THE EVOLUTION OF MATTER.

INTRODUCTION.

THIS work is devoted to the study of the Evolution of Matter—that is to say, of the fundamental component of things, of the substratum of the worlds and of the beings which exist on their surface.

It represents the synthesis of the experimental researches which I have during the last eight years published in numerous memoirs. In their result they have shown the insufficiency of certain fundamental scientific principles on which rests the edifice of our physical and chemical knowledge.

According to a doctrine which seemed settled for ever, and the building up of which has required a century of persistent labour, while all things in the universe are condemned to perish, two elements alone, Matter and Force, escape this fatal law. They undergo transformations without ceasing, but remain indestructible and consequently immortal.

The facts brought to light by my researches, as well as by those to which they have led, show that, contrary to this belief, matter is not eternal, and can vanish without return. They likewise prove that the atom is the reservoir of a force hitherto unrecognized, although it exceeds by its immensity those forces with which we are acquainted, and that it may perhaps be the origin of most others, notably of electricity and solar heat.

Lastly, they reveal that, between the world of the ponderable and that of the imponderable, till now considered widely separate, there exists an intermediate world.

For several years I was alone in upholding these ideas. Finally, however, their validity has been admitted, after numbers of physicists have determined in various ways the facts I have pointed out, principally those which demonstrate the universality of the dissociation of matter. It was above all the discovery of radium, long after my first researches, that fixed attention on these questions.

Let not the reader be alarmed at the boldness of some of the views which will be set forth herein. They are throughout supported by experimental facts. It is with these for guides that I have endeavoured to penetrate unknown regions, where I had to find my way in thick darkness. This darkness does not clear away in a day, and for that reason he who tries to mark out a new road at the cost of strenuous efforts is rarely called to look at the horizon to which it may lead.

It is not without prolonged labour and heavy expense that the facts detailed in this volume have been established.[1] If I have not yet obtained the suffrages of all the learned, and if I have incensed

[1] To make this book easier to read, the experiments in detail have been brought together at the end of the volume, to which they form a second part. All the plates illustrating the experiments have been drawn or photographed by my devoted assistant, M. F. Michaux. I here express my thanks to him for his daily assistance at my laboratory during the many years over which my researches have extended. I also owe hearty thanks to my friend E. Sénéchal, and the eminent Professor Dwelshauvers-Déry, Corresponding Member of the Institut, who have kindly revised the proofs of this volume.

many among them by pointing out the fragility of dogmas which once possessed the authority of revealed truths, at least I have met with some valiant champions amongst eminent physicists, and my researches have been the cause of many others. One can hardly expect more, especially when attacking principles some of which were considered unshakeable. The great Lamarck uttered no ephemeral truth when he said, "Whatever the difficulties in discovering new truths, there are still greater ones in getting them recognized."

I should be armed with but scant philosophy if I remained surprised at the attacks of several physicists, or at the exasperation of a certain number of worthy people, and especially at the silence of the greater number of the scholars who have utilized my experiments.

Gods and dogmas do not perish in a day. To try to prove that the atoms of all bodies, which were deemed eternal, are not so, gave a shock to all received opinions. To endeavour to show that matter, hitherto considered inert, is the reservoir of a colossal energy, the probable source of most of the forces of the universe, was bound to shock more ideas still. Demonstrations of this kind touching the very roots of our knowledge, and shaking scientific edifices centuries old, are generally received in anger or in silence till the day when, having been made over again in detail by the numerous seekers whose attention has been aroused, they become so widespread and so commonplace that it is almost impossible to point out their first discoverer.

It matters little, in reality, that he who has sown should not reap. It is enough that the harvest grows. Of all occupations which may take up the too brief hours of life, none perhaps is so worthy as the search for unknown truths, the opening out of new paths in that immense unknown which surrounds us.

BOOK I.

THE NEW IDEAS ON MATTER.

CHAPTER I.

THE THEORY OF INTRA-ATOMIC ENERGY AND OF THE PASSING AWAY OF MATTER.

§ 1. *The New Ideas on the Dissociation of Matter.*

THE dogma of the indestructibility of matter is one of the very few which modern has received from ancient science without alteration. From the great Roman poet, Lucretius, who made it the fundamental element of his philosophical system, down to the immortal Lavoisier, who established it on bases considered eternal, this sacred dogma was never touched, and no one ever sought to question it.

We shall see in the present work how it has been attacked. Its fall was prepared by a series of earlier discoveries apparently unconnected with it: cathode rays, X rays, emissions from radio-active bodies, etc., all have furnished the weapons destined to shake it. It received a still graver blow as soon as I had proved that phenomena at first considered peculiar to certain exceptional substances, such as uranium, were to be observed in all the substances in nature.

Facts proving that matter is capable of a dissociation fitted to lead it into forms in which it loses all its material qualities are now very numerous. Among the most important I must note the emission by all bodies of particles endowed with immense speed, capable of making the air a conductor of electricity, of passing through obstacles, and of being thrown out of their course by a magnetic field. None of the forces at present known being able to produce such effects, particularly the emission of particles with a speed almost equalling that of light, it was evident that we here found ourselves in presence of absolutely unknown facts. Several theories were put forth in explanation of them. One only—that of the dissociation of atoms, which I advanced at the commencement of these researches—has resisted all criticism, and on this account is now almost universally adopted.

It is now several years since I proved by experiment for the first time that the phenomena observed in substances termed radio-active—such as uranium, the only substance of that kind then known—could be observed in all substances in Nature, and could only be explained by the dissociation of their atoms.

The aptitude of matter to disaggregate by emitting effluves[1] of particles analogous to those of the cathode rays, having a speed of the same order as light, and capable of passing through material substances, is universal. The action of light on any substance, a lighted lamp, chemical reactions of very different kinds, an electric discharge, etc., cause these effluves to appear. Substances termed radio-active, such as uranium or radium, simply present in a high degree a phenomenon which all matter possesses to some extent.

When I formulated for the first time this general-

[1] No exact equivalent for this word can be found in English, and I have therefore retained it throughout.—F. L.

ization, though it was supported by very precise experiments, it attracted hardly any attention. In the whole world one physicist, the learned Professor de Heen, alone grasped its import and adopted it after having verified its perfect correctness. But the experiments being too convincing to permit of long challenge, the doctrine of the universal dissociation of matter has at last triumphed. The atmosphere is now cleared, and few physicists deny that this dissociation of matter—this radio-activity as it is now called—is a universal phenomenon as widely spread throughout the universe as heat or light. Radio-activity is now discovered in nearly everything; and in a recent paper Professor J. J. Thomson has demonstrated its existence in most substances—water, sand, clay, brick, etc.

