A LECTURE ON "MATTER," INCLUDING "RADIANT MATTER."

BY ALEXANDER E. OUTERBRIDGE, JR.

[*Delivered at the International Electrical Exhibition of the FRANKLIN
INSTITUTE, October 9, 1884.*]

The Chairman of the Committee on Exhibitions introduced the lecturer, stating that, by request of the Committee, Mr. Outerbridge would repeat an address, which he delivered before the INSTITUTE in 1881, adding thereto the results of some of the more recent investigations on the nature of matter. The lecturer, after a few introductory words, spoke as follows :

The ideas which have prevailed in the past, in regard to the nature of the ultimate particles of matter out of which worlds are formed, reveal the speculative tendency, as well as the intellectual status, of the human mind in different epochs of the history of civilization. The present era might very well be designated as an interrogatory age, for is there not an evident tendency to question Nature eagerly, to accept nothing on the evidence of tradition, and but little comparatively on the basis of pure hypothesis ?

Plausible explanations of various phenomena have so often been accepted with confidence, only to be overthrown by others equally unstable, that the mind has become, as it were, suspicious, and demands the most rigid physical tests to corroborate new theories. The experimental feature of scientific study has thus been stimulated until it has attained an importance and perfection never before approached, and this cause largely contributes to popularize even the most abstruse subjects of inquiry. It is one of the little pathways through the intricate mazes of Nature's mysterious realms that we propose to explore together this evening.

The question, "*What is matter ?*" is one that has exercised the intellects of the profoundest thinkers in all ages, and it is, apparently, as far from being definitely answered in this nineteenth century as in the classic days of the Greek philosophers. It would seem, indeed, that the modern views of matter, based upon strictly scientific data and mathematical reasoning, approach in some respects quite closely to those propounded by the Attic

philosophers, which were evolved purely from the inner consciousness of these poetic sages and must be regarded rather as expressions of sentiment than as deductions from observed facts. The poetical fancies of Lucretius, which have been preserved to us in his great work, "*De Rerum Natura*," through a lapse of 2,000 years, may be read with renewed interest in the light of modern scientific thought.

The delicacy of the apparatus devised by modern physicists, and the refinement of experimental research rendered possible thereby, are among the greatest marvels of this wonderful age. The physicist is pushing his researches into paths which but a few years ago were thought to be forever hidden somewhere in the vast realm of the "unknowable," and the boundary line between so-called physical and metaphysical science is continually narrowing; the philosopher has advanced, step by step, until he seems almost to have grasped the ultimate particles which constitute the physical basis of the universe, and to have revealed to mortal eyes particles of matter which are too minute even for the mind's eye to conceive.

Our ideas of size and weight are purely relative, and that which appears a small or light object from one point of view, may become large and heavy by a different comparison. To most of us, perhaps, a "grain weight" suggests a little thing; we know that the apothecary and a few other exact dealers split up the grain into halves, quarters, tenths, and perhaps even hundredths, but we are apt to regard such discriminations as bordering on the fanciful; yet, strange to say, there seems to be a sort of vanishing point in our minds, beyond which, if an object is small enough to pass, it becomes larger and more important in our estimation by reason of our astonishment at its minuteness. The most ordinary microscopical specimen is an illustration of this, but when we realize that the ability of the spectroscope to reveal small particles of matter begins where the finest microscope searches with its highest power in vain, that the grain of matter may be divided, not merely into hundredths, or thousandths, or tens of thousandths, but into millionths and tens of millionths, and that a single one of these particles may be readily detected by this little searcher and held up for our inspection, our wonder and amazement enhance our respect for its occult powers.

The astronomer tells us that a comet often throws out a tail longer than the distance between the earth and the sun, and broad

in proportion; yet the matter forming this tail is so attenuated that, if it could all be gathered up and properly compressed, it might be carted away in a wheelbarrow, yet we have merely to point this little tell-tale at the comet and instantly we perceive what the matter is! Think of it! Not merely may we grasp infinitesimal particles at our hand, but we may sweep the firmament, "gather up the star dust" and tell its composition. But we have not yet reached the end of our scientific excursion; indeed, we have only entered the threshold of the scientist's sanctum, and the wonders of the arcanum eclipse those of the portico.

