HARPER'S MODERN SCIENCE SERIES

CONCERNING THE NATURE OF THINGS

By

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Illustrated with Many Diagrams and Plates

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INTRODUCTION

It may be well to explain to American readers for whom this special edition is published that the Juvenile Lectures of the Royal Institution were first instituted in 1825. At a general meeting of the members in December of that year, the Managers reported "that Mr. Millington had engaged to deliver a set of Lectures on Natural Philosophy, suited to a Juvenile Auditory, during the Christmas recess, to be continued and concluded in those of Easter and Whitsuntide." For some reason the actual delivery of the course was commenced on Christmas, 1826, by J. Wallis on "Astronomy."

In February, 1826,. the Managers reported that "they had consulted with Mr. Faraday on the subject of engaging him to take part in the Juvenile Lectures proposed to be given during the Christmas and Easter recesses. The Managers found it would be exceedingly inconvenient to withdraw Mr. Faraday from his experimental investigations to conduct such lectures." Faraday, however, found time in subsequent years to give no less than nineteen courses of Christmas Lectures. He was extremely interested in the importance of Science Lectures to young people, and his Juvenile Lectures were masterpieces of exposition.

Tyndall gave a number of these courses, and others were given by Dewar, Ball, Fleming, S. P. Thompson, Lodge, Boys, and other well-known lecturers.

It has become a tradition in the Royal Institution that the lectures shall be fully illustrated by experiments, and it has generally been the case that both lectures and experiments have been to some degree novel, in both the matter and the manner of their exposition. The audience consists not only of the juveniles for whom the lectures are primarily intended, but also of seniors who are interested in the attempts to explain new points or show novel illustrations.

I have written this in the hope that those in America who do me the honor of reading this book will sympathize in the problem of exposition which I have tried to solve. The English edition contains a preface which will be found reproduced in the following pages, and will help further to explain the immediate purpose of the lectures. W. B.

LONDON, JANUARY, 1925.

PREFACE TO THE ENGLISH EDITION

It was my endeavor at the Christmas Lectures given at the Royal Institution in 1923-24 to describe certain features of the recent discoveries in physical science. Many of the facts that have come to light might well be the subject of "Lectures adapted to a Juvenile Auditory," and would be at the same time interesting and helpful; interesting because they display a beautiful order in the fundamental arrangement of Nature, and helpful because they have given us light on many old questions, and will surely help us with many that are new.

I was aware of two special difficulties. The first was the difficulty of understanding the minuteness of the scale on which the action and properties of the atoms must be represented; but, after all, this was only a difficulty due to unfamiliarity, and would come to a timely end. The other was the difficulty of grasping arrangements in space. There are some who think that this difficulty is incurable, and that it is due to the want of some special capacity, which only a few possess. I am persuaded that this is not the case: we should have nearly as much difficulty in grasping events in two dimensions as in three were it not that we can so easily illustrate our two-dimensional thoughts by pencil and paper. If one can turn over a model in one's hand, an idea can be seized in a mere fraction of the time that is required to read about it, and a still smaller fraction of the time that is required to prepare the description.

Perhaps some of the readers of this book will be sufficiently interested to make models of the few crystal structures that are mentioned in it, and may even go on to other structures that are described in larger books or in original papers.

I have added somewhat to the lectures as originally given. The additions are intended to make the treatment of the subject a little more complete: they were not very suitable for consideration at the lectures, but are perhaps permissible in the book because the reader can omit them if he desires or read them more than once, or consider them with a model in his hand.

At the end of the book there is a short note on the making of models.

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CONCERNING THE NATURE OF THINGS

CHAPTER I

The Atoms of Which Things Are Made

NEARLY two thousand years ago, Lucretius, the famous Latin poet, wrote his treatise, *De rerum natura*—concerning the nature of things. He maintained the view that air and earth and water and everything else were composed of innumerable small bodies or corpuscles, individually too small to be seen, and all in rapid motion. He tried to show that these suppositions were enough to explain the properties of material things. He was not himself the originator of all the ideas which he set forth in his poem; he was the writer who would explain the views which were held by a certain school, and which he himself believed to be true. There was a rival set of views, according to which, however closely things were looked into, there would be no evidence of structure: however the water in a bowl, let us say, was subdivided into drops and then again into smaller drops and so on and on, the minutest portion would still be like the original bowl of water in all its properties. On the view of Lucretius, if subdivision were carried out sufficiently, one would come at last to the individual corpuscles or *atoms,* the word atom being taken in its original sense, something which *cannot be cut.*

There is a mighty difference between the two views. On the one, there is nothing to be gained by looking into the structure of substances more closely, for however far we go we come to nothing new. On the other view, the nature of things as we know them will depend on the properties of these atoms of which they are composed, and it will be very interesting and important to find out, if we can, what the atoms are like. The latter view turns out to be far nearer the truth than the former; and for that all may be grateful who love to inquire into the ways of Nature.

Lucretius had no conception, however, of atomic theories as they stand now. He did not realize that the atoms can be divided into so many different kinds, and that all the atoms of one kind are alike. That idea is comparatively new: it was explained with great clearness by John Dalton at the beginning of the nineteenth century. It has rendered possible the great advances that chemistry has made in modern times and all the other sciences which depend on chemistry in any degree. It is easy to see why the newer idea has made everything so much simpler. It is because we have to deal with a limited number of sorts only, not with a vast number of different individuals. We should be in despair if we were compelled to study a multitude of different atoms in the composition of a piece of copper, let us say; but when we discover that there is only one kind of atom in a piece of pure copper, and in the whole world not many different kinds, we may feel full of enthusiasm and hope in pressing forward to the study of their properties, and of the laws of their combinations. For, of course, it is in their combinations that their importance lies. The atoms may be compared to the letters of the alphabet, which can be put together in innumerable ways to form words. So the atoms are combined in equal variety to form what are called molecules. We may even push the analogy a little further and say that the association of words into sentences and passages conveying meanings of every kind is like the combination of molecules of all kinds and in all proportions to form structures and materials that have an infinite variety of appearances and properties and can carry what we speak of as life.