What becomes of matter when it dissociates? Can it be supposed that when atoms disaggregate they only divide into smaller parts, and thus form a simple dust of atoms? We shall see that nothing of the sort takes place, and that matter which dissociates dematerializes itself by passing through successive phases which gradually deprive it of its material qualities until it finally returns to the imponderable ether whence it seems to have issued.

The fact once recognized that atoms can dissociate, the question arose as to whence they obtained the immense quantity of energy necessary to launch into space particles with a speed of the same order as light.

The explanation in reality was simple enough, since it is enough to verify, as I have endeavoured to show, that, far from being an inert thing only capable of giving up the energy artificially supplied to it, matter is an enormous reservoir of energy—*intra-atomic energy*.

But such a doctrine assailed too many fundamental scientific principles established for centuries to be at once admitted, and before accepting it various hypotheses were successively proposed. Accustomed to regard the rigid principles of thermodynamics as absolute truths, and persuaded that an isolated material system could possess no other energy than that supplied from without, the majority of physicists long persisted, and some still persist, in seeking outside it the sources of the energy manifested during the dissociation of matter. Naturally, they failed to discover it, since it is within, and not without, matter itself.

The reality of this new form of energy, of this intra-atomic energy of which I have unceasingly asserted the existence from the commencement of my researches, is in no way based on theory, but on experimental facts. Though hitherto unknown, it is the most powerful of known forces, and probably, in my opinion, the origin of most others. Its existence, so much contested at first, is more and more generally accepted at the present time.

From the experimental researches which I have detailed in various memoirs and which will be summarized in this work, the following propositions are drawn:—

1. *Matter, hitherto deemed indestructible, vanishes slowly by the continuous dissociation of its component atoms.*

2. *The products of the dematerialization of matter constitute substances placed by their properties between ponderable bodies and the imponderable ether—that is to say,*

between two worlds hitherto considered as widely separate.

3. *Matter, formerly regarded as inert and only able to give back the energy originally supplied to it, is, on the other hand, a colossal reservoir of energy—intra-atomic energy—which it can expend without borrowing anything from without.*

4. *It is from the intra-atomic energy manifested during the dissociation of matter that most of the forces in the universe are derived, and notably electricity and solar heat.*

5. *Force and matter are two different forms of one and the same thing. Matter represents a stable form of intra-atomic energy; heat, light, electricity, etc., represent instable forms of it.*

6. *By the dissociation of atoms—that is to say, by the dematerialization of matter, the stable form of energy termed matter is simply changed into those unstable forms known by the names of electricity, light, heat, etc.*

7. *The law of evolution applicable to living beings is also applicable to simple bodies; chemical species are no more invariable than are living species.*

For the examination of these several propositions a large part of this work will be reserved. Let us in this chapter take them as proved and seek at once the changes they bring about in our general conception of the mechanism of the universe. The reader will thus appreciate the interest presented by the problems to which this volume is devoted.

§ 2. *Matter and Force.*

The problem of the nature of matter and of force is one of those which have most exercised the sagacity of scholars and philosophers. Its complete solution has always escaped us because it really implies the knowledge, still inaccessible, of the First Cause of things. The researches I shall set forth cannot therefore allow us to completely solve this great question. They lead, however, to a conception of matter and energy far different from that in vogue at the present day.

When we study the structure of the atom, we shall arrive at the conclusion that it is an immense reservoir of energy solely constituted by a system of imponderable elements maintained in equilibrium by the rotations, attractions and repulsions of its component parts. From this equilibrium result the material properties of bodies such as weight, form, and apparent permanence. Matter also represents movement, but the movements of its component elements are confined within a very restricted space.

This conception leads us to view matter as a variety of energy. To the known forms of energy—heat, light, etc.—there must be added another—matter, or intra-atomic energy. It is characterized by its colossal greatness and its considerable accumulation within very feeble volume.

It follows from the preceding statements that by the dissociation of atoms, one is simply giving to the variety of energy called matter a different form—such as, for example, electricity or light.

We will endeavour to give an account of the forms under which intra-atomic energy may be condensed within the atom, but the existence of the fact itself has a far greater importance than the theories it gives rise to. Without pretending to give the definition so vainly sought for of energy, we will content ourselves with stating that all phenomenality is nothing but a transformation of equilibrium. When the transformations of equilibrium are rapid, we call them electricity, heat, light, etc.; when the changes of equilibrium are slower, we give them the name of matter. To go beyond this we must wander into the region of hypothesis and admit, as do several physicists, that the elements of which the aggregate is represented by forces in equilibrium, are constituted by vortices formed in the midst of ether. These vortices possess an individuality, formerly supposed to be eternal, but which we know now to be but ephemeral. The individuality disappears, and the vortex dissolves in the ether as soon as the forces which maintain its existence cease to act.

The equilibria of these elements of which the aggregate constitutes an atom, may be compared to those which keep the planets in their orbits. So soon as they are disturbed; considerable energies manifest themselves, as they would were the earth or any other planet stayed in its course.

Such disturbances in planetary systems may be realized, either without apparent reason, as in very radio-active bodies when, for divers reasons, they have reached a certain degree of instability, or artificially, as in ordinary bodies when brought under the influence of various excitants—heat, light, etc. These excitants act in such cases like the spark on a mass of powder—that is to say, by freeing quantities of energy greatly in excess of the very slight cause which has determined their liberation. And as the energy condensed in the atom is immense in quantity, it results from this that to an extremely slight loss in matter there corresponds the creation of an enormous quantity of energy.

From this standpoint we may say of the various forms of energy resulting from the dissociation of material elements, such as heat, electricity, light, etc., that they represent the last stages of matter before its disappearance into the ether.

If, extending these ideas, we wish to apply them to the differences presented by the various simple bodies studied in chemistry, we should say that one simple body only differs from another by containing more or less intra-atomic energy. If we could deprive any element of a sufficient quantity of the energy it contains, we should succeed in completely transforming it.

As to the necessarily hypothetical origin of the energies condensed within the atom, we will seek for it in a phenomenon analogous to that invoked by astronomers to explain the formation of the sun, and of the energies it stores up. To their minds this formation is the necessary consequence of the condensation of the primitive nebula. If this theory be valid for the solar system, an analogous explanation is equally so for the atom.

The conceptions thus shortly summed up in no way seek to deny the existence of matter, as metaphysics has sometimes attempted to do. They simply clear away the classical duality of matter and energy. These are two identical things under different aspects. There is no separation between matter and energy, since matter is simply a stable form of energy and nothing else.

