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THE STRUCTURE OF THE UNIVERSE[1]

The phrase, "the structure of the universe," is apt to bring to mind only the great and majestic forms which are revealed to us by the telescope, the stars, nebulæ and galaxies. In the present discussion however I wish to include in one view the entire range of physical things from the infinitesimal to the infinite; for to the mathematician there is no such thing as absolute size—a thing is either large or small only by comparison.

Up to the present time we have succeeded in extending our vision equally, so to speak, in both directions. We find ourselves almost midway in a series of physical units. On the one side we have the electrons, atoms and molecules, and on the other we have the ordinary masses, stars and galaxies. The galaxies are more or less definite aggregations of stars. The stars are amazingly great organizations of hot gases. The gases in turn are resolved into their constituent molecules; the molecules yield up their atoms, and finally we find that the atoms are built up of two kinds of electrons. Each physical unit is analyzed into units of the next lower order, and synthesized into those of the next higher order. Each unit is an organization endowed with the proper amount of energy to carry on its existence and to insure its identity.

Our direct vision is bounded on the one side by the electrons and on the other side by the galaxies. But the common properties of energy and organization lead us naturally to imagine that the electrons in their turn are organizations of still smaller units, let us call them sub-electrons; and the sub-electrons are organizations of still smaller units, and so on, ad infinitum. Turning to the other end of the series we can fancy that there are organ-

[1] Read before the Chicago chapter of the Sigma Xi, March 11, 1920.

izations of galaxies, say super-galaxies, and still higher organizations of super-galaxies, and so on without limit. To be sure this is mere speculation and rests upon no direct physical evidence. But let us not forget that even in the days when the atom was our smallest physical unit there were many men who refused to regard it as such upon grounds which were purely metaphysical. The mere fact that the physicists have been able to take one more step down the series by conquering the extraordinary experimental difficulties, and that the astronomers in their turn are beginning to perceive in the spiral nebulæ other galaxies than our own is quite encouraging to the purely metaphysical notion that the series of physical units is an unending one, without bottom and without top.

Thus we have a conception of an infinite, three-dimensional continuum of space about which we can move at will, at least within certain limits; a conception of an infinite one-dimensional continuum of time through which we move always in one direction, without choice on our part; and finally, a conception of an infinite one-dimensional series of physical units in which our position is fixed—it is only in thought that we can move along this series. If to these we add energy and consciousness, neither of which admit the notion of dimensions, we have perhaps exhausted the catagory of fundamental conceptions.

The physicists and astronomers have nothing to do with consciousness objectly. They are interested only in the conceptions of space, time, the series of physical units, and energy. In particular, they are interested in the properties of the physical units, the nature of their wonderful organizations and the flow of energy which is associated with them. The astronomers, fortunately, are able to furnish us with photographs of the objects with which they deal, so that we are able to study them more or less thoroughly one at a time. No two of the galaxies are alike in detail although in their broad outlines there are striking similarities. The globular cluster is one type of organization of which we have some eighty specimens, and the spiral cluster is another, and of these we have some hundreds of thousands.

Descending from the galaxies to the stars we are unable to make out the structural details notwithstanding their vast size, owing to their still more vast remoteness. Only one specimen, our own sun, is sufficiently friendly to submit to anything like a close inspection. Nevertheless a classification of the stars according to their colors and their types of spectra is entirely possible. Thus the inherently brilliant white Orion-type stars have continuous spectra, save for a few broad lines of absorption due to helium and hydrogen, with a complete absence of the metallic lines. The brightest part of the spectrum is in the violet. Then come the stars of the solar type with the yellow as the brightest part of the spectrum, with many lines of hydrogen and the metals. Then the orange stars with metallic lines and absorption bands due to chemical compounds. Finally, the deep red stars with heavy absorption bands due to carbon compounds. The individualities of the stars, however, are preserved for no two of the spectra are exactly alike.

