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The Structure of the Universe: Being a Presentation of Professor Osborne Reynolds' Theory of Gravitation

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Osborne Reynolds.

THE STRUCTURE OF THE UNIVERSE; BEING A PRESENTATION OF PROFESSOR OSBORNE REYNOLDS' THEORY OF GRAVITATION.

(With Experiments.)

By John Mackenzie, Minneapolis.

First Statement of Reynolds' Theory in This Country.

The title of my lecture this evening sounds high. When one talks about the structure of the universe it would seem that he has a large subject on his hands. I may also state that as far as I know what I will present to you this evening has not up to the present time been presented to or dealt with by any other scientific, philosophical or literary society in this country, and with the exception of the general mention of Reynolds' theory of gravitation by my friend Professor Henry Crew of the Northwestern University, in his recent work on "General Physics" I am not aware that the theory has yet been noticed in the United States.

Wonderful Developments of Modern Science.

Numerous and wonderful have been the discoveries of science from the time of Newton to the present day; and the end is not yet. As Henry C. Jones, Professor of Physical Chemistry in Johns Hopkins University in his work entitled, "The Electrical Nature of Matter" remarks: "It seems not too much to predict that as the 19th century surpassed the preceding 18th in the development of scientific knowledge and the discovery of truth, just so the twentieth century will exceed them all in the gifts of pure science to the story of human knowledge." I hope my lecture this evening will show you to some extent how true this is, and that indeed, already in this century the portals have been opened by the master mind of Osborne Reynolds to a new and further advance of dynamical science by the solution of the problem of all problems,—the cause of gravitation.

As To Professor Reynolds.

Professor Osborne Reynolds was born at Belfast, Ireland, on Aug. 23, 1842. He graduated at Queen's College, Cambridge, in 1867, his name being fifth in the list of wranglers in the mathematical tripos.

In 1868 he became Professor of Engineering in Owens College, Manchester, England,—an institution which is regarded as probably the greatest engineering college in the world. Owing to ill health he resigned his professorship a year and a half ago. Professor Reynolds' researches and contributions dealing with various mechanical and dynamical subjects rank very high with all engineers, and, as all students of the subject know, his researches have largely created the modern science of hydrodynamics.* The third volume of Reynold's

* He has been presented with many honors by various scientific institutions, and his name is familiar throughout the world to all who take an interest in the physical sciences.

Scientific Works is entitled: "The Sub-mechanics of the Universe," and is published under the auspices of the Royal Society. This is a work of pure science, is highly technical, and deals wth the structure of the universe from a dyamical and mechanical point of view, and explains the cause of universal gravitation. Combining as Reynolds does the rare gifts of pure science and practical science, we get a tangible definite theory or rather explanation as to the structure of the universe, which is the result of twenty years of experimental and mathematical investigation, and which is something very different from the fruitless speculations on gravitation which have been indulged in by many of the speculative philosophers in the past. We have here at last a simple, sensible, dynamical theory of the physical universe and gravitation. The problem, however, as you will realize later, is solved by an apparent paradox.

Newton Discovered the Law But Not the Cause.

We are aware of the fact that Newton discovered and enunciated *the law* of universal gravitation, but he did not discover *the cause.* Newton proved the law by which all the material bodies in the universe were governed. This law, as you know, states that all masses of matter in the universe attract each other with forces proportional to the masses and inversely proportional to the square of the distance between them. This law governs the smallest particle of matter as well as the mightiest sun in the universe. But, while Newton *speculated* on the cause of gravitation, or the *reason why* bodies act in this way, he was unable to solve the problem. There have been many attempts since the time of Newton to solve the problem. The history of physical science is replete with the baffled efforts of the greatest intellects to find the solution. One has only to read Taylor's "Kinetic Theories of Gravitation" to realize the many fruitless attempts to solve this problem in the last two centuries, and indeed some philosophers came to the conclusion that the problem could never be solved. There are indications that Fourier and even the great Laplace considered gravitation as one of the "primordial causes" which might remain forever impenetrable to us.

The Gifts of Pure Science to Practical Science.

In the eyes of a certain class of people the many long years of toil and patient investigation of the true scientific investigator count for nothing unless they immediately bring forth some brilliant, or sensational discovery, or one which can be immediately turned into money. Some people have no use for science unless they can see immediate money in it. We should not forget, however, that the so-called "practical" fellows would very soon have nothing to work on were it not for the researches carried on and the principles discovered by the students of pure science. We have only to reflect on the practical value of Newton's discovery of the law of gravitation. This was a discovery in pure science, and has it not given the world its science of mechanics? Were it not for the mighty Newton and the great Galileo, who, out of their pure love of scientific investigation laid down the laws of motion and pure mechanics, the world could

have had no engineers. And coming down to modern times, were it not for Faraday and Maxwell who discovered the principles of electric induction and electromagnetic waves there colud be no Edison or Marconi to apply them.

The Vast Apparently Empty Space of the Universe Compared to the Small Space Occupied by Matter.

When we look into the sky on a clear dark night through a powerful telescope the stars and planets appear to be set in a vast vault-like space showing the perspective of distance to a certain extent. They seem to lose the appearance which they present to the unaided eye of being set simply on a plane background. As we look into the vast abysses of space we realize that notwithstanding the great number of stars the actual space they occupy in the universe is as nothing compared to the vast spaces all round them which appear to be absolutely void. We may say that the room taken up or occupied by what we call "matter" in the universe is exceedingly small compared with the space which seems to be empty. Professor Newcomb has stated that probably there are about 100 million suns in the universe, averaging five times larger than our sun. This would give a total amount of matter of 500 million suns equal to our sun, and he supposes these suns to be equally distributed throughout a sphere 30,000 light years in diameter. In other words, light, which travels, as you know, at a velocity of 186,000 miles per second would take 30,000 years to pass from one side of such a universe or sphere to the other side. This would mean a sphere billons of billions of miles in diameter; whereas, our sun, which is something like 800,000 miles in diameter, even if enlarged 500 million times would still be but an infinitesimally small speck of matter in such a vast universe of otherwise empty space.

What is This Apparently Empty Space?