It would, no doubt, be possible for a higher intelligence to conceive energy without substance, for there is nothing to prove that it necessarily requires a support; but such a conception cannot be attained by us. We can only understand things by fitting them into the common frame of our thoughts. The essence of energy being unknown, we are compelled to materialize it in order to enable us to reason thereon. We thus arrive—but only for the purposes of demonstration—at the following definitions:—Ether and matter represent entities of the same order. The various forms of energy: electricity, heat, light, matter, etc., are its manifestations. They only differ in the nature and the stability of the equilibria formed in the bosom of the ether. It is by those manifestations that the universe is known to us.

More than one physicist, the illustrious Faraday especially, has endeavoured to clear away the duality existing between matter and energy. Some philosophers formerly made the same attempt, by pointing out that matter was only brought home to us by the intermediary of forces acting on our senses. But all arguments of this order were considered, and rightly, as having a purely metaphysical bearing. It was objected to them that it had never been possible to transform matter into energy, and that this latter was necessary to animate the former. Scientific principles, considered assured, taught that Nature was a kind of inert reservoir incapable of possessing any energy save that previously transmitted to it. It could no more create it than a reservoir can create the liquid it holds. Everything seemed then to point out that Nature and Energy were irreducible things, as independent one of the other as weight is of colour. It was therefore not without reason that they were taken as belonging to two very different worlds.

There was, no doubt, some temerity in taking up anew a question seemingly abandoned for ever. I have only done so because my discovery of the universal dissociation of matter taught me that the atoms of all substances can disappear without return by being transformed into energy. The transformation of matter into energy being thus demonstrated, it follows that the ancient duality of Force and Matter must disappear.

§ 3. *Consequences of this Principle of the Vanishing of Matter.*

The facts summed up in the preceding pages show that matter is not eternal, that it constitutes an enormous reservoir of forces, and that it disappears by transforming itself into other forms of energy before returning to what is, for us, nothingness.

It can therefore be said that if matter cannot be created, at least can it be destroyed without return. For the classical adage: "Nothing is created, nothing is lost,"[1] must be substituted the following:—Nothing is created, but everything is lost. The elements of a substance which is burned or sought to be annihilated by any other means are transformed, but they are not lost, for the balance affords proof that their weight has not varied. The elements of atoms which are dissociated, on the contrary, are irrevocably destroyed. They lose every quality of matter, including the most fundamental of them all—weight. The balance no longer detects them. Nothing can recall them to the state of matter. They have vanished in the immensity of the ether which fills space, and they no longer form part of our universe.

1 Attributed to Lavoisier.—F. L.

The theoretical importance of these principles is considerable. At the time when the ideas I am upholding were not yet defensible, several scholars took pains to point out how far the time-honoured doctrine of the everlasting nature of matter constituted a necessary foundation for science. Thus, for instance, Herbert Spencer in one of the chapters of *First Principles*,[1] headed "Indestructibility of Matter," which he makes one of the pillars of his system, declares that, "Could it be shown, or could it with reason be supposed, that Matter, either in its aggregates or in its units, ever becomes non-existent, it would be needful either to ascertain under what conditions it becomes non-existent, or else to confess that true Science and Philosophy are impossible." This assertion certainly seems too far-reaching. Philosophy has never found any difficulty in adapting itself to new scientific discoveries. It follows, but does not precede them.

It is not only philosophers who declare the impossibility of assailing the dogma of the indestructibility of matter. But a few years ago the learned chemist Naquet, then Professor at the Faculté de Médecine of Paris, wrote—"We have never seen the ponderable return to the imponderable. In fact, the whole science of chemistry is based on the law that such a change does not occur; for, did it do so, good-bye to the equations of chemistry!"

Evidently, if the transformation of the ponderable into the imponderable were rapid, not only must we give up the equations of chemistry, but also those of mechanics. However, from the practical point of view, none of these equations are yet in danger, for

[1] Sixth ed. (1900), Part II., chap. iv., p. 153.—F. L.

the destruction of matter takes place so slowly that it is not perceptible with the means of observation formerly employed. Losses in weight under the hundredth part of a milligramme being imperceptible by the balance, chemists need not take them into account. The practical interest of the doctrine of the vanishing of matter, by reason of its transformation into energy, will only appear when means are found of accomplishing with ease the rapid dissociation of substances. When that occurs, an almost unlimited source of energy will be at man's disposal gratis, and the face of the world will be changed. But we have not yet reached this point.

At the present time, all these questions have only a purely scientific interest, and are for the time as much lacking practical application as was electricity in the time of Volta. But this scientific interest is considerable, for these new notions prove that the only elements to which science has conceded duration and fixity are, in reality, neither fixed nor durable.

Everybody knows that it is easy to deprive matter of all its attributes, save one. Solidity, shape, colour, chemical properties easily disappear. The very hardest body can be transformed into an invisible vapour. But, in spite of every one of these changes, the mass of the body as measured by its weight remains invariable, and always reappears. This invariability constituted the one fixed point in the mobile ocean of phenomena. It enabled the chemist, as well as the physicist, to follow matter through its perpetual transformations, and this is why they considered it as something mobile but eternal.

It is to this fundamental property of the invariability of the mass that we had always to come back. Philosophers and scholars long ago gave up seeking an exact definition of matter. The invariability of the mass of a given quantity of substance—that is to say, its coefficient of inertia measured by its weight, remained the sole irreducible characteristic of matter. Outside this essential notion, all we could say of matter was that it constituted the mysterious and ever-changing element whereof the worlds and the beings who inhabit them were formed.

The permanence and, therefore, the indestructibility of mass, which one recognizes throughout the changes in matter, being the only characteristic by which this great unknown conception can be grasped, its importance necessarily became preponderant. On it the edifices of chemistry and mechanics have been laboriously built up.

To this primary notion, however, it became necessary to add a second. As matter seemed incapable by itself of quitting the state of repose, recourse was had to various causes, of unknown nature, designated by the term forces, to animate it. Physics counted several which it formerly clearly distinguished from each other, but the advance in science finally welded them into one great entity, *Energy*, to which the privilege of immortality was likewise conceded.

And it is thus that, on the ruins of former doctrines and after a century of persistent efforts, there sprang up two sovereign powers which seemed eternal—matter as the fundamental woof of things, and energy to animate it. With the equations connecting them, modern science thought it could explain all phenomena. In its learned formulas all the secrets of the universe were enclosed. The divinities of old time were replaced by ingenious systems of differential equations.

These fundamental dogmas, the bases of modern science, the researches detailed in this work tend to destroy. If the principle of the conservation of energy—which, by-the-by, is simply a bold generalization of experiments made in very simple cases—likewise succumbs to the blows which are already attacking it, the conclusion must be arrived at that nothing in the world is eternal. The great divinities of science would also be condemned to submit to that invariable cycle which rules all things—birth, growth, decline, and death.