Nothing need be said with respect to ordinary masses, for they are matters of our everyday experience. No two leaves even from the same tree are exactly alike. But when we descend to the stage of the molecules the situation is very different. The physicists have not yet given us any photographs of them to study, and no one can say that he has ever seen a molecule. Their numbers are so amazingly great that an individual study of them is quite out of the question. Nevertheless, as the chemists assure us, classification is quite possible, and their variety is astonishingly great. But when we study the properties of even a single variety and attempt to work out their structural organizations we must not forget that it is only the properties common to large numbers which stand out and characterize the variety. If the human race could be studied only through the statistics of population, we might arrive at the conclusion that the Chinese are a variety of the human race, but that one Chinaman was just like another. Analogy would lead us to doubt whether all the molecules even of water are alike. Could they be examined individually and in detail, marked differences would probably be found.

The case is similar with respect to the atoms, although the number of varieties of atoms seems to be limited while the number of varieties of molecules does not. Our information with respect to atoms is largely statistical. But even so, the chemists are recognizing the isotopes of the various elements, and certainly two varieties of lead are now known where previously we had but one; illustrating beautifully the principle that differences and individuality tend to grow with increasing acquaintance.

When we descend one more step in the scale of the physical units and reach the electrons, we are so remote from our own position in the scale and our acquaintance with these units is so far from being intimate that it is not surprising that we regard all positive electrons as being alike, and all negative electrons as being alike. We seem to have reached that ultimate simplicity for which the mind is always seeking. Nor is our information with respect to the electron entirely statistical, for Millikan has performed the amazing feat of measuring their electrical charges one at a time, and finds that in this respect they actually are measurably alike. So far then as we think of the electron as possessing the single property of the electrical charge we are justified in assuming that they are all alike. The human mind, however, is incurably speculative, and few of us, I fancy, would be willing to admit that this is their only property, or that the electrons really are all identical, or that the electron is not still further resolvable into smaller units.

Since the beginning of the present century the physicists have been very busy with the atom. The phenomena of radioactivity and of the X-rays have led them along a brilliantly lighted path in their exploration of its interior, and they have supplied us with verbal pictures of considerable clearness. The electrical charge of a positive electron is numerically equal to the electrical charge of a negative electron, but its mass is nearly two thousand times greater while its diameter is only one two-thousandths as great. If we could apply the ordinary notions of density to these statements we should have to say that the density of a positive electron is ten million million times the density of a negative electron, although its electrical charge is equal. But the ordinary notions of density perhaps do not apply.

If we accept the picture that a hydrogen atom consists of a negative electron moving in a circular orbit about a positive electron, we have so far as relative sizes and distances are concerned a veritable planetary system, except that the diameter of the satellite is two thousand times the diameter of the primary, for their distances apart are relatively as great as between the sun and Neptune. The nucleus of a helium atom has two free positive electrical charges and two negative satellites; lithium has three, and so on; there is a chemical element for each integral multiple up to 92 which belongs to the element uranium, with perhaps a half dozen gaps in the entire series; and furthermore, there is no chemical element which does not fit into the series. We have therefore a complete ordering of the chemical elements upon a purely numerical basis, which makes intelligible the periodic law of these elements which has been long known by the chemists on the basis of their chemical properties.

Notwithstanding the brilliant achievements of the physicists in their work with the atom their analysis is by no means completed. Many fascinating questions remain to be answered. For example, are all of the elements merely hydrogen atoms locked together in a very tight embrace, and if so will a sufficiently violent bombardment separate them? Rutherford's success in obtaining hydrogen from nitrogen by a bombardment with α-particles is certainly suggestive. If the answer is to be in the affirmative, what is the nature of this embrace? How do the electrons, positive and negative, arrange themselves?

How are the lines in the spectrum to be accounted for? And how does an atom radiate energy, anyway? It is a delightful situation for the mathematical physicist to face, for he has already achieved a very solid foothold, and we may be sure he will not be slow to push his advantage.

