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ARTICLE I.

ECCLESIA LUTHERANA.

By JOSEPH A. SEISS, D. D.

I. *The Church.*

THERE is one, holy, catholic Church—the pillar and ground of the truth—the communion of saints—outside of which there are no promises of salvation.

This Church is *one*; not in the local assembly of its members; not in exact uniformity in minor details of doctrine, government or worship; not in uninterrupted harmony and perfect peace between its different members; not in universal subjection to one visible ruler; but in the conjunction of all its parts, in one invisible and divine Redeemer, their procession from one beginning, and their common dependence upon the foundation of the prophets and apostles, Jesus Christ himself being the chief corner-stone.

This Church is *holy* as proceeding from a holy original, as partaker of a holy calling, as embracing holy faith, as clothed with the Saviour's righteousness, and as embodying the sanctification of the Holy Ghost.

has already discovered eight hundred and fifty species of fishes, in a fossil state, and eighty species of reptiles, including saurians and snakes, and fifty-one species of birds, and over two hundred mammals, and seventy-five species of insects, the individuals amounting to millions, and yet not a solitary bone of a human being. This is a strong presumptive evidence that there were no human beings in those early ages of the world. Hence we may safely infer that he who made the world, and revealed its date to Moses, was not mistaken.

The Bible and Geology do not contradict each other. *Nunquam aliud Natura, aliud Sapientia dicit.* They agree, as Professor Hitchcock says, in the fact that man was among the latest of the animals created to inhabit the earth. And this is an important fact.

ARTICLE V.

THE DISCOVERY OF THE LAW OF GRAVITATION.

By Prof. J. T. Duffield, D. D., Princeton, N. J.

The law of gravitation, that all matter attracts all matter, directly as the mass, and inversely as the square of the distance, whether we consider the extent of its reach, or the number and variety and peculiar interest of the problems of which it furnishes the solution, or the grandeur of many of those problems by reason of the magnitude of the elements involved, whether we consider the power which it gives us to anticipate nature, so to speak, and predict with the minutest accuracy and the certainty of a mathematical demonstration celestial phenomena, for ages yet to come; whether we regard it as a confirmation of our belief in the unity of the Great Author of the universe, or as an illustration of his infinite wisdom, accomplishing results so sublime and so manifold, by means so admirably simple, we cannot but regard it as the most important truth in the whole book of nature, and its discovery as the most interesting event in the history of physical science. As there is but one material universe, and the law of gravitation solves the enigma of *its* structure, no other problem, of equal interest and importance, can ever occupy the attention of the student of nature.

Kepler has remarked that: "The occasions by which men have acquired a knowledge of celestial phenomena, are not less admirable than the discoveries themselves." If this be so, the history of the discovery of that great law of nature by which all celestial phenomena are determined can never cease to be a matter of peculiar interest.

In the account which we propose to give of this discovery, we shall select as our chronological starting point, the beginning of the seventeenth century. At that period the theory in regard to the structure of the material universe, which, with few exceptions, had been held from time immemorial, still prevailed. The earth was regarded as the centre of the universe, about which the sun, moon, planets and stars performed their ceaseless revolutions. More than half a century before (in 1543) Copernicus, in his memorable work, "*De Orbium Cœlestium Revolutionibus,*" had, indeed, announced the true system of the uuiverse, yet as he was led to the adoption of the theory he proposed, not so much by positive evidence in its favor, as by the difficulty of reconciling certain phenomena with the Ptolemaic theory; moreover, as the objections to this theory were, from their very nature, such that few could appreciate their force, whilst in the *apparent* motions of the heavenly bodies, every one could see what seemed to be an ocular demonstration of its truth, it is not strange that the doctrine of Copernicus should have been, for so long a time, generally regarded as nothing more than an interesting, yet fanciful, speculation. It remained for a subsequent age to furnish proof of the truth of the Copernican system which could not be gainsayed or resisted.

At the beginning of the seventeenth century, the dicta of Aristotle, in regard to matters of science as well as philosophy, were still accepted, as they had been for many centuries preceding, as of infallible authority. In regard to the subject of our inquiry, he taught that bodies at the surface of the earth fell, or tended to fall, toward the centre of the earth, not in virtue of any attraction of the earth, but in virtue of the fact that the centre of the earth was the centre of the material universe—that if the earth itself should be moved out of its place, and then left free to move, it would return to its place by the same law of nature which controlled all terrestrial bodies. He taught, moreover, that celestial bodies were different in kind from bodies terrestrial—that whilst the latter were imperfect, corruptible and changeable, the former were perfect, (and, therefore, according to his fancy, perfectly spherical in form) incorruptible, unchangeable and self-luminous. Being different in kind, he held that they were subject to entirely different physical laws; that, whereas the motion of terrestrial bodies, when free to move, was rectilinear, by a necessity of their nature, the motion of celestial bodies was circular by a like necessity of their nature. His language on this point is worth quoting as an illustration of the contrast between the ancient and modern method of philosophizing in regard to natural phenomena. He says: "All simple motion must be rectilinear or circular, either to a centre or from a centre, each of which is rectilinear, or about a centre. It is natural for two of the elements—earth and water—which are heavy, to tend to a centre, two—air and fire—which are light, to tend from a centre. As the motion of all the terrestrial elements is, therefore, rectilinear, it seems reasonable that celestial bodies, which are of a different nature, should have the only other simple motion possible, namely, circular motion."