But if the present researches shake the very foundations of our knowledge, and in consequence our entire conception of the universe, they are far from revealing to us the secrets of this universe. They show us that the physical world, which appeared to us something very simple, governed by a small number of elementary laws, is, on the contrary, terribly complex. Notwithstanding their infinite smallness, the atoms of all substances—those, for example, of the paper on which these lines are written—now appear as true planetary systems, guided in their headlong speed by formidable forces of the laws of which we are totally ignorant.

The new routes which recent researches open out to the investigations of inquirers are yet hardly traced. It is already much to know that they exist, and that science has before it a marvellous world to explore.

CHAPTER II.

HISTORY OF THE DISCOVERY OF THE DISSOCIATION OF MATTER AND OF INTRA-ATOMIC ENERGY.

WHAT brought into prominence the facts and principles summarized in the preceding chapter which will be unfolded in this work? This I will now proceed to show. The genesis of a discovery is rarely spontaneous. It only appears so because the difficulties and the hesitations which most often surround its inception are generally unnoticed.

The public troubles itself very little with the way in which inventions are made, but psychologists will certainly be interested by certain sides of the following account.[1] In fact, they will find therein valuable documents on the birth of beliefs, on the part played, even in laboratories, by suggestions and illusions, and finally on the preponderant influence of prestige considered as a principal element of demonstration.

My researches preceded, in their beginning, all those carried out on the same lines. It was, in fact, in 1896 that I caused to be published in the *Comptes Rendus de l'Académie des Sciences*, solely for the purpose of establishing priority, a short notice

[1] In order not to lengthen this history unduly I do not give here any of the texts on which it is based. The reader will find them at the end of the book.

summing up the researches I had been making for two years, whence it resulted that light falling on bodies produced radiations capable of passing through material substances. Unable to identify these radiations with anything known, I pointed out in the same note that they must probably constitute some unknown force—an assertion to which I have often returned. (To give it a name I called this radiation black light (*lumière noire*).)

At the commencement of my experiments I perforce confused dissimilar things which I had to separate one after the other. In the action of light falling on the surface of a body there can be observed, in fact, two very distinct orders of phenomena:—

1. Radiations of the same family as the cathode rays. They are incapable of refraction or of polarization, and have no kinship with light. These are the radiations which the so-called radio-active substances, such as uranium, constantly emit abundantly and ordinary substances freely.

2. Infra-red radiations of great wave-length which, contrary to all that has hitherto been taught, pass through black paper, ebonite, wood, stone, and, in fact, most non-conducting substances. They are naturally capable of refraction and polarization.

It was not very easy to dissociate these various elements at a time when no one supposed that a large number of bodies, considered absolutely opaque, were, on the contrary, very transparent to the invisible infra-red light, and when the announcement of the experiment of photographing a house in two minutes and in the dark-room through an opaque body would have been deemed absurd.

Without losing sight of the study of metallic radiations, I gave up some time to the examination of the properties of the infra-red.[1] This examination led me to the discovery of invisible luminescence, a phenomenon which had never been suspected, and enabled me to photograph objects kept in darkness for eighteen months after they had seen the light.

These researches terminated, I was able to proceed with the study of metallic radiations.

It was at the commencement of the year 1897 that I announced in a note published in the *Comptes Rendus de l'Académie des Sciences*, that all bodies struck by light emitted radiations capable of rendering air a conductor of electricity.[2]

A few weeks later I gave, also in the *Comptes Rendus*, details of quantitative experiments serving to confirm the above, and I pointed out the analogy of the radiations emitted by all bodies under the action of light with the radiations of the cathode ray family, an analogy which no one till then had suspected.

It was at the same period that M. Becquerel published his first researches. Taking up the forgotten experiments of Niepce de Saint-Victor, and employing, like him, salts of uranium, he showed, as the latter had already done, that these salts emitted,

[1] In order not to confuse things which differ, I have reserved the term *lumière noire* for these radiations. They will be examined in another volume devoted to the study of energy. Their properties differ considerably from those of ordinary light, not only by their invisibility, an unimportant characteristic due solely to the structure of the eye, but by absolutely special properties—that, for instance, of passing through a great number of opaque bodies and of acting in an exactly contrary direction to other radiations of the spectrum.

[2] This property is still the most fundamental characteristic of radioactive bodies. It was by working from this only that radium and polonium were isolated.

in darkness, radiations able to act on photographic plates. Carrying this experiment farther than his predecessor, he established the fact that the emission seemed to persist indefinitely.

Of what did these radiations consist? Still under the influence of the ideas of Niepce de Saint-Victor, M. Becquerel thought at first that it was a question of what Niepce termed "stored-up light" (*lumière emmagasinée*)—that is to say, a kind of invisible phosphorescence, and, to prove it, he started experiments described at length in the *Comptes Rendus de l'Académie des Sciences*, which induced him to think that the radiations emitted by uranium were refracted, reflected, and polarized.

This point was fundamental. If the emissions of uranium could be refracted and polarized, it was evidently a question of radiations identical with light and simply forming a kind of invisible phosphorescence. If this refraction and polarization had no existence, it was a question of something totally different and quite unknown.

Not being able to fit in M. Becquerel's experiments with my own, I repeated them with different apparatus, and arrived at the conclusion that the radiations of uranium were not in any way polarized. It followed then that we had before us not any form of light, but an absolutely new thing, constituting, as I had asserted at the beginning of my researches, a new force: "The properties of uranium were therefore only a particular case of a very general law." It is with this last conclusion that I terminated one of my notes in the *Comptes Rendus de l'Académie des Sciences* of 1897.

For nearly three years I was absolutely alone in maintaining that the radiations of uranium could not be polarized. It was only after the experiments of the American physicist, Rutherford,[1] that M. Becquerel finally recognized that he had been mistaken.

It will be considered, I think, very curious and one

Apparatus employed in 1897 by Gustave Le Bon to demonstrate, by the absence of polarization, that the radiations emitted by salts of uranium are not invisible light.

FIG. 1.

