considering the extreme tenuity of the nebulous substance. In all probability, the condensation would advance so rapidly as to

be perceptible, within a few years of observation, if the elasticity were the only force opposed to the attraction. But the most delicate scrutiny of astronomers has not yet established an instance of increasing aggregation. The extreme slowness of the process indicates internal motion as the most powerful, and probably the chief, antagonist of the attraction.

The simplest form of motion, and that which it is most reasonable to suppose, consists in a rotation of the nebula about an axis. In a balanced condition, the centrifugal force arising from rotation is everywhere equal and opposite to the attraction. But such a dynamic equilibrium could only be partial and temporary. There would be no centrifugal force in the direction of the axis of rotation; while there must be attraction in that direction, on each side of a medial plane, which may be called the equatorial plane, and towards that plane. This attraction, unresisted by centrifugal force, will condense the nebula towards the plane, until the elasticity developed by the condensation shall balance the attraction. The centrifugal

force may, in some regions and for some periods of time, prevail over the attraction, and a diffusive process be introduced. But it does not follow that, in this case, aggregation and the development of light and heat will be excluded. The annular nebulæ are fine exhibitions of this phenomenon; and their light, when they are purely gaseous, must arise from condensation occurring in the body of the ring. The mathematical formulæ which would express the possible constitution of one of these nebular rings have not yet been written. But if I held them in my hand, you would not thank me to display them. They would dazzle more than they would illumine you. The most scientific audiences refuse to listen to the awkward ostentation of algebraic demonstration; they would rather rend their indiscreet lecturer than be choked by the pearls of his pedantry. I submit to the inevitable judgment, and proceed with the nebular history.

We have reached the period of the transition *from Nebula to Star;* which may be considered under the heads of *Round Nebula, Nebulous Star, Star, Double Star,* and *Solar System.*

The *Round Nebula* is the natural and obvious result of symmetrical aggregation. Increasing aggregation and density are invariably accompanied by the development and emission of light and heat. But the emitted heat of a gaseous body is always less than that which is generated. It cannot be otherwise. A higher temperature is required to balance the increased mutual attraction of the particles, arising from their greater proximity. The increase of density and elasticity is never sufficient. The nebulæ present, then, the astonishing paradox of cooling bodies which are always growing hotter. The opposite paradox of bodies which are absorbing heat and thereby growing colder is equally admissible; and, strange to say, seems to have been actually observed. As the atoms of a contracting body approach each other, they may, in the course of time, come into so close proximity as to induce chemical action, notwithstanding the increase of heat. Compounds will then be formed, which will be gaseous, liquid, or solid, conformably to their temperatures of liquefaction and solidification, in comparison with the temperature at

which they are generated. The spectroscope, in its discrimination between solid and gas, indicates the progress of change in either direction. In the solidifying nebula, the spectrum will mostly change from a constitution of individual lines to one of continuity, modified however by the conditions of temperature; but the reversed order of change may be manifested in the expanding nebula. Contraction corresponds to the direct law of sidereal progress. But several years ago I ventured to indicate that expansion was not only a possible phenomenon, but a necessary and unavoidable complement, of direct progress. The interchange of heat between the celestial bodies should produce it; and it has now been unmistakably observed.

The light radiated from the heated gas is not only different in the character of its spectrum from that of the solid or liquid, it also seems to be less intense, and thereby supplies the characteristic distinction between the round nebula and the *Nebulous Star*. The feebler brilliancy of the nebulæ is not to be attributed to their greater distance, but to

their actual deficiency of light. It is, indeed, a reason for supposing them to be nearer than the stars of small magnitude, at least when they retain any visible portion of gaseous light. Their natural position in the sidereal constitution is not where the progress of condensation is most advanced, but upon the outskirts of our galaxy, where it has but just begun. We should look for them in that part of this region which is nearest to us; that is, in the direction perpendicular to the plane of the Milky Way. Hence it is that we find them clustering in the vicinity of the galactic poles.

If the nebulæ were as remote as they have sometimes been assumed to be, their apparent changes in position or structure would be proportionably slow, and require long periods of time to be detected. But skilful and indefatigable observers, especially those at Washington, have succeeded in discovering some interesting nebular motions and transformations. If these observations tend to contract our ideas of the dimensions of the visible sidereal universe, there is the greater necessity of an unlimited ideal space com-

mensurate with the expansibility of the human intellect.

After the nebula has advanced to the stage of cluster, the brightness must be less, in proportion to the small size of the constituent stars. The stellar structure will increase the distance at which the nebula may be seen; but the relations of brightness and proximity will not be greatly modified by the resolvability.

The continued condensation of the nebulous star will be accompanied by an increase of brightness and distinctness and an absorption of nebulosity, until it appears quite as a true *Star*. Liquefaction or partial consolidation will occur near the surface; the higher the temperature, the closer the particles are pressed together. But the body remains gaseous throughout its general mass, with only a superficial flaming photosphere. The surface must be in perpetual ebullition; and, when shaken by the frozen meteors which are on all sides dashing in upon it with a velocity of many hundred miles a second, may throw up its gases as high as we are from the moon. Disturbed by its own colder planets, it is liable to terrific storms. Hurricanes may

whirl apart the luminous masses, and produce breaks in the photosphere, through which the telescope may be able to penetrate into the dark abyss below; and the very darkness may be light to the human mind. It may reveal to the philosopher the probable absence of an interior nucleus; for any such nucleus would be heated up under the pressure of the stellar atmosphere and the blows of the meteors, till it exceeded the photosphere and the surrounding gas in brightness. Bright spots would then seem to be possible, but not the dark ones with which we are familiar, and which have been studied with the greatest success by the American astronomer, Professor Langley.

When there are several points of condensation in a nebula, making it a double, triple, or multiple nebula, it naturally terminates in the corresponding evolution of a *Double, Triple,* or *Multiple Star.* Various internal motions might produce peculiar combinations of nebula and star, which might be retained in the resulting stellar group, and would deserve delicate observation and critical analysis. The path of star about star obeys the law of universal gravitation, and tends to

the conic section as naturally as did the studies of the Greek geometers. Its determination demands of the observer consummate skill and the exercise of extreme patience. Near the close of the last century, and at the beginning of the present one, Sir William Herschel, guided by his masterly astronomical insight, perceived that there were too many stars in close apparent proximity to be accounted for on the mere optical ground of an accidental nearness of direction, without supposing a physical relation. He undertook to measure their relative positions, with all the accuracy in his power. Since his time, for more than fifty years, the finest instruments and the greatest observing skill have been devoted systematically to the measurement of the double stars. Many thousands of pairs have been observed, and more than a hundred thousand measurements have been made; and, as the result, we have only about a dozen good orbits. In most cases the change of position has been imperceptible, so that one man's life cannot avail to ascertain the duration of the period of revolution, which, in the large proportion of unknown orbits,

must exceed fifteen centuries. Hence arises a new and serious obstruction, in the necessity for combining together the observations of different astronmers, each affected by his own personal peculiarities.

The frequent difference of color between the constituent stars of a binary system is an interesting and suggestive phenomenon. It is an evidence that, during the transition from nebula to star, there is a tendency to a process of differentiation, by which the material collected in one centre differs from that collected in the other. This might arise from the union of various causes, — from the law of diffusion, by which, in equilibrium, each gas is a vacuum to the others; from the different temperatures and pressures at which they liquefy or solidify; and from the peculiar conditions of each chemical combination. Without undertaking to discuss the mode of operation, it is obvious that here is sufficient suggestion for the origin of the individual color and the diverse glory of the twin stars.

The binary constituents are often of equal brilliancy, and probably, therefore, of equal magnitude. But, in a multiple system, one

star is frequently of superior magnitude to the others, which move around it as if they did it homage. Our own *Solar System* is the familiar example of such a sidereal constitution. The non-luminousness of some of its members is a secondary and relative phenomenon, which does not impair the value of the record. No planet or satellite can have lost all its primitive heat, and the general character of motion must have been transmitted from the stellar condition.

We have eight primary planets, all of which revolve about the central sun in the same direction, which is that of the sun's rotation about its axis, and nearly in the plane of the solar equator. Six of these planets rotate upon their axes in the same direction, and with their axes nearly parallel to the solar axis. About two hundred asteroids are now known. How many more will be discovered, after the visual orbs of Peters and Watson have gone to sleep, we cannot foretell. But we can predict, with a high degree of certainty, that they will all revolve in the company of their brethren, in the same common direction. There are twenty-two

satellites, including Saturn's ring, all of which revolve about their primaries, in the direction of their rotation, and nearly in the planes of their equators. Whence comes this common motion? I might carry you into the vague regions of probability, and compute the chances, greater than the number of sands upon the sea-shore, against this concurrence of events as an accidental phenomenon. But this is not a case to be decided by the rules of chance. It must be presented to the tribunal of good sense and sound judgment. We have here the unanimous declaration of a community of origin. Every philosopher must approve the conclusion reached by the great geometer Laplace, that this grand phenomenon, so precisely corresponding to the nebular theory, is an independent confirmation of its validity.

The successive steps of the planetary development are necessarily obscure. What is now the solar system was probably once a round, rotating nebula, which might have been early transformed into a nebulous star. The nebulous gas, surrounding the nucleus, would take the form of a thin disk, similar

to Saturn's ring, perpendicular to the axis of rotation. The disk might be divided ideally into concentric circular rings, each of which would have its distinct velocity of rotation, sufficient to generate the centrifugal force necessary to balance the attraction towards the centre. Each particle of the nebula might, indeed, be regarded as a small planet, revolving in its proper time about the nucleus. The outer rings would, consequently, rotate more slowly than the inner ones, and would tend to retard them by some species of attrition, while they themselves would be accelerated. The outermost ring would thus be accelerated, and its centrifugal force increased, until it actually separated from the inner mass, and formed a ring around it similar to Saturn's ring.

But such a ring could not long be retained in its position. It would soon move bodily in some direction in its own plane, until it was brought into collision with the included mass, and so broken up. Why does not this happen with the ring of Saturn? Because it is sustained by the near satellites; or perhaps because its condensation has ad-

vanced so far that its nebular continuity is destroyed, and it has become a cluster of meteors; or perhaps because it preserves an atmospheric connection with the planet through the medium of the dusky ring. But the supposed ring about the sun has neither of these forms of support. It might be actually formed, but would almost immediately be destroyed. The temporary formation and destruction could hardly fail to introduce inequality of density and a concentrating tendency, which might continue to draw in the nebular substance, until chemical action was induced, and a planet was formed.

By the same process, new planets might be formed from the remaining nebula. Each planet, when formed, would exert an influence upon the nebula within its orbit and on its subsequent condensation. Although we may not to-day possess the geometric skill to define the nature of this influence, we may infer it from the actual order of the solar system. The nearly circular orbits of the two outer planets, and especially of Neptune, correspond to the small disturbing influence to

which they were subjected from exterior bodies. The larger mass and eccentricity of the next planet, Saturn, and the preponderating mass of Jupiter, indicate the concentrating tendency of the outer planets. The greatly diminished size of the four inner planets is a probable consequence of the undue proportion of material absorbed into the four outer planets and the small remnant of nebulous gas left for their construction. Jupiter, the king of the planets, had appropriated the lion's share. His excessive influence had caused the great eccentricity of the orbit of Mars. The same royal power had induced repeated condensation, at point after point, in the nebula immediately within his orbit; in consequence of which the system has lost a primary planet, and gained nobody knows how many insignificant asteroids. The largest of these little planets has perhaps no greater superficial area than that contained by the State of Texas, while the smallest that we know has a diameter of only some twelve or fifteen miles. But it were better to freeze on the least of the asteroids, in the full sight of God's firmament,

than to roast upon the fiery surface of Jupiter, beneath an impenetrable atmosphere of clouds.

The distribution of the planets has been thought to obey a law pointed out by Bode, which is that the mean distance of each orbit from the next exterior one is twice as great as from the next interior orbit. The law does not extend to the planet Neptune; but the existence of this planet was unknown in the time of Bode. It was known, however, that the law fails in the interval from Mars to Jupiter. Hence Bode surmised that there might be an undiscovered planet in that interval. The subsequent discovery of four asteroids astonished astronomers; and the cluster of which these four bodies were but the first known members is now large enough to satisfy the demands of the ideal law. But the unwarranted extension of Bode's law misled Leverrier in determining the limits within which the mean distance of Neptune could lie. It is fortunate for celestial mechanics that there is no such uncertainty about the universality of the law of gravitation.

The commensurability of the mean motions of the planets is a more important phenomenon in the theory of their mutual perturbations. It may easily have arisen from the perturbative action exerted during the period of concentration, especially if it be admitted that the orbital eccentricities were larger at the beginning than they are at present. The system is filled with examples of commensurability of mean motions. The year of Uranus is just about one half that of Neptune; and we here have a case of the occurrence of the simplest of ratios. The year of Saturn is one third of that of Uranus, giving the next ratio in the order of simplicity. In the other annual ratios there is a frequent approximation to the ratios of one half and one third, not unlike that which botanists have found in the arrangement of the leaves of plants. Thus the year of Jupiter is nearly two fifths of that of Saturn, which introduces the third fraction of the law of phyllotaxis. All astronomers are aware of the vast importance of this fraction in the theories of these two planets. The year of our earth is about three halves of that of Venus

and one half that of Mars, and the year of Mercury is about two fifths of that of Venus. In the three inner satellites of Jupiter, and the four inner satellites of Saturn, the fraction one half occurs four times in the ratios of their mean motions.

These appear to be small facts; but they bind together the origin and growth of planets and satellites into one harmonious history. The still smaller facts of the spectroscope show the presence throughout the stellar world of the same elementary substances which we find to be necessary for organic structure on this earth. The same nitrogen and hydrogen are found in the youngest of the gaseous nebulæ, and foretell future solar systems, with their habitable planets, when ours shall have passed away.

Can this vast speculation of the Nebular Theory be a reality? Can man, with his diminutive stature, measure this great world? With his threescore years and ten, can he read this stupendous history? Whence comes so sublime a power, if it is not God's gift, bestowed with his blessing?