The year 1609, marks a new era in the history of Astronomy. In this year two events occurred, independent, yet alike memorable as contributing to the overthrow of the theory in regard to the structure of the material universe which had previously prevailed, and establishing the doctrine of Copernicus upon an immovable foundation. The invention of the telescope, by Galileo, and the immediate discovery, by means of it, of the inequalities of the moon's surface, the phases of Venus, the satellites of Jupiter and the rings of Saturn, at once annihilated the fancies of Aristotle as to the perfectly spherical form of the planets, their self-luminosity, and their difference in kind from bodies terrestrial. The other memorable event referred to was, the publication of Kepler's great work on "the Motions of Mars," in which, with much that was fanciful, two of the three laws of planetary motion were for the first time announced. Some twelve years later, in his work, entitled "Harmonies," he announced the third law of planetary motion, fully establishing his right to the title, by which he has since been distinguished, the Legislator of the Heavens.

These laws of Kepler are: 1st. That the orbits of the planets are elliptical, the sun being at one of the foci; 2d. That the radius vector, that is, a line drawn from a planet to the sun, passes over equal spaces in equal times; 3d. That the squares of the times of revolution of the different planets, are to each other as the cubes of the mean distances from the sun.

Together with these laws of planetary motion, two of the three axioms of the science of Mechanics, known as *the Laws of Motion*, were about this time discovered, or, rather, were now, for the first time, distinctly apprehended and enunciated. The first of these was given by Kepler—the law of inertia, namely, that a body will persevere in the state in which it is, whether of rest or of motion, until it is acted on by some force; or, more precisely, a body at rest will continue at rest until acted on by some force, and when acted on by any single force, if free to move, its motion will be rectilinear, uniform and continuous until the body is acted on by some other force. The second law of motion was announced by Galileo, and is known as the law of the coexistence of motions, or independence of forces. It may be expressed as follows: If a body be acted on by several forces simultaneously, it will obey the impulse of each force, just as it would if the others were not acting. The simplest illustration of this law, is what is known as the parallelogram of forces. If the direction and intensity of two forces acting simultaneously on a body, be represented by the sides of a parallelogram, the body will describe the diagonal of the parallelogram; that is, at the end of a unit of time the body will be just where it would have been if the forces had, each for a unit of time, acted consecutively.

The true system of the universe, the laws of planetary motion and the fundamental principles of mechanics having become known, for the first time in the history of the race, any intelligent inquiry as to the physical cause of the motions of the heavenly bodies became possible. With earnestness and assiduity, proportioned to the grandeur and interest of the problem, men of science at once applied themselves to its solution, and yet half a century of gradual progress toward the truth elapsed before the desired result was reached. From the facts which we shall have occasion to mention, it will appear how much, or rather, how little, foundation there is for the common belief that the idea of the law of gravitation was wholly original with Newton—suggested to him for the first time by observing the fall of an apple, and then suddenly coming forth from his brain, like Minerva from the head of Jove, unheralded and complete. The ordinary method of transition from wide-spread and plausible error to the truth, is by slow and gradual progress, and the discovery of the law of gravitation, so far from being an exception to this rule, is but one of its most striking illustrations. Such an *accident* as that which the discovery of the law of gravitation is generally supposed to have been, is of the kind which only happen to men of large knowledge, profound thought, and often intense and protracted mental effort. Simple as this law is now known to be, and easily apprehended, and even demonstrated by ordinary minds, it needed one endowed with the most gigantic intellect probably ever given to mortal—availing himself of the suggestions and the results of the labors of those who had preceded him in the same field of inquiry—to make the discovery.

In tracing the history of this discovery, from the epoch when, by the previous discovery of all the necessary data, it for the first time became possible, the first place in the order of time, and next to Newton in the order of merit, is undoubtedly due to Kepler. Possessing a singularly lively imagination—we might say, volatile fancy—combined with a love for the truth, that amounted to a ruling passion, and a breadth of knowledge, in his favorite science, far in advance of any other man of his age, he was eminently fitted for the work, which he so successfully performed, of scientific discovery. Fertile in hypotheses—sometimes the most extravagant—he was indefatigable in his labors to test his hypotheses by the facts. Without the slightest pride of opinion, he seemed to take a satisfaction in exploding his own theories, when they were false, that was only exceeded by his delight when successful in demonstrating their truth. Of the men who have contributed to the advancement of science, there are few to whom we are under greater obligation, or whose character, as an investigator of nature, is more worthy of admiration, than "the Legislator of the Heavens"—the father of modern Astronomy.

In the introduction to his memorable work on "the Motions of Mars," referred to above, he opposes the doctrine of Aristotle on the subject of terrestrial gravity, and in the course of the discussion, uses the following remarkable language.

"A mathematical point, whether the centre of the universe, or not, has no power to move heavy bodies to approach it. Let philosophers prove, if they can, that natural things have any sympathy with that which is nothing.

"The true theory of gravity is founded on the following axioms. *Gravity is a mutual affection between cognate bodies toward union or conjunction, similar to the magnetic virtue.* If we assume the earth to be the centre of the world, heavy bodies are not carried toward its centre in virtue of its quality of centre of the world, but in virtue of its quality of centre of a cognate round body; so that wheresoever the earth may be placed, or whithersoever it may be carried by its animal faculty (alluding to a fanciful theory, which we shall have occasion presently to notice) heavy bodies will always be carried toward it.