If the private affairs of the atom belong to the domain of the physicist, their social affairs belong to the chemist. And what tremendously social creatures they are! Few of them are content to live by themselves. The vast majority of them cling more or less tenaciously to other atoms or groups of atoms, and these groups are the chemists' molecules, the smallest particles of what we call ordinary matter. This grouping is not a mere random affair. The atoms exhibit a distinct choice not only as to their associates but as to the manner in which they will associate together.

Just as the physicist has his problems as to the structure of the atoms so the analytical chemist is busy breaking up the almost infinite variety of molecules he finds about him to learn what atoms enter into their structure and what are the relations which exist between those atoms. In this endeavor he has been highly successful and the great majority of molecules he can read as an open book, but the subtile strain of carbon molecules will doubtless tax his ingenuity for a long time to come. On the other hand, the synthetic chemist is slowly learning how to coax the atoms into those particular groups which either his theory tells him are possible or for which nature herself has already furnished an example. In the domain of ordinary masses the architect and engineer, the painter and sculptor and the skilled artisans of a thousand varieties have learned how to build up their structures to suit their various purposes. But the physicists have not yet dreamed of building up an electron nor an atom. The biologists have little hope of ever constructing a living organism. The geologists are content to examine their rocks and to make the past live again in their vision; while the astronomers in the very nature of things must maintain a respectful distance from the objects which engage their interest. Outside the domain of ordinary masses it is the synthetic chemist alone who can engage in the process of physical construction, the building up of those units which are the object of their study. The world is very greatly their debtor to-day, and this debt will increase enormously as the chemists rise higher and higher in their ability to control the groupings of the atoms in the molecules.

Our greatest familiarity and closest intimacy with nature naturally lies in that portion of the scale of physical units to which we ourselves belong, viz: ordinary masses. It is here that the geologists and biologists are at home. But so infinitely varied is the aspect here presented to us that these sciences divide and subdivide in their study of particular phases of things that we seem to have a whole host of sciences. To geology belong such sciences as meteorology, geography, paleontology, and mineralogy. Biology divides into the two great branches, zoology and botany, and these two branches subdivide and split up very much like the cells, about which they are so fond of talking, until one is actually lost in their numbers. Resting securely above these, at least so far as complexity of their phenomena is concerned, are the psychologists and sociologists.

Would an inhabitant of an atom, supposing him to be as small relatively as we are to the earth, find the world about him as complicated and varied as we find ours to be? Would he require a thousand and one different sciences, of which we do not even dream, in order to interpret what was going on about him and adapt things to his use as we are doing? Fortunately science does not have to answer, for there is no evidence. Science always turns away disdainfully when there is no evidence, and rightly so. It is none of her affair. But the same human being, if he is a scientist, is also a philosopher and a speculator. Perhaps he is a scientist because he is a philosopher and a speculator. At any rate, we can not but be impressed with the richness and luxuriance of our own field of units when we compare it with the poverty with which our mental pictures endow the other fields; and so far as I am concerned, at least, I am willing to admit that this striking contrast is a fair measure of our ignorance with respect to what is going on in these other fields.

Turning our eyes upward towards the sky we see the friendly stars, for they seem friendly to one who cultivates their acquaintance. Symbols, they are, of permanence and stability for they maintain their light and their positions unchanged century after century. In order to gauge their distances we have only to imagine our sun moved far enough away that its light is reduced to that of ordinary starlight. Our imaginations are utterly impotent to grasp the ninety-three millions of miles which separate us from the sun, but this distance, great as it is, must be taken three hundred thousand times to bring us even to the nearest star; and even this prodigious distance is less than the average distance between the stars. It is hard to appreciate the vastness of astronomical space. If two unlike things can be compared, we might say that the vastness of astronomical space is comparable with the vastness of the number of atoms. Imagine, if you please, fifty millions of atoms placed side by side. Their total span would be one centimeter. Imagine then the number of atoms in a cubic centimeter of water. It is something like 3×10^{22}. Think then of the number of atoms in the ocean, or in the entire earth; or worse still, in the entire solar system. It turns out that there are something like 6×10^{55} atoms in the entire solar system. But if we give to the sun its fair share of the empty space about it, about twenty cubic parsecs, we can say that the sun's share of space is 6×10^{56} cubic centimeters; so that if all the atoms in the solar system were uniformly distributed throughout the sun's share of space there would be ten cubic centimeters of space for each atom, and relative to their respective sizes the distances between the atoms would be just about the same as the distance between the stars. Under these conditions the inhabitants of an electron would have much the same problem in determining the ordinary properties of matter that we have in determining the collective properties of the stars.