IV.

PLANET, COMET, AND METEOR.

THE final stage of the nebular history is the *Congealed Star;* which may have its *Inorganic* and *Organic Period;* of which *Planet, Satellite, Comet,* and *Meteor* are special forms; and which is destined to become again, at last, a *Chaotic Mass.*

Through some process of condensation, the star may begin at the surface to liquefy permanently, and may after a time become liquid throughout. But a solid surface may always require the presence of an incumbent atmosphere; and there may be solid portions distributed through the mass of a gaseous or liquid star, under laws which have not yet been sufficiently explored.

The difference between the gaseous and liquid states is strikingly manifested in the conditions of temperature and density. The

contraction and heat resulting from compression are large in the gas and small in the liquid. We have seen how, notwithstanding its radiation of heat, the gaseous nebula grows hotter and denser and smaller; whereas the congealed star is constantly cooling at its surface. It may be in a liquid state, and still be classed as a *Congealed Star*. The subsequent solidification is a physical phenomenon, which is reserved for later discussion. Should a rigid surface be early formed over an included liquid, it must continue to cool, contract, and undergo innumerable forms of flexure from the gases within, from the waters falling from the atmosphere, and from other external causes. It will pass through the geologic *Inorganic Period*, the epochs of which, studied by philosophers, are replete with grand ideal speculation.

The surface will, at length, become cool enough for *Organic Life*. At the same time, life will make its appearance, — plants first, and then in their proper order the different branches of the animal kingdom, concluding with fish, bird, beast, and man. Whence did they come? Were they latent in the womb

of creation; or did they exist only in the intention of the creator, and demand a new creative act? What is the difference to science, which only studies the laws of change? What the difference to religion, which sees the divine hand as plainly in the nebula as in the star; in the inorganic period as visibly as in the organic; in the growth of planets from the formless chaos, through the nutriment of the falling meteors, as distinctly as in the development of a Shakspeare from a helpless, thoughtless infant? What difference can it make to man's faith in a creator, if he does not think of him as a pagan Jupiter, the slave of some power of fate, which subjects the destiny of to-morrow to the accidents of yesterday, but as the source of all intelligence, whose works are the products of law and the result of deliberate intention? With the infinite wisdom of such a being would it not be incompatible to construct a habitable world, and never provide for it its appropriate inhabitants? The pre-established harmony is essential to the plan.

The *Planet*, *Satellite*, *Comet*, and *Meteor* are different forms of the congealed star.

They are simultaneous in existence, and not belonging to successive stages of the history. Starting from a common origin, they have passed through a process of differentiation, and are fitted for different functions. They may all be regarded as *bolides;* and they fill the celestial spaces with every conceivable variety of magnitude, motion, and physical aspect.

I shall begin with the *Comet.* From the strangeness of its appearance in the inaccessible firmament, the comet has been the immemorial wonder and dread of mankind. It has been the beard or tail of some invisible monster. It has been the sword of some angry god. It has been the pen of the furies, writing in the book of fate the death of kings, the fall of empires, the speedy coming of famines and pestilences and destructive wars. It has been a light which has filled the souls of philosophers with darkness. Even the great Aristotle, with his clear belief in Nature and his contempt for superstition, could propose no theory which was not a tissue of gratuitous and inconsequent hypotheses. He thought the comet, with its regular mo-

tions, to be a phenomenon like the flitting and uncertain *ignis fatuus*, an exhalation from the earth. But, before presuming to reproach him, listen to what the generous Pingré says in his learned cometography: "Little minds may be elated when they can cast some malicious sarcasm upon the most solid reputations of all time. But they do not perceive that their mean words defile the mouth which utters them, more than they tarnish the glory against which they are breathed." Observe, also, the modesty with which the Greek philosopher propounded his cometic explanation: "If any man can give one that is more satisfactory, and more in accordance with natural principles, he will establish a legitimate claim to our gratitude."

Nevertheless, even in cometology, where modern progress has been so essentially aided by the discovery of gravitation and the invention of the telescope, the instinct of the ancient thinkers achieved some memorable results. Passing by the researches of the Pythagoreans, we need only refer to the writings of Seneca in the first century of the Christian era. "I know," writes Seneca,

"no nobler research, nor a more useful science, than that which undertakes the study of the stars; but to perfect this science, is it not expedient to examine whether the nature of the comets differs from that of the other celestial bodies? If we reflect on their motions, on their vicissitudes of rising and setting, on their light and brilliancy, we shall be struck with the analogy which we perceive between them and these other bodies. We need an exact history of the comets which have hitherto appeared; for it is their rarity of appearance which prevents our deciding upon the regularity of their movement. We are ignorant whether, describing fixed orbits, they do not reappear at periodic and determinate intervals of time." This was the prediction of thoughtful genius. Modern astronomy, profiting by the ancient suggestion, has demonstrated this, like many other truths. The dwarf of to-day who stands on the shoulders of the giant of yesterday can see a greater distance than the giant. Let him copy the ancient modesty, and not plume himself upon his height, as though it were due to his taller stature.

The perfect comet combines nucleus and train. The beauty belongs to the train, which is unsubstantial and temporary; while the mass and density reside in the almost invisible but permanent nucleus. The solid nucleus moves about the sun in a nearly parabolic orbit, obedient to the same law of attraction which governs the motions of any one of the planets; whereas each particle of the train moves in its own hyperbolic orbit, in consequence of a repulsion from the sun, often two or three times as great as the ordinary solar attraction, — or as Hooke, the antagonist of Newton, might have claimed, of a principle of *levity*, which he believed to be as universal as gravity.

These particles of the train are electrified bodies, and have the same electricity as that of the sun; the particles which are most highly electrified advance to the front edge of the tail, while those which are the least electrified fall back to the rear. Each particle seems to retain an undiminished electricity during the whole period of visibility. Some of the particles are electrified just enough to balance the solar gravitation; so that, after separat-

ing from the nucleus, they become neutral to the sun's action and move uniformly in straight lines, but without ceasing to be part of the tail. The particles which are less highly electrified remain attracted by the sun, but move in hyperbolic orbits, — in the opposite branch of the hyperbola, however, to that in which the repelled particles move. These hyperbolic orbits are as real a phenomenon, and subject to as certain and definite a geometry, as the planetary ellipses themselves. Their mathematical relation to the parabolic orbit of the nucleus is singularly simple to him who can read the formulæ of algebra. They conform to Kepler's first two laws, and beautifully illustrate the dynamic principle of the preservation of areas.

This theory, in an imperfect state, was rudely applied by Bessel to the tail of Halley's comet, in 1835. But the comet discovered by Donati in 1858 offered as fine an opportunity as can be desired for its full verification. How grand was the beauty of that comet! All the world stopped in the street, when it became visible after twilight,

and wondered at it with bated breath. A few centuries ago it would have caused universal dismay, and men would have paled at the frightful portent. But the Christian of to-day beholds it as the loveliest messenger of divine wisdom. A multitude of observations were made upon the train as well as the head, in all civilized countries, and the theory of the train was sustained in every detail. The elegance of the shape strictly conformed to the ideal constructions of the geometer.[1]

But some allied phenomena of a different nature presented themselves. There was exhibited another class of tail perfectly straight, quite indistinct, and having a direction exactly opposite to that of the sun from the comet. It resembled the lines of light and shadow which we often see thrown upon the terrestrial clouds, especially near sunrise or sunset, and which are familiarly but ignorantly named "the sun drawing water." It does not seem unreasonable to accept the obvious suggestion, and to regard these false tails as similar shadowy phenomena.

If the nucleus of a comet were taken

[1] Gould's *Astronomical Journal*, v. 186; vi. 50. — EDITOR.

away, the train would continue to move off through space, undisturbed by the loss of its head. Singular as this phenomenon may seem, it has been actually observed. At midday on the 28th of February, 1843, groups of people in many of the towns of New England, especially at Portland, collected at the corners of the streets, gazing up towards the sun. Protecting their eyes in the shadows of the houses, they saw a brilliant object a few degrees from the sun. Such a marvellous spectacle had never before been beheld. A thoughtful ship captain, Mr. F. G. Clarke, brought out his sextant, and carefully measured the distance of the strange body from the sun's limb. These unique observations are on record; and, submitted to rigid criticism, attest the accuracy of the observer.[1] The same remarkable phenomenon was seen on the same day, also, in Mexico, in various cities of Italy, and at the Cape of Good Hope. On the 27th it was seen by Captain Ray at Conception in South America; and he then estimated — though he did not measure — the distance of the

[1] *American Journal of Science*, xliv. 412–417; xlv. 229, 230. — EDITOR.

strange body from the sun at five minutes of arc, or one sixth of the sun's apparent diameter.

A few days later, a wonderfully brilliant tail of a comet was seen skirting the horizon soon after sunset, and reaching more than one third of the way round the sky. What we now saw was tail without head, as we had before seen head almost destitute of tail. But head and tail were members of the same comet.

Many mathematicians in America and Europe busied themselves in determining the path of this remarkable comet. One of the most noted orbits was that computed by Sears C. Walker, the brightest and most suggestive of intellects, the gayest and warmest of hearts, and the most ponderous and Johnsonian of bodies among American astronomers, filled to the brim with wit, learning, and profound science. At the comet's perihelion, it passed nearer to the sun than any known comet, with the single exception of that of 1680, computed by Sir Isaac Newton; in the discussion of which, in the *Principia*, he broached the first approximation to the true

theory of the cometary tail. These two comets approached the sun so closely that it would seem quite possible that they touched its surface, or at least swept in within the corona.

It would not have been an absurd hypothesis to suppose that these two comets were ejected from the sun at the time of perihelion, if it had not been for the fact that the comet of 1680 was seen on its way down to the sun, and for the remarkable phenomenon which we are about to describe in the case of the comet of 1843. It may be claimed as an admissible supposition that each of them was, at some former time, the product of a solar eruption, according to Buffon's theory of the origin of comets. This would require only a force sufficient to double the greatest observed velocity given to the solar jets of hydrogen; but a juster interpretation of the last-named phenomenon than that which involves an extravagant volcanic action, is that it is simply the splash of the falling meteor.

In about two hours, the comet of 1843, like that of 1680, went round the sun, from one side to the other. What could have become of the tail, which was reaching out

about a hundred millions of miles from the sun as far as to the earth's orbit? There have been those who have actually adopted the incredible — I may say the impossible — hypothesis that the tail rotated through this immense circuit, developing a centrifugal force which all the united powers of the universe could not have sustained. But, no! The comet practically left its tail behind it, and began to grow a new tail as it receded from the sun. There were thus two tails, nearly side by side, stretching from opposite sides of the sun in nearly the same direction. The new tail began at the head of the comet; whereas the old deserted tail began without any head at some distance from the nucleus, and extended further from the sun than the new tail.

That such a phenomenon should be presented by this comet was suggested by a geometer, before he knew that it had been actually seen; and it was as veritable a prediction as if it had been made before the observation. On several nights at the beginning of March, and before the comet had been observed by European astronomers, a double

tail was seen in Chili, by M. Charles Darlu, and at Monte Video by Dr. Martin de Moussy. M. Darlu describes the second tail as beginning near a point about one third of the length of the first from the nucleus, and extending much further than the first. Dr. de Moussy describes the second tail as by the side of the principal tail, but of less dimensions, and not attached to it at any point. A similar phenomenon was seen, early in March, at various other places at which the comet could then be observed.[1] But the visible separation of the two tails lasted for only a few days, because the earth passed, almost at once, through the plane of the comet's orbit, so that one tail eclipsed the other.

The nucleus of the comet is surrounded by a mist, which is called the *coma*, or *hair;* the name *comet* signifying a *hairy* star. The height of the coma above the nucleus de-

[1] *Comptes Rendus*, xvii. 362; xxi. 774. *Royal Astronomical Society Notices*, v. 297, 302, 303; and *Memoirs*, xv. 231. *Astronomische Nachrichten*, xxi. 199. Herschel's *Outlines* (589). For further information concerning this comet, see *Royal Astronomical Society Notices*, vols. v, vi; *Comptes Rendus*, vol. xvi; *Astronomische Nachrichten*, vols. xx, xxi; Gould's *Astronomical Journal*, vols. i, ii; Cooper's *Cometic Orbits* (Markree Catalogue), pp. 159–163. — EDITOR.

pends on the mass of the nucleus, and gives the measure of its weight; or, more exactly, the least limit of weight which will suffice to maintain such a height of atmosphere.

The nucleus is usually so closely surrounded by the dense mist that its diameter cannot be measured; but at times the mist rises, uncovers the nucleus, and leaves it with a sharp stellar aspect. The least diameter determined at such times may be larger than the actual one, but cannot be smaller. From the combination of mass and diameter, the density of the nucleus can be computed. In the case of Donati's comet, the diameter of the nucleus was perhaps not more than a hundred miles, while the height of the atmosphere extended to eighteen thousand miles. You may be surprised to learn that the corresponding density of the nucleus was at least equal to that of iron. What an unexpected contrast is here presented to the prevalent notions concerning the sun and the comets! The solid sun is reduced by science to the state of gas, while the substance of the ethereal comet is a solid and heavy metal.

In its approach to the sun, the surface of

the nucleus is rapidly heated; it is melted and vaporized and subjected to frequent explosions; the vapor rises in its atmosphere with a well defined upper surface, which is known to observers as an *envelope.* Various envelopes, including each other, are often observed. Mr. Bond, then director of the Harvard College Observatory, measured the envelopes for the Donati comet repeatedly and carefully. The uniformity of the law of ascent (about nine hundred miles a day) was remarkable; it is altogether inconsistent with the acceleration or retardation of freely moving matter. But it is the characteristic mode of ascent of a mist rising in an atmosphere.

The electrification of the cometary mist is analogous to that of our own thunder-cloud. Any portion of the coma which has received the opposite kind of electricity to the sun and to the repelled tail will be attracted. This gives a simple explanation of the negative tails which have been sometimes seen, directed towards the sun. In cases of violent explosion, the whole nucleus might be broken to pieces, and the coma dashed around so as to give varieties of tail, and even multiple tails.