The question occurs, What is the nature of this apparently empty space? Is it a complete void or vacuum, or does it contain a medium of some kind? Now, on this point there have been many speculations. To all appearances the planets, moons, stars, comets and meteors which move through this space with great velocities meet with no resistance from this medium, if there be a medium. The earth moves through it at a speed of 19 miles per second in its journey round the sun, and recent experiments of Professor Michelson seem to prove conclusively that if there be a medium in this space none of it is entangled with the earth or carried along with the earth in its motion through space.

Another question arises. Is the powerful force of gravity which binds the different bodies of the solar system together, and in fact the whole material universe, conveyed through absolutely empty space? In other words, can momentum be transmitted across an absolute void, or is there such a thing as "action at a distance?" We know that the gravitative pull of the sun on the earth is equal to a force more than a million million steel rods, each seventeen feet in diameter could stand. The earth is 92,000,000 miles from the sun. Is this immense force transmitted across an absolute void? While the eye sees noth-

ing in space, it would seem to our better judgment that there must be some sort of mechanism which transmits this gigantic force. Other considerations lead us to this conclusion. We know that powerful magnetic storms originating in the sun are transmitted instantaneously to the earth and throughout the whole solar system with such intensity occasionally as to put many of the telegraph instruments and wires in the country out of commission until they pass.

The Density of the Medium.

Until recent years very little of a definite nature has been known as to the nature of the medium of space. So far as any evidence it gives of its existence to our senses is concerned, it would appear to be something very unsubstantial, and for this reason it has been called the "ether." Newton had an idea that it was a very thin, highly attenuated fluid which pervaded all space, so very thin in fact, that if you could scatter a pill box full of air throughout the space of the solar system its density would then be about the density of the ether of space.

With the development of electrical science and the study of electric and magnetic forces, however, different ideas began to be entertained as to the density of the so-called ether, until to-day we have the leading physicists postulating the necessity for an ether of very high density and very much greater than the density of any known substance. In his Yale lectures on "Electricity and Matter" Sir J. J. Thomson, in discussing the nature of electrical mass, says: "The view I wish to put before you is that it is not merely a part of the mass of a body which arises in this way, but that the *whole* mass of any body is just the mass of ether surrounding the body which is carried along by the Faraday tubes associated with the atoms of the body. In fact, that all mass is mass of the ether, all momentum, momentum of the ether, and all kinetic energy kinetic energy of the ether. This view, it should be said, requires the density of the ether to be immensely greater than that of any known substance." And in his presidential address to the British Association at Winnipeg last August he said: "Since we know the volume of the corpuscle as well as the mass, we can calculate the density of the ether attached to the corpuscle; doing so, we find it amounts to the prodigious value of about 2,000 million times that of lead." He states, however, that this density would be the density of the ether only in the immediate vicinity of the corpuscle, and that its density in free space would not be so high if the ether is not compressible. Sir Oliver Lodge, in his last edition of "Modern Views of Electricity" also says: "The ether is now turning out to be by far the most substantial body known,—in comparison with which the hitherto contemplated material universe is like a vapor of extreme tenuity,—a barely perceptible filmy veil."

These conclusions of Thomson and Lodge as to the density of the medium of space are arrived at by the study of electromagnetic and electrostatic forces. Professor Reynolds works out his conclusions from mechanical and dynamical considerations, and arrives at the density of the medium of space as being ten thousand times that of

water, or 480 times denser than platinum, which is the densest matter on earth.

In view of this great density of the medium of space, does it not seem rather paradoxical that what we call matter, that is, the planets, suns, moons, comets and so forth, which are so much less dense than the medium should move through the medium apparently without resistance and at such high velocities? Our earth, as you know, moves in its orbit at a velocity of 19 miles per second. You have all seen bubbles moving in water. Reynolds shows that the earth and all the other material bodies move through space in a similar manner. They are less dense than the medium in which they exist, and, as we shall see, their movements are due to differences of pressure in the surrounding medium. They are like so many filmy soap bubbles which a child blows from the stem of a pipe. Real mass is not in the material things which we see, but in space where the eye sees nothing. The sober conclusion of the most advanced dynamical science is that matter is a negative thing so far as its mass is concerned, and that the space occupied by "matter" contains very much less mass than the space where no "matter" exists.

Is the Medium Continuous or Granular?

We now come to another important point. I have here on the table a glass full of small shot and another glass full of jelly. The glass of shot we will take to represent a universe composed of what we will call a "granular medium," that is, a medium composed of discrete or separate parts or grains; the jelly represents a universe composed of what we will call a "continuous medium," that is a medium not made up of discrete or separate parts, but continuous in its structure. These two kinds of structures represent the two views which are held as to the nature of the structure of the medium of space. We have ascertained that this medium is very dense; now let us endeavor to find out the character of its structure. On the correct answer to this question hinges the true solution of the problem of gravitation.

We have had atomic systems of philosophy from the earliest ages. Democritus and Lucretius are the ancient fathers of the atomic systems. In his great poem on the origin of things Lucretius speculates on the atomic system of the universe, and tries to show that the origin of the universe was due to a "concourse of atoms." There have been many speculations on this point from that day to this; but it has remained for modern science, with its experimental and mathematical methods, to arrive at the truth.

Analogy would suggest that the medium of space would be granular in its structure. We are not acquainted with anything that cannot be divided into parts. The atomic theory in chemistry, whose modern founder was Dalton, and which has proved so fertile, postulates that the chemical unit is the atom, and that the atom is the unit from which is built up systems of molecules, organic and inorganic, in the universe around us; that all things are combinations and compounds of atoms. The atom, indeed, has been weighed and measured. Maxwell and Kelvin did this for us, and we know in fact

about how many atoms could be laid alongside each other in the length of an inch. They tell us that from ten million to one hundred million atoms could be laid alongside each other to make up an inch in length. Of course, anything so small as this is inconceivable; but we know that the inconceivability of a thing now-a-days does not mean that it is impossible. Kelvin stated that if a drop of water were enlarged to the size of the earth, which we know is about 8,000 miles in diameter, the atoms or molecules of which it is composed would appear about the size of base balls.

