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THE MEANING OF THE CRYSTAL[1]

By Sir WILLIAM HENRY BRAGG

DIRECTOR OF THE ROYAL INSTITUTION OF GREAT BRITAIN

IN the time which is allotted to me I should like to explain, if my audience will allow, the scope of the work in which, with my son and others, I have been recently engaged. I must first beg to remind you of certain facts. The elements of construction of the universe are the atoms, of ninety-two different kinds. The first constructive step is the assembling of the atoms into molecules. A molecule is a company of atoms in an association, which has some permanence great or small. The number of kinds of molecules is enormous. The water molecules consist of two atoms of hydrogen and one of oxygen. The molecule of ordinary salt contains one atom of chlorine and one of sodium; the molecule of an organic substance is generally more complicated, as, for example, that of naphthalene, which contains ten atoms of carbon and eight of hydrogen. If the atoms are likened to the letters of the alphabet, the molecules must be compared to words.

The next step in nature's architecture is the linking of molecules to form solid substances, such as the subjects which we see around us and ourselves. The properties of all substances depend upon the way the molecules are put together, just as a house, or its interior, has a character and a usefulness, which depend upon its design, or just as the meaning of a sentence depends on the words it contains and on the way they are arranged.

This second step is not always made: the hindrance to its accomplishment is heat. Heat is a mode of motion. When, for example, the molecules of water are set in very rapid motion by imparting sufficient heat to them, the forces that would make them combine are overcome; the molecules exist as independent individuals and we have water vapor or steam. With less heat and less motion the molecules are always in part-

[1] Medal Day address, delivered at the Franklin Institute, Philadelphia, Pa., on May 21.

nership, but always changing partners, and we have water. Still less heat, and the molecules become permanently attached to each other in unchanging positions, and thus ice is formed. Some molecules feel heat more than others, so that at ordinary temperatures some substances are solid, some liquid, and some are gases.

It is the great aim of scientific research to connect the properties of a substance with the design of its construction. Gases have the simplest design, and the laws of gases are fairly well understood. Liquids come next, and we know something of their laws also. In particular we have learned much of what happens when liquids of different kinds are mixed together; we have watched when molecules pull each other to pieces and make molecules of new patterns out of the old. This is the province of science which we call chemistry. The enormous advances in pure and applied science, for which chemistry is responsible, show how great are the results of research even in this limited field.

But when we come to solids we have to admit that we know very little indeed of the way in which their properties depend on their composition. The fact is that their properties depend on the arrangement of the molecules; these now have definite positions, and the pattern of the arrangement is all important. There was very little of this in liquids and none at all in gases. To make headway we must therefore learn the laws of arrangement. Until recently this has not been possible, and we have been unable to enter a field of research which may well turn out to be the richest of all fields. But the X-rays have now opened the door for us; let me briefly explain how.

I must first say a few words about the capacities of our eyes. It is a strange fact that the eyes of men can see only a minute fraction of the things and the happenings that surround them. The light which brings us our knowledge—daylight, artificial light or lamplight—is narrowly limited in quality, and on that account tells us only a small part of the whole tale. We are accustomed to recognize differences in quality. We speak of red, green, blue and indeed of an infinite variety of shades. The student of physics estimates their differences by reference to the standard of wave-lengths, the waves referred to having their being in a hypothetical medium called the ether. He is not quite sure, in these days, of the amount of reality which should be assigned to these waves, but that is of far less importance than it sounds. The ether and its wave-length furnish for us a most useful language in which to express our thought and measurement. It then appears that the length of the ether waves may lie anywhere between very wide limits. In vision we use a minute section of that range. If we had never found any other means of detecting ether waves except our eyes, we might never have known the limits to our knowledge. But now, as I may remind you, we use very long invisible waves for transmission by radio, and, quite frequently, short invisible rays for the purposes of photography.

Now the quality or wave-length of the light determines what we can see by its means. Small details can be made out by short waves, and become less distinct if the light is of longer wave-length. Even within the narrow range of vision this difference can be observed. In certain microscopes used by biologists only light of extremely small wave-length is employed, the smallest that can be brought to bear upon the photographic plate, or the human retina, and in this way the power of the microscope is extended. On the other hand, it is curious to observe what a difficulty there is in picking up details in a red light, although the wave-length is only twice that of the shortest visible blue.