In the process of extending our conceptions of space the astronomers have been magnificently in the lead. In the extension of our conceptions of time, however, they have allowed the geologists to take the lead, although, even without any specific evidence, one would be willing to admit that astronomic time must exceed geologic time as greatly as astronomic space exceeds geologic space. As would be expected direct evidence is very hard to get, as the three hundred years since the invention of the telescope, and the two hundred years since exact observations in the modern sense of the word began, is far too short an interval for much change to have occurred. The proper motion of the great majority of the stars is less than one second of arc in a century. In a million years these motions will be less than three degrees; and motions of this magnitude occur in the field of ordinary masses in about one second. On this basis one second would correspond with a million years, and the three score years and ten of human existence would correspond to over two million billion years. In our conceptions of ordinary time we have risen to a point where a human lifetime seems short. Shall we ever attain a viewpoint where the corresponding astronomical period seems short?

Just as in the kinetic theory of gases the collisions of the molecules are the important events from a dynamical point of view, so in our galaxy of stars the close approach of two stars is dynamically an event of fundamental importance. An approach as close as the earth is to the sun would be a close approach, and for any one star such a close approach may be expected once in four million billion years, or a little more than the corresponding lifetime. The importance of these close approaches will be appreciated if it is borne in mind that it is the only method which we know by which a star could be destroyed so that its identity would be lost; for, notwithstanding the temporary stars, internal explosions scattering the remains beyond the possibility of a gravitational reassembling is unbelievable, and a slow evaporation would eventually reduce a star to an ordinary mass. The geologists give the earth five hundred million years or more in substantially its present condition so that if it is slowly evaporating the time required for it to completely disappear would be at least of the order of magnitude which we have just been discussing. Such evidence as we have, however, indicates that the earth is growing rather than diminishing. From the viewpoint of our galaxy, a million billion (10^{15}) years would seem to be a reasonable unit of time.

Once in a very long time a star through a series of unfortunate encounters with other stars will acquire so high a velocity that it will escape from our galaxy altogether, and like the lost Pleiad, wander hopelessly through the ages in search of its sister stars; but very many of our astronomical time units will have elapsed before this process could sensibly diminish the number of stars in the galaxy. Whether or not the galaxy is already very old as some of us think, or whether it is relatively young as is thought by others, it seems to be fairly clear that in the course of time, at least, it will be very old even as measured in our very lengthy time units. As we muse upon this certainty we wonder whether the light of the stars will go out; or will they continue to shine in the remote ages to come.

In the past a very great restraint has been placed upon our vision by the gravitational hypothesis as to the source of a star's energy. According to this hypothesis the gravitational potential energy of the star is converted into the energy of heat and light and radiated away. The entire life of our sun, at its present rate of living, could not possibly exceed fifty millions of years, and there is a similar restriction upon all of the other stars. Under no reasonable assumptions as to the rate of expenditure could the period be extended to more than a few hundred millions of years. At the expiration of this period the star becomes a cold and solid body and remains such until its very existence is snuffed out in some great catastrophe. It is much the same as though a child were intellectually bright for one, or two, or perhaps five minutes near the beginning of its life, and then all the rest of its existence was spent in mental darkness; and this was true, not as an accident, but as a regular thing.