There seems indeed to be no observed phenomenon of the tail or the coma, which is not consistent with a reasonable modification of the theory which has been presented.

A vibration of the nucleus, corresponding to a rotation upon the axis, combined perhaps with the motion of a magnet attracted by the sun, was observed by Bessel, in the case of Halley's comet in 1835; and an analogous phenomenon was observed in the case of Donati's comet.

The relations of the comets to the solar system present an interesting and instructive study. With very few exceptions, their visible paths are so nearly parabolic, and the positions of their nuclei and centres of gravity so uncertain in the midst of their comæ, that it is quite out of the question to obtain nice enough data to measure exactly the extent of their orbits, and ascertain how great may be their deviations from exact parabolas, and whether the deviations are such as to make them ellipses or hyperbolas. If an orbit is actually parabolic or hyperbolic, and if there is no decrease in the central attractive force as the comet approaches the sun, it must have

entered the solar system from outer space, and cannot be one of our permanent partners. It will leave the system again, and we may never expect its return; unless, indeed, having passed through the circuit of other suns, after myriads of years, it reappears in an orbit entirely different from its former one, so as to afford no evidence through which it may be recognized. But if it moves in an ellipse, and does not leave our system, it will return in a sensibly unchanged orbit, through which it may be detected.

The astronomer is often asked, upon the announcement of a comet: "Is it a new one?" and the tone of inquiry usually implies a feeling of satisfaction in witnessing the discovery of a new star. But it is just the reverse with the astronomer himself. He ransacks the records, hoping against hope that he may enjoy the good fortune of ascertaining that the new comet is an old one, — old, at least, in the sense that it has been observed once before, but not twice. On its first reappearance, a comet is certain to be loaded with the name of the geometric discoverer of its path. Its theory is computed; its future

returns are rigidly predicted; its social position is definitely established, and it takes its place among the registered members of our constellation. But a comet may belong to our system, and yet go so far from the sun that the intervals between its periods of visibility may be as long as three hundred thousand centuries. Of the three hundred comets which appear in a century, we must not, then, lose patience, if we do not recover one into the catalogue of elliptic orbits.

There are a few comets of which the non-parabolic character is evident at once. Their orbits are decidedly elliptical; their periods do not exceed a baker's dozen of years; and they are intimately related to the planets in their positions and directions of motion. Professor Newton, of Yale College, has given a distinct and satisfactory explanation of the mode in which these comets were probably diverted from their original parabolic paths by the action of the planet Jupiter.[1] It was a royal sport, and the final character of the cometary orbit was the natural termination of the

[1] *American Journal of Science* [III.] xvi. 165; *British Association Report* for 1879, p. 272. — EDITOR.

game. These comets must be excluded from our general discussion.

Omitting them, we find nothing in the position of the other orbits which indicates relation to the solar axis of rotation or to the planetary planes of revolution. They are as uniformly distributed as if they had entered our system indifferently from every direction, and without reference to the prevailing motion of the planets or to their mutual organization. They are simply the largest of an immense swarm of *Meteors* which are floating all around us, — a swarm of which by far the greater portion consists of bodies too small to be seen by the light thrown upon them from the sun; and this invisible portion greatly surpasses, in number and even in combined mass, all the visible components of our constellation.

The invisible meteors become visible when they come into collision with the earth's atmosphere. They are known as *Shooting Stars*, when seen flying through the sky; while their metallic remains, found upon the earth, and having a peculiar iron constitution, are called *Meteorites*. But there is sufficient reason for

regarding the chemical constitution of active meteors as not limited to that which has been found in the dead meteorites. There are problems of geology which admit of their most satisfactory solution by attributing to the meteors varieties of constitution, and indeed any composition which has ever been observed among inorganic substances.

The heat derived from the collision of meteors with the sun, earth, and planets is of fundamental importance in the cosmical discussions in which we are most directly interested. The whole collection of meteors in the vicinity of the sun may be called the *Solar Nebula;* and the sun itself, with the attendant planets, may be regarded as included in this comprehensive term. It would be vain to undertake the exact determination of the distribution of material in our nebula. It is almost certain, indeed, that it is an irregular collection; but there are indications that there is a sufficient approximation to a law of distribution to justify the attempt at its discovery. The narrow deviations from uniformity of the solar heat and of the terrestrial seasons show that there can be no extravagant

variation in the meteoric collisions. Moreover, the nearly parabolic paths of the comets correspond to a constant law of velocity and to a fall from a very great distance.

Imagine a paraboloid of revolution with the sun in its focus; and imagine all the parabolic orbits of the comets to be turned into such a position as to have all their axis coincide in direction and position with the axes of the supposed paraboloid. All orbits which have a less perihelion distance than the paraboloid will be included within it; and their number will, if they are evenly distributed through space, be proportional to the area of the section of the paraboloid, made by any fixed plane perpendicular to its axis. The area of this section will be itself proportional to the perihelion distance of the paraboloid; whence it follows that the comets ought to be uniformly distributed *in reference to perihelion distance.* This simple law, applied to all the observed comets, is verified with as great an accuracy as can be demanded in such an investigation. It is reasonable to extend the same law of distribution to all the smaller meteors which are not too remote from the sun.

If the comets are cosmical and enter the solar system from outer space, they must take about eight million years to come so near the sun as to be visible from the earth. Now there are rather more than three comets of parabolic orbit seen each year; so that there must be, on the hypothesis of their cosmical origin, as many as fifty millions of such comets at any one time, —say the present moment, — contained within the solar sphere.

The mass is, however, more important than the number. We may assume each comet to be as heavy as those which have been approximately weighed; that is, to have a mass which exceeds, on the average, a sphere of a hundred miles in diameter, with a density equal to that of the earth. Such a mass is about one five-hundred-thousandth part of the earth's mass. The aggregate mass of the comets just enumerated may be estimated, then, as one hundred times that of the earth.

If the perihelion distance is extended so as to embrace the comets which approach the sun as near as Neptune, the mass is increased to three thousand times as great as

the earth; and the perihelion distance may be extended much further, and still remain well within the sun's legitimate radius of control. Without resorting to the meteors, which might easily increase our estimate a million fold, it is easy to see that the hypothesis of the cosmical origin of the comets refutes itself. The velocity of a comet which approached the sun under so enormous an increase of attraction as would arise from this immense aggregation of meteors, could not fail of manifestation, and would exceed any that has been exhibited in the cometary motions.

In the approach of the comets to the sun, they have been seen to burst asunder, probably in consequence of the solar heat. If we reflect upon the immense variations of heat of the unprotected moon, we cannot be surprised at this phenomenon. When we find by computation that the heat to which the Great Comet of 1843 was exposed was sixty thousand times as great as that of the hottest equatorial noon-day sun upon our earth, we may wonder that any portion of it remained as nucleus. In some cases *débris* of

comets are distributed all along a cometary path. These *débris* are meteorites, and when they enter our atmosphere are visible as shooting stars, diverging from some fixed point in the heavens. They may, like other meteorites, be deflected and pass out again into space; they may be burned up by the heat arising from their concussion and rapid motion, and portions of them may fall upon the earth as meteoric stones. Pursuing their paths in groups, they give us the celebrated meteoric showers of August and November. Their theory has been luminously discussed by Professor Newton.[1]

The sun's corona, which is evidently separated from its body by a vacant space, in which the gaseous jets are free to move above the solar atmosphere, seems to be composed of meteorites. They probably have an independent history, and may consist of a combination of rings, corresponding to that of Saturn. The heat to which they are subjected must fill their spaces with gas; and thus may be explained the spectroscopic phenomena of the corona.

[1] *Am. Jour. Sci.* [II.] xxxvi. 300; xxxvii. 377; xxxviii. 53; xxxix. 193; xliii. 285. *Nature*, xix. 315. — EDITOR.

The principal body of the meteors seem to discharge an important function in the solar economy. The sun's light and heat may have been derived, in the outset, from gaseous compression; and some astronomers are still disposed to regard this as their source. Combustion, or any form of chemical action, has been abandoned by physicists. The rival theory to the theory of gaseous compression is that of the derivation of heat from the concussion of meteors which are constantly falling into the sun. It is not as fuel that they are supposed to act, supplying heat by combustion; but they are congealed masses, which have an energy exhibited under the form of rapid motion. When they are stopped by striking the sun, the energy is taken out of them, and passes from them into the sun, where it is exhibited as heat, and radiated into space to warm our earth and the other planets. This theory was proposed by Mayer,[1] and has been ably developed by that admirable physical philosopher, Sir William

[1] *Beiträge zur Dynamik des Himmels, Heilbronn*, 1848. *American Journal of Science*, xxxvi, 261; xxxvii, 187; xxxviii, 239, 397. Youman's *Correlation and Conservation of Forces*, p. 259. — EDITOR.

Thomson,[1] to whose scientific investigations the nations are largely indebted for their modes of telegraphic communication. But there are some important additions to Thomson's theory, which it is my purpose to submit to you.

Our own sun may be assumed to have been, in the outset of its present history, a round nebula, and then a nebulous star. In an early stage, it was condensed into meteors, intermingled with gas; and it is not unlikely that the corona was formed at that period, which was as early as the development of the planets and of the solar system from the central denser portion of the nebula.

The meteors, or bolides, may be assumed to move, like the larger comets, in parabolic orbits, and to partake of the cometary law of distribution. They must strike the sun in sufficient quantity to replace the heat constantly given off by radiation. The amount of that heat, although it has no especial bearing upon our present argument, has been measured and may be stated. It is of such a

[1] *Comptes Rendus*, xxxix. 682. *Edinburgh Transactions*, xxi. 63. *Philosophical Magazine*, [IV.] viii. 409; ix. 36. *British Association Report* for 1861, sections, p. 27. — EDITOR.

measure that it requires a mass of our bolides equal to about one one-hundred-and-fiftieth part of the earth's mass to fall annually into the sun. The corresponding mass of bolides which annually enter the sphere of which the earth's orbit is a circumference must, in accordance with the law of distribution which has already been brought to view, exceed this amount in the ratio of the earth's distance from the sun to the sun's semi-diameter; that is, it must be more than two hundred times as great, or nearly three halves of the weight of the earth. Each meteor, however, when it strikes the sun, will have an energy much greater than that which it had when it was at the earth's distance from the sun, — greater in the inverse ratio of the distance from the sun, and therefore greater in exactly the same ratio as that in which the whole mass of meteors is diminished. The aggregate meteoric energy, therefore, which passes in through the spherical surface of which the radius is the earth's distance and the centre the sun's centre, is precisely the same with that which is thrown into the sun. But each meteor which does not strike the sun will

again pass off; so that there will be nearly the same amount of meteoric energy passing out through our spherical surface. Thus the whole amount of meteoric energy which passes through this supposed spherical surface, in both directions, will be nearly twice that which is communicated to the sun.

Some of these meteors will strike the earth; and we will strive to ascertain the relative amount of the heat thus communicated to the earth directly by the collision of the bolides, and that which it receives from the sun by radiation. The radiant heat of the sun, being supposed to be diffused uniformly, will communicate to the earth that minute portion which the earth will intercept. The measure of this is not necessary for our argument; but we may state that it is rather less than one half of one thousandth of one millionth of the heat emitted by the sun. Now, of all the energy communicated to the earth by the collision of meteors, one half is restored to the striking body in the form of planetary velocity; for the meteor passes, in consequence of the collision, from the velocity of a body moving in a parabolic orbit to

that of the earth into which it is absorbed; and the energy which belongs to the latter velocity is one half of that which belongs to the former. The remaining half of the energy of the meteor is destroyed in the form of visible motion, and converted into heat. But the mass of bolides intercepted by the earth must bear to the whole mass which passes through the spherical surface of which the earth's orbit is a great circle the same minute ratio which the solar heat, intercepted by the earth, bears to the heat emitted from the sun. Thus we are brought to the startling conclusion, that the heat which the earth receives directly from the collision of meteors is the same in amount as that which it derives from the sun by radiation. It is remarkable that this strange result is supported by accurate observations, made long ago by a most eminent and trustworthy authority, but which have never been discussed in relation to their significance, though they have never been invalidated.

Every one knows that at sunset there is a rapid fall of the thermometer, which of course proceeds from the sudden cutting off of the

direct rays of the sun. The thermometer continues to sink during the night, at a rate which was submitted to careful analysis by Pouillet. From this analysis, accompanied by ingenious observations, he discovered that heat must come to the earth from some other source than the sun. Pouillet called this heat *the heat of space.* He carefully measured it, and found it to be only a little less than that derived from the sun.[1] Whence can it come? Not from the earth itself, for the earth would not give out a thousandth part of this amount. Not from vacant space: no physicist would hold so untenable a doctrine. It is unreasonable to assign it to the stars, as Pouillet appears to have done; such an hypothesis involves too vast a difference between the ratio of stellar to solar light, and the ratio of stellar to solar heat. Those of you who have witnessed a total eclipse of the sun know how the smallest portion of the sun puts out the light of all the stars; how unreasonable is it, then, to suppose that the combined heat of the stars

[1] *Comptes Rendus*, vii. 24–65. Poggendorff, *Annalen*, xlv. 25–56, 481–500. Taylor's *Scientific Memoirs*, iv. 44–90. — Ed.

is as great as the heat of the sun! But the meteoric theory fully explains the phenomenon. The doubt, indeed, is reversed, and the question arises, why did Pouillet's observation make the meteoric heat less than the solar? The difference would seem to be partly due to the penetrability of the earth's atmosphere to the solar rays, whereas a large portion of the meteoric heat must be absorbed into the upper atmosphere and radiated into space, before it can reach the surface of the earth. Again, it is possible that five sixths of the sun's heat is derived from the meteors, and the remainder from the sun's continued compression. Pouillet's observations may be claimed as strongly supporting the meteoric theory of the solar heat.