"If the earth were not round, heavy bodies would not tend from every side toward its centre, but to different points from different sides.

"If two stones were placed in any part of the universe, near each other, and beyond the sphere of the influence of a third cognate body, these stones would come together at an intermediate point, each approaching the other a distance proportional to the comparative mass of the other.

"If the moon and the earth were not retained in their orbits, by their animal force, or some other equivalent, the earth would mount to the moon by a fifty-fourth part of their distance from each other, and the moon would fall toward the earth through the other fifty-three parts, that is, assuming that the substance of each is of the same density.

"The sphere of the attractive virtue which is in the moon, extends to the earth and entices up the waters, but as the moon flies rapidly across the zenith and the waters cannot follow so quickly, a flow of the ocean is occasioned toward the westward.

"If the attractive virtue of the moon extends to the earth, it follows, with greater reason, that the attractive virtue of the earth extends to the moon and much farther, and, in short, nothing which consists of earthy substance, however constituted, although thrown up to any height, can ever escape the powerful operation of this attractive virtue."

These views of Kepler—so novel at the time they were announced by him, and yet which we now know to be, in the main, so correct—were published more than thirty years before Newton was born. As we read them, our first feeling is one of surprise that any subsequent investigator of the phenomena of gravitation should be able, by his discoveries, to achieve for himself a fame which should not only render his name immortal, but should almost wholly hide from view the merit of the great pioneer in this field of inquiry. To appreciate, however, the important work which yet remained to be performed, we should bear in mind, that, whilst Kepler's views, in regard to terrestrial *gravity*, were so remarkably just, he, at the same time, in common with the age in which he lived, and we may say, with all preceding ages—regarded the tendency of bodies near the earth, to fall toward its centre, and the motions of heavenly bodies, as entirely different phenomena, and not at all referable to the same physical cause. He indeed speculated on the possibility of referring the motions of the planets to an attractive force emanating from the sun, similar to that which caused bodies near the earth to tend toward its centre, and concluded that such an hypothesis was untenable, inasmuch as the motion in one case was rectilinear, and in the other curvilinear. Again, not to over-estimate the merit of Kepler in connection with the discovery of the law of gravitation, we should remember that a theory as to the physical cause of natural phenomena, even if it be in the main correct, will furnish no complete solution of the problems which those phenomena present, unless it express accurately and precisely the *measure* as well as the *mode* of the action of the assigned cause. For example, to know merely that all matter attracts all matter, would not enable us to explain the phenomena of gravitation; we need to know precisely how the intensity of this attraction is affected by the comparative magnitude of the masses, and by the distance of the masses from each other. Now the theory of Kepler, in regard to gravity, was correct as to the first of these points, namely, that the intensity of this attraction was directly as the mass, but he was in error in regard to the second point, as he supposed that the intensity of the attraction was inversely as the distance, instead, of what was subsequently found to be the fact, the square of the distance.

Once more, to estimate at its just value the part which Kepler performed in the discovery of the laws of gravitation, we should bear in mind, that an hypothesis, even if subsequently it be found to be correct, is of no *authority* until its truth be demonstrated. It may be of great importance, by way of suggestion, in directing the labors of subsequent inquirers, but the chief merit of the discovery of the truth is due to the individual who furnishes its demonstration. When this is done, and not before, that which was previously but an hypothesis takes its place among the recognized laws of nature.

As, in Kepler's day, the tendency of bodies near the earth to fall toward its centre, and the motions of the heavenly bodies were regarded as phenomena of entirely different laws of nature. His views as to the physical cause of *planetary* motion, next claim our attention. He supposed that the motions of the planets in their orbits, was due to an influence emanating from the sun, but assuming that, if this influence were an *attractive* force, similar to terrestrial gravity, its effect would be to cause the planets to fall toward the sun in straight lines, instead of their actual motion of revolution about the sun; he supposed that the emanation was of a corporeal nature, somewhat analagous to light; that as the sun revolved on its axis, this emanation revolved with it just as the spokes of a wheel, when the hub revolves, and that the planets were swept along in their orbits by the revolution of this emanation—the force which caused them to move, being a *propulsion*, and not an *attraction*.* As the hypothesis would seem to require that the times of revolution of all the planets, should be the same, whereas, in fact, they are different, the nearer performing their annual revolution in a less time than the more remote—he supposed that the density of the emanation diminished as its distance from the sun increased, that consequently its virtue, or propulsive energy, diminished in like manner, just as the intensity of light diminishes with the increase of distance from the luminous centre. This would account, in a general way, for the fact that the times of revolution of the planets nearer the sun, are shorter than the times of revolutions of those more remote, but the precise difference in the observed times of revolution, was not exactly that which would be required by the hypothesis. Moreover, he had discovered that the orbits of the planets were not circular, as would seem to be required by his hypothesis, but elliptical, the sun being at one of the foci; also, the ever-varying radius vector always passed over equal spaces in equal times, hence the motion of the planet in its orbit was not uniform, as his hypothesis would require, but ever-varying; and this variation, too, was evidently not fortuitous or uncertain, but increased or dimin-

* This hypothesis, as to the physical cause of the motions of the planets, is deserving of notice, as being historically the germ, or first form of the idea, from which was subsequently developed the great law of gravitation.