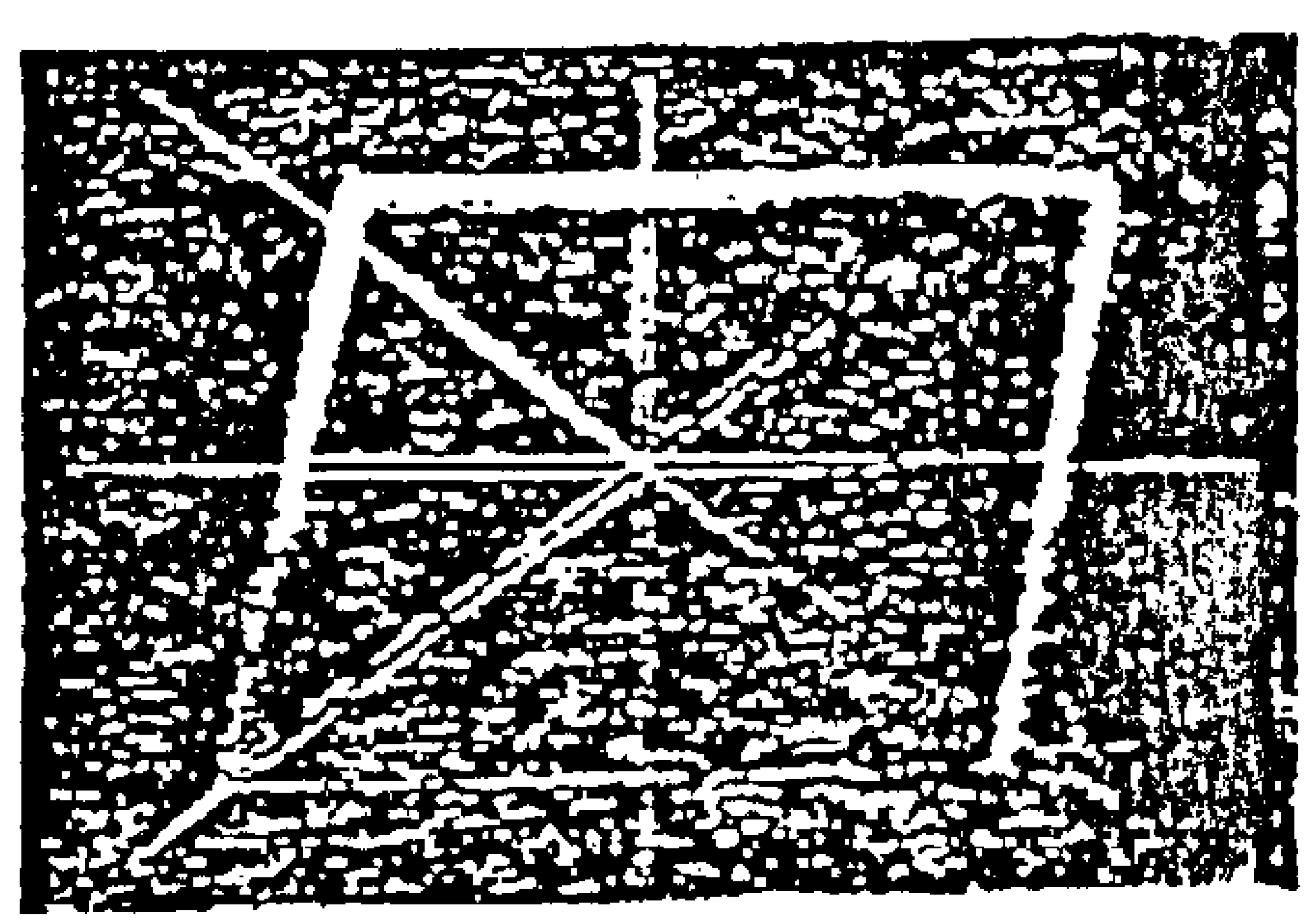

FIG. 2.

One of these is the classic method of plates of tourmaline with crossed axes, and is too well known for any description of it to be given here. It only differs from the one with which M. Becquerel thought he had demonstrated the polarization of the uranium rays, in having the tourmalines framed in a thick strip of metal so as to prevent the uranium emanation from going round them. The second apparatus was contrived by me for the purpose of verifying the negative results obtained by means of the tourmalines. It is composed of a strip of metal in which very fine lines have been cut and covered over with Iceland spar. If this be interposed between a source of visible or invisible light and a photographic plate, we obtain, through the double refraction, a duplication of the lines which indicates the polarization of the emerging rays. This duplication is very clearly seen in the photograph of the apparatus here reproduced, which has been taken in ordinary light.

[1] Professor Rutherford is a Canadian, and holds the Macdonald chair of Physics at McGill University, Montreal.—F. L.

of the most instructive chapters in the history of science that for three years not one single physicist was to be met with in the whole world who thought of repeating—though they were extraordinarily simple—the experiments of M. Becquerel on the refraction, reflection, and polarization of the uranium rays. On the contrary, the most eminent published ingenious theories to explain this very refraction, reflection, and polarization.

It was a new version of the story of the child with the golden tooth on which the scholars of the day wrote important treatises, till one day it occurred to a sceptic to go to see if the said child was really born with a golden tooth. It will be difficult, after such an example, to deny that, in scientific matters, prestige forms the essential element in conviction. We must therefore not scoff too much at those in the Middle Ages who knew no other sources of demonstration than the statements of Aristotle.

Leaving to its fate the doctrine which for several years I alone upheld, I continued my researches, enlarged the circle of my investigations, and showed that similar radiations arise, not only under the action of light, but also under very varying influences, chemical reaction especially. It became therefore more and more evident that the radiations of uranium were only, as I said from the very first, a particular case of a very general law.

This general law, which I have not ceased to study, is as follows:—Under divers influences, light, chemical reaction, electric action, and often even, spontaneously, the atoms of simple bodies, as well as those of compound bodies, dissociate and emit effluves of the same family as the cathode rays.

This generalization is at the present day almost universally admitted, but the preceding statement of facts shows that it needed some courage to formulate it for the first time. Who could have supposed any relationship between the radiations of uranium and any effluves whatever, cathodic or otherwise, since nearly all physicists then admitted, on M. Becquerel's authority, the polarization and the refraction of these rays?

When the question as to polarization was definitely settled, it took but little time to establish the correctness of the facts stated by me. But it was only after the German physicists, Giesel, Meyer, and Schweidler, discovered, in 1899, that the emissions of radioactive bodies were, like the cathode rays, capable of deviation by a magnet, that the idea of a probable analogy between all these phenomena began to spread. Several physicists then took up this study, the importance of which increased day by day. New facts arose on all sides, and the discovery of radium by Curie gave a great impetus to these researches.

M. de Heen, Professor of Physics at the University of Liége, and Director of the celebrated Institute of Physics in that town, was the first to accept in its entirety the generalization I had endeavoured to establish. Having taken up and developed my experiments, he declared in one of his papers that in point of importance they were on a par with the discovery of the X rays. They were the origin of numerous researches on his part, which led to remarkable results. The movement once started, it had to be followed up. On all sides radioactivity was sought for, and it was discovered everywhere. The spontaneous emission is often very weak, but becomes considerable in substances placed under the influence of various excitants—light, heat, etc. All physicists are now agreed in classing in the same family the cathode rays and the emissions from uranium, radium, and bodies dissociated by light, heat, and the like.