The constant dashing in of cold bolides upon the sun would occasion the mighty disturbance of its surface and the vast gaseous jets of which we have spoken. The mass of the sun would be increased, but at so slow a rate that many decades of centuries of nice observation will be required to perceive the effect. But there are modes in which it is

not impossible that the increase of mass may be detected, through the revelations of geometry. The constant increase of the solar mass would have an influence on the planetary orbits. It would diminish their eccentricities, according to a law of easy computation. Hence it is possible that the orbits of the planets may have been originally very eccentric, almost like those of comets; and their present freedom from eccentricity may have resulted from the growing mass of the sun. What modification of the nebular theory may be involved in this supposition cannot easily be imagined, without the guidance of some indication from Nature.

Returning to the original round nebula, from which the solar system was formed, we must suppose that it has gone through changes which are represented in many of the nebulæ. A central spherical portion seems to have concentrated into the sun and planets, leaving an outer spherical envelope, which was much slower in the process of condensation, and finally became an envelope of bolides. The natural orbits of the bolides were nearly circular paths, of which the sun

was at the centre. The variety of directions of the planes of the orbits was so great that they constituted a nearly uniform system, constantly approaching each other, and by their mutual heat producing explosions. They were thus broken up into an increased number of smaller irregular masses, such as we are familiar with in the meteoric stones. Thus we find all the varieties that exist among the bodies of the solar system harmoniously explained. Would it not be stranger than any fiction, — would it not violate all physical analogies, — if this ideal hypothesis of the meteoric structure of our system, sustained by such a variety of observation, were not a close representation of its actual history?

V.

THE COOLING OF THE EARTH AND THE SUN.

THE geological and paleontological records of the earth's history demand a long continued supply of heat from the sun, and an equally enduring solidity at the earth's surface. Is the nebular theory competent to meet this demand; or does it require serious modification? Whatever may be the answer to these questions, we may rest assured that Nature is harmonious with herself, and that the inconsistencies by which science may be embarrassed are temporary clouds in the intellectual atmosphere. They will be swept away by the besom of the true wizard.

In attempting to penetrate the past obscurity, we may fail to arrive at satisfactory results; but our investigation will not be a barren one. The expected treasure may not

be unearthed; but there will be a harvest of knowledge commensurate with the labor of the tilling, and an inheritance of truth which will manifest the wisdom and divinity of the testament whence we have derived such stimulus to inquiry.

We shall find the conservative opinion confirmed, that all the phenomena on scientific record are within the legitimate powers of the agents now in operation, and require the introduction of no extravagant and unknown force. The various stages of the investigation will carry us over a wide range of real and positive science, but nowhere shall we escape the dominion of ideality.

The attempt has been made by Darwin and other naturalists, and by various geologists, to estimate *the length of time* necessary for the evolution of the different forms of life and for the accomplishment of the geological transmutations. The rate at which erosion proceeds and the whole thickness of the eroded surface of the earth have been subjected to careful examination. A vast series of organisms has been traced back to an apparent commencement, which

occurred with the Cambrian rocks. There was a previous independent history, more indistinct in its evidence, possibly as long as all that follows. But, from the Cambrian period on, there has been an unbroken series of development, down to the present day. Even those very great naturalists who have been averse to the doctrine of evolution have been profound believers in the laws of the succession of species. Lamarck and Darwin have not been abler expositors and discoverers of these laws than Cuvier and Agassiz. The difference of doctrine is one of form rather than of substance It is not unlike that between Newton, who carefully declared gravitation to be simply the expression of the law by which the planets tended towards the sun, and the Newtonians, who speak of the sun's *attraction* for the planets, as if it were the product of some power of volition.

Disciples are ever dangerous to the doctrine of the masters. Pythagoras was not a Pythagorean, nor Plato a Platonist, nor Aristotle an Aristotelian, nor is Darwin a Darwinite. The scholar most honors his master

when, instead of accepting his doctrine on his authority, he imitates him in going directly to the source of truth, and submitting the master's teachings to severe criticism, adopting what he finds to be true, amending the defective, and rejecting the erroneous. May this ever be the quality of American discipleship! and then our science will remain worthy of the atmosphere of freedom.

The succession of organisms has been naturally exhibited in geologic periods, which are of uncertain length. The order of succession has been accurately defined by the relative position of fossil remains in different localities. The more thorough the researches of geologists have been, the greater has been the harmony of their conclusions concerning this order. The subsequent attempt to present the estimate of the duration of successive periods in numbers of years has introduced a vague element, which is foreign to the science. It is obvious that each geological period is long; but how long, is a matter of uncertain definition.

We shall find that the estimates in years of the duration of the corresponding changes

which have taken place in the *physical* condition of the earth are hardly more distinct and accurate, notwithstanding the aid furnished by the mathematician. No power of computation can give precision to that which is inherently inexact. Nevertheless, no other medium than that of years has been hitherto proposed for the comparison of the estimates made by the different sciences. It performs the office of money in the exchange of values in the market. It is not impossible that a way may be found by which the amount of energy absorbed in the various processes of change may take the place of time, in forming the estimates. Thus, if at some period less heat is required and slower evolution manifested, there may during that same period occur a diminished production of heat; so that the work may correspond to the power available for its production.

The amount of time needed for the geological history has been rated by geologists and zoölogists as high as three hundred millions of years. In later estimates the demand has been greatly reduced, so that a period of fifty millions of years may not now appear to be

too great a restriction. How does this estimate compare with the limitations of time from the physical point of view? Sir William Thomson has profoundly discussed them; and no philosopher is more competent than he to avail himself of all the resources of physics and geometry. He has been aided by Professor Tait, the eminent mathematician and skilful expounder of Quaternions.

We may first question *the earth*, and consider its testimony. Where and how does it hold its power of bringing forth grass and the herb yielding seed? The power does not extend over those portions of the surface which are covered with ice and snow; and it is equally deficient in large extents of parched deserts. It requires certain intermediate conditions of superficial temperature. Heat is essential to growth, whatever else may be needed; but excess of heat is destructive to life.

How do we know that the required heat does not come up from the earth's interior, whence the hot geysers and the molten lava arise? There is heat enough within. The temperature increases, the further we penetrate into the earth. The rate of increase near the sur-

face may be roughly stated to be, on the average, about one degree of Fahrenheit for every fifty-five feet of descent. Consider how few feet of earth are a complete protection from the coldest frosts of winter, and you will require no weight of authority to demonstrate to you that the daily ascent of heat through these fifty-five feet of earth is quite imperceptible. Were it wholly taken away you would never miss it.

None the less, the decrease of heat in ascending from the interior is a vital fact in the history of our planet. Its story cannot be impeached. At the depth of about two miles the heat equals that of boiling water, which involves the death of all living things. With your permission, I will pass for an instant from the consideration of these grand phenomena of Nature to a trivial and homely, but instructive example. Two days in each week I am wont to find upon my breakfast-table a loaf of Boston brown bread. I have observed a systematic difference between these loaves. That of the first day is hotter in the interior than at the surface; while the reverse is the case with the second day's loaf.

My cook, though no physical philosopher, can explain to you the simple cause of this difference. The loaf of the first day is fresh from the baker's oven, and is undergoing the process of cooling; while that of the second day, having been put back into the oven after it was cooled, and being placed on the table before it was equally heated throughout, honestly reveals its history. In the same manner the earth tells us that, like the loaf of the first day, it is in the process of cooling; and that, at some past time, its surface must have had about as great a temperature as it now has in its hottest interior.

In the liquid state of the earth, its temperature would be subject to the law of convective equilibrium. The convective equilibrium of a gas or liquid is that condition of pressure, density, and temperature by which any portion of the mass, when conveyed from one position to another within the mass, immediately assumes the density and temperature of its new locality, in consequence of the change of the pressure. In a gas, the changes of density and temperature are great; while they are small in the case of

the almost incompressible liquid. The law of temperature in the solid and intermediate states depends on the order of solidification. There is a deficiency of observation concerning the solidifying process. Hence there is room for variety of opinion and of hypothesis, for legitimate suggestion regarding the direction of future inquiry, and for faith in the power of scientific investigation to develop the truth.

You all know how and why water solidifies first at its surface, — that it expands near the point of crystallization, and that this causes it to become lighter and therefore to rise, and appear as ice at the surface. But this is regarded by physicists as an exceptional phenomenon. Most metals are thought to have the opposite property, and to become heavier as they solidify, so as naturally to sink to the bottom, throughout the process of cooling into solidity. Hence it is plausibly maintained that the solidification of the earth began at the centre, and extended upward to the surface; so that when the surface became solid, the globe was solid throughout.

This doctrine is not only adopted on physical grounds by Sir William Thomson, but he has undertaken to demonstrate that the supposed fluidity of the earth's interior is inconsistent with astronomical phenomena. His argument deserves careful analysis, as a profound scientific discussion of undeniable facts.

Thomson first considers *the tides*, the exact knowledge of which is so essential to navigation. They depend upon the attractions of the sun and the moon on the different portions of the terrestrial ocean, causing it to rise in one place and fall in another; while the land remains stationary, and is the basis from which the height of the water is measured. Were the body of the earth quite destitute of rigidity, the land would rise and fall with the sea, and there would be no tidal variation of depth. Even in the Gulf of Maine, where we have now a change of depth of sixty feet in six hours, from high to low tide, there would be neither tide nor tidal current nor inward rush of ocean over the bottom of the sea, which would rise just as fast as the upper surface. With an

exceedingly small rigidity, such as there would be if the earth's surface were a thin crust, the tides would be proportionally small.

Theory is incompetent to ascertain what would be the precise magnitudes of the tides on a perfectly rigid earth. The dynamical conditions of the problem present almost insuperable difficulties. Were it a question of pure equilibrium, or of so slight a motion as to render inertia an unimportant element, the solution would not be difficult. But the inertia involves the consideration of conservation of force, of meeting currents, of the velocity of the tide-wave, of depths of the sea varying in time and space, of vibrating surfaces and nodal lines, and of special laws peculiar to each of the three great classes of tides, — the diurnal, the semi-diurnal, and the fortnightly. There is too great complication for the clearest and strongest mind to unravel, without the aid of fuller observation. Until, then, we have obtained better means for the comparison of theoretical with observed tides, we must submit to be governed by the opinion of the wisest, with such ap-

proximation to theory as can be derived from legitimate argument.

Sir William Thomson's exact computations have undoubtedly shown that "if the rigidity [of the earth, on the whole,] were as great as that of steel, the relative rise and fall of the water would be reduced by elastic yielding to two thirds, or if the rigidity were only that of glass, the relative rise and fall would be actually reduced to two fifths, of what it would be were the rigidity perfect." I suppose, therefore, that we may safely, for the present time, adopt the opinion of this philosopher that "the tidal effective rigidity of the earth must be greater than that of glass;" and that, instead of living "on a mere thin shell of solid substance, inclosing a fluid mass of melted rocks or metals," the tidal phenomena indicate "that the earth as a whole is much more rigid than any of the rocks that constitute its upper crust."[1] But as there is no historical record to tell us of the tides of past geological ages, we cannot carry back this argument to any distant past.

Thomson has sought to corroborate the

[1] Thomson and Tait's *Natural Philosophy*, i. §§ 832–846.

evidence of the tides by that which is furnished by a far more accurately determined phenomenon, *the precession of the equinoxes.* His discussion of this subject is too profound, original, and suggestive not to be presented here. But I must begin by recalling to your memory the phenomenon to which the discussion relates.[1]

The earth's equator and axis of revolution, though fixed in the earth, are constantly moving in space; and their changes of position are recognized by astronomers in the daily reduction of their observations. The *equinoxes* are the directions in which the plane of the earth's orbit, called the *ecliptic*, cuts the plane of the equator. When, in its seeming annual path, the sun arrives at either of these directions from the earth, the days and nights are equal throughout our globe; and it is from this circumstance that the name of the equinoxes is derived. The plane of the ecliptic is nearly stationary, but the equinoxes retrograde; that is, they move in a

[1] Sir W. Thomson has withdrawn, or seriously modified, the part of his argument here criticised, in view of the "quasi-rigidity induced in a liquid by vortex motion." *Brit. Assoc. Rep.* for 1876, sections, p. 5. — EDITOR.

direction opposite to that of the sun's apparent yearly motion among the stars. This motion, called *the precession of the equinoxes*, has been known for two thousand years, or since the time of Hipparchus, the father of mathematical astronomy. Its annual amount is about fifty seconds of arc; so that either equinox will pass through the whole circuit of the ecliptic, and return to its present position in the firmament, in a little less than twenty-six thousand years. There is a corresponding motion of the earth's axis among the stars; the pole of the equator describing a circle about the nearly stationary pole of the ecliptic.

An essentially similar phenomenon to precession is to be found, where you would perhaps little expect it, in the spinning of a boy's top; so that the geometer recognizes the same idea in the plaything of the child and in the vast object of astronomic study. Before the top has reached what the lad significantly styles its state of sleep, you must have observed how the axis rotates swiftly around a vertical line. This motion typifies the precession of the equinoxes. But in a fraction of a second it

completes a circuit for which the observer of the terrestrial axis must wait twenty-six thousand years. There is the same ideal connection with another plaything known as the "devil-on-two-sticks," and also with the scientific toy called the "gyroscope." There has been no mystery in these motions for the past seventy years, notwithstanding that astonishing discoveries of elucidation are still occasionally heralded to the world in the public journals.

Not only is there a resemblance in certain phenomena of the axial motions of the top and the earth; there is also a similarity of causation. But it is too involved a problem of analytic mechanics for present discussion. I may, however, venture to call your attention to a few leading facts. The direct tendency of the earth's attraction upon the top is to make it fall; and it would fall if it were not for its rotation upon its axis. In the same way the boy's hoop, when rolling forward with speed, cannot be forced to fall, until it is nearly stopped, and its velocity of rotation greatly reduced; and so also the rapid rotation of the wheel of the bicycle tends to keep it erect,

and also to preserve its onward direction of motion. Geometrical analysis develops the fact that this is merely a manifestation of the simplest law of motion, by which each particle of matter, in consequence of its inertia, tends to preserve its rectilinear and uniform velocity. On the same principle, the sun and the moon always conspire to bring the equator into coincidence with the ecliptic; and the earth would yield to their attractions if it were not for its rapid rotation upon its axis. But the force, applied in the one case to the top, and in the other to the earth, cannot be nullified by inertia. Neither mass has any power of volition, by which the offered force can be rejected; it must be accepted in strict obedience to the laws of mechanics, and logically combined with the force that has been previously imparted.