ished in the exact ratio to the varying distance of the planet from the sun, required by the law just mentioned, of equal spaces in equal times. These facts, apparently so inconsistent with his hypothesis, Kepler accounted for, by supposing that each of the planets was animated by an intelligent spirit, by whose agency the motion of the planet was, in part at least, determined. We have seen an allusion to this theory in the quotation above given, on the subject of gravity. He regarded each of the heavenly bodies, and the earth as one of them, as literally a huge animal, and in one of his works, describes, with some minuteness, the habits of that particular animal, on whose body it is our lot to live. "If any one," says he, "from the top of a high mountain, throw a stone down into its deep clefts, a sound is heard, just as when you thrust a stone into the ear or nose of a ticklish animal, it shakes its head and runs shuddering away. And what is so like breathing, especially the breathing of those fish who draw water into their mouths and spout it out again at their gills, as that wonderful tide. For although it is so regulated by the course of the moon, that I have, in the preface of my work on the Motion of Mars, mentioned it as probable, that the waters are attracted by the moon, as the iron by the loadstone, yet if any one maintain that the earth regulates its breathing according to the motion of the sun and moon, as animals have daily and nightly alternations of sleep and waking, I shall not think his philosophy unworthy of being listened to, especially if any flexible parts should be discovered, in the depths of the earth, to supply the functions of gills." Again, he says, "the earth sometimes appears lazy and obstinate, at other times, after important and long-continued conjunctions (of the heavenly bodies) she becomes exasperated, and gives way to her passions, and this continues even after the conjunctions have passed; for the earth is an animal, not like a dog, ready at every nod, but more like an elephant or a bull, slow to become angry, yet so much the more furious when incensed." As the mistakes and foibles of those whose achievements have determined the subsequent course of political history, are matters of interest to every intelligent mind, even so are the errors and vagaries of those whose lives mark new eras in the intellectual progress of the race. It is due to Kepler, to remark that, however absurd the grotesque fancy, just mentioned, may appear to us, from the earliest ages, down to the time when the true doctrine as to the physical cause of the motions of the heavenly bodies became fully established, the belief of it extensively prevailed.

Kepler's hypothesis of an emanation from the sun of a corporeal nature, by whose revolution the planets were propelled in their orbits, was received with more or less favor, for a time, but was soon superseded by another memorable hypothesis, no more reasonable or plausible, and yet from the time of its announcement until the publication of "The Principia" demonstrated its fallacy. It was adopted by most men of science, and may be said to have been the accepted theory on the subject. We refer to the *Vortices of Descartes.* This distinguished philosopher, born 1596, rose to eminence about the time of Kepler's death, which occurred in 1630. By the force of his genius, illustrated not only by that achievement for which his name will ever be held in honored remembrance—the invention of Analytical Geometry—but by the abundance and the ability of his labors in every department of science and philosophy, Descartes, for more than half a century, occupied a position in the learned world, scarcely inferior to that which, for ages preceding, had been held by Aristotle.

As to the cause of planetary motion, Descartes assumed the existence, throughout the limits of our system, of a subtle transparent fluid in ceaseless revolution about the sun as its centre, and that the planets floated in this fluid, and were, consequently, carried round the sun by its motion, just as in a whirlpool a cork or floating body is carried round by the motion of the water. To account for the difference in the times of revolution of different planets, he supposed that the velocity of the revolution of the fluid, at different distances from the sun, was different. To account for the revolution of the satellites of the planets, he assumed that, in the neighborhood of each planet, this fluid revolved about the planet as a centre. To this purely fanciful hypothesis there are several fatal objections, as was subsequently demonstrated by D'Alembert, of which it will be sufficient to mention that the very existence of a spherical vortex, is a mechanical impossibility. And yet such was the weight of the authority of its author, and the ingenuity with which it was defended by himself and his followers, that, as was mentioned above, it not only was received with general favor, but for more than half a century it was accepted by most men of science without questioning, and continued to be maintained by some, even after Newton had announced and demonstrated the law of gravitation. It is a notable illustration of the tenacity of error, when once it becomes firmly fixed and wide-spread, that for some years after the publication of "The Principia," a Latin translation from the French of "The Physics of Robault"—a work entirely Cartesian—continued to be the text-book in Philosophy at the University of Cambridge—Newton himself being, at the time, Lucasian Professor of Mathematics. We have the authority of Playfair for the statement (which, indeed, has been called in question by Sir David Brewster, in his "Life of Newton," though so far as we have been able to see, without any sufficient reason) that the doctrines of "The Principia" were introduced into the regular course of instruction, at Cambridge, by strategem. Dr. Samuel Clarke, a zealous advocate of the Newtonian Philosophy, prepared a new and more elegant translation of Robault, with copious notes, in which the doctrines of "The Principia" were explained and defended, and it was by this work, more directly than by the Lectures of Newton himself, that Cartesianism was finally driven from the University.