This strange limitation surely prompts our inquiry as to the reason, if one can be given. It is a fact that waves shorter than the visible cannot penetrate the miles of the atmosphere, so that even if our eyes could see them they would have no use for their powers. If our eyes responded to waves much longer than the normal we should certainly miss much detail that we value. Again it is a fact, of an entirely different bearing, that the perception of light depends on a curious process in which electrons are shifted out of their usual positions in the atoms of the retina. Now the shifting cannot be accomplished if the wave-length of the light is more than about a thousand times longer than the diameter of the atom. As atoms of all sorts have sizes which do not differ widely among themselves, a certain limit is set to the light which the eye, as constituted, can detect. The waves must not exceed a certain length. Since the eyes of all creatures are made and act in much the same way, that which is light to one is light to all. Sir John Lubbock thought that ants could see blue light better than red, and I have seen it stated that certain insects do not appreciate light that has come through yellow glass. Whether these are actual facts or not, it is certain that the range of vision is very small. I do not know that any of these considerations answer the question, why? Mathematicians tell us that a ray of light, the emblem of directness, in continuing its way through space will in time return to where it began, and if we seek to distinguish between cause and effect, we are apt, proceeding step by step, to be in much the same case and to find that the last effect is also the first cause.

The consequence of the limitation is a corresponding restriction of the visible world. We are normally unconscious of all but a fraction of our surroundings.

We have tried to extend our powers. We have first made use of the simple lens, then of the microscope, trying by these means to give to our eyes the more extended use of the light waves that can be seen. But to this effort there is a limit. When the optician has done his wonderful best, and when the shortest light waves are used, there is necessarily a halt; and at one time it seemed that the halt must be a permanent stop. But what new worlds, or rather new comprehensions of the old world, have been opened up by these means alone! We are so accustomed now to the new vision that we have forgotten how strange it must have been to the early users of its powers. When Hooke wrote his "Micrographia" in the middle of the seventeenth century he was in a mood of amazement at what the newly invented microscope told him. Section after section of this fascinating book describes the wonderful and hitherto invisible details of common objects—a hair, a piece of silk, a needle point and so forth. No doubt there were those who thought that these incursions into a new world of knowledge were unjustifiable, and what the eye could not see naturally was not worth seeing, and was not intended to be seen. We have learned that these minute things and happenings affect deeply and immediately our health and happiness and our ability to use the resources of nature. And every improvement in the use of ordinary light by the microscope has added to our realization of the infinite and the unity of nature.

But as I have said, where we have made use of ordinary light, we come to a dead stop in this direction. It is here that X-rays, being what they are, furnish us unexpectedly and magnificently with a new range of vision. Consisting of ether waves, in the same sense that light so consists, but being some ten thousand times shorter, they can take note of details which are far finer than light can show us. It is very important to realize that minuteness does not mean insignificance or want of relation to ourselves. The world which they can portray is as full of richness and variety, movement and interest as that which we see normally. It is true that our eyes see none of it, and so it is not associated with the ideas of beauty in form and colors. We cannot thoughtlessly take pleasure in it, as we may in the other. We must grasp what the X-rays tell us by means of delicate and complicated scientific methods, and our admiration and interest are of the mind only.

What sort of things do we now perceive? We see, if I may use the word in a broad sense, that arrangement of atoms and molecules in the solid body, of which we have been so eager to obtain knowledge. We stand in front of nature's architecture and examine her use of the elements in her construction. And here I must speak of a very important matter. We should still be unsuccessful did we not avail ourselves of one of nature's most remarkable characteristics, one which we have not indeed fully appreciated until now. It is her extraordinary tendency to regularity and order. If it were not for this uniformity, even the new rays could not help us. The effect of a single atom upon X-rays is far too small to detect. The effect is there, as it would not be with visible light, but it is insufficient in quality. But nature arranges her atoms in regular order in millions of millions, and the combined effect is big enough to affect our instruments. It is just as when the wind turns over all the leaves of the poplar tree at the same moment and the whole tree appears silvery gray, and so we learn what we could not have observed from the behavior of a single leaf. A more exact analogy is found in certain colorations of nature, in the hues of butterflies, for example, where a regular assemblage of fine scales makes for color, though each scale is too minute to be visible.