For reasons which are plain enough to him who will go through with the studies necessary to apprehend them, the motion of rotation imparted to the axis in either case is perpendicular to that which would be imparted if the body were at rest. Take a common globe, mounted on a stand; rotate

it swiftly upon its axis, and then try to turn the axis in any direction: you will instantly perceive a strong tendency to turn in a perpendicular direction; that is, you will witness a phenomenon similar to precession. The greater the applied force, or the less the mass of the moving body, the greater must be the precession.

Now, with the earth, the protuberance at its equator constitutes, as it were, a handle, by which the sun and the moon strive to turn it; and the consequence of their action is that the earth's axis is made to rotate about a line perpendicular to the plane of the ecliptic. This constitutes the precession of the equinoxes.

The magnitude of the earth's protuberance has been measured in various ways,— by the length of the degree in different latitudes; by the swinging of the pendulum in many places; and by a peculiar phenomenon of the lunar theory. Supposing the earth to be solid throughout and perfectly rigid, the corresponding precession has been computed, and it agrees with observation. Were the earth deficient in rigidity, its form would

partially yield to the solar and lunar attractions, and a portion of the force would be consumed in distorting the earth's figure; so that the remaining force, effective for the production of precession, would be diminished, and give a result less than the actual observation. On the other hand, if the earth's interior were fluid, the solid mass to be rotated would be diminished, so that the actual precession would be too small.

Here are two nearly allied phenomena which may exist simultaneously and produce opposite effects. It is not impossible that they may exactly balance each other, by reason of numerical relations between the imperfect rigidity of the earth and its partial solidity. We should then still have the same precession as that due to perfect rigidity and complete solidity. Thomson regards such an accidental agreement as quite improbable, especially with the thin shell which would be required for the assumed geological phenomena and the great accompanying deformation of the earth. Such improbable accidents are nevertheless constantly occurring.

There is, however, a feature of the case which Sir William Thomson seems originally to have overlooked. If the enclosed fluid did not partake of the change of axis of the external solid, it would continue to rotate on its original axis, while the axis of rotation of the external shell was turning into a different position. These axes would thus be ever separating, and a resisting friction would be developed, which would tend to diminish the excessive precession. Thus, if they came to be separated as far as twenty degrees, for instance, and if the shell were quite thin, the difference between the velocities of the contiguous points of the outer surface of the interior fluid, and of the inner surface of the solid shell, would exceed three hundred miles an hour throughout great regions of the two surfaces. The friction thus developed would act as a resistance to the separation of the axes. If, at any instant, the influences on which precession depends were to be removed, the friction would soon restore the axes to coincidence. It must, in the course of time, become sufficient to prevent any further sep-

aration; and when this stage is reached, the axial motion pervades the whole globe, and is the same in amount as if the solidity were complete. The effect of want of rigidity will remain, but be diminished in amount; and this appears to be accordant with actual observation.

There remains for our consideration the argument for the solidity of the earth which Thomson has derived from *the increasing density of the cooling metals*, in regard to which another class of objections will soon be presented for your criticism. But these you will more readily appreciate, after you have listened to the exposition of Thomson's profound researches on *the cooling of a solid earth.*

His determination of the corresponding time which must be assigned, from the accomplishment of the earth's solidification to its present condition of temperature near the surface, is undeniably correct in principle, and his allowance for the numerical uncertainty of the data is more than ample. The principal elements of the investigation are: (1) The initial temperature of the earth; (2) The average conductivity of the earth's

crust; and (3) The law by which the temperature of cooling solids increases with the depth below the surface.

The initial temperature is that at which the rocks would melt, and which is assumed by Thomson, from the best physical experiments, as seven thousand degrees of Fahrenheit. The conductivity of the earth's crust, derived from various extensive investigations, is considered by him to be, on the average, at the rate of four hundred degrees of Fahrenheit a year, through a stratum in which the temperature increases by one degree for each foot of thickness. This datum is the least certain, and demands renewed examination. Finally, the mathematical theory of the cooling is adopted from the admirable treatise upon Heat by the great French geometer, Fourier. It is simple, and presents the law of temperature in a form which is readily adapted to the proposed problem. An exceedingly short time, probably not more than a single year, will be required to reduce the superficial temperature from seven thousand degrees to a temperature which may be assumed to be sensibly that of the

present day. Hence, there would be no physical obstacle to the immediate introduction of simple organic forms upon the earth's surface. Then Thomson finds that the rate at which the temperature of the earth would increase for every foot of descent below its surface would become

in	10,000	years,	2°
"	40,000	"	1°
"	160,000	"	½°
"	4,000,000	"	$\frac{1}{10}$°
"	100,000,000	"	$\frac{1}{50}$°

The present rate of increase of temperature corresponds, then, to an interval of a hundred millions of years from the possible commencement of organic life.

Do these great numbers embarrass you, and interfere with your reception of the truth which lies buried beneath them? We can lessen the numbers by changing our unit of time. To the inhabitant of the planet Neptune, this vast period of a hundred million years is only about six thousand of his centuries. If we call the period of the equinoctial circuit an *æon*, it is only forty centuries of æons. You must not be

surprised, therefore, if I cannot sympathize with the weakness of your numerical ideality.

Whenever a contribution of numbers shall be taken up, the generosity of the mathematicians will be found to be inexhaustible. Archimedes wrote a treatise, which he dedicated to Gelo, Prince of Syracuse, in order to exhibit to him the human capacity for number. He showed the prince how he could express in numbers the sands upon the seashore of Syracuse, and those around the whole island of Sicily: nay, much more than that; how, if the volume of the seashore were of such immensity as to embrace all the visible world, and if the sands were finer than the finest dust blown by the gentlest wind, the number of particles would be far below his power of expression. He devised the most ingenious system of numeration which ever entered the imagination of science. He condensed a universe of number, vaster than creation, into a single phrase, and laid it at the feet of the son of Hiero.

The million of centuries assigned by Thomson for the geological history appears like an infinity to him who is accustomed

to measure time by the standard of human events. The geologist of yesterday may have been content with it. But science has not educated him out of humanity; and his insatiate appetite for time seems to grow with what it feeds on. Now we hear a murmuring demand for six hundred millions of years as required for the formation of the geological strata![1]

Notwithstanding my faith in Sir William Thomson, who is justly regarded as the highest living authority in questions of cosmical physics, I cannot accept his process of the earth's solidification, with its corresponding limitation of the geologic ages. Were our planet, when liquid, thoroughly homogeneous, and did it remain so as it crystallized, I could offer no reasonable objection to his hypothesis. But it has become too obviously heterogeneous for the maintenance of such a belief. The excessive radiation at the surface, when it was at the primitive temperature of seven thousand degrees, must have induced the beginning of crystallization as a superficial phenomenon. It is probable

[1] *Proceedings of the Royal Society*, xxviii. 281–283. — Ed.

that the solidified portions, from their superior weight, descended, at the outset, as Thomson supposes, into the interior. Up to this point, then, his doctrine is admirable; except that, at the instant of crystallization, the various materials combined in the liquid are likely to have separated from each other. Certain of them may have remained as slag at the surface, and formed the commencement of an outer crust. This is so usual a phenomenon in all processes of art that the only question would seem to be, how much it may amount to. It also appears to be indicated by the various geologic strata and by upheavals, that the earth's interior is formed of much purer metal than its surface.

Even though the slag were not separated at the outset, the rocks, combined into solid form too soon to resist the internal heat, would be melted in their descent. Whether the portions first melted would be the denser or the lighter parts must depend upon their relative fusibility. But the result would not be essentially modified in either case. If the denser constituents were the most fluid, they would be melted out, and leave the

lighter constituents to ascend and become annexed to the surface. If, on the contrary, the lighter parts were the most fluid, they would, when melted, reascend to the surface and be frozen again. In any case, therefore, it seems undeniable that there is a permanent superficial solidification at an exceedingly early stage of the history, even if, at the same time, there is the formation of an interior solid nucleus. This process must continue to the end, the thickness of the crust, and also the volume of the central nucleus, constantly increasing. These interior and exterior solid portions will be separated by a liquid stratum, which is ever decreasing in thickness, to supply the increasing solidity above and below it.

What must be the effect of this interior fluid and thickening outer crust upon the rate of cooling, and on the length of time required for physical changes of temperature? According to Thomson's hypothesis, the greater part of the heat which passes through the surface comes from a depth of less than eighty miles; and the whole body of the earth beyond that depth remains at the

original temperature of solidification. In other words, the external cooling has penetrated, at the farthest, to a depth of only eighty miles, and at that depth its effect is scarcely perceptible. The average depth of the cooling of the earth's crust is about twenty miles; so that these upper twenty miles afford an ample supply for all the heat which comes from the interior in a thousand centuries.

Now, the hypothesis of the liquid interior adds immensely to the reservoir of supply, without increasing the rate of exhaustion. Every degree of heat communicated to the surface of the liquid is rapidly distributed through its whole mass by convection; so that the temperature of the liquid surface cannot be lowered by a single degree without a corresponding diminution of the temperature of all the inner mass. Hence, in place of the superficial reservoir of twenty miles in depth, we shall have all the body of our globe to draw upon. The supply of heat will thus be more than sixty-fold augmented; and no physical obstacle can mathematically be interposed to embarrass the researches of

geologists, to interfere with the extension of their ages of erosion, and to diminish the possibility of an increased duration of organic life.[1]

We may now turn from the Earth to the more brilliant testimony of the *Sun.*

How long can this luminary have continued to give out its present great amount of heat? Some distinguished astronomers and physicists have contended, for not more than twenty millions of years. But it is not difficult to show, that, on the very principles justly adopted in the computation, the period may be increased to at least five hundred millions of years.

It has been correctly assumed that the amount of heat radiated from the sun is to be measured by the energy which the sun itself has received from the accumulation of material near its centre. This is simply the trans-

[1] For Sir W. Thomson's views on the subject of the Cooling of the Earth and of its Rigidity, the leading references are as follows: *Philosophical Transactions*, vol. cliii. pp. 573–582; *Transactions of the Royal Society of Edinburgh*, vol. xxiii. pp. 157–169; Thomson and Tait, *Treatise on Natural Philosophy*, vol. i, §§ 832-849, and Appendix (D); *British Association Report* for 1876, Sections, pp. 3–12. See also Tait's *Recent Advances in Physical Science.*—EDITOR.

mutation of energy from the form of swift motion to that of intense heat. If the computations are correctly performed, it makes no difference whether the increase of material energy was derived from new matter falling into the sun in the form of meteors, or from the compression of the mass of the sun itself into a smaller space, combined with an increasing density at the solar centre. There are phenomena, however, in which the difference is visibly manifest, and by which we are enabled to distinguish the character of the augmentation of energy. The addition of new matter to the sun involves a shortening of the year of every planet, and cannot reach an amount which would be inconsistent with astronomical phenomena, and especially with the observed precession of the equinoxes at the time of Hipparchus. The mass supposed to be required for the maintenance of the sun's heat, and adopted in the computations above referred to, can be shown to be twenty-five times as great as is necessary. The actual distribution of the solar material was not properly considered. It is from this element that I derive the vast

increase of the sun's possible duration, even if it had always given out heat at the same rate as at the present time.

But we have reason to believe that the heat radiated from the sun is greater now than it has ever been before. The increase of mass which has occurred can hardly fail to be exhibited in the number and augmented energy of the meteors which fall into it; and this increase will continue, until there is a corresponding diminution of the nebulous cloud from which the comets and meteors are falling. It is therefore possible, and even probable, that the sun has given out less heat in past ages than it is now radiating. The apparent inference is that the earth was cooler then than it is at present. But this inference would not seem to conform to the earlier phenomena of our geologic history; and there are sufficient reasons for its rejection.

In a former lecture, I told you of the meteors striking the earth and thereby heating it. I told you that the heat derived from the meteors might be as great as that received from the sun. You may have thought that the meteors struck the solid earth;

which would have been a more terrific phenomenon than the severest hailstorm or than a bombardment by artillery. But fortunately we are protected from them by the cushion of the earth's atmosphere. It is on this that the immediate blows fall, and the heat is mostly deposited in the upper regions of the atmosphere, — though a few of the larger meteors have penetrated the atmosphere, and exhibited their powers of destruction upon the inhabitants of the earth. In the same way, a large part of the sun's heat is at first communicated to the upper atmosphere; and, finally, that portion which is not radiated from the atmosphere descends to the surface of the solid earth, partly by radiation and partly by convection.

It is in this wise that the earth's surface is heated up. It is, at the same time, emitting heat by radiation; and the heat must increase until the radiation is sufficient to throw off all the external heat received from the sun and the meteors. Consequently, the more the radiation is retarded by the surrounding atmosphere, the greater will be the heat attained by the surface of the earth;

unless there be a corresponding diminution in the heat communicated to the earth. If the height of the atmosphere in past times had been twice what it is now, or if, by the addition of aqueous vapor or carbonic acid, the resistance to radiation had been doubled, the heat of the surface upon which we live must have been likewise doubled. In that case, our present sun would have been too powerful for organic life; animals and vegetables would have been scorched out of existence. We should have been better off without this sun, which we now bless for its beneficent light and heat: the meteors would have given us the needed temperature.

How such a state of things would increase our respect for these almost invisible bodies! and how it would destroy the admiration and the worship of the sun! But we have come to the knowledge of the beneficence of the unseen meteors through the visible meteors and the stars. To the wise man, it strengthens his faith in the divine harmony and the omnipresent ideality.

VI.

POTENTIALITY.