In recent years, however, somethng very much smaller than the atom has been discovered by science. You have all heard of the electron. An electron is an atom of electricity. It is now maintained by physicists that the ordinary chemical atom which I have just spoken of, is a compound thing, and is composed of aggregations of thousands of electrons. An electron has been defined as an "electric point charge" in the ether. It seems to be an almost infinitely small point of electricity, and the idea is that aggregations of these electric point charges or electrons, when combined into a system form what is known as the chemical atom. Configurations of such a system have been worked out by Thomson, Larmor and others, and it would appear that the system of the chemical atom which is an aggregation of electrons is far more complicated than the solar system. The infinitely small is turning out to be more complex than the infinitely great. The universe within the atom seems to be more complicated than the universe outside. The electron is, of course, very much smaller than the atom, and, like the atom, its size is inconceivable. One may get an idea of the size of the electron as compared with the size of the atom if we suppose the electron to be about as large as the head of a pin revolving inside the Minneapolis Auditorium, the Auditorium being taken to represent the size of the atom. These electrons which make up the atomic system move with very high velocities in the atomic system. The mass of the moving electron has been measured, as well as the electric charge which it carries.

So we see that by the discovery of the electron we have simply discovered a smaller kind of atom than the old chemical one. The electron theory, then, still maintains the granular structure of the ether or medium of space. I ought to say, however, that there are still some physicists, notably, Sir Oliver Lodge, who seem to maintain that the medium of space is not granular or of a discrete structure, but that it is a "perfectly continuous, incompressible and inextensible medium filling all space without interstices or breach of continuity." The continuous medium theory, however, has so far completely failed to give the slightest clue to the cause of gravitation, and all that Lodge has to say is that "gravitation is explicable by differences of pressure in the medium, caused by some action between it and matter not yet understood." He is right in saying that it is caused by differences of pressure in the medium, but he cannot find the proper mechanism to produce these necessary differences of pressure in his continuous medium.

By an elaborate analysis Reynolds shows that the medium of space

must be granular in its constitution. He shows that space is occupied by uniform spherical grains of changeless shape and size. It is occupied by what he calls "spherical grains in normal piling." The opening statement in his "Sub-mechanics of the Universe" is:

"By this research it is shown that there is one and only one, conceivable purely mechanical system capable of accounting for all the physical evidence, as we know it, in the universe."

"The system is neither more nor less than an arrangement of indefinite extent, of uniform spherical grains generally in normal piling so close that the grains cannot change their neighbours, although continually in relative motion with each other; the grains being of changeless shape and size; thus constituting to a first approximation, an elastic medium with six axes of elasticity symmetrically placed."

It is worthy of note that Newton also had the conception that the real sub-stratum of the physical universe is granular in its structure, for in the fourth edition of his "Opticks" page 375 he says: "All things considered, it seems probable that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles, of such sizes, figures and with such other properties, and in such proportion in space as most conduced to the end for which he formed them, and that these primitive particles being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break to pieces; no ordinary power being able to divide what God himself made one in the first creation."

The question has been asked, why are most sports but the variants of one object, the propulsion of a sphere? Billiards, baseball, polo, golf, slinging, marbles, squash, handball, football, racquets, cricket, hockey, bagatelle, tennis, shooting, pelota, all have as their basic pursuit the driving of a ball, the propulsion of a sphere. Tipcat, shuttlecock and top spinning are the employment of modifications of the sphere. May the reason not be that poor mortal man attempts by these means to get in a small way into the tremendous scheme of the universe, which is the everlasting movement of the spheres?

The Fundamental Atom.

We considered above the size of the chemical atom and also the approximate size of the electron, aggregations of which, according to the electron theory make up the chemical atom. We saw how very small the electron is as compared with the chemical atom. We shall now enquire as to the size of the grain in Reynolds' granular medium. Reynolds shows that its diameter is the seven hundred thousand millionth part of the wave length of violet light. A wave of violet light is about the 70 thousandth part of an inch in length. Reynolds' cosmic grain, then, is very much smaller than even the electron. It is at least as much smaller than the electron as the electron is smaller than the chemical atom, the sizes of all three being equally inconceivable. This cosmic grain of Reynolds is the absolute or fundamental atom of the universe. It is the smallest entity which can exist in space. Reynolds has shown by dynamical and

mathematical considerations that this grain is the smallest possible entity which can exist in the universe. It is the "absolutely rigid granule, ultimate atom or primordian." In Section VIII. of the "Sub-mechanics" he says:

"Although the absolutely rigid atom is as old as any conception in physical philosophy, the properties attributed to it are outside any experience derived from the properties of matter. In this respect the perfect atom is in the same position, though in a different way, as that other physical conception—the perfect fluid. Both of these conceptions represent conditions to which matter in one or other of its modes, apparently approximates, but to which, the results of all researches show, it can never attain, although this experience shows that there is still something beyond. * * * It becomes clear therefore that any fundamental atom must be considered as something outside—of another order than—material bodies, the properties of which are not to be considered as a consequence of the laws of motion and conservation of energy in the medium, but as the prime cause of these laws."

This last statement involves a very important principle; for, whereas other theories of the atom have been based on the motion of a so-called perfect fluid continuously filling space, like Kelvin's vortex atomic theory, or upon an electronic system of electrostatic and electromagnetic forces, as developed by Thomson, Larmor and Lodge, the atom in these systems being the *result* of the laws of motion and conservation of energy, Reynold's fundamental atoms or cosmic grains, by their *motions and arrangements* are themselves the cause of the laws of motion and conservation of energy, the whole explanation and philosophy being purely dynamical, just as Newton's explanation of the law of gravitation is purely dynamical.

Arrangement or Piling of the Grains.

We come now to one of the most important points in the whole subject; that is, the arrangement or piling of the grains in the medium. We have all doubtless seen cannon balls piled in heaps on military reservations. Now, there are different ways in which shot or other spheres may be piled. I have here before me on the table six different regular arrangements or piling of small rubber balls, and in these different arrangements the number of balls varies in proportion to the total volume or space occupied by the balls. There are six regular arrangements in which balls touching each other may be piled, shown by these six models, and in each of these arrangements, as stated, the full spaces or the spaces occupied by the balls, and the empty spaces or the interstices between them vary. I have calculated the relation or proportion of full space to empty space in these six different arrangements, and find that in the closest arrangement or piling, where the grains are arranged in parallel tiers in triangular form, taking the total volume of the pile as 100, the full space occupied by the balls amounts to 79.818 and the empty space to 20.182, or about 4 to 1, whereas in the most open arrangement of piling, where the grains are placed vertically over each other in parallel tiers in the square position, like this model, the full space is only

52.381 and the empty space 47.619, or about 11 to 10. The other four methods of piling lie between these two extremes. I append to this lecture the figures of the proportions of full space to empty space in the six arrangements.