That mysterious agency, or force, called electricity, has been utilized not only for hundreds of practical purposes, so fully illustrated in this grand exhibition, but it has been employed by the physicist as a sort of fairy finger to probe Nature's inmost structure, and it has enabled him not only, as it were, to see her mind but, in some sense, to feel her pulse.

Professor Crookes, in his beautiful investigations on "radiant matter," has availed himself of this index, with the most surprising results. Here are a number of his tubes and bulbs, from which he has exhausted the air until only about $\frac{1}{1,000,000}$ th part of the original quantity remains. We may regard this residual matter as consisting of many millions of individual molecules, and we can capture these minute particles and compel them to do tangible work. This tube, for example, contains a sort of miniature railway, which is to be operated by projecting these particles with great force against the driving wheel of the engine. Here is a little wind-mill which is to be similarly driven. Here is a tube containing a piece of refractory metal, platinum, which is to be so terribly battered by hitting it with a rapid succession of charges of these molecular bullets, that it is made to glow with a bright light, and if the bombardment should be continued to melt before it like wax. Here is a tube containing a common piece of chalk which may be made to shine with a luminosity rivalling the famous "Koh-i-noor." Even little pieces of glass may outshine the finest emeralds, rubies, and sapphires, when under the marvellous influence of this philosopher's wand.

You must not imagine that these little tubes are merely scientific toys, they are designed to illustrate new properties of matter; but before exhibiting their beautiful effects, I wish to familiarize you

with some of the modern ideas in regard to the nature of the ultimate particles of matter. I am sensible of the difficulty of attempting to elucidate to a general audience, in a brief period of time, a subject so abstruse in character, so bound up in mathematical deductions and dealing with such minute figures as this. I shall try, therefore, to lead you by gradual and easy steps up to that point of observation from which the philosopher reviews, by the aid of his acute mental vision, the transcendent processes eternally operating in Nature's workshop, whereby the most complex structures are evolved from simple elements.

The idea that motion is intimately associated with all matter in some way is not a modern notion, and it was regarded by Faraday's far-reaching mind as a sort of necessary concomitant of familiar matter, though the time was not yet ripe for its full development as a scientific theory. The great forces, light, heat and electricity, were formerly thought to be ponderable substances, which might be squeezed out of a body like water from a sponge; now they have all been resolved into mere "modes of motion," and it is not illogical to infer, from the general drift of modern scientific speculation, that the now seemingly complex laws of Nature's operations may all come, eventually, to be included in the study of the laws of motion.

Sir William Thomson said, in his address at the meeting of the British Association in Montreal: "It is scarcely possible to help anticipating, in idea, the arrival at a *complete theory of matter in which all its properties will be seen to be merely attributes of motion.*"

Before endeavoring to explain such a strange proposition (for it must, no doubt, at first, impress an intellectual person who is not familiar with the course of reasoning upon which it is predicated, as incomprehensible), it will be well to consider briefly some of the properties of matter with which we are more familiar, such as its wonderful divisibility, its universal porosity, and its universal transparency. The metal gold, for example, is susceptible of visible dissection to a remarkable degree. The gold beater, as you doubtless know, will hammer out the metal into leaves so thin that more than 4,000 are required to make a pile one millimetre in thickness. But vastly thinner gold leaves may be obtained in another way. By electro-plating a known weight of

gold upon one side of a sheet of copper foil of given dimensions, a coating of gold may be obtained upon the copper whose thickness is readily ascertainable by a simple calculation; then, by using a suitable solvent, the copper may be removed, when the leaf of gold will remain intact.

After a series of careful experiments, I have obtained, in this way, sheets of gold, mounted on glass plates, which are not more than $\frac{1}{40,000}$ th of a millimetre thick; and I have some specimens to show you which I have good reason to believe are not more than $\frac{1}{400,000}$ th of a millimetre. To give you an idea of this thickness, or, rather, thinness, I may say that it is about $\frac{1}{200}$ th part of a single wave-length of light. Such figures are not hap-hazard guesses, but are based upon reliable and understandable data, and are easily susceptible of verification.