Whilst Kepler's speculations, as to the cause of the motions of the heavenly bodies, was soon supplanted by the hypothesis of Descartes, his more just views in regard to terrestrial gravity, commended themselves to the scientific world, and speedily passed into universal and abiding favor. In the memorable work of Galileo on the true system of the universe—completed the very year of Kepler's death, and published two years after; a work which, aside from its own merit, "The Holy Inquisition," by the persecution of its author, has made immortal—we find the doctrine of Kepler, on the subject of gravity, distinctly stated and elaborately defended. The Inquisition had power to imprison Galileo, and commit copies of his work to the flames, but the truth it contained could not be burnt or bound. The earth "still moved," and matter continued to attract matter, unawed by the terrors of the Inquisition. The truth, once distinctly apprehended and announced, was never again to be lost, but was destined to grow in importance, and be extended in its application far beyond the conceptions even of the great prophets of nature who were the first to proclaim it. The doctrine of Kepler, on the subject of gravity, may be regarded as, historically, the foundation of that sublime superstructure which, in a subsequent age, was reared by Newton, and which, by reason of the magnitude of its proportions and the multiplicity of its details, all pervaded and determined by the most admirable unity, now stands, and in all probability, will ever stand, as the most imposing monument ever erected by the human intellect.

Although Kepler's theory, that bodies terrestrial mutually attracted each other, met with ready reception, more than thirty years elapsed after the publication of his work, before the idea was entertained, at least favorably, of accounting for the revolutions of the heavenly bodies on the theory of the universality of the attraction of gravitation. Kepler, indeed, as we have remarked above, alludes to such an hypothesis only, however, to expose, as he imagined, its fallacy. The motions of the heavenly bodies being curvilinear, whilst the motions of bodies, under the influence of gravity, were rectilinear, it was taken for granted, as a thing self-evident, that the two phenomena must be due to entirely different physical causes. Familiar as we are with the fact, that, by the two laws of motion above-mentioned, the hypothesis of an attractive force of the sun, combined with the hypothesis of a tendency of the planets to move in a straight line, in virtue of an original impulse communicated to them, would satisfactorily and readily account for their curvilinear motion, it cannot but be a matter of surprise, that the truth should have remained so long unrecognized.

The credit of having been the first to generalize the idea of gravity, and refer the revolutions of the heavenly bodies to the attraction of matter for matter, appears to be due to Borelli, an Italian philosopher, a pupil of Galileo. It is announced in a work which he published "on the Satellites of Jupiter," in 1666, although, as we shall have occasion to notice subsequently, Newton had conceived the same idea, at least as early as 1665. Both Newton and Huyghens, however, attributed to Borelli the honor of having been the first to announce the important truth.

The idea, having been suggested, was at once accepted by many with favor, and immediately led to the investigation of a hitherto unexplored field in the department of mechanical philosophy. Whilst the labors of others, in this field, were not unimportant, particularly those of Wallis, the name which is especially deserving of honorable mention, in this connection, is that of Huyghens. In a work published in 1672, we meet, for the first time, with a scientific discussion of *the doctrine of Central Forces.* His investigations were remarkably satisfactory and complete as to the phenomena of *circular* motion, the attractive force being at the centre, and contributed largely to the success of the labors of subsequent inquirers.

A great step had been taken toward the solution of the problem of planetary motion, but a formidable difficulty yet remained to be overcome. The orbits of the planets were not circular, but elliptical, and the sun—the centre of the attractive force—was not at the centre of the ellipse, but at one of the foci. For the complete solution of the actual problem which the phenomena presented, a calculus was needed, which neither Borelli nor Huyghens possessed, and the pre-eminent genius of Newton was illustrated, probably more by the invention of the needed calculus, than by his successful application of it to the solution of the important problem in question.

The general fact having been established that the curvilinear motion of the heavenly bodies was explicable on the hypothesis of a central attractive force, it was soon surmised that the particular character of the planetary orbits—involving as it did a continual variation in the distance of each planet from the sun, as well as a continual variation in the velocity of the planet's motion—could be due to no other cause than a difference in the intensity of the sun's attractive force at different distances. The query was: What was the precise law of this variation in intensity, which would account for the phenomena? Was the attraction inversely as the distance? or, as the square of the distance? or, as the cube? or, was it such as admitted of any precise expression? Guided, probably, by the known fact as to the distribution of light, of heat, indeed, of any emanation radiating in all directions from a centre, several individuals, independently as it would seem, adopted the conclusion which was afterwards demonstrated to be correct, namely: that the attractive force of matter for matter, varied inversely as the *square* of the distance, that is, at double the distance the attraction is one-fourth, at treble the distance one-ninth, and so on. The first to announce the true law of variation in the intensity of the attraction, was a French philosopher, Bouilland, or as his name ordinarily appears, in the Latinized form, Bullialdus. About the same time, Sir Christopher Wren, the distinguished architect of St. Paul's—Dr. Hooke, for a long time Secretary of the Royal Society, and the eminent mathematician astronomer, Halley, had arrived at the same conclusion. It was still, however, but a conjecture. In spite of the most earnest and persevering effort, no one was able to furnish a demonstration.

As contributing to the discovery of the demonstration, the place of merit, next to that of Newton, though, of course, far inferior, is doubtless due to Hooke. His labors were probably of aid to Newton, by way of suggestion, without, however, affording any just ground for the charge which Hooke subsequently made, that Newton was wearing the laurels to which he himself was justly entitled. As early as 1666, Hooke exhibited, in the presence of Royal Society, an experiment, now quite familiar, but at the time new and of exceeding interest. He supended from the ceiling a long wire to the end of which a ball of wood was attached—a simple pendulum on a large scale. On removing the pendulum from the vertical position, and then giving it a lateral impulse, at right angles to the plane in which it tended to oscillate, the ball described an ellipse—the eccentricity of the ellipse varying with a variation in the intensity of the lateral impulse. An ocular demonstration was thus given of the important fact that elliptical motion could be produced by the combined action of two forces—one impulsive and the other central—and that the particular form of the ellipse depended upon the relative intensities of the two forces. Although, in the experiment, the attractive force was at the centre of the ellipse, whilst in the case of planetary motion it was at one of the foci, still the fact exhibited must have been highly suggestive to any subsequent inquirer as to the cause of planetary motion.