One of Reynolds' most inportant steps toward the discovery of the cause of gravitation was the discovery of the dilatancy of granular media under pressure. For instance, when shot or sand or other spherical grains are put into a bag or other closed surface and shaken, they settle into a very close position, and when in this position the spaces or interstices which exist between the grains are about the smallest possible. They may then be said to be in what Reynolds calls "normal piling" and when in this position the shape of the bag containing the shot or grains cannot be changed without at the same time changing its bulk or volume; because if you endeavor to change the shape of the containing vessel under such conditions, you are at the same time disturbing the grains from their closest possible positions into another arrangement less close, whereby the spaces or interstices between the grains are enlarged, thereby producing a vacuum, or working against atmospheric pressure. I have here two hollow rubber balls, one filled with small shot and completely closed, except for a small opening which does not allow the shot to escape, and into which a glass tube is inserted to measure the dilatation. Colored water is poured into the bag through the tube to fill the interstices between the shot, and if the bag is then subjected to distortional squeezing, as it now is, the water, as you see, sinks in the tube. It is drawn into the bag to fill the expanded spaces between the grains caused by the distortion. This is an experimental model universe. I have here another similar bag filled only with water, but, as you see, when it is similarly squeezed the water rises in the tube. I have here also one of these thin rubber balloons which children play with, filled with sand and just enough water to fill the interstices between the sand when lying flat as you see it now. It is closed tightly so as not to admit any air. It is now placed on its edge, and, as you see, sustains a weight of 200 pounds without flinching. This appears to be nothing short of magical, but when the phenomena of dilatation of granular media under pressure is understood it is perfectly simple. (Experiment.)

This remarkable property of dilatancy of all granular media was discovered by Reynolds. It also furnished him the clue to the cause of gravitation. In order to get granular media under pressure it must be bounded by a closed surface. Reynolds says: "If, as in the universe, the grains in normal piling extend indefinitely, there can be no mean motion of the boundaries, whatever the pressure may be; and thus the grains are virtually within a closed surface."

Here is a model made out of small rubber balls of the way the cosmic grains are arranged in space according to Reynolds. This arrangement is what he calls "normal piling," and is such that the grains are placed in a set of squarely formed layers horizontally, each sphere resting on four in the layer below, and in its turn supporting four in the layer above, these last four being vertically over the first four. Besides touching these eight in adjoining layers it touches

four in its own layer, making twelve in all. There are therefore twelve grains piled around each grain. This then is the arrangement or piling of the grains throughout the universe of space where no matter exists.

Matter is Absence of Grains.

Where matter exists there is a different arrangement in the piling of the grains, and the regular or normal piling of the grains is broken. There is a less number of grains per unit volume in the spots where matter exists than there is in the regular medium of space. Where this deficiency which results in what we call "matter" exists, there is what Reynolds calls "abnormal piling" of the grains. This deficiency forms a sort of crack, or gap, or loose joint in the medium, and there is a break in the gearing of the grains between the matter and the medium outside. An atom of matter consists of a nucleus of grains in normal piling surrounded by a surface or spherical shell of grains in abnormal piling. The grains in abnormal piling form what Reynolds calls "a singular surface of misfit" between the regular piling inside, which forms the nucleus of the material atom and the normally piled grains of the medium outside. This "surface of misfit" or spherical shell together with its nucleus is called a "negative inequality" and the magnitude of the negative inequality is reckoned by the number of grains which are deficient, and as the number of grains present in a given volume of the medium determines the mass of the medium, an absence of grains means an absence of mass. Therefore, matter is absence of mass or negative mass. These surfaces of misfit or spherical cracks in the medium are places of weakness in the medium, and it is shown that they travel through the medium after the manner of solitary waves.

Mean and Relative Motion of the Medium.

We have now to consider whether the grains of the medium are fixed and stationary in their places, or whether they have motion among one another. Reynolds shows that the grains of the medium are not fixed but that they have a mean and relative motion. The medium is not inert and rigid and lifeless. It thrills with energy and pulsates with universal motion. It possesses two kinds of motion, first, the relative motion of the grains among one another, and, second, a mean motion, which is a motion of the mass of the medium as a whole from one position in space to another. The average relative velocity of the grains among one another is shown to be about one and one-third feet per second, while the mean path of the grain, that is, the average distance a grain has to move before it strikes its neighbor, is shown to be the four thousand millionth part of the diameter of the grain. It is the relative motion of the grains among one another which renders the medium elastic, and, as Reynolds says, is the prime cause of elasticity in the universe. The mean and relative motions of the medium are illustrated by the movement of a cloud of dust, a swarm of bees, a shower of hail, a current of air, a stream of water, or a cloud in the sky. In each of these phenomena we have movement of the mass of the particles as a

whole and also the individual movement of the particles of which the mass is composed with relation to each other. The movement of the mass as a whole is called the mean motion, and the relative movement of the particles in the mass is the relative motion of the medium.

The Pressure and Stress of the Medium.

Let us now ask, What is the pressure of this medium of space? We certainly do not feel its pressure; neither do we feel atmospheric pressure, though we know that the atmospheric pressure on the surface of the earth at sea level is nearly 15 pounds on the square inch. At great ocean depths we also know that the hydraulic pressure amounts to several tons per square inch; and we also know that as we go down into the earth the pressure of the surrounding rocks and strata increases very rapidly, until at great depths it amounts to hundreds of tons on the square inch. We probably do not realize that every square foot of surface of a man's body is subjected to an atmospheric pressure of about one ton, so if the surface area of a human body is say 10 feet, that body is subjected to a total pressure of about 10 tons. We are ordinarily unconscious of such a pressure, because it presses upon us equally in all directions, but if this pressure should be suddenly removed from one side of our body we would soon realize it, and the pressure on the other side would hurl us through space with the speed of a cannon ball.