If, notwithstanding my assertions and my experiments, these analogies were not at once accepted, it is because the generalization of phenomena is at times much more difficult to discover than the facts from which this generalization flows. It is, however, from these generalizations that scientific progress is derived. "Every great advance in the sciences," said the philosopher Jevons, "consists of a vast generalization revealing deep and subtle analogies."

The generality of the phenomenon of the dissociation of matter would have been noticed much sooner if a number of known facts had been closely examined, but this was not done. These facts, besides, were spread over very different chapters of physics. For example, the loss of electricity occasioned by ultra-violet light had long been known, but one little thought of connecting the fact with the cathode rays. More than fifty years ago Niepce de Saint-Victor saw that, in the dark, salts of uranium caused photographic impressions for several months; but as this phenomenon did not seem to be connected with any known fact, it was put on one side. For a hundred years the gases of flames had been observed to discharge electrified bodies without any one attempting to examine the cause of this phenomenon. The loss of electric charges through the influence of light had been pointed out several years before, but it was regarded as a fact peculiar to a few metals, without any suspicion of how general and important it was.[1]

All these phenomena and many others, such as electricity and solar heat, are very dissimilar in appearance, but are the consequences of the same fact — namely, the dissociation of matter. The common link which connects them appeared clearly directly we established that the dissociation of matter and the forms of energy which result from it are to be ranked among the most widely spread natural phenomena.

The establishment of the fact of the dissociation of matter has allowed us to penetrate into an unknown world ruled by new forces, where matter, losing its properties as matter, becomes imponderable in the balance of the chemist, passes without difficulty through obstacles, and possesses a whole series of unforeseen properties.

I have had the satisfaction of seeing, while still alive, the recognition of the facts on which I based the theories which follow. For a long time I had given up all such hope, and more than once had thought of abandoning my researches. They had, in fact, been rather badly received in France. Several of the notes sent by me to the Academy of Sciences provoked absolute storms. The majority of the members of the Section of Physics energetically pro-

[1] It is precisely in the interpretation of these early facts, which no one had ever thought of connecting with radio-active phenomena, that the difficulty lay. This is what Mr. Whetham has entirely failed to grasp in his review of this work published in *Nature*. The perusal of the volume in which this specialist has endeavoured to popularize the researches on radio-activity will show, moreover, that he has failed to comprehend these phenomena.

tested, and the scientific press joined in the chorus. We are so hierarchized, so hypnotized and tamed by our official teaching, that the expression of independent ideas seems intolerable. To-day, when my ideas have slowly filtered into the minds of physicists, it would be ungracious to complain of their criticisms or the silence of most of them towards me. Sufficient for me is it that they have been able to avail themselves of my researches. The book of nature is a romance of such passionate interest that the pleasure of spelling out a few pages repays one for the trouble this short decipherment often demands. I should certainly not have devoted over eight years to these very costly experiments had I not at once grasped their immense philosophical interest and the profound perturbation they would finally cause to the fundamental theories of science.

With the discovery of the universal dissociation of matter is linked that of intra-atomic energy, by which I have succeeded in explaining the radio-active phenomena. The second was the consequence of the first-named discovery.

The discovery of *intra-atomic energy* cannot, however, be quite assimilated to that of the universality of the dissociation of matter. This universal dissociation is a fact, the existence of intra-atomic energy is only an interpretation. This interpretation, besides, was necessary, for, after having tried several hypotheses to explain the radio-active phenomena, nearly all physicists have finally fallen in with the explanation I proposed when I announced that science was face to face with a new force hitherto entirely unknown.

It may interest the reader to know how the researches which have thus been briefly recorded were received in various countries.

It was especially abroad that they created a deep impression. In France, they met with a hostility which was not, however, unanimous, as will be seen by this extract from a study published by M. Dastre, Professor at the Sorbonne and a member of the Institut:—

"In the course of five years a fairly long journey has been covered on the road towards the generalization of the fact of radio-activity. Starting with the idea of a property specific to uranium, we have reached the supposition of a well-nigh universal natural phenomenon.

"It is right to recall that this result was predicted with prophetic perspicacity by Gustave Le Bon. From the outset this scholar endeavoured to show that the action of light, certain chemical reactions, and lastly the action of electricity, call forth the manifestation of this particular mode of energy. . . . Far from being rare, the production of these rays is unceasing. Not a sunbeam falls on a metallic surface, not an electric spark flashes, not a discharge takes place, not a single body becomes incandescent, without the appearance of a pure or transformed cathode ray. To Gustave Le Bon must be ascribed the merit of having perceived from the first the great generality of this phenomenon. Even though he has used the erroneous term of *Lumière noire*, he has none the less grasped the universality and the principal features of this product. He has above all set the phenomenon in its proper place by transferring it from the closet of the physicist into the grand laboratory of nature." (*Revue des Deux Mondes*, 1901.)

In one of the annual reviews on physical studies which he publishes annually, Professor Lucien Poincaré has very clearly summarized my researches in the following lines:—

"M. Gustave Le Bon, to whom we owe numerous publications relating to the phenomena of the emission by matter of various radiations, and who was certainly one of the first to think that radio-activity is a general phenomenon of nature, supposes that under very different influences, light, chemical action, electrical action, and often even, spontaneously, the atoms of simple bodies dissociate and emit effluves of the same family as the cathode and X rays; but all these manifestations would be particular aspects of an entirely new form of energy, quite distinct from electrical energy, and as widely spread throughout nature as heat. M. de Heen adopts similar ideas." (*Revue Générale des Sciences*, January 1903.)

I have only one fragment of a phrase to correct in the above lines. The eminent scholar says that I was "one of the first" to show that radio-activity is a universal phenomenon. This should read "the first." It suffices to turn to the texts and to their dates of publication to be convinced of this fact.[1]

It is natural enough that one should not be a prophet in one's own country. It is sufficient to be a little of one elsewhere. The importance of the results brought to light by my researches was very quickly understood abroad. Out of the different studies they called forth, I shall confine myself to reproducing a few fragments.

The first is a portion of the preamble to four articles devoted to my experiments in the *English Mechanic*:—[2]

[1] My first memoir on the radio-activity of all bodies under the action of light appeared in the *Revue Scientifique* of May 1897. The one on radio-activity by chemical reaction in April 1900. The memoir demonstrating the spontaneous radio-activity of primary bodies appeared —in the same review—in November 1902. The first experiments by means of which physicists sought to prove that radio-activity could be detected in substances other than uranium, thorium, and radium were published by Strutt, McLennan, Burton, etc., only between June and August 1903.

[2] The issues from January to April 1903.