The discovery of the subatomic energies, as manifested in the radioactive processes, some twenty years ago has helped the situation somewhat, lengthening the period of a star's brilliancy two, three, five, perhaps ten times, but that is all. The dismal picture remains, notwithstanding the protests of the geologists and the biologists, and the absolute failure of the astronomers to find any evidences of these cold and solid bodies and dead galaxies, which should be vastly more numerous than the live ones. But if the results are still unsatisfactory the discovery and exploration of the subatomic world has at least relieved us of a dogmatism which could say, and once did say, "You have so much time for your evolution. and no more." It has opened our eyes to the perception of new things, and awakened our minds to new possibilities for which direct physical evidence is still wanting.

The doctrine of the conservation of energy has been a well established doctrine among all classes of scientists for seventy-five or eighty years. Notwithstanding this, we have allowed the greatest flow of energy with which we are acquainted, the prodigious energy of the stars, to escape into the blackness of space unnoticed and forgotten, quite contrary to that somewhat more hazy doctrine which we call the economy of nature. We simply did not know what to do with it. Suddenly we discover that the atoms are wonderful organizations of energy. The vastness of their numbers, comparable only with the vastness of astronomical space, suggests that their organization is an astronomical matter, for the astronomers alone can furnish energy in sufficient amount and equip a laboratory of sufficient size. That the details of this equipment are unknown need occasion no surprise, but the products of this mighty laboratory are visible upon the sky. Irregular nebulæ of gaseous materials occupying enormous volumes of space are found in abundance there, and much evidence of dark nebulosity against luminous backgrounds. Is it too much to suppose that these nebulæ consist of atoms recently formed in the laboratory of space and beginning to assemble for their careers in the world of matter? This would seem to be the simplest guess, and it is worth considering.

The physicists are inclined to believe that the property of mass is due to the electric charges of the electrons. If now a negative electron should collide and unite with a positive electron the electric charges would disappear, and so also would the property of mass. If the speed of this collision were equal to the velocity of light, which seems probable enough from the known speeds of the electrons then the energy set free is calculable. It is found that one gram of matter passing through such an experience would liberate five billion calories of heat. The unit resulting from this collision would not possess the property of mass, but it would be an organization of some kind. If we suppose that the radiant energy of the stars as it flows through space should succeed in splitting this unit again into two electrons the property of mass would be restored, but a corresponding amount of radiant energy would have disappeared.

So far as I know the physicists have not announced a law that for every positive electron there exists a corresponding negative electron, but the electrical neutrality of matter seems to imply that it is true. If the two kinds of electrons exist as the result of the splitting of a single unit it is easy to see why it should be true, but quite a considerable puzzle otherwise.

It seems almost axiomatic that no organized physical system can endure a condition of unlimited violence without breaking down; and since the atom is such a system it seems inevitable that under suitable conditions it will collapse, and its energy of organization will be set free. The extreme conditions as to temperature and pressure which exist in the interior of a star seem to make this an ideal place for an atom to break down and give up its energy and its property of mass, if such an event is to occur anywhere. Such a process seems almost necessary if we are to account for the energies of the stars over the extended periods of time which the dimensions and forms of the galaxies seem to imply. On such a basis the sun possesses in its present mass a sufficient store of energy to last, at its present rate of radiation, five thousand millions of years. Such a period of time is short from an astronomical point of view, but as the sun travels through space at a speed of about twelve miles per second it must pick up atoms, and molecules, and an occasional solid fragment, and in this way add to its mass. Occasionally it will pass through nebulous regions and add to its mass with relative rapidity. We can suppose that on the whole the sun, and the other stars also, gather in as much energy as they radiate, and the embarrassment arising from their relatively short periods of luminosity and their reckless expenditure of energy disappears.