IDEALITY is pre-eminently the foundation of the mathematics. Observation supplies fact. Induction ascends from fact to law. Deduction, applying the pure logic of mathematics, reverses the process and descends from law to fact. The facts of observation are liable to the uncertainties and inaccuracies of the human senses; and the first inductions of law are rough approximations to the truth. The law is freed from the defects of observation and converted by the speculations of the geometer into exact form. But it has ceased to be pure induction, and has become ideal hypothesis. Deductions are made from it with syllogistic precision, and consequent facts are logically evolved without immediate reference to the actual events of Nature. If the results of computation coincide, not

merely qualitatively but quantitatively, with observation, the law is established as a reality, and is restored to the domain of induction.

If, on the contrary, there is some inexplicable divergency between the computed and the observed facts, the law must be rejected. It cannot be accepted as an expression of the rigid theory embodied in Nature. There is nevertheless a truth at its foundation, — as surely as there is a base to a mountain, or a bottom to a well. It includes some mathematical conception, which remains as undeniable a phenomenon as Nature herself. It is her spiritual child, of as legitimate a birth as her recognized material offspring. It is an ideal potentiality, which may include the actual; and is loyally submissive to the inflexible laws which control the human mind. Its fixed seat in the soul is not to be disturbed by the blindness of the body. It is a criterion to discriminate between the accuracy of theory and observation. It is a judge, having power to decide upon the jurisdiction of his own tribunal.

In the studio of the painter, the sculptor,

and the poet, ideal art is prone to conceal its natural figure under the garb of reality. But in the frozen cave of geometry, the thoughts which may trickle in from the actual world are crystallized into glittering, passionless, and unsympathizing stalactites; and the mathematical sage cares not whence they came, — whether they fell as dew from the quiet sky, or as rain from the clouds driven by the wind. Whatever be their origin, they are ideal truth.

The laws of planetary motion, which Kepler deduced from the observations made by Tycho Brahe, are more exact embodiments of fact than the observations themselves. But their defect is their want of elasticity. They give a precise, unchanged orbit, in which each planet moves with a fixed law of velocity. There is no recognition of the disturbing influence of other planets. There is no suggestion of such influence, in their simple statement of the forms of motion.

Obedient to intellectual instinct, man inquires into the cause of these motions. He subjects them to elementary analysis; considers the instantaneous tendencies to motion,

and finds them to be direct manifestations of a simple law of gravitation. The planet gravitates to the sun, the satellite gravitates to the planet. The comprehensive mind of Newton asks: Why should there be limitation in the attractive force? Why should not planet gravitate to planet? Why should not every particle of matter in the universe gravitate to every other particle? Thus was born the simple potentiality which has opened the way to all the problems of celestial mechanics, to the study of the motions and figures of the stars and of their tidal changes of figure.

How simple the fundamental idea; and how complicated the details of theory to be elaborated! They have absorbed the labors of astronomers for the last two centuries, in the observatory at night, and in the study by night and day. Statistics do not inform us how many computers have been engaged in the task, how many volumes of logarithms have been consumed, how many thousands of figures have been written down, how many pens of goose and gold have been used up. But if each pen were worth a gold mine;

if each figure were a golden thought; if each volume were the life of a philosopher; if each computer were a man of genius, — the whole expenditure of material and brain would be insignificant in comparison with the unbounded domain subjected to the authority of ideality.

The work has not, however, been accomplished without intellectual perplexity and frequent trial of faith. The universality of the law of attraction, in so unexampled an harmonious accord with the simplicity of the human spiritual longing, was not established without the striking of some false notes. Strong minds have doubted whence the discord came, — whether it was in the instrument or in Nature's intention; whether the geometer might not have erred, or whether there might not be some obscure complication of law awaiting his discovery. Feeble scientists may be alarmed at the breath of the wind among the leaves, and may exclaim, in their terror, that the heavens are falling. But the doubts of genius are the foresight of the lofty soul which perceives some celestial truth just rising above his extended horizon.

During the first century after the discovery

of universal gravitation, *six* planets were known, whose masses and normal orbits were to be determined, and whose irregularities of motion were to be reconciled with their mutual perturbations. If their theories had been established with ultimate precision, and submitted to the critical comparison with observation which is practised to-day, the exterior planet Saturn would have presented inexplicable deviations from its proper theory. What would have been the consequence? Recent experience has sufficiently informed us. There would have been scepticism respecting the validity and accuracy of the Newtonian law. The repulsive force manifested in the tail of the comet, the resisting medium adopted by an eminent authority to explain his comet's diminishing years, would have been food enough for the intellectual nourishment of many a standing doubter. Nevertheless, there would have been stout hearts which would not have yielded to unreasonable scepticism. They would have faithfully and exhaustively explored the region of legitimate research, to discover some possible cause of the

anomalous irregularities. If the telescope had failed, the pen of the geometer would have detected the disturbing planet. But Herschel, with his great telescope, anticipated the mathematical computations. URANUS was discovered; and the theories of the *seven* planets were ere long presented to astronomy by the untiring genius of Laplace, accompanied by astronomical developments, grander than new planets.

In the subsequent attempt to construct tables which should serve for the prediction of the places of the planets, it was ascertained that the irregular motions of the new outer planet still required the intervention of some unseen power. Two great geometers, independently of each other, computed the elements of a planet which should reconcile the discrepancies. They coincided in its orbit and position. In the very direction predicted by them the planet NEPTUNE was found, in consequence of their predictions, and apparently in full confirmation of them. Neptune completely accounts for the previous defects of the theory of Uranus, and leaves no apparent indication of the further exten-

sion of the solar system. The discovery was an extraordinary achievement, and deserves the wreath of immortality which has been awarded to Adams and Leverrier.

But there is a supplement to the story, which seems incredible. The statement is one which violates popular prejudice; it has been wrongfully attributed to contemporary jealousy; it would not be introduced here, but it is too pertinent an example of geometric potentiality to be omitted. The observed planet is quite distinct, in orbit and theory, from that which was predicted; and the theory of prediction throws no light upon the actual theory, nor has it any but an accidental connection with it.

It is not rare that there are several different possible causes of an event, and through the influence of incomplete evidence or prejudice the wrong cause has been selected. Under the wisest administration of justice, there has been so skilful an array of circumstantial evidence that the innocent man has been punished even to the loss of life. To the present case I have given a critical and laborious investigation. My examination has

covered a far wider range of theory than that included in the original researches. I have carefully revised the computations of Adams and Leverrier. I find in them no error, no lack of judgment, and no failure in respect to any legitimate mode of investigation. Nevertheless, I strictly adhere to the correctness of my early statement. I am aware that there are great names opposed to me; but their opposition has arisen from the mistaken conclusions of ill-digested argument. The time must come when personality will disappear, and nationality sink into oblivion; and you must await the final rendering of the verdict of astronomy.

My position is that there were *two possible planets*, either of which might have caused the observed irregular motions of Uranus. Each planet excluded the other; so that, if one was, the other was not. They coincided in direction from the earth at certain epochs, once in six hundred and fifty years. It was at one of these epochs that the prediction was made; and at no other time for six centuries could the prediction of one planet have revealed the other. The observed planet was

not the predicted one. It was excluded through the limitations which had been determined by Leverrier himself, after a prodigious outlay of profound and ingenious research. He had proclaimed the investigation of the limits as essential to the full solution of the problem. It was certainly its larger moiety, and most intricate portion; and he had worthily solved it. It is inconceivable how the great master can have consented to abandon his choicest production and most brilliant jewel to popular applause and its ignoble bribery. The potential planet is as splendid a reality as the true planet, and as marvellous a discovery.

Physical potentiality is Protean in its forms. *Work done* is the representative and equivalent of the energy by which it was accomplished; if it could undo itself or be undone, it would set at liberty the same amount of energy, and this could be applied to the performance of other work. The energy which is used in performing work, and which is buried in the work, may be considered as *latent energy;* and, in reference to its possible development and transformation, may

be designated as potentiality. All mechanical philosophers recognize this potentiality, and agree that the aggregate energy of the material world, including the potential as well as the actual, has never suffered increase or decrease. Man's will has no power over it; not so much as it may have to add a cubit to his stature, or to change the color of his hair.

A profound analysis of the operations of Nature has led Sir William Thomson to the conclusion that there are paths of work which cannot be retraced, and in which there is an absorption of energy which cannot be recovered. If this be so, there is energy which is practically lost; or, in other words, there is a continual diminution of the available energy of the physical world.

When, in the winding of a clock, the weight is raised, it represents in its position the power of gravity which resisted its elevation. There is potentiality in its position. As the weight descends and turns the machinery, overcoming the friction which retards the descent, the potential energy of the position decreases, and is transformed into

work and thence into heat. In the same way, the planet which has ascended to its greatest distance from the sun has acquired its position of maximum potential energy. At the same time, it has lost an equal amount of actual energy, which is manifest in decreased velocity. If a stone were to fall from the top of a monument, it would, on reaching the ground, acquire a velocity which, reversed in direction, would be the exact amount required to carry it up again to the point from which it fell. But if it were permitted to strike the ground, the power would be again transformed, and would be represented in the heating, bending, and breaking of itself and of the surface upon which it fell.

Heat is but a name for the energy of the motion of vibration of the particles of a body. When water is heated to a certain temperature, it passes into the form of steam; and a large amount of heat is absorbed in the process of transition. Upon the reversal of the process, the steam cools, returns to the form of water, and develops the power needed for the steam engine. In this case, potential energy

is represented by the form of steam. Again, in the passage from ice to water there is a similar absorption of heat; so that the liquid represents potentiality in comparison with the solid form of water. There is no chemical transformation in which there is not a corresponding exhibition of potentiality. It extends even to the organic world. When the tree grows, it absorbs the solar heat, which is treasured up as potentiality in the form of wood or coal.

The coal of the geological strata, formed ages before the birth of man, was from the beginning designed for his use, as certainly as the charcoal which is brought to market, or as to-day's sunlight. The supply of material essential to man's civilization, so long anterior to the demand, — how can you explain it? It could have had no influence in the production of man; but it is the evidence of the plan of his coming, inwrought into the course of evolution, — in the same way as the openings in the frame-work of a building demonstrate the future stairs and chimneys. If you were to travel to another planet, and there behold a similar deposit of coal, occurring

where man was absent, would you not justly infer that that planet was intended at some time to be peopled by civilized beings like ourselves? Whether you believe in the law of development or in the law of design, what other conclusion is consistent with your doctrine? There is *a spiritual potentiality of plan*, as visible to the penetrating eye of the seer as any physical potentiality.

The past and the future are equally ideal. The present is, alas! the only reality. The past is irrecoverably lost as an actuality; but, restored by history, it is an ever-living instructor. The future, inferred from the instructions of the past, is soon to become the present, and its approach is watched for with intense interest. In the market it means failure or it means untold wealth; in politics it means ambition rewarded or punished; in religion it means heaven or eternal suffering or absolute death. To be able to foretell an eclipse or a comet or the place of the planets or the aspects of the stars was to endow the race with a higher sense; it was giving to civilized humanity authority over those powers of darkness which the superstitious

barbarian worshipped. There is a singular charm in prediction, even when one cannot be present at its verification. But to verify prediction is to receive the homage of Nature.

Is spiritual prediction a hopeless impossibility, like that of the storms of the next century? What is to be each individual's future; and what the future of all mankind? Science has banished the prophetic rule of the stars. But the continuity of law has taken possession of the throne of augury vacated by astrology. It is not unreasonable to hope that honest and reverent inquiry will have its due and promised reward, even when it seeks to penetrate the mysteries of the spiritual future.

There was once an age of stone upon the earth. Its records are found in all lands. Though it had not a simultaneous existence over the whole earth, its history is one and the same everywhere. Man was scarcely elevated above the beasts, and used no implements of peace or war but those formed most inartificially of earth or stone. His dwelling was a cave or a wretched hut of wood and mud, of similar architectural merit to that of

the bird's nest or the beaver's dam. He was destitute of written language. From that inferior stage, the lord of creation has gradually and naturally risen to his present possession of arts, science, and literature, and with a constantly increasing rate of progress. If the stone age was an advance upon a still earlier unknown condition, how low that condition must have been! Lower perchance than that of the apes and monkeys of to-day, from which proud man, in his foolishness, so dreads being forced by the doctrines of evolution to trace his descent.

On the other hand, is the story already completed? Have we reached the last act, and are we suddenly brought to a stop upon the very threshold of the divine temple? No miracle has accomplished the past progress. Is the end to be a destructive work worthy of a demon? Such a conclusion is not more disheartening than it is unphilosophical. It is contrary to analogy and experience, not less than to hope and faith. To religion it is falsehood, and to evolution it is absurdity. Each new invention and discovery in the arts and sciences has hitherto opened the way to

many others, still more surprising. The law of progress will not be suddenly interrupted; it cannot cease without previous indication and some evident diminution in the rate of advance. We have a just and abiding faith that our planet will endure for the development of our children and our children's children, to the latest generation. Our trust is founded upon the eternal laws which govern the universe, and upon the rock of ages, that the promise of creation will be fulfilled, and that the end will not come without unmistakable signs and warnings.

But while the race may last, may not the individual be sacrificed? How many millions of germs of plants and animals are destroyed, for one which escapes destruction and becomes fruitful! How many children die, while so few arrive in health at maturity! It seems to be the law of life that individuals should be produced in numbers sufficient to insure the permanence of the race. When the supply has been deficient, the race has died out. Such has been the case with families of plants and animals, and with the aborigines of many countries; and such is the

inevitable destiny of our own aborigines. It is the law of material life.

But the law of spiritual life demands other evidence and principles of investigation. In the material world one atom can replace another without prejudice to the system. Tree can ever be substituted for tree, and beast for beast, each in its kind; so that species is everything, and individual nothing. But it is quite the reverse in the spiritual world. An individual cannot hold the place of another, as father, mother, or child; as husband or wife; as king, or warrior, or statesman, or judge, or trusted friend, or beloved pastor. The spiritual individual is everything. The destruction of any soul would be an irreparable loss; nothing can be conceived more utterly at variance with the harmony of creation. It is an absolute impossibility; and we may hold it, not irreverently, to be a limitation even of Almighty Will. A man can tell a lie, and thereby demonstrate his feebleness; the pagan god can deceive, because he is weak and limited. But our God, for the reason of his infinite strength and of his eternal omniscience, must forever coincide

with himself. Otherwise, instead of being an infinite and necessary reality, he would be an infinite impossibility. At one and the same instant, he would be and not be God. We may dismiss the argument for the ideality of physical science as an unreal fable, when we set aside our assurance of the immortality of the spirit as a delusive promise.