"During six years Gustave Le Bon has continued his researches on certain radiations which he at first termed *Lumière noire.* He scandalized orthodox physicists by his audacious assertion that there existed something which had been quite unknown. However, his experiments decided other searchers to verify his assertions, and many unforeseen facts were discovered. Rutherford in America, Nodon in France, de Heen in Belgium, Lenard in Austria, Elster and Geitel in Switzerland have successfully followed in the lines of Gustave Le Bon. Summing up to-day the experiments made by him for the last six years, Gustave Le Bon shows that he has discovered a new force in nature which manifests itself in all bodies. His experiments cast a vivid light on such mysterious subjects as the X rays, radio-activity, electrical dispersion, the action of ultra-violet light, etc. Classical books are silent on all these subjects, and the most eminent electricians know not how to explain these phenomena."

The second of the articles to which I have above alluded is one in *The Academy* of the 6th December, 1902, under this heading: "A New Form of Energy":—

"Hardly anything is more marked than the way in which the ideas of men of science with regard to force and matter have completely changed during the last ten years. . . . The atomic theory that every scrap of matter could be divided in the last resort into atoms each in itself indivisible and combining among themselves only in fixed proportions, was then a law of scientific faith, and led to pronouncements like those of a late President of the Chemical Society, who informed his hearers in his annual allocution that the age of discovery in chemistry was closed, and that henceforth we had better devote ourselves to a thorough classification of chemical phenomena. But this prediction . . . was no sooner uttered than it was falsified. There came before us Mr. (not then Sir William) Crookes' discovery of what he called 'radiant matter,' . . . then Röntgen's rays . . . until now M. Gustàve Le Bon . . . assures us that these new ideas are not several things but one thing, and that they all of them point to a form of matter spread throughout the world indeed, but so inconceivably minute that it becomes not matter but force. . . . The consequences of the final acceptance of [M. Le Bon's] theory are fairly enormous. . . . As for chemistry, the whole fabric will be demolished at a blow; and we shall have a *tabula rasa* on which we may write an entirely new system wherein matter will pass through matter, and 'elements' will be shown to be only differing forms of the same substance. But even this will be nothing compared with the results which will follow the bridging of the space between the material and the immaterial which M. Le Bon anticipates as the result of his discoveries, and which Sir William Crookes seems to have foreshadowed in his address to the Royal Society upon its late reception of the Prince of Wales."

I will add to these quotations a passage from the divers articles which M. de Heen, Professor of Physics at the University of Liége, has kindly devoted to my researches:—

"The resounding effect produced in the world by the discovery of the X rays is well known, a discovery which was immediately followed by one more modest in appearance, but perhaps more important in reality—viz., that of Black Light, as the result of the researches of Gustave Le Bon. This last scholar proved that bodies struck by light, especially metals, acquire the faculty of producing rays analogous to the X rays, and discovered that this was not simply an exceptional phenomenon, but, on the contrary, one of an order of phenomena as common throughout nature as calorific, electricity, and luminous manifestations, a thesis which I also have constantly upheld from that time."

But all this is already ancient history. The anger which my first researches provoked in France has vanished. The staffs of the laboratories formerly so hostile have welcomed with sympathetic curiosity the first editions of this work. The proof of this I have found in several articles, and especially in the review by one of the most distinguished young scholars of the Sorbonne, of which I give a few extracts:—

"It will be Dr. Le Bon's title to fame that he was the first to attack the dogma of the indestructibility of matter, and that he has destroyed it within the space of a few years. In 1896 he published a short note which will mark one of the most important dates in the history of science, for it has been the starting-point of the discovery of the dissociation of matter. . . . To the already known forms of energy, heat, light, etc., another must be added, namely, matter or *intra-atomic energy*. The reality of this new form of energy, which Dr. Le Bon has made known to us, rests in no way upon theory, but is deduced from experimental fact. Although unknown till now, it is the most mighty of known forces, and may even be the origin of most of the others. . . . The beginning of Dr. Le Bon's work produces in the reader a deep impression; one feels in it the breath of a thought of genius. . . . Dr. Le Bon has been compared to Darwin. If one were bound to make a comparison, I would rather compare him to Lamarck. Lamarck was the first to have a clear idea of the evolution of living beings. Dr. Le Bon was the first to recognize the possibility of the evolution of matter, and the generality of the radio-activity by which its disappearance is manifested."[1]

The reader will, I hope, excuse this short pleading. The repeated forgetfulness of certain physicists has compelled me to utter it. The new phenomena I have discovered have cost me too much labour, too much money, and too much annoyance for me not to try to keep a firm hold on a prize obtained with so much difficulty.[2]

[1] Georges Bohn, *Revue des Idées*, 15th January 1906.

[2] It will be considered a curious proof of the narrow and timid mentality of some of our French "Dons" that two of them, namely, MM. M. Abraham and P. Langevin, having thought it useful to reprint

in two huge volumes everything that has been written on ionization and radio-activity, did not dare to allow the title of any one of my memoirs to appear there. Among these last, however, there are some, and notably one on the radio-activity which certain substances acquire by chemical reactions so simple as hydration, of which the fundamental and theoretical importance has not escaped some eminent foreign physicists, since they have taken the trouble to repeat and develop my experiments at length with due acknowledgment to the author.

BOOK II.

INTRA-ATOMIC ENERGY AND THE FORCES DERIVED THEREFROM.

CHAPTER I.

INTRA-ATOMIC ENERGY—ITS MAGNITUDE.

§ 1. *The Existence of Intra-atomic Energy.*

I HAVE given the name of Intra-atomic Energy to the new force, differing entirely from those hitherto observed, which is produced by the dissociation of matter—that is to say, by the whole series of radio-active phenomena. From the chronological point of view, I ought evidently to commence by describing this dissociation; but as intra-atomic energy governs all the phenomena examined in this work, it seems to me preferable to begin by its study.

I shall therefore suppose an acquaintance with the facts concerning the dissociation of matter which I shall set forth later, and shall confine myself at present to recalling one of the most fundamental of these facts—the emission into space, from bodies undergoing dissociation, of immaterial particles animated by a speed capable of equalling and even of often exceeding a third of the speed of light. That speed is immensely superior to any we can produce by the aid of the known forces at our disposal. This is a point which must be steadily kept in mind from the first. A few figures will suffice to make this difference evident.

A very simple calculation shows, in fact, that to give a small bullet the speed of the particles emitted by matter in process of dissociation would require a firearm capable of containing one million three hundred and forty thousand barrels of gunpowder.[1] As soon as the immense speed of the particles emitted was measured by the very simple methods I describe elsewhere, it became evident that an enormous amount of energy is liberated during the

[1] Here are the particulars of this calculation:—

Determination of the expenditure of energy necessary to give to a material mass a speed equal to that of the particles of dissociated matter.—If we leave aside the resistance of the air, which would involve complicated calculations, it is easy to determine the dimensions a material mass should possess, to acquire, under the influence of a given expenditure of energy—that, for instance, employed to launch a bullet—a velocity of the order of magnitude of that of the particles of dissociated matter. This calculation will at once show the power of intra-atomic energy.