To an audience of astronomers much could be said in favor of accounting for the sun's heat in this manner, but such evidence would be of but little interest to those who are not astronomers. The main point of interest to them would be that under this hypothesis the geologists and biologists are freed from the restraints as to time, for the astronomers could furnish them with all of the time which they wished. There would be no fixed upper limit to the life of the sun, and the stars in general could continue to illuminate their paths through space for indefinite ages still to come. The haunting fear of a general stellar death is gone and the forbidding picture of the galaxy as a dismal, dreary graveyard of dead stars fades away from our sight; and in its stead we see an indefinite continuation of our present active, living universe with its never-ceasing ebb and flow of energy. Those wonderful organizations which we call the physical units will continue to be built up when the conditions are favorable, pass their allotted time in such activities as are suitable to their nature, and finally yielding up the energy by which they were organized, be resolved again into the elements from which they came. The individual perishes, but the race lives on.

The astronomer with his telescope, the biologist with his microscope, the physicist with his spectroscope, and the mathematician with his logic are all busily engaged in unravelling the mysteries of the structure of the universe. They do not always think of their work in this relation. Ordinarily they will tell you that their work is directed towards the answer to some specific question in a relatively circumscribed field. But eventually the mental pictures which result from this detailed work are integrated into one grand picture of the structure of the universe itself, and all that is trustworthy in this grand picture rests upon the labors of the individual workers in their various fields.

There are certain questions, however, of a very fundamental character which no amount of labor will ever answer, and to these questions we are at liberty to return such answers as happen to please us. In other words, they belong to the domain of esthetics and not to the domain of science; and yet they are so deep and fundamental that all of our scientific pictures rest upon them. For example: Is the physical universe limited in space, or is it not limited? If it is not limited, or infinite as we say, is the portion of it which we see peculiar, or is it fairly representative? Is the epoch of time in which we live a peculiar epoch, or is it a fairly representative one? Is the universe as a whole definitely changing from its present state, or is it a permanent thing, the same yesterday, to-day and forever? I might continue with other and similar questions but there is not time now. You are at liberty to choose your own answers and upon them to rest your interpretation of the universe, or your philosophy.

For myself, I wish to think of the physical universe as infinite—it jars upon my sensibilities to think of it otherwise. I am unwilling to admit that we occupy an essentially peculiar position in either space or time. As for the universe as a whole, it has always been and always will be essentially as it is to-day. It is infinite, eternal and unchangeable.

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THE PAN-PACIFIC SCIENTIFIC CONGRESS AND THE BISHOP MUSEUM OF HAWAII

During the month of August, 1920, a congress will be held at Honolulu to outline the scientific problems of the central and southern Pacific Ocean, and to suggest methods for their solution. Delegates from Australia, New Zealand, the United States, and possibly Japan will take part in the discussions, and will formulate a program of research for future guidance in anthropology, geography, geology, and biology. Also it is hoped to lay a foundation for a greater utilization of the economic resources of the Pacific. The delegates are to be the guests of the Bernice Pauahi Bishop Museum of Polynesian Ethnology and Natural History, situated in the city of Honolulu. It should be noted here that the idea of a wider Pacific exploration was first put forth by this museum in 1906, and that during the past thirty years the museum has been at work on the ethnology and biology of the central Pacific. Its trustees now desire to take up the wider problems of the Pacific—and they are of fundamental importance—in cooperation with other institutions of research. Yale University, as a result of a gift from Mr. Bayard Dominick of $40,000 for scientific exploration in the southern Pacific, is enabled to enter upon thorough cooperation in the plan, and Professor Herbert E. Gregory, of the Yale faculty, is now the director of the Bishop Museum and the leader of the congress. Other institutions which have expressed a desire to cooperate are the National Academy of Sciences, the National Research Council, the U. S. National Museum, the U. S. Coast and Geodetic Survey, the Carnegie Institution of Washington, Harvard University, the American Museum of Natural History, the California Academy of Sciences, and the Scripps Institution for Biological Research.

That the results already accomplished by the Bishop Museum are extensive may be gathered from the following account. Fernão de Magalhães, making his way southwest across the rough Atlantic, was the first to