The atomic theory of Lucretius did not contain, therefore, the essential idea which was necessary for further growth and progress. It withered away, and the very atom came to be used in a vague, incorrect fashion as meaning merely something very small: as sometimes in Shakespeare's plays, for instance. In another and very different application of "atomic" theory Lucretius was strangely successful. He had the idea that disease was disseminated by minute particles. At the time of the Renaissance Fracastoro was inspired by the atomic theory of infection as he read it in the poem of Lucretius; but after his day the secret of bacteriology was again covered up until it was laid bare by Pasteur.[1]

Let us think of Nature as a builder, making all that we see out of atoms of a limited number of kinds; just as the builder of a house constructs it out of so many different kinds of things—bricks, slates, planks, panes of glass, and so on. There are only about ninety sorts of atoms, and of these a considerable number are only used occasionally. It is very wonderful that all the things in the world and in the universe, as far as we know it, are made of so few elements. The universe is so rich in its variety, the earth and all that rests on it and grows on it, the waters of the seas, the air and the clouds, all living things that move in earth or sea or air, our bodies and every different part of our bodies, the sun and moon and the stars, every single thing is made up of these few kinds of atoms. Yes, one might say, that is so: but if the builder is given bricks and mortar and iron girders he will build you an infinite variety of buildings, palaces or cottages or bridges; why may not Nature do something

[1] See "The Legacy of Rome" (Oxford University Press), p. 270—an article by Dr. Singer.

like that? But one has to think that when a builder sets out to make a structure he has a plan which has cost thought to devise, and he gives instructions to his workmen who are to carry out his wishes, and so the structure grows. We see him walking about with his plans in his hand. But the plans of the structures of Nature are locked up in the atoms themselves. They are full of wonder and mystery, because from them alone and from what they contain grows the infinite variety of the world. How they came to be such treasure-houses we are not asking now. We ask ourselves what these atoms are like: we have been asking the question ever since their exceeding importance began to be realized more than a hundred years ago. Have they size and form and other characteristics such as are possessed by bodies with which we are familiar? We must look into these points.

But first let us realize that in the last twenty-five years or so we have been given, so to speak, new eyes. The discoveries of radioactivity and of X-rays have changed the whole situation: which is indeed the reason for the choice of the subject of these lectures. We can now understand so many things that were dim before; and we see a wonderful new world opening out before us, waiting to be explored. I do not think it is very difficult to reach it or to walk about in it. In fact, the new knowledge, like all sudden revelations of the truth, lights up the ground over which we have been traveling and makes things easy that were difficult before. It is true that the new lines of advance now open lead the way to fresh difficulties: but therein lies the whole interest and spirit of research. We will try to take the first steps into the new country so that we may share in the knowledge that has already come, and comes in faster every day.

We go back to our questions about the atoms. Before the new period set in remarkably accurate answers had already been given to some of them, at least. In this theater of the Royal Institution, Lord Kelvin gave several addresses which dealt with the properties of atoms, and especially with their sizes. By several most ingenious and indirect devices he arrived at conclusions which we are now able to test by accurate methods; and we find that he was remarkably close to the truth. It was, of course, far more difficult to say what was the size of any particular atom than it was to say how much larger one atom was than another. For instance, the sizes of the atoms of potassium and carbon could be roughly compared by taking into account the relative weights of equal volumes of the solid potassium metal and of diamond, which is a form of pure carbon. Potassium is lighter than water, the diamond is three and a half times as heavy. We know from chemical observations that the individual potassium atom is rather more than three times as heavy as the carbon atom. If we suppose that the packing of the atoms in the two cases is the same (as a matter of fact, we now know that it is only approximately so) we must conclude that the atoms in the metal potassium are much larger than the carbon atoms in the diamond, because, though heavier individually, they pack so as to make a lighter material.

To make a reasonable estimate of the actual size of any one atom is a much more difficult matter, but all the four lines of reasoning which Kelvin employed led him to very nearly the same result. "The atoms or molecules of ordinary matter must be something like the 1/10,-

000,000th or from the 1/10,000,000th to the 1/100,000,000th of a centimeter in diameter."[1] Our new methods tell us that the diameter of the carbon atom in diamond is 1.54 hundred-millionths of a centimeter, and that of the atom in the metal potassium is 4.50 hundred-millionths. We see that Lord Kelvin's estimate was wonderfully near the truth, considering the indirect and inexact methods which alone were at his disposal.

In Fig. 1 are shown sections of certain atoms on a scale of fifty millions to one. The inserted figures give in each case the distance, in hundred-millionths of a centimeter, between the centers of two neighboring atoms in the pure substance. For example, the distance between two carbon atoms in the diamond is 1.54 hundred-millionths of a centimeter. In the case of oxygen the diameter has been calculated from the structure of crystals in which oxygen occurs. If the lecture room of the Royal Institution were magnified as much as the atoms of Fig. 1, its height would be greater than the distance from the earth to the moon. We need

[1] From a Friday Evening Discourse before the Royal Institution of Great Britain, March 4th, 1881.