We cannot claim for the thinnest of these films that they represent a single layer of molecules. Taking Sir William Thomson's estimate of the size of the final molecules, and considering that each layer corresponds to one page of a book, our thinnest film would then make a pamphlet having more than a hundred pages. It is found that when such a film is interposed between the eye and any object, it is as transparent as a piece of glass. This may be readily proved by projecting a picture on the screen and interposing the leaf of gold in the path of the light and you see that the only apparent effect is to tinge the light a pale greenish color, none of the detail of the picture is lost, though all the light is coming through a piece of gold as absolutely continuous in its structure, when examined under a microscope, as though it were an inch thick. By placing in the lantern a piece of ordinary gold leaf, having a thickness of about $\frac{1}{200,000}$ th of an inch, and a piece of electro-plated gold leaf about $\frac{1}{3,000,000}$ th of an inch thick, mounted side by side on a glass slide and focusing their images on the screen, you will see a very great difference in the amount of light transmitted by the two, owing to the difference of thickness. Plates of platinum and other metals similarly prepared are equally transparent; indeed, all metals, and probably all substances are transparent when reduced to sufficiently thin plates.

Faraday made some most interesting investigations on the size of finely-divided particles of gold diffused through various liquids and he obtained gold films by reducing gold from solution by phosphorus

which he thought were not over $\frac{1}{100}$ th part of a single wave length of light, but he had no means of determining their thickness accurately as we have in the case of these electro-gold films, where, knowing the weight of gold deposited and the surface covered, the exact thickness may be directly calculated. By treating these thin films after they are attached to the glass plate with a weak solution of potassium cyanide they may be still further reduced in thickness until the film becomes so transparent as to be incapable of reflecting the usual gold color.

Tyndall tells us that the blue color of the sky is due to reflection of light from innumerable particles or spherules of floating matter. He has reproduced the sky phenomena by artificial means, and he tells us that the matter forming the real sky is so attenuated that if it could be properly gathered up and compressed, a gentleman's portmanteau would probably hold it all; and he says, further, "Whether the actual sky be capable of this amount of condensation or not, I entertain no doubt that a sky quite as vast as ours, and as good in appearance, can be formed from a quantity of matter which might be held in the hollow of the hand."

We might naturally suppose from these considerations that no absolute knowledge could ever be obtained regarding the nature of the infinitesimal particles out of which worlds are formed. It was thought in former days that the human mind could never hope to take cognizance of such minute portions of matter as constitute the ultimate molecule. One very eminent scientist said, "Data cannot be furnished by observation or experiment on which to found an investigation of it." Yet so great has been the progress of thought in recent years, aided by the wonderfully delicate means of research at command of the modern physicist, that Sir Wm. Thomson now claims that the ultimate molecules are "pieces of matter measurable dimensions, with shape, motion, and laws of action: of intelligible subjects of scientific investigation." The same eminent author has deduced, by four different and equally profound methods of calculation, the probable size of these molecules, and in order to make his dimensions intelligible to ordinary people, he asks us to imagine a single drop of water magnified to the size of the earth, the molecules of which it is composed being increased in the same proportion, "the structure of the mass would then be coarser than that of a heap of fine shot, but not so coarse as that of a heap

of cricket balls." You know that the gases oxygen and hydrogen when united to form water are greatly compressed, yet the atoms are far from being in actual contact; the estimate has been made that the particles composing a drop of water are not nearer together when compared with the spaces between them, "than 150 men would be if scattered over the whole of England, or one man to 400 square miles." To the ordinary mind this seems incredible.

In order to comprehend the modern idea of the nature of matter, you should try to realize that the molecules composing even the most dense solid substances with which we are familiar (such as gold, platinum, etc.,) are not in contact, and are free to move within certain well-defined limits. In the fluid condition of matter, these particles have a wider range of motion; while in the gaseous state, the excursions of the molecules are limited only by the size of the containing vessel.

All the phenomena of gases are now explained upon the assumption that the molecules are constantly flying about and hitting against each other, and the characteristic properties of gases are directly traced to this state of constant collision among the molecules; in scientific phraseology, this dictum is called "the kinetic theory of gases."