Located as we are on our tiny earth, which is whirling through infinite space at a speed of 19 miles per second, we are immersed in a vast ethereal ocean. Can we ascertain whether the medium of this ocean has any pressure? Reynolds shows that the mean pressure of the medium of this universal ocean of space is nearly seven hundred and fifty thousand tons on the square inch, being more than three thousand times greater than the strongest material can sustain. A statement like this seems paradoxical, and we cannot by any stretch of the imagination conceive of such a pressure existing in what we have hitherto regarded as empty space. Yet such is the sober truth, found necessary to account for the physical facts that we know. Clerk Maxwell, the great Scotch mathematician and physicist, arrived at the same conclusion as to pressure and stress of the ether from a consideration of electromagnetic and electrostatic forces. In his article on "Attraction" in the Encyclopoedia Brittanica, after discussing this subject, he says: "The state of stress, therefore, which we must suppose to exist in the invisible medium is 3,000 times greater than that which the strongest steel could support."

Now it seems rather strange to us at first that the medium of space is of such great density. We have been accustomed all our lives to think of matter as being in fact the only solid reality, and universal space as simply nothing. It will thus be seen that the old style philosophical materialist will find slight comfort in Reynolds' theory, for the materialist's so-called real matter is shown to be only a kind of froth or foam or bubble in the universal granular ocean, which is ten thousand times denser than water. The presence of what we call "matter" in space means a place where there is a sort

of crack, a gap or fissure in the uniform medium. It may be interesting here to mention Kelvin's vortex atomic theory of matter, from which so much was expected, but which has failed to give any clue to gravity, and any theory of matter which does not contain a solution of the problem of gravitation can have no permanent value, for gravitation is the supreme problem before physics to-day. The next great advance in physical science lies in the solution of this problem.

The Vortex Atomic Theory.

Kelvin conceived a perfect fluid continuously filling space, and he supposed that what we call an atom of matter is the rotating portion of this fluid. We can make air, water or any other fluid more or less rigid by imparting rapid motion to it. The motion differentiates that portion of the fluid which is in motion from that portion which is not in motion, like the smoke ring which sometimes ascends from the funnel of a locomotive. The idea was that if the fluid were frictionless and vortex motion once started in it that motion would continue forever. He conceived that atoms might be composed of such rings of ether in motion, the ether being supposed to be the perfect fluid. The atoms were a sort of ether squirts. This theory of matter was quite interesting and something new at the time, and the dynamics of the theory were worked out by Helmholtz and J. J. Thomson, but notwithstanding that it promised so much, it has been for the most part given up, and it has not been able to throw any light on the problem of gravitation. I spoke about the electron theory of matter in a previous part of this lecture. Neither has this theory, however fascinating in many respects, been able to produce an explanation of gravity. The gravitational force is entirely different from and belongs to another order than the electrostatic and electromagnetic forces, and all the endeavors to get an explanation of gravitation out of them have led to negative results.

Mass.

We have spoken about mass. Now let us see what mass is. Of course, mass has been defined as the amount of matter in a body, or the inertia of a body. We should not confound mass with weight. The book which is lying on this table has a certain weight here which can be ascertained exactly, but if I transferred it to the Equator of the earth it would weigh less than it does here, and if I took it to the North Pole it would weigh more. In other words, the weight of a body on the earth's surface depends on its distance from the center of the earth, and *vice versa*, and we know that the surface of the earth at the Equator is 13 miles further away from the center of the earth than the North Pole is. But the book at any place on the earth's surface would still have exactly the same mass, and indeed it would still have the same mass at any place in the universe. Weight depends on the force of gravity, and we know the force of gravity varies at different points of the earth's surface, according to their distance from the earth's center; but the mass does not vary so long as the law of the conservation of matter holds good. If the book were placed millions of miles from the earth away out in

interstellar space where there was no planet or sun to attract it, it would remain suspended in space without motion, and would have no weight; but its mass would be the same as before. How is this? Because it would require exactly the same amount of force to move it over a certain distance in a certain time. Mass is measured by the amount of force required to move it over unit distance in unit time, and unit mass is that quantity of mass which is moved unit distance in unit time by unit force, no matter in what part of the universe it may be placed, whether it may be on earth, or on the planet Mars or Jupiter or billions of miles away in interstellar space. But this only gives us a measure of mass. It does not tell us what mass is. It is only in recent years by the study of X rays, cathode rays, and other electrical discharges in the Crookes' tube that physical science has been able to gain some definite knowledge on this subject. As I stated in a previous part of this lecture, a good deal is now known about the behaviour of the particles, called electrons or corpuscles, which make up the discharge which passes from the negative to the positive pole of the tube. The mass of these particles, the electric charge which they carry, and the velocity with which they travel have been measured. These particles may be called electric points, or electric point charges, and it is found that their mass is not a constant quantity, but that it varies with the speed with which they travel in the tube. As their velocity is increased their mass becomes greater, as it is diminished their mass becomes less; so that their mass is a function of their velocity. They have no mass apart from motion. This being the case, their momentum is also a function of their velocity, as is also their energy, for momentum is the product of mass and velocity and energy the product of mass and the square of the velocity. I spoke about the electrons which whirl around inside the system of the atom with very high velocities, in some cases with nearly the velocity of light. Calculations have been given by Sir J. J. Thomson showing the enormous amount of electronic energy due to the motions of the electrons inside the atomic system. It is found that inside the atoms of one gram of hydrogen gas there is contained an amount of electronic or corpuscular energy, which if set free, would be sufficient to raise one million tons 300 feet high. We know the energy which is liberated in an explosion of dynamite or guncotton. That is atomic energy, caused by what we call chemical affinity. But we see how much greater sub-atomic energy is. Perhaps the day will come when man will know how to set free this sub-atomic energy, but for the present it is probably better that he does not know.

Negative Inequalities.

The ordinary chemical atom, then, seems to be a sort of hole or sink or hollow place in some medium which fills space, and to be a locus or point into which pours tremendous energies from this medium. This hole or sink or hollow place in space which is the locus of the atom is what Reynolds calls a "negative inequality" in the medium, or a "singular surface of misfit" due to a deficiency of grains below the number in the regular normal piling in the sur-

rounding space. He calculates that the real core of the atom consists of the normally piled grains, and that this normally piled core is surrounded by a spherical shell containing a deficiency of grains, the thickness of this spherical shell being probably about five times the diameter of the grain. This spherical shell is surrounded on the outside by the normally piled grains which extend outwards into space indefinitely. Wherever these spherical negative inequalities exist, however, there is set up in the medium surrounding them a system of strains due to the pressure of the medium, which result in producing a curvature in the normal piling of the medium.