In 1674 Hooke published a dissertation, entitled "An attempt to prove the motion of the earth by observations," in which he says: "I shall hereafter explain a system of the world, differing in many particulars from any yet known, depending upon three suppositions." The first—which he gives at some length—is a distinct statement of the universality of the attraction of gravitation. The second is substantially Kepler's law of inertia. The third is "that the attractive powers of the heavenly bodies are so much the more powerful, by how much the nearer the body wrought upon is to their own centres." And, he adds, "Now what these several degrees are, I have not yet experimentally verified, but it is a notion which, if fully prosecuted, as it ought to be, will mightily assist the astronomers to reduce all celestial motions to a certain rule, which, I doubt not, will never be done without it." From this declaration it is evident, first, that at this time he was still in doubt as to the true law of gravitation; and, secondly, that he was endeavoring to discover it by *experiment*—a method by which he could never have arrived at the truth. A few years later, as appears from his correspondence with Newton, Wren, and Halley, he was fully convinced that the intensity of the attraction of gravitation was inversely as the square of the distance, and he even professed to be able to furnish a demonstration. In this, he was either insincere at the time, or discovered subsequently that his supposed demonstration was defective, as he never presented it, though repeatedly urged by Wren and Halley to do so.

We are now prepared to understand and appreciate aright the precise work which Newton performed in connection with the discovery of the law of gravitation. Born on Christmas day, of the year 1642, the year in which Galileo died; in 1665 we find Newton a student of Trinity College, Cambridge, which he had entered in 1660. But twenty-three years of age, he had already not only mastered all of value that had previously been written on Mathematics, Astronomy and Natural Philosophy, but he had discovered the Binomial Theorem, and had conceived, and to an extent developed, the Differential Calculus—an achievement with which few other events in the history of science deserve to be compared, after we except his own subsequent brilliant discoveries in Optics, and his successful application of the calculus to the discovery of the law, and explanation of many of the most interesting phenomena, of gravitation. In the summer of 1665, he left Cambridge, on account of the plague which prevailed there at the time, and returned to his native town of Woolsthorpe, in Lancastershire. It was during this visit to Woolsthorpe, that the famous incident occurred, which, as is generally supposed, first suggested to him the idea of gravitation, and was the occasion of his great discovery. The account of it is given by his cotemporary and friend, Pemberton. One day, as he was sitting under an apple tree in the garden, an apple fell before him. This turned the current of his thoughts, and led him to reflect upon the nature of that mysterious influence which urges all terrestrial bodies toward the centre of the earth, causing them, when free, to move, to fall with a constantly accelerated velocity, which continues, moreover, to act without sensible diminution in intensity, at the top of the highest towers, or even the summit of the loftiest mountain. The thought was suggested to his mind, why may not this power extend to the moon? And, if so, is not this the influence which retains her in her orbit round the earth? He at once applied himself to the determination, if possible, of the truth of this conjecture. If the moon were really retained in her orbit by terrestrial gravity, he concluded that the planets were retained in their orbits by a similar influence of the sun. Moreover, if the attractive influence of the earth extended to the moon, and that of the sun to the farthest limits of our system, he concluded that the intensity of the attraction, in each case, diminished as the distance from the centre of attraction increased. If this were so, it would manifest itself by a difference in the velocities of the planets, they being at different distances from the sun, and he, accordingly, inferred that by a comparison of the velocities of the motions of the several planets with each other, the law of the variation of the intensity of the attractive force might be determined. Kepler's third law, that the squares of the times are as the cubes of the mean distances, furnished him at once with the necessary data for the calculation. He was not, at the time, able to solve the precise problem which the actual phenomena presented, the planetary orbits being elliptical, and the attractive force at one of the foci, but assuming the orbits to be circular, and the attractive force at the centre, he found that Kepler's law would follow, if the variation in the intensity of the attraction were *inversely as the square of the distance.*

It deserves to be noticed, that to solve even this problem, Newton must at the time have been familiar with the doctrine of central forces, though Huyghens' work on that subject was not published until more than six years after.

Though the data which Newton assumed, were not precisely those which the planetary system presented, the result reached was highly interesting, and calculated to encourage and direct further inquiry. The next question to be determined was, the law of the variation of the earth's attraction— Was this also inversely as the square of the distance? If so, the universality of the attraction of gravitation, varying in intensity according to the law just mentioned, would be almost indubitable.