Professor Crookes has gone still farther upon this road; by exhausting the air from his tubes to a very high degree of rarefaction, he has so greatly decreased the number of molecules and correspondingly increased their house room, that collisions occur among them as they fly about with far less frequency than before, hence the ordinary characteristics of gases disappear, while a whole new series of phenomena are developed. "It is upon the visible evidence afforded by the peculiar behavior of the so-called "radiant matter" in these tubes, when under electrical excitation, that Professor Crookes rests his claim to have revealed matter in a state "as far removed from gas as gas is from liquid, or liquid from solid," and he calls this new condition the "fourth state of matter." Whether this claim rests upon a sure foundation and is destined to be recognized as true, I do not venture to form a decided opinion, but that he has revealed new phenomena of a surprising and beautiful nature, we have incontestable evidence before us in these remarkable radiant matter tubes.

Now, let us try to approach a little nearer to an understanding of the idea recently elaborated by Sir Wm. Thomson, in his Mon-

trear address (entitled, "Steps toward a Kinetic Theory of Matter,") that all the properties of matter with which we are familiar are merely attributes of motion. Those of you who heard his lecture in this city, on the "Wave Theory of Light," will remember that he said that the luminiferous ether is no longer to be regarded as hypothetical, but that it is one thing which we are sure of; furthermore, that it may be regarded as a substance having great rigidity, and therefore capable of acquiring motion at the rate of millions and millions of vibrations per second—in the case of visible light waves giving from 400,000,000,000,000 to 800,000,000,000,000 per second.

Now with regard to the character of the atom. Suppose that a particle of this all-pervading, highly-attenuated, rigid yet elastic substance, which, for want of a more appropriate name, is called "the luminiferous ether," be endowed, by a creative act, with rotary motion; it is evident, to a thinking mind, that new properties would be imparted to the particle by virtue of this motion, just as new powers are imparted to grains of sand when caught up and carried along in a whirlwind, or to particles of water forming a water-spout. Suppose that no opposing forces, like gravitation, tend to annul this motion, then the particle will remain forever differentiated from the great mass of ether in which it has its being. This is the simplest explanation, as I understand it, of Sir Wm. Thomson's "vortex-atom," he believes that "what we call matter," may be only the rotating portions of something which fills the whole of space.

Helmholtz's investigations on the nature of rotary motion, in a theoretically perfect fluid, prepared the way for the vortex-atom, and the now well developed "kinetic theory of gases" is the natural precursor of the "kinetic theory of matter," which, although still in the embryonic stage, gives promise of developing into more than a mere scientific speculation, and of emerging into an accepted theorem. The creation of a new theory is generally, and very properly, a slow process; for when once established it clings tenaciously to the mind, and if fallacious, it sometimes fetters the progress of human thought for many generations.

Following in this mental path, Professor P. G. Tait says: "This property of rotation may be the basis of all that appeals to our senses as matter." Professor Crookes likewise says: "The space

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covered by the motion of molecules has no more right to be called matter than the air, traversed by a rifle bullet, to be called lead." Again he says: "From this point of view then matter is but a mode of motion."

In order to render the distinctive characteristics of Professor Crookes' radiant matter phenomena apparent to those not already familiar with the subject, we will first exhibit a number of very beautiful Geissler tubes, *i. e.*, tubes from which the air has been only partially removed. These tubes are of great size, and are marvels of the glass-blower's art. You will observe that the tubes are of various and complicated form, and contain spirals, bulbs, and goblets of different kinds of glass. A platinum wire is hermetically sealed into each end of the tubes. Here is a large coil of wire, called an "induction coil," having a smaller central coil which you do not see. A galvanic battery on the stage supplies an electric current which passes through the centre coil; an automatic break piece makes and breaks connection rapidly between this coil and the battery; the terminal wires from the large exterior coil are connected with the platinum wires entering the Geissler tube; when the electric lights illuminating the room are extinguished and the battery is put in operation, a succession of induced electric pulsations of high tension will be sent from this exterior coil into the tube. Now, you see it filled with brilliant and beautiful light. Observe that the electric flashes seem to pervade the whole tube, and to follow all its intricate twists and turns. Here is another tube exhibiting the curious phenomenon of "stratification" in a remarkable way. Here is another, which is divided into separate compartments containing traces of different gases, and you see that the color of the light is different for each gas.

Passing on, now, to the Crookes tubes, we will show them in the order adopted by Professor Crookes, on the occasion of his original address before the British Association, projecting on the screen, at the same time, diagrams showing their mechanism, omitting some tubes which have become injured on the journey across the water, and including others of recent device.