I will now try to show how the motion of these negative inequalities which we call matter is possible in such a medium, and how these negative inequalities gravitate toward each other through the medium according to the law of gravitation. How does matter move through space? How does the earth move through space at the rate of nearly 20 miles per second? Reynolds' solution of the problem is very interesting. It moves by propagation. He compares it to a bubble rising in water. He says: "* * * it follows as two negative centers approach each other under their mutual attractions the mass in the medium recedes, which is an inversion of the preconceived ideas. Such action however is not outside experience, since every bubble which ascends from the bottom of a glass of soda water involves the same action. The matter in the bubble having the density of air requires the descent of an equal volume of water at a density 800 times greater than that of air. It is the negative inequality in the density of matter, which under the varying pressure of the water causes the negative or downward displacement of the material medium—water and the positive or upward displacement of the negative inequality in the density within the singular surface."

Propagation of "Matter" Through Space.

I have here a dozen billiard balls, divided into two rows of half a dozen each close together, one row a little higher than the other and resting in a continuous groove, so the upper ones may run down and strike the lower ones. There is a gap of say 18 inches between the two rows. We allow the upper six balls to run down and strike the end of the lower six one by one. The result will be that as each ball from the upper row strikes the end ball of the lower row the ball at the far end of the lower row will run away from the lower row the moment of the impact of the ball from the upper row, and it will run away with the same speed as the speed of the impinging ball which strikes the front end. In other words, all the motion or momentum of the striking ball will be communicated through the whole row of lower balls instantaneously and will be delivered to the last ball, which will carry away the motion or momentum. Meantime, as each ball runs away from the rear end and one comes in in front the whole six balls have run down and taken up their positions in front, delivering their momentum to the lower row, the whole row of lower balls will have moved forward its entire length, or six diameters. This illustrates how positive and negative momentum may move through a body at the same time in opposite directions, for as

each ball strikes the front end it communicates a certain amount of positive momentum to the mass as a whole, which travels through the mass in a positive direction, and an equal amount of momentum travels through the mass in an opposite, or negative direction, which results in the motion in the opposite direction of the mass as a whole. The real motion of the mass is in the opposite direction to that of the impinging balls. If the balls moved quick enough the eye would lead us to suppose that the motion of the lower row of balls was continuous, and not done by successive impacts, just as in moving pictures which appear to represent a continuous scene, but which we know is made up of a multitude of separate scenes taken in rapid succession. We may take the gap between the two rows of balls to represent the inequality which is to propagate through the medium, for instance the earth moving through space. There is an incoming of grains in front and a leaving of grains in the rear, the momentum of the incoming grains being transmitted instantaneously throughout the whole mass from front to rear, the real mass of the medium moving in the opposite direction to that of the inequality. Reynolds says: "If the medium is stationary and the molecules are moving with the earth the grains within the surfaces do not partake of the mean motion of these surfaces, being replaced continuously by other grains by the action of propagation, by which the singular surfaces in their motion are continually absorbing the grains in front and leaving those behind without any mean effect on the motion of the grains. And thus there is perfect freedom of the molecules or aggregate matter, although the grains which constitute the nuclei are changing at the rate of 20 miles a second. To be standing on a floor that is running away at a rate of 20 miles a second without being conscious of any motion is our continual experience, but to realize that such is the case is certainly a tax on the imagination. Such motion has all the character of a wave in the medium, and that is what the singular surfaces which we call matter are—waves. We are all waves."

Cause of Gravitation.

We now come to what is really the most important part of our subject, namely, the cause of gravitation, and if you have been able to comprehend what has already been stated, I think you will have no trouble in understanding what is now to be explained, that is, why two bodies or masses of matter in space may approach each other according to the Newtonian law of gravitation.

In the first place we must rid our minds of the idea that there is any such thing as "attraction" inherent in masses of matter themselves. Though in popular language we speak about the sun attracting the earth, the earth attracting the moon, etc., in reality they do not attract each other. All motions are really produced by pressure of some kind or other exerted upon the bodies which move. Air currents, ocean currents, the tides, as well as movements of rigid bodies are produced by pressure exerted in some way, and the gravitation or motion of bodies in universal space is no exception to this. Reynolds shows that wherever these "negative inequalities" or "singular surfaces of misfit" which we have seen to be matter, exist, there we have

a sort of gap or crack in the granular medium, which forms a surface of weakness, and it is shown that the pressure of the medium is less between these "negative inequalities" or surfaces of weakness than it is on the outside. There is a strain set up in the granular medium in normal piling between them, which produces a curvature in the normal piling. This produces space variations or dilatations between the grains in the curved normal piling. These spaces vary according to the degree of the curve, and the total of the enlarged spaces or dilatations so produced by the curvature is exactly equal to the total of the spaces from which the grains are absent in the negative inequalities which produce the curve. Owing to this, as has been said, the pressure of the medium is less between the negative inequalities or masses of matter than it is in the medium outside, with the result that the extra outside pressure drives the negative inequalities together. The old physics calls this "space variation of the potential." As the bodies approach the curvature is annihilated and the medium is restored to the regular normal piling.

It is somewhat difficult at first for one to understand this process; but the dynamical reasoning upon which it is based is thoroughly sound. Reynolds says: "This law of attraction, which satisfies all the conditions of gravitation, is now shown by definite analysis to result from negative local inequalities in an otherwise uniform granular medium under a mean pressure equal in all directions, as a consequence of the property of dilatancy in such media when the grains are so close that there is no diffusion and infinite relative motion and further it is shown to be the only attraction which satisfies the conditions of gravitation in a purely mechanical system."

"Gravitation is not the result of that dilatation which results from uniform *parallel* strains in the medium in normal piling, but results solely from those components of the dilatations caused by the *space variation of the inward strains.*

"Thus, as long as the dilatation strains are parallel there is no attraction; but if there is curvature in the strains there will be efforts, proportional to the inverse square of the distance, to cause the negative inequalities to approach from a finite distance.