But how is it with the immense apparent failure of spiritual intention? If we may interpret the actual facts of experience, with what judgment shall we judge? Each day solves some riddle of the past, but there will always be riddles to be solved. Nature's riddles are man's intellectual nourishment: they are the bread and wine of his science and his ideality. To shrink from them is cowardice and want of faith. To solve them is to bring light into the world, and to drive out ignorance and superstition: it is the anticipation of futurity, the beginning of immortality, and salvation from intellectual death.

What shall we say concerning the suffering with which this world is afflicted? What of sin? These awful topics are above my

sphere, and it is with extreme diffidence that I venture to throw my small light into their dark mysteries. If you reject my speculations as idle and illogical fancies, I hope that you will find them neither rash nor irreverent.

What is man? What a strange union of matter and mind! A machine for converting material into spiritual force! A soul imprisoned in a body! Is not the body a dungeon, — a tenement of decay, from which the soul will rejoice to free itself, and wing its flight to the perennial spring-time of heaven and to perpetual rest in the bosom of the Father? Perpetual rest! — for an immortal soul, whose only life is action! Why not remain in the sleep of the grave, and never be awakened by the last trump? Such a doctrine may satisfy the wisdom of Confucius, or delight the Buddhists, but has no place in Christian philosophy.

The body is the vocal instrument through which the soul communicates with other souls, with its past self, and even, perhaps, with its God. Were the communication between soul and soul direct and immediate,

there would be no protection for thought; each man would take full possession of the thoughts of every other man, and there would be no such thing as personality and individuality. The body is needed to hold souls apart and to preserve their independence, as well as for conversation and mutual sympathy. Hence body and matter are essential to man's true existence. Without them, he must, as is supposed in the Chinese theology, be instantly absorbed into the infinite spirit. In this case, creation would be a false and unmeaning tragedy. The soul which leaves this earthly body still requires incorporation. The grandest philosopher who has ever speculated upon this theme has told us in his sublime epistle that there are celestial bodies as well as bodies terrestrial. It may not be vain to strive at some insight into the possible nature of the celestial bodies; and it may perchance furnish us with some grounds of consolation for the seeming evils of man's lot.

Our present bodies are admirably adapted to the demands of this life; and the forces, as well as the construction, of the material world are fitted to the interchange of thought, and

as a vehicle of the divine truths required for the beginning of our education. The inertia of matter is indispensable for a trustworthy medium. Matter must transmit thought precisely as it is received, without suspicion of transformation. It must be competent to receive all forms of thought, and incapable of resistance to any.

Above all other intellectual appetites is the soul's passionate love of *unity*. It is a controlling principle of material phenomena, and of every form of human art and poetry. By the attraction of gravitation, masses are held together in one system, or combined into a single body. By the chemical forces, discrete portions of matter are drawn together in an endless variety of new forms; each of which endures till it has discharged its appropriate function, whether for an instant or for an age. In these forms, it is curious how the mathematical formula of the compound indicates its attributes: it is as if the union had been effected by some ideal geometer. Everywhere there is a texture of substance, fitted to the health, comfort, and adornment of humanity. Can we fear lest the celestial bodies

will be less adapted to the souls which they are to clothe? Is it not a fair and just inference that each body will be nicely fitted to its soul, as if organized and crystallized under a controlling influence from within?

What better suggestion can be made, which shall give us the full benefit of the discipline, education, ties, and sympathies of this life? We shall be known as we are. Soul will recognize soul through its external covering, with unerring certainty. The stature of each body will correspond to the magnitude of the soul. The intellectual supremacy and consummate beauty of a Shakspeare will be more apparent in his celestial body than in his ideal statue. The countenance of the great law-giver of Judæa will shine as when he descended from Mount Sinai. No crown will be needed to designate legitimate royalty, nor any celestial aureole, encircling the head, to mark the loving and majestic presence of the apostles and the true saints.

On the other hand, we may justly apprehend that the deformity of our future body will conform to our spiritual errors in the present life. Would not such be the natural

and legitimate punishment for sin? It is a punishment we can endure; in humble trust in the infinite mercy as well as the supreme justice, before which we stand. But, surrounded by love and sympathy, who would not speedily repent and hasten to be restored to his intended excellence, and fill heaven with joy at his recovery? We then might recognize how suffering and sin are short-lived violations of material and spiritual law, and essential to free agency; how they are the evidence of unlimited potentiality, and how they are amply compensated by the freedom and the pardon with which they are associated.

The diversity of mind is hardly less noteworthy than the uniformity of body and the fixedness of spiritual and natural laws. It would be a detraction from creative fertility to conceive a possible character which did not exist. Nevertheless, we must admit that there are limits to spiritual possibility. Certain general principles of human nature must be diffused through all souls which are intended for mutual intercourse. Such is mathematical truth, which all men accept as

absolute. But shades of opinion are as many as there are men, as justifiable in their variety as flowers and fruit, as season and song; and they are essential to a well-organized society, in which mind may grow and expand. The graces of ideality may not be cramped by the narrowness and bigotry of one mind or of a multitude.

Two exactly twin souls would be dull and useless companions, and they are more unknown to Nature than two undistinguishable faces. The wildest conflicts of opinion which arise from the diversity of mind are needed for the purification of the atmosphere of thought. Two similar souls may start from the same neighborhood, in close and intimate friendship, and keep along together, side by side, for months and years, subject to the same influences. However little their paths may diverge, their distance apart will at length become perceptible, and, like that of two straight lines, drawn from the same point, will at length exceed any proposed magnitude. But, at the same time, the sphere of each mind's sympathies is likely to enlarge even more rapidly, so that the circle of co-

incident thought and affection may always increase in extent, while each, by his augmented diversity, will be a worthier friend of the other.

Experience justifies the assertion that all forms of mind required in this world are here to be found. How will it be with the greater demands of the future world? Whence is the supply to come? Mostly, we may believe, from other worlds; but why not in part from those immature spirits which began their existence here, where there are marriage and offspring, and are ready for a different training, partly perhaps under our own guidance, in the different circumstances of the celestial life?

There may hereafter be a wide and ever-widening enlargement in the avenues of sensation, and in the speculations and opportunities offered for discussion. How many new problems came with the discovery of America! And how there has been a corresponding increase in the dimensions and variety of intellect! The birth of Christianity changed the whole firmament of thought. It was a new spiritual world into which the

race was transported. Centuries of profound brooding were required, ere mankind could shake off the torpor of the ancient darkness and awake to the morning light of the gospel. But when at last the eyes were fully opened, the natural world was revealed in a new light, learning revived in grander aspects, and science was transformed from speciality to generality.

We have here five imperfect senses, and they are as many as we can control in this terrestrial imbecility. A lifetime is required for most of us to become journeymen in the use of any one of them, and no man has yet been known who was a master of them all. Their wide range of perception in different persons and their great capacity for education give us undoubted intimation of how much they may be extended in a more delicate and sensitive organization. That the immense extent of unheard and unseen vibrations with which the universe is palpitating should never become available to the soul, is contrary to the analogies of Nature. It is far from unreasonable to suppose that there will be a corresponding variety of ways

of knowledge, and of opportunities for scientific study, for the development of strange inventions for reinforcing the senses, and for the creation of wonderful, grand, and lovely forms of fancy and imagination. In the exquisite organization of the celestial substance, the range of sensible vibrations may be increased immeasurably; and the ultimate limits to which future perception and education may advance is possibly a mystery, transcending the powers of research even of the archangels.

The increased possibilities of future inquiry may not only arise from increased capacities of sensation, but also from better conditions for exact and delicate observation. No quickening of the senses can relieve the astronomer from our flittering and obscuring atmosphere; nor can the carpet of the good fairy lift him above its influence; nor can he, by any art, sweep the skies clear or quiet their ceaseless twinkle. Why have such curious and intricate celestial problems been presented to man's appetite for knowledge? Why have the seers of the stars been treated to this Barmecide feast? Have as-

tronomers committed the unpardonable sin of Tantalus? Have they ventured too near the heavenly throne, where the heathen gods still hold their rule, and regard with jealous eyes the spiritual Babel of our modern science, aspiring to the highest heaven; or have we been granted a true sight of the promised land? The changing surface of the sun and his planets; the wonderful system of Saturn with his mysterious ring and his many satellites; the intricate maze of the cluster of Hercules and of the Pleiades; the immense nebular and stellar transformations,— are a stimulus to research, presented by the divine teacher, and a promise, surer than the rainbow, that we shall be delivered from this deep flood of ignorance.

Do we need a nearer approach to the planets and stars? There is Halley's comet, upon which we might be conveyed through the whole extent of the solar system; and there are other comets, which might carry us out to the home of the meteors, or to the most distant regions of space.

Such is the glory and majesty of the intellectual future life, naturally suggested to

the faith of the Christian philosopher. How infinitely grand, in comparison with the sensual joys promised by other forms of religion! It is a daring flight upon the wings of pure logic by which the modern geometer has soared away from the realities of the ancients into the strange ideality of the fourth dimension of space, with its impossible triangles and its inconceivable metamorphoses. But this future and this present are the natural and reasonable expansion of the ideal development which began with the nebular theory.

Judge the tree by its fruit. Is this magnificent display of ideality a human delusion; or is it a divine record? The heavens and the earth have spoken to declare the glory of God. It is not a tale told by an idiot, signifying nothing. It is the poem of an infinite imagination, signifying IMMORTALITY.

APPENDIX.

APPENDIX.

A.

THE questions of cosmical physics which are discussed in the third, fourth, and fifth lectures were the leading object of Professor Peirce's study during his last years, — a study which was by no means completed at his death. The views here expressed must, therefore, be regarded only as representing a stage in the progress of his thought, and as affording a general sketch of the full theory which he was seeking to develop. In regard to these three lectures, he had made up his mind not to print them until he had been able to bring them into a form more completely satisfactory to himself, and to supply them with notes addressed to the technically scientific reader.

In the mean time, he continued a series of communications which he had already begun, to the American Academy of Arts and Sciences. On March 14 and April 11, 1877, he presented communications on "An Application of Lane's Law of the Accumulation of Solar Heat," and on "The Temperature of a Perfect Gas which is in Convective Equilibrium." (*Proc. Amer. Acad.*, xii. 286, 287.) On March 13, 1878, he "made some remarks on the internal struc-

ture of the earth with reference to Lipswich's results in regard to its density, and to the theory of Sir William Thomson." (*Ibid.*, xiii. 433.) On April 9, 1879, he made a communication on "The Meteoric Constitution of the Solar System." (*Ibid.*, xiv. 329.) On June 11, 1879, he made a communication on "The Meteoric Constitution of the Universe." (*Ibid.*, xv. 370.) On October 8, 1879, he presented the following "Propositions in Cosmical Physics":—

"1. All stellar light emanates from super-heated gas. Hence the sun and stars are gaseous bodies.

"2. Gaseous bodies, in the process of radiating light and heat, condense, and become hotter throughout their mass.

"3. It is probable that their surfaces would become colder if there were not an external supply of heat from the collision of meteors.

"4. Large celestial bodies are constantly deriving superficial heat from the collision of meteors, till at length the surface becomes super-heated gas, which constitution must finally extend through the mass.

"5. Small celestial bodies are constantly cooling till they become invisible solid meteors.

"6. The heat of space consists of two parts: first, that of radiation principally from the stars, which is small, except in the immediate vicinity of the stars; the second portion is derived from the velocity with which the meteors strike the planet at which the observation is taken; and this velocity partly depends upon the mass of the star by which the orbit of the planet is defined, and partly upon the mass of the planet itself.

"7. If the planets were originally formed by the colli-

sion of meteors, it is difficult to account for an initial heat sufficient to liquefy them, and at the same time to account for their subsequent cooling, without a great change in the number and nature of the meteors; and any such hypothesis seems to invalidate the meteoric theory.

"8. If the planets were not originally formed by the collision of meteors, their common direction of rotation becomes difficult of explanation." (*Ibid.*, xv. 201.)

He also submitted the same propositions, for criticism and as a basis of discussion, at the first of a series of informal scientific meetings held at Harvard University during the academic year 1879–80; and, a few weeks later, he read at one of these meetings the following additional propositions, which, however, he did not publish, except so far as they may have been virtually contained in previous communications to the Academy: —

"9. Space is filled with invisible meteors, which by their collision supply the heat and light of the sun and stars, and are the principal source of the heat of the planets, partly by direct collision.

"10. Their collision with the sun causes the vast jets of gas and the violent commotions of the sun's surface.

"11. The meteors are the source of the star-dust observed on the earth, and also supply carbon and other substances foreign to our planet, or of which there is a deficiency.

"12. The collisions with Jupiter and Saturn occasion the heat of those planets.

"13. The nebulous stars and the stars in the nebulæ correspond to this meteoric constitution of the sidereal universe."

B.

As Professor Peirce refers in his sixth lecture to the view he maintained respecting the discovery of Neptune, and as his position in this matter has not always been precisely noted, or treated with careful justice, it seems advisable to add here a brief account of the leading facts of the case, with a citation of the words which he actually used in the original discussion.

The problem of determining the elements of an unknown planet, which should account for the observed perturbations of Uranus, was taken up independently by Mr. Adams in England and by M. Leverrier in France. Both geometers began from the hypothesis that the mean distance of the new planet from the sun could not be far from satisfying Bode's law. That law gave for the mean distance of the required planet 38.8, that of the earth being taken as unity. Adams at first assumed a mean distance of 38.4, but, in his second hypothesis, assumed 37.6. Leverrier assigned to his predicted planet a mean distance of 36.154. He also undertook to determine *limits* between which the mean distance must lie; and he found as these limits, 35.04 and 37.90. The part of M. Leverrier's work which was involved in these determinations was undoubtedly one of the most remarkable portions of his investigation.