The tube having a negative terminal in the centre and a positive one at each end, showing the "dark space" surrounding the negative pole and exhibiting "the mean free path" of the molecules, is most interesting.

Another tube with one negative and three positive terminals showing that radiant matter always travels in straight lines independently of the position of the positive pole, and still another showing that radiant matter will not turn a corner, prove conclusively that the phenomena differ widely from those exhibited in the Geissler tubes, where the electric current followed all the convolutions of the tube, entering at one terminal and emerging at the other.

[The tubes showing mechanical action were exhibited by projecting the images of the moving vanes, etc., upon a screen by means of a lantern.*]

The lecturer said, in conclusion: Although I am conscious of having imperfectly succeeded in my effort to elucidate so large a subject as the modern conception of the nature of matter, in the brief time allowed, I still venture to hope that this little glimpse I have given you into the minute world of molecules and atoms (which has been compared to the great world in which the stars revolve), may tempt you to explore more deeply the interesting paths of knowledge here indicated, which have been opened to view by toiling investigators who have taken the light of "pure science" for their guide and have done much to enlarge the horizon of our mental vision and to expand our intellectual capacities.

It is interesting to note how frequently it happens that original investigators, working from different standpoints and with dissimilar objects in view, will, independently of each other, accumulate a mass of observations all tending to elucidate some hitherto unexplained physical law, which only require to be collated in order to reveal their true significance.

Such an original investigator in Nature's domains may be compared to a pioneer who penetrates a primeval forest, hewing down, with his keen hatchet, first a narrow pathway through the wilderness which he explores, until he reaches a favorable camping ground; he then clears a space admitting sun-light and air and

* A detailed description of Professor Crookes' "Radiant Matter" will be found in the JOURNAL OF THE FRANKLIN INSTITUTE, vol. cviii., No 5, p. 305, and a reprint of Professor Crookes' papers on the subject with illustrations, has been prepared by Messrs. J. W. Queen & Co., of this city, from whose exhibit the apparatus used in this lecture was obtained. For these reasons the details of these beautiful experiments are omitted in this report.

erects his habitation; meanwhile, perhaps, other adventurers approach through the forest from different directions; presently the clearings begin to encroach upon each other, cultivated fields appear, the rugged face of the landscape gradually changes, its every aspect becomes familiar, and its once strange and novel features cease to excite wonder or remark. This analogy is not a mere fancy, all the advances in scientific knowledge have been made in little detachments. Narrow lines of investigation have been projected and explored by patient toilers who dig out a few roots here and there, which are carefully garnered until their genus can be determined by further study. In this way separate facts are being constantly stored up, to be collated and classified at a proper time.

While we, matter-of-fact people, may not understand the motive that induces the original investigator to plod on in his narrow path, continually prying into some obscure corner of Nature's vast forest of mysteries, we can all appreciate and enjoy the beautiful results which modern science offers as rewards to her votaries, and we cannot too greatly venerate the genius of those who could conceive the possibility of such results and who possess the ability to produce them.

CELLULAR STRUCTURE OF CAST STEEL.—MM. Osmond and Werth have been experimenting for several years in the laboratory at the workshops of Creusot upon the structure of melted steel. Preparing plates as thin as possible and fixing them to glass by the aid of Canada balsam, they were exposed to cold, weak nitric acid until the iron was dissolved, leaving a nitrate derivative of a hydrate of carbon, so as to reveal the distribution of the carbon in the steel. A microscopic examination shows that this distribution is by no means uniform and that melted steel is composed of small granulations of soft iron, which are generally separated from one another by cells of a carburet of iron. In other words, there is a kind of cellular tissue, the iron constituting the nucleus, and the carburet the walls of the cellules. These elementary or simple cellules are collected into compound cellules, which are separated by void lines. The lines form closed polygons, which are of large dimensions in the cast ingots, but which become smaller and smaller, broken and confused, in proportion as the metal is more perfectly worked. The contact faces of the compound cellules are composed of soft iron without the interposition of carburet. The compound cells may be readily identified with the grain of the steel and their faces are also regions of minimum cohesion.—*Comptes Rendus*, February 16, 1885.