"Thus gravitation is the rsult of those components of the dilatations (taken to a first approximation) which are caused by the variations of the components of the inward strains, caused by curvature in the normal piling of the medium.

"The other components of the strains, being parallel distortions, which satisfy the conditions of geometrical similarity, do not affect the efforts.

"Then, since if the grains were indefinitely small, while the curvature in the normal piling was finite, there would be no effort. And multiplying this parameter by the curvature of the medium, and again by the mean pressure of the medium, the product measures the intensity of the efforts to approach.

"The dilatation diminishes as the centres of the negative inequalities approach, and work is done by the pressure outside the singular

surfaces, to bring the singular surfaces of the negative inequalities together.

."The efforts to cause the approach of the centers correspond exactly to the gravitation of matter if matter represents the absence of mass, and thus the inversion of preconceived ideas is complete. Matter is measured by the absence of mass necessary to complete the normal piling. And the effort to bring the negative inequalities together is also an effort on the mass to recede; and since the actions are those of positive pressure, there is no attraction involved, the efforts being the result of the virtual diminution of the pressures inwards, and in this inversion we have a complete, quantitative, purely mechanical explanation of the cause of gravitation.

"The mechanical actions on which this attraction depends are completely exposed in the foregoing analysis, and offer a complete explanation of the cause of gravitation."

Positive Inequalities.

In addition to their being "negative inequalities" in the medium or places where there is an absence of grains, there may be places where there are a greater number of grains than exists in the normal piling, and such places are called "positive inequalities" in the medium. In these cases the curvature which will exist in the normal piling between two "positive inequalities" will be the reverse of the curvature in the case of two negative inequalities, producing a repulsion between two such positive centers, which will drive such positive inequalities or centers away from each other, just the opposite of gravitational attraction. There would, therefore, be no evidence in the universe of such positive inequalities, as through the force of repulsion they would be scattered to the remote regions of the universe.

Other Phenomena Explained.

What is electricity? Reynolds explains that electricity is due to what he calls a "complex inequality." That is, a certain cluster of grains may be by some means moved from one position in space to another, and a current of electricity is a flowing back of these grains to their former positions. Calculations are given to show that the efforts to revert in the case of such complex inequalities correspond to electricity.

Magnetism is due to rotational stresses in the medium between spherical clusters and surrounding grains, the stresses being opposite ways round in different portions. The strains accompanying these rotational stresses involve dilatation, and attractions and repulsions will be exhibited.

The theory also explains other physical phenomena, such as cohesion, light, heat, aberration, refraction and polarization of light, the association and dis-sociation of molecules, the dispersion of the spectrum, and other natural phenomena. Reynolds says: "Considering that not one of these phenomena had perviously received a mechanical explanation it appears how indefinitely small must be

the probability that there should be another structure of the universe which would satisfy the same evidence."

Steps Taken By Reynolds.

Some may ask, if Reynolds' theory is such a great one why is it that we do not hear more about it? Also what does the scientific world think of the theory? In answer to the first question I may say that there has scarcely yet been time since the publication of Reynolds' work for the theory to become known. The "Sub-mechanics of the Universe" was published in 1903, but the mathematical difficulties of the work are so great, that few are able to grasp the proofs. Neither are all the proofs of the theory in this work. The final theory is the result of five successive steps or discoveries. These steps or discoveries were made, as Reynolds says, "apart from any idea that they would be steps towards the mechanical solution of the problem of the universe." These steps and discoveries are to be found in Volumes I. and II. of Reynolds' Scientific Papers. The first of these steps was taken in 1874, the second in 1879, the third in 1883, the fourth in 1885, and the fifth in 1895. Each deals with a particular physical problem, and taken altogether they form the base on which the great superstructure, "The Sub-mechanics of the Universe" is built. I append to this lecture the names of the subjects dealt with in the five successive steps referred to. So it need not be a matter of surprise that more is not heard of the theory yet.

Solved By A Paradox.

In addition to this the ideas which flow from the theory seem at first strange to our minds and to our preconceived ideas, and it is only by rational analysis that we can arrive at the conceptions which the theory contains. The solution of the problem of gravitation seems to be solved by a paradox. Yet this should not deter us from attacking it. The history of science rather proves that every intellectual advance realizes a paradoxical opinion, and that "intellectual development may be traced to the successive discomfitures of common sence." Who ever believes progress to be as certain in the future as it has been in the past, must admit, *a priori* the existence of phenomena which conflict with what we know at present, and from the fact that man's knowledge about the world has received continual additions, it immediately follows that to *every time* other truths are given than those hitherto demonstrable. Every generation has supposed that it stood on the apex of the pyramid, and has supposed all phenomena of nature to be deducible from just those laws known to it, so that all future generations had the mere subordinate task of dragging new stones on to a structure of which the architectural conception was complete. But true progress is not extensive but vertical, and so it has always been such investigators as were free from this prejudice who have been destined to make revolutionary discoveries.

The history of knowledge is like the development of a mine. When the ore has been worked out down to one level a new level must

be started deeper down. The ore on one level will only last a certain time, and if we would keep enlarging the mine the explorations must go to deeper levels. In like manner in the history of science we find that science reaches a certain stage under the domination of some reigning method or idea, and that it is then unable to go any further until a new discovery is made, or until the mine of knowledge is tapped, as it were at a deeper level. This gives science a new impulse and new ideas and knowledge flow from such discovery. Such for instance were the great discoveries of Copernicus and Newton, and I think that Reynolds' theory of the cause of gravitation is destined to be another epoch making discovery. It is an inversion of ideas hitherto conceived as to matter and mass, from which will probably flow a series of wonderful discoveries as to the true mechanism of the universe in which we live.