On Sept. 23, 1846, Neptune was observed by Dr. Galle at Berlin, in consequence of a letter to

him from M. Leverrier, and within one degree of the place in the heavens assigned by the latter. The announcement created an intense excitement throughout the civilized world. The prediction thus so brilliantly verified was deemed to surpass any previous triumph of mathematical astronomy; and the error which was afterward found to be involved in it does not materially lessen its glory. Such, at least, was the judgment of Professor Peirce, to whom the skill, power, and thought shown in the mathematical investigation were the true ground of admiration for the exploit. It is to be regretted that the correction of the error was not received, on the part of the French astronomer, with the magnanimity and fairness which it is always painful not to find associated with high intellectual power.

The elements of the new planet were computed from observation, and it was then found that the mean distance was, in fact, only 30. This surprising result was communicated to the American Academy by Mr. Sears C. Walker on 16 March 1847. At the same meeting of the Academy, Professor Peirce remarked, "That the orbits given by Mr. Walker differ so widely from the predictions, that he has been induced to make a careful re-examination of the observations. He has not only himself verified Mr. Walker's distance of 30, and the consequent angular motion; but Mr. George P. Bond, of the Cambridge Observatory, has also, at his request, verified this distance and motion from the Cambridge observations alone. From these data, without any hypothesis in regard to

the character of the orbit, he has arrived at the conclusion, that THE PLANET NEPTUNE IS NOT THE PLANET TO WHICH GEOMETRICAL ANALYSIS HAD DIRECTED THE TELESCOPE; that its orbit is not contained within the limits of space which have been explored by geometers searching for the source of the disturbances of Uranus; and that its discovery by Galle must be regarded as a happy accident." He continued: —

"Mr. Adams, in his *Explanation of the Observed Irregularities of Uranus*, considered two hypothetical orbits, in one of which the mean distance is 38.4, or just double that of Uranus, and in the other it is 37.6; while M. Leverrier, in his *Researches into the Motions of the Planet Herschel, called Uranus*, after deriving some rough approximations from the consideration of the mean distance 38.4, proceeds to the accurate examination of the three distances 39.1, 37.6, and 36.2. The extension of the investigations to any other mean distances can be made only by assuming a continuous law to pervade the subject of inquiry, and that there is no important change in the character of the resulting perturbations. Guided by this principle, well established, and legitimate, if confined within proper limits, M. Leverrier narrowed with consummate skill the field of research, and arrived at two fundamental propositions; namely, —

"1. That the mean distance of the planet cannot be less than 35, or more than 37.9. The corresponding limits of the time of sidereal revolution are about 207 and 233 years.

"2. That there is only one region in which the disturbing planet can be placed, in order to account for the motions of Uranus; that the mean longitude of this

planet must have been, on Jan. 1, 1800, between 243° and 252°.

"Neither of these propositions is of itself necessarily opposed to the observations which have been made upon Neptune, but the two combined are decidedly inconsistent with observation. It is impossible to find an orbit which, satisfying the observed distance and motion, is subject at the same time to both of these propositions, or even approximately subject to them. If, for instance, a mean longitude and time of revolution are adopted according with the first, the corresponding mean longitude in 1800 must have been at least 40° distant from the limits of the second proposition. And again, if the planet is assumed to have had in 1800 a mean longitude near the limits of the second proposition, the corresponding time of revolution with which its motions satisfy the present observations cannot exceed 170 years; and must therefore be about 40 years less than the limits of the first proposition. Neptune cannot, then, be the planet of M. Leverrier's theory, and cannot account for the observed perturbations of Uranus under the form of the inequalities involved in his analysis.

"It is not, however, a necessary conclusion that Neptune will not account for the perturbations of Uranus, for its probable mean distance of about 30 is so much less than the limits of the previous researches, that no inference from them can be safely extended to it. An important change, indeed, in the character of the perturbations takes place near the distance 35.3; so that the continuous law by which such inferences are justified is abruptly broken at this point, and it was hence an oversight in M. Leverrier to extend his inner limit to the distance 35. A planet at the distance 35.3 would revolve about the sun

in 210 years, which is exactly two and a half times the period of the revolution of Uranus. Now, if the times of revolution of two planets were exactly as 2 to 5, the effects of their mutual influence would be peculiar and complicated; and even a near approach to this ratio gives rise to those remarkable irregularities of motion which are exhibited in Jupiter and Saturn, and which greatly perplexed geometers until they were traced to their origin by Laplace. This distance of 35.3, then, is a complete barrier to any logical deduction, and the investigations with regard to the outer space cannot be extended to the interior. . . ." (*Proc. Amer. Acad.*, i. 65–67.)

On this occasion, Mr. Peirce expressed no opinion on the question whether the actual planet, as well as the predicted one, would account for the perturbations of Uranus. It was necessary that that question should remain altogether unanswered, until the test of computation had been applied to it; since the mathematical theory of the predicted planet was not the mathematical theory of the planet which had been discovered. It is, however, noticeable that M. Leverrier said, less cautiously, 29 March 1847, that "the smallness of the eccentricity which resulted from Mr. Walker's calculations would be incompatible with the nature of the perturbations of the planet Herschel." (*Comptes Rendus*, xxiv. 531.)

At the meeting of the Academy held on the 4th of May Professor Peirce stated that he was strongly of the opinion, that the irregularities of motion exhibited by Uranus were not due to the influence of Neptune. (*Proc. Amer. Acad.*, i. 144.) On 4 April 1848, how-

ever, he retracted this expression of opinion, and announced that, having completed his investigation, he had ascertained that Neptune would completely account for the perturbations of Uranus; and that "the theory of Uranus is now perfect," "provided that mass of Neptune be adopted which is derived from Mr. Bond's observations of Lassell's satellite." (*Ibid.*, p. 332.)

At the same meeting of the Academy, Mr. Peirce remarked, "that his original views were unchanged in regard to the importance to be attached to the vast discrepancies between the predicted and observed orbits of the planet which disturbs the motions of Uranus." He said: —

"Neptune is not the planet designated by geometry, although it is a perfect solution of the problem which analysis had undertaken to investigate, and had really solved, but in a form radically different from the actual solution of nature. This is not a personal question; it is certainly not one in which the reputations of Adams and Leverrier are concerned. The accuracy of their investigations is not assailed; but it is expressly admitted that they announced the correct results of most profound analytical researches.

"The fair consideration of this question cannot be made without recalling the true office and position of geometry in science, which alone entitles it to the appellation of the key to the physical world. Mathematics is the science of exact measurement; accuracy is its sole aim and object, and it is this which places it in harmony with a creation which is subject to perfect law and undeviating order. An inaccurate result cannot be a geo-

metrical one; a result, inaccurate beyond certain well-defined limits, does not belong to the exact science; an inconsistency which exceeds a certain amount may not be neglected by him who deals with nothing but *more or less*, without disturbing the very foundations of his faith.

"The geometrical statement was distinctly made, that the planet which disturbed Uranus could not be at a less mean distance from the sun than thirty-five times the earth's mean distance from the sun; that is, that no planet which was within this distance could cause the observed irregularities in the motions of Uranus. Neptune's mean distance from the sun is only thirty times the earth's mean distance, and yet Neptune does account for the perturbations of Uranus. It is five hundred millions of miles nearer the sun than it was distinctly stated by geometry that it possibly could be, in order to be capable of producing the effect which it actually does produce. The spirit of mathematical accuracy cannot be supposed to be sufficiently elastic to embrace so great an inconsistency, amounting to one sixth part of Neptune's distance from the sun, and to one half of the distance of his orbit from that of Uranus.

"Whence comes this enormous difference between the theoretical and observed planets? Had it been quite small, it might have been regarded as an excusable numerical error. Had it even amounted to once or twice the radius of the earth's orbit, it might have been deemed an error, although it would then have been a grievous one, and would have seriously marred the beauty of the result. But, as it is, it cannot be assumed to be a mere error, without admitting that such an one radically vitiates the whole theory. Whoever adopts this opinion, be it the author of

the theory himself, is bound to show where the error is, and how far it extends. Such an opinion has never been advanced by me, and I am not responsible for it. I admit, however, that I have not fully investigated this point, but maintain that the profound geometry of M. Leverrier is not to be set aside without proof, or even argument. M. Leverrier found that the planet which would best account for the disturbed motion of Uranus was at the mean distance 36 from the sun; and that, by increasing or decreasing the mean distance of the hypothetical disturber, the want of coincidence between the observed and computed motions of Uranus increased until, at the mean distances of 38 on the increase and 35 on the decrease, the residual differences between theory and observation became so great as to be wholly inadmissible. He therefore came to the natural conclusion, from such a result, that the mean distance of the required planet from the sun could not be less than 35, or more than 38; and he contented himself with this conclusion, without extending his inquiries to still smaller mean distances; and any facts in regard to these inner distances which are *at variance with this result* are certainly not to be included under his theory. I have confined my remarks to M. Leverrier's researches, but nothing in Mr. Adams's less comprehensive investigations, in which there is no attempt to ascertain the limits, is opposed to these conclusions.

"It has been intimated, that too rigorous an agreement with observation was insisted upon in the original inquiries, and that the limits might have been extended to include Neptune, by a more liberal concession to other unknown planets, or to an error in the mass of Saturn. The inspection of the preceding table completely refutes such a suggestion, for it now appears that Neptune satis-

fies the observations of Uranus more perfectly than the best planet of previous theory. If Leverrier was, as I have supposed, correct in his former computations, he must have found by extending them, that, although the action of his hypothetical planet agreed less perfectly with observation by the contraction of the radius of its orbit from 36 to 35, and that this disagreement would have still further increased by a still further contraction, there was a distance at which the disagreement ceased to increase, and would on the contrary begin to diminish, until at the distance 30 it would have vanished, and the disturbed motions of Uranus would have been wholly explained. But this singular change in the character of the disturbing force, if it really occurs, — and the only doubt in regard to it is derived from a supposed but unproved inaccuracy in Leverrier's investigations, — was excluded from the range of this geometer's investigations; and now that observation has led to its discovery, geometry cannot claim it as one of its predictions. The defect of the theory must be as frankly admitted, as the more serious charge of error is boldly repelled.

"From some indistinct remarks which have been thrown out in regard to the mass of Neptune, which is not too small to be excluded from the limits of the theory, there seems to be an indisposition to confess this defect. But on turning to the original formulæ, it will be found that, although this small mass is not positively excluded, its adoption does not contribute to advance the claim of geometry upon the planet. It shows, on the contrary, most decisively, that the orbits of theory are all of them fundamentally different from those of Neptune. For the mean distance which corresponds to this mass in the theory is about $35\frac{1}{2}$, and the eccentricity very much

greater than in the best hypothetical orbit, while the discrepancy between the theoretical and observed action on Uranus is increased beyond the admitted limits.

"The case might safely rest there; but I desire to dwell upon the essential and radical difference between Neptune's action upon Uranus and that of the planets of theory. For this purpose, I will read an extract from a report made by me last September to the honorable committee of the Overseers of Harvard University who visited the Observatory:—

"'The differences are not accidental, but inherent in the very nature of the case, while the points of resemblance are purely accidental. The solutions of Adams and Leverrier are perfectly correct for the assumption to which they are limited, and must be classed with the boldest and most brilliant attempts at analytical investigation, richly entitling their authors to all the *éclat* which has been lavished upon them on account of the singular success with which they are thought to have been crowned. But their investigations are nevertheless wholly inapplicable to the theory of the mutual perturbations of Uranus and Neptune. The successive periods of conjunction and opposition, occurring at intervals of eighty-four years, — that is, in about the time of revolution of Uranus, — this planet is always at the same part of its orbit when it is most affected by the action of Neptune. The action of Neptune, consequently, assumes a fixed, permanent, undisturbed character, so that it can hardly be recognized as perturbation by the practical observer. It is far otherwise with the ordinary class of perturbations, where the place of greatest disturbance varies from point to point of the orbit; thus the place of greatest disturbance in the case of the theoretical planet would not have remained stationary,

but have varied 80° upon the orbit of Uranus at each successive conjunction and opposition; so that the disturbance could not in this case be disguised to any great extent under the fixed laws of ordinary elliptic motion. In the case of Neptune, its action on Uranus is to be detected in the comparatively small differences between its character and that of an elliptic motion, and the difference between the influence at opposition and that at conjunction. In undertaking, therefore, anew the solution of the problem of the perturbations of Uranus, with the assumption of the actual period of Neptune, instead of that adopted in the former theories, I found at once that I could not profit by the previous researches of Adams and Leverrier. The problem now presented, instead of being of the usual character, assumed a differential form by the disguise of the primary perturbations under the aspect of elliptic motions, and the whole question now rested upon the secondary perturbations, which were comparatively unimportant in the previous theories.' . . . " (*Ibid.*, pp. 338–341.)

The full list of references in this matter is as follows: *Proceedings of the American Academy*, i. 41, 57–68, 144–149, 285–295, 332–342.

The view which was maintained by M. Leverrier will be found in the *Comptes Rendus*, xxvii. 273–279, 325–333.

It has sometimes been urged that M. Leverrier's problem was simply to point out the place of the new planet in the heavens; and that problem he undoubtedly successfully solved. But this by no means describes the scope of his endeavor. His contention was — and it was this which gave the true *éclat* to his

prediction — that he had accomplished his result by first calculating the *elements* of the unknown body; as is emphatically shown by the remarks of M. Arago, made at the Academy of Sciences in Paris, 19 October 1846. (*Comptes Rendus,* xxiii. 746.)

Many years later, Professor Peirce resumed the consideration of this question, and made an investigation, which occupied him for several months, of the whole range of space in which it would have been possible to find a planet, having an orbit of small eccentricity, and accounting for the observed irregularities in the motion of Uranus. The results of this computation were very curious, and confirmed Professor Peirce, as he has stated in his sixth lecture, in the views above cited; but they were never reduced to a publishable form.

THE END.