We see, for example, the atoms of carbon in the diamond and their perfect alignment according to a simple plan which gives every atom four other atoms as neighbors equally and regularly spaced about the first. We begin to understand how the design gives the diamond its unique hardness. We see the carbon atoms rearranging themselves according to a new plan to make the soft and slippery graphite. We see the atoms of oxygen, which far exceed all others in number, drawn up in regular order like a pile of shot to form the structure of most of the earth, and held together by atoms of silicon, magnesium, aluminum and so forth. The beautiful forms of the crystals of snow and ice are observed to be derived from the underlying and particular arrangement of the oxygen and hydrogen atoms. We begin to understand the details of construction of those long chains of certain atoms which are of such tremendous importance in the construction of living organisms. It is not to be forgotten that chemical investigation has long made us aware of their existence, but now we see, I think it is fair to say, what hitherto we have only inferred. We get a first rough idea of the actual forms of those curious hexagonal rings of carbon (the benzene ring) which are also of first importance to living things, and in other structures are the basis of dyes and many other great classes of compounds. It is indeed the whole range of nature's first compiling of atoms and molecules to form ourselves and the things about us that now opens to our view. Our untrained eyes do not yet interpret all, even a small fraction of what they see. But as results accumulate and workers grow in number and power, so at the same time our interpretation becomes more accurate and effective. There is infinite opportunity for research, first of all in description of what the X-ray reveals, just as Hooke disclosed what the microscope told him, and then the greater and even wider enterprise of connecting the structure of bodies with the properties which they possess. You will understand the fascination of this new field of research.

A MOMENTOUS HOUR AT PANAMA[1]

By Dr. JOHN FRANK STEVENS

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THERE has been published from time to time such a mass of information about the Panama Canal, a project which aroused much controversy a quarter of a century ago, that any reference to it after the lapse of years may seem to be quite superfluous; but as is often the case in human affairs, history does not always record events which have had a profound influence for good or evil upon the solution of the problems involved. The history of the planning and construction of the Panama Canal is no exception to such general rule.

The condition of affairs on the isthmus during a part of the year 1905 can truly be described as desperate; by many well-wishers even it was regarded as hopeless. When the speaker arrived there in July of that year, he found not even the skeleton of a general organization. Supreme authority was vested in no one. The Sanitary Department was the only one having the semblance of a proper organization, and it was doing a limited amount of work under what would probably have proved a fatal handicap had it continued. The usual tropical diseases were prevalent, and that scourge of the white race, yellow fever, was taking its deadly toll daily. While the situation was in some degree psychologic, the danger was great, enough so that unless the disease was promptly checked and thereafter held under control, the success of the great enterprise would be jeopardized.

The tragic story of the French attempt to build a canal there was in many mouths, and predictions were freely made that the history of the Americans on the isthmus would be a repetition of the De Lesseps failure. Under the then existing conditions it would not have been possible to hold the small force of clerical and skilled white labor which had been collected, much less to induce thousands of other whites to enter the service. Especially so in view of the pessimistic attitude which some of the American press had taken, and the exaggerated accounts which they were publishing as to living and health conditions on the isthmus, some influential members openly advocating that the whole undertaking should be abandoned as affording no hope of a successful outcome.

[1] Medal Day address, delivered at the Franklin Institute, Philadelphia, Pa., on May 21.

At that time few of the general public knew anything of the so-called mosquito theory of the transmission of yellow fever, and they mostly regarded it as purely theoretical. Not so with the medical scientists who had successfully demonstrated it in Cuba, and of those scientists was Colonel William C. Gorgas, of the Medical Corps of the Army, who was the head of the Sanitary Department on the isthmus. He was working intelligently with a small but efficient staff, but with an utter lack of cooperation on the part of his immediate superiors. He was one of the first officials that I met there, and from him I gained my real insight into the famous theory.

Of Colonel (later General) Gorgas, his work and supreme service to mankind, it is unnecessary to speak here. His memory is so deeply cherished and his fame is so secure that no words of mine can add to either. Best of all, he was a kindly, sincere man, the highest type of gentleman, and I am proud to have known him, not only officially, but also as a warm friend.

The then chairman of the Isthmian Canal Commission accompanied me on my first visit to the isthmus, remaining there but five days, as the situation did not appeal to him. At that time Colonel Gorgas was reporting to the governor of the Canal Zone. Neither the governor nor the chairman had the least faith in the efficacy of the mosquito theory—at least they so emphatically advised me at once, and their actions confirmed their words.

Quoting from a brochure of General Gorgas's life and activities, written by the president of the American College of Surgeons:

> Finally, in June, 1905, the governor and chief engineer [my predecessor], members of the executive committee of the commission, united in a recommendation to the Secretary of War that the Chief Sanitary Officer (Colonel Gorgas) and those who believed with him in the mosquito theory should be relieved, and men with more practical views be appointed in their stead. They stated that the sanitary authorities had visionary ideas with regard to the cause of yellow fever, and no practical methods even of carrying them into effect.

The President declared his faith in the theory and directed that every possible support and assistance be