The method by which Newton undertook to determine the variation of the earth's attractive influence—so simple when once suggested—was entirely original with him, and is one, though but one, of the grounds for attributing to him, pre-eminently, the honor of the discovery of the law of gravitation. Hooke, and doubtless others, subsequently labored for years to determine whether the intensity of the earth's attraction diminished with an increase of the distance from the centre, and if so, according to what law, and yet all their efforts were fruitless. Newton's method was simply this, assuming the supposed distance of the moon from the earth, to be correct, the length of the entire orbit of the moon may be readily determined. Moreover, the time of a complete revolution of the moon about the earth being known, the arc which she describes in one minute of time becomes known. Regarding this arc, which differs but little from a straight line, as the diagonal of a parallelogram, by the parallelogram of forces one of the sides of this parallelogram would represent the distance which the moon actually falls toward the earth, under the influence of the earth's attraction, in one minute of time. The arc, just mentioned, being known, this distance, which is the versed sine of the arc, may be readily determined. A measure is thus obtained of the intensity, at the moon, of the earth's attraction. By comparing this with the intensity of the attraction at the surface of the earth, as indicated by the distance a body near the surface will fall in one minute, the law of the variation in the intensity may be determined. Upon making the necessary computations, the result was not just that which Newton anticipated, or rather, hoped for. The distance which the moon ought to have fallen in one minute, according to the hypothesis, was one-sixth greater than that which, as it appeared, she actually did fall. Most men would have regarded this discrepancy as of little account, and accepting the result as, for the time at least, a sufficiently accurate demonstration of the hypothesis, would at once have given it publicity. Newton, however, though he could not but feel well assured that the true law of gravitation was indicated in the result he had reached, with that singular reticence as to his labors, and indifference to fame, which were among the marked features of his character, not only did not publish his investigations, but did not even, in his correspondence with his friends, allude to the subject. For more than thirteen years he does not appear to have made any further progress toward the solution of the problem of gravitation. Though his attention was, doubtless at times, directed to it, he was mainly occupied, during this period, with other scientific labors, particularly in investigating the phenomena of light, making more brilliant discoveries on this subject which, even if he had not subsequently discovered the law of gravitation, would have entitled him to a distinction among men of science, scarcely inferior to that which is now universally awarded him.

In 1679, after Bouilland, Hooke, Wren, Halley and others had become well convinced of the true law of gravitation, and yet were unable to furnish a demonstration of it, Newton was led to a renewed investigation of the subject. Hooke had for some time been investigating the motion of projectiles, and in a letter to Newton about this time, asserted that a body acted on by an impulsive force, and at the same time by an attractive force varying in intensity inversely as the square of the distance, would describe an eccentric ellipse. What proof Hooke had of the fact asserted, does not appear. It may be regarded as certain that he was not able to give a mathematical demonstration of it. As he had become well convinced that the attraction of gravitation varied according to the law mentioned, it is altogether probable that the main, if not the sole, ground for his assertion, was the fact that the orbits of the planets are elliptical. However this may be, Newton at once appreciated the importance of the assertion, if it could be demonstrated, and was led to attempt the solution of the problem suggested by Hooke, or rather, the converse problem, namely, to determine the law of the variation in intensity of a central force which would cause the body acted upon to describe an ellipse. By the aid of the calculus, which he had by this time considerably perfected, he finally succeeded, after long and laborious effort, in demonstrating, in its most general form, the truth of Hooke's assertion. The importance of the result cannot be overestimated. The enigma, which the elliptical orbits of the planets had presented, was solved, and the fact of the sun's attraction, and the precise law of the variation in the intensity of that attraction, was at last established beyond the possibility of further doubt or questioning.

The demonstration of the universality of gravitation, however, was still incomplete. The sun, indeed, attracted the planets, with a force varying inversely as the square of the distance, but was this a property common to all matter? Was it identical with that attraction of the earth, which caused bodies near it to fall toward its centre? Were the revolutions of the planets and the revolution of the moon phenomena referable to one and the same great law of nature? The result which Newton had reached in his investigations, in 1665, seemed to render this doubtful, or, at least, presented a difficulty, for the time, inexplicable. Accordingly, with that characteristic reticence to which we have previously referred, Newton refrained from communicating to any one the important discovery he had made, preferring to await the solution of the difficulty which the anomalous fact of the apparent intensity of the earth's attraction at the moon presented.

Three years afterwards, in June, 1682, Newton attended a meeting of the Royal Society. Whilst in London, he accidentally learned that Picard, in France, had just measured an arc of the meridian with great accuracy, and that the result which he obtained for the length of a degree in that latitude, differed somewhat from the measurement previously accepted as reliable. Newton at once perceived the importance of this fact in connection with the determination of the intensity of the earth's attraction. If the commonly received measure of a degree of the meridian was erroneous, the accepted estimate of the size of the earth was erroneous; moreover, if the assumed semi-diameter of the earth was incorrect, the supposed distance of the moon from the earth, in the calculation of which the earth's semi-diameter is involved, must also be incorrect. The possible explanation of the annoying result he had reached in 1665, was immediately suggested. Obtaining accurately the measurement of a degree of the meridian as given by Picard, immediately on his return to Cambridge he determined the size of the earth and the distance of the moon, on the supposition that Picard's measurement was the true one. With the data thus obtained, he returned to the problem at which he had labored sixteen years before, and by the same method then pursued, he sought anew to determine the law of the variation of the earth's attraction. Perceiving, as he advanced in the calculation, the tendency of the numbers to produce the desired result, he became so much agitated that he was unable to finish the computation, and was under the necessity of requesting a friend to do it for him. The identity of the force which causes bodies near the earth to fall toward its centre, and that which causes the heavenly bodies to revolve, was fully established, the universality of the law of gravitation was finally and forever demonstrated—the solution of the grand problem of the universe was complete.