Reynolds' explanation of the motion of matter through space is in itself a new and most wonderful conception. It takes place by propagation. Propagation means generation, renewal. The motion of the earth through space is not a *bodily translation*, but the movement of a form or wave having the shape of the earth, by means of an exchange of momentum between the cosmic grains on opposite sides of the surface, just as the gap between the two rows of balls in the experiment which you saw, moves forward as the balls pass across from one surface to the opposite one. The gap between the two rows of balls is the "negative inequality," which we call "matter." Reynolds puts it: "Thus it is that the inequality in density, the integral of which is the volume of the grains, the replacement of which would restore the uniformity of the medium, obliterating the inequality, constitutes the mass propagated. And as this, for a negative centre is negative, its propagation requires the displacement of an equivalent positive mass in the opposite direction to that of propagation of the negative inequality." This is the supreme paradox of the whole theory, and leads to an inversion of ideas as to the structure of the universe. It would strike us as chimerical were it not established by sound mathematical and dynamical investigation. Remember also the statement of Sir J. J. Thomson, arrived at from another line of investigation that "all mass is mass of the ether, all momentum, momentum of the ether, and all kinetic energy kinetic energy of the ether. This view, it should be said, requires the density of the ether to be immensely greater than that of any known substance."

From these new views and conceptions I look for great developments in philosophy in the near future.

Notices of the Theory.

In regard to the scientific world, the theory has scarcely as yet entered the stage of criticism. There have been some notices of the theory in England. The "Sub-mechanics of the Universe" was published in 1903. Whetham in his "Recent Development of Physical Science" published recently, referring to Reynolds' work, says: "The mathematical analysis by which these deductions are established is attempt will stand the criticisms that will be directed against it; but very complex and difficult, and it is yet too soon to say if this bold

Professor Osborne Reynolds' great reputation and the twenty years he has labored at this research will ensure for it a careful consideration from those competent to judge of its merits."

Professor J. D. Everett, at the end of an article on "Normal Piling" published in the Philosophical Magazine, says: "I have not made any attempt to verify the elaborate statistical calculations with which Professor Reynolds' paper abounds. My present purpose is not controversy but explanation, and the style of the paper is so exceedingly technical that a good deal of explanation seems to be necessary before an intelligent controversy can begin. I have chiefly aimed at an explanation of the geometrical conditions which underlie the system supposed, thereby clearing the way for more searching criticism, and helping towards the working out of the very fruitful suggestions which the theory contains."

Professor G. H. Bryan, in a review of Reynolds' work in "Nature" concludes by saying: "It may safely be described as one of the most remarkable attempts that have been made in recent years to formulate a dynamical system of accounting for all the physical phenomena at present known. A theory such as is here set forth may not improbably play the same part in modern science that was assumed by the atomic theory and the kinetic theory of gases in the science of the time when these theories were propounded. It may be confidently anticipated that Professor Osborne Reynolds' granular medium will play an important part in the physics of the future."

Influence on Philosophy.

What will be the influence of Reynolds' theory on philosophy? So far as this is concerned I think it is destined to play a very important part in philosophy. Previous systems of philosophy have been very ignorant as to the structure of the universe. They have been composed mostly of metaphysical guesswork. Philosophy requires the aid of positive science to explain the fundamental arrangement of the universe; and hitherto no medium has ever been suggested which would cause a statistical force of attraction between two bodies at a dinstance. The explanation of gravitation as enunciated by Reynolds carries with it probably the greatest scientific conception that has ever entered the mind of man, and any philosophy of the future which has any pretentions to arrive at the truth must take Reynolds' theory into consideration. Notwithstanding all the great systems of philosophy which have been spun from the brain of man throughout the ages, not one of them has been able to explain the simplest and most familiar phenomenon, viz., the fall of a stone to the ground. Ever since man has been upon the earth he has seen the phenomena caused by gravitation. He has seen the avalanche hurtling down the mountain side, the rivers rolling onward to the sea, and countless other phenomena caused by gravity which happened daily before his eyes. To the astronomer every movement of the heavenly bodies is caused by gravity; the geologist has constantly before his eyes evidences of its action in the formation of the earth, and the physiologist sees its action in the structure of our bodies; in short, there is not a single department of nature where gravity has not

played a most important role. It is the most universal agent known. And, notwithstanding all this does it not seem strange that its cause has remained unknown until now? Yet, this need not surprise us; for the predominant characteristic of man is, and has always been his ignorance of the things concerning himself and nature around him. Taking the history of mankind as extending over several thousand years at least, we may say that it was only yesterday that he learned that his blood circulated in his body, that the atmosphere had weight, and that the earth went round the sun. With the liberation of man's mind through the aid of science he is now beginning to realize something of his own possibilities, and to cast a prophetic eye towards the future, which holds within its womb possibilities for him yet undreamed of, as the fruit of his knowledge. Man's mind is not yet exhausted. It is only beginning its career of conquest over nature.

Dr. Carl Barus in his "Progress of Physics in the Nineteenth Century" remarks: "Just as the 19th century began with dynamics and closed with electricity, so the 20th century begins anew with dynamics to reach a goal, the magnitude of which the human mind can only await with awe."

March 8, 1910.

List of the Steps Which Led Reynolds to the Discovery of Gravitation.

1. On the Extent and Action of the Heating Surface of Steam Boilers. Pages 81-85, Vol. I. Papers on Mechanical and Physical Subjects. 1874-5.
2. On Certain Dimensional Properties of Matter in the Gaseous State. Pages 257-390. Vol. I., Papers on Mechanical and Physical Subjects. 1879.
3. On the Equations of Motion and the Boundary Conditions for Viscous Fluids. Pages 132-137. Vol. II., Papers on Mechanical and Physical Subjects. 1883.
4. Experiments showing Dilatancy, a Property of Granular Material, possibly conected with Gravitation. Pages 217-227, Vol. II., Papers on Mechanical and Physical Subjects. 1886.

   On the Dilatancy of Media Composed of Rigid Particles in Contact. With Experimental Illustrations. Pages 203-216. Vol. II., as above. 1885.
5. On the Dynamical Theory of Incompressible Viscous Fluids and the Determination of the Criterion. Pages 535-577, Vol. II. Papers on Mechanical and Physical Subjects. 1895.
   —*Cambridge University Press, London.*

Relation of Full Space to Empty Space in Different Pilings of Round Particles.

		Space of Volume.	Full Space.	Empty Space.
1.	Vertical Position	100	52.381	47.619
2.	First Triangular Position.....	100	59.864	40.136
3.	Second " "	100	69.841	30.159
4.	Third " "	100	79.818	20.182
5.	Fixed Pyramidal "	100	72.877	27.123
6	Fixed Quadrilateral "	100	74.830	25.170