We might have supposed that Newton would have eagerly hastened to announce his great discovery, and secure for himself the eminent honor to which he was entitled, and yet more than two years elapsed before the discovery was published to the world; and then, not of his own motion, but at the instance of his friend Halley, who subsequently boasted that he was the Ulysses who had discovered Achilles and brought him forth from his concealment. In the month of August, 1684, Halley, having become satisfied that Hooke could not furnish the demonstration of the law of gravitation, which he had repeatedly promised, visited Cambridge to confer with Newton on the subject, on which he had become deeply interested, and been long laboring without any satisfactory result. He inquired of Newton, what would be the curve described by the planets, on the supposition that the attractive influence of the sun diminished as the square of the distance? Newton at once replied, "An Ellipse." When asked how he knew this? he replied: "I have calculated it." Halley, surprised and delighted at the announcement, asked to see the demonstration. Newton was unable to lay his hands on the calculation he had made two years before, nor could he, at the moment, reproduce it. He promised Halley, however, that he would send him the demonstration as soon as he was able, and in the month of November following, he fulfilled his promise. Halley immediately revisited Cambridge to obtain Newton's consent to the publication of the discovery. In this he succeeded, and on the 10th of December he informed the Royal Society of the discovery, and that Newton had consented to prepare a paper on the subject for the Society. In February, 1685, the promised communication was received—a paper of twenty-four pages, containing four theorems and seven problems. He refers to it in the accompanying letter, as his "notions about motion." This humble, yet most memorable paper ever presented to the Society, was the germ of "The Principia."

The great discovery having been made public, Newton seems to have felt that the time had come to enter on the gigantic task he had, doubtless, proposed to himself when the discovery was first made, but which other occupations had hitherto prevented him undertaking, namely, putting his demonstration in a complete and rigidly conclusive form, and applying it to the solution of the many interesting and sublime problems which the phenomena of the material universe presented. For two years, he dismissed from his mind all other occupation, and devoted himself, with all the energy of his mighty intellect, to the Herculean task. With untiring industry, prolonged attention and intense thought, probably never paralleled in the history of intellectual effort, he lived but to meditate and to calculate; oftentimes so wholly absorbed with the grand themes which occupied his mind, as to be, for the time, unconscious of all the ordinary concerns of life. Frequently, on rising in the morning, he would sit for hours on his bedside, arrested by some new conception, and had it not been for the attention of the members of his family, would often have neglected to take his daily food.

We cannot enter upon any detail, or present even a summary, of the magnificent results of these labors. They are to be found in his immortal werk, the "Philosophiæ Naturalis Principia Mathematica," given to the world in 1687, under the auspices of the Royal Society. Of this work, the great Laplace, who, of those who have applied the highest powers of the human mind to the investigation of the phenomena of gravitation, stands second, only because Newton lived before him, says: "The universality and generality of the discoveries it contains, the number of profound and original views, respecting the system of the universe, it presents, and all presented with so much elegance, will insure to it a lasting pre-eminence over all other productions of the human mind." "It is a work," says Sir David Brewster, "which will be memorable, not in the annals of one science or one country only, but which will form an epoch in the history of world, and will ever be regarded as the brightest page in the records of human reason. It is a work which would be read with delight in every planet of our system, and in every system in the universe. There was but one earth on whose form and movements and tides the philosopher could exercise his genius; one moon whose perturbations and inequalities and action he could study; one sun whose controlling force and apparent motions he could calculate and determine; one system of comets whose eccentric paths he could explore and rectify; one universe of stars to whose binary and multiple combinations he could extend the law of gravity. To have been the chosen sage, summoned to the study of that earth, these systems and that universe, the favored lawgiver to worlds unnumbered, the high-priest in the temple of boundless space, was a privilege that could be granted to but one member of the human family; and to have executed the task, was an achievement which, in its magnitude, can be measured only by the infinite in space, and in the duration of its triumphs, by the infinite in time."

ARTICLE VI.

LUTHERAN HOME MISSIONS.

By Rev. MORRIS OFFICER, A. M., Mansfield, Ohio.

The work of Christian Missions includes not only the preaching of the Gospel to the destitute, but also the organization among them of the Christian Church, and, indeed, the establishment of the pastoral charge. It is authoritatively to declare the plan, the method, and the conditions of salvation, to those who are ignorant thereof, and thus to raise up in each place, or district, a Christian society, by which this same preaching, and the other gospel ordinances, can be permanently and independently maintained.

The preaching is the great burden of the work, and, virtually, includes the organizing; but still, it is not complete without organization itself, for this latter is involved in the gospel's permanent method of operation, and is a necessary part of the arrangement by which the independent maintenance of the new pastoral district, is attained, and missionary labor brought to a successful termination.

Such was the apostolic usage; for, while the work began by the going forth of the Christian herald, to "preach the gospel," and continued by his "teaching all things whatsoever Christ had commanded," it did not end till "the things wanting were set in order, and elders (pastors) were ordained in every city." And whether each one of these elderships, or pastoral districts, provided its incumbent a pecuniary support, or whether he, in part, or altogether, maintained himself, out of his own possessions, or by engaging in some secular pursuit, it is not important here to inquire, since the rule for the whole ministry is, that "They who preach the gospel shall live of the gospel," and the exception to the