The energy developed by an ordinary bullet animated by a speed of 640 mètres per second is given by the formula

$$T = \frac{1}{2} m V^2 = \frac{1}{2} \frac{0.015}{9.81} \times 640^2 = 313 \text{ kgm.}$$

Let us inquire the weight x to be given to a bullet for it, with the same quantity of energy, to acquire a speed of 100,000 kilometres per second *in vacuo*. This is $313 = \frac{1}{2} \frac{x}{9.81} \times 100{,}000{,}000^2$. By working out the calculation it is seen that the bullet would require to have a weight rather above 6 ten-millionths of a milligramme to equal the speed of the particles of dissociated matter, with the powder-charge necessary to launch a rifle-bullet.

With the above data, and knowing that it takes 2.75 gr. of powder to throw a Lebel bullet weighing 15 grammes, it is an easy matter to calculate that, to give this bullet a speed of 100,000 kilomètres per second 67 million kilogrammes of powder would be required—that is, 1,340,000 barrels of powder each weighing 50 kilogrammes.

dissociation of atoms. Physicists then sought in vain and many are still seeking the external source of this energy. It was understood, in fact, to be a fundamental principle that matter is inert and can only give back, in some form or other, the energy which has first been supplied to it. The source of the energy manifested could therefore only be external.

When I proved that radio-activity is a universal phenomena and not peculiar to a small number of exceptional bodies, the question became still more puzzling. But, as this radio-activity is above all manifested under the influence of external agents—light, heat, chemical forces, etc.—it is comprehensible that we should seek for the origin of this proved energy among these external causes, though there is no comparison between the magnitude of the effects produced and their supposed causes. As to spontaneously radio-active bodies, no explanation of the same order was possible, and this is why the question set forth above remained unanswered and seemed to constitute an inexplicable mystery. Yet, in reality, the solution to the problem is very simple. In order to discover the origin of the forces which produce the phenomena of radio-activity, one has only to lay aside certain classical dogmas. Let us first of all remark that it is proved by experiments that the particles emitted during dissociation possess identical characteristics, whatever the substance in question and the means used to dissociate it. Whether we take the spontaneous emission from radium or from a metal under the action of light, or again from a Crookes' tube, the particles emitted are similar. The origin of the energy which produces the observed effects seems therefore to be always the same. Not being external to matter, it can only exist within this last.

It is this energy which I have designated by the term *intra-atomic energy*. What are its fundamental characteristics? It differs from all forces known to us by its very great concentration, by its prodigious power, and by the stability of the equilibria it can form. We shall see that, if instead of succeeding in dissociating thousandths of a milligramme of matter, as at present, we could dissociate a few kilogrammes, we should possess a source of energy compared with which the whole provision of coal contained in our mines would represent an insignificant total. It is by reason of the magnitude of intra-atomic energy that radio-active phenomena manifest themselves with the intensity we observe. This it is which produces the emission of particles having an immense speed, the penetration of material bodies, the apparition of X rays, etc., phenomena which we will examine in detail in other chapters. Let us confine ourselves, for the moment, to remarking that effects such as these can be caused by none of the forces previously known. The universality in nature of *intra-atomic energy* is one of its characteristics most easy to define. We can recognize its existence everywhere, since we now discover radio-activity everywhere. The equilibria it forms are very stable, since matter dissociates so feebly that for a long time one could believe it to be indestructible. It is, besides, the effect produced on our senses by those equilibria that we call matter. Other forms of energy—light, electricity, etc., are characterized by very unstable equilibria.

The origin of intra-atomic energy is not difficult to elucidate, if one supposes, as do the astronomers, that the condensation of our nebula suffices by itself to explain the constitution of our solar system. It is conceivable that an analogous condensation of the ether may have begotten the energies contained in the atom. The latter may be roughly compared to a sphere in which a non-liquefiable gas was compressed to the degree of thousands of atmospheres at the beginning of the world.

If this new force—the most widespread and the mightiest of all those of nature—has remained entirely unknown till now, it is because, in the first place, we lacked the reagents necessary for the proof of its existence, and then, because the atomic edifice erected at the beginning of the ages is so stable, so solidly united, that its dissociation—at all events by our present means—remains extremely slight. Were it otherwise the world would long ago have vanished.

But how is it that a demonstration so simple as that of the existence of intra-atomic energy has not been made since the discovery of radio-activity, and especially since I have demonstrated the generality of this phenomenon? This can only be explained by bearing in mind that it was contrary to all known principles to recognize that matter could by itself produce energy. Now, scientific dogmas inspire the same superstitious fear as did the gods of old, though they have at times all their liability to be broken.

§ 2. *Estimate of the Quantity of Intra-atomic Energy contained in Matter.*

I have said a few words as to the magnitude of intra-atomic energy. Let us now try to measure it.

The following figures will show that, whatever may be the method adopted, we arrive, by measuring the energy liberated by a given weight of dissociated matter, at totals immensely superior to all those obtained by hitherto known chemical reactions—the combustion of coal, for example. It is for this reason that substances, in spite of the slightness of their dissociation, are able to produce during this phenomenon the intense effects which I have to enumerate.

The different methods in use for measuring the speed of the particles of dissociated matter, whether radium or any metal whatever, have always given nearly the same figures. This speed is almost that of light for certain radio-active emissions. For others we get a third of that speed. Let us take the lesser of these figures, that of 100,000 kilomètres per second, and endeavour, on that basis, to calculate the energy that would result from the complete dissociation of one gramme of any matter we please.

Let us take, for instance, a copper one-centime piece, weighing, as is well known, one gramme, and let us suppose that by accelerating the rapidity of its dissociation we could succeed in totally dissociating it.

The kinetic energy possessed by a body in motion being equal to half the product of its mass by the square of its speed, an easy calculation gives the power which the particles of this gramme of matter, animated by the speed we have supposed, would represent. We have, in fact,

$$T = \frac{0.001^{k}}{9.81} \times \frac{1}{2} \times \overline{100,000,000}^{2} = 510 \text{ thousand.}$$

millions of kilomètres, figures which correspond to about six thousand eight hundred million horse-power if this gramme of matter were stopped in a second. This amount of energy, suitably disposed, would be sufficient to work a goods train on a horizontal line equal in length to a little over four times and a quarter the circumference of the earth.[1]

To send this same train over this distance by means of coal would take 2,830,000 kilogrammes, which at 24 francs a ton, would necessitate an expenditure of about 68,000 francs. This amount of 68,000 francs represents, therefore, the commercial value of the intra-atomic energy contained in a one-centime coin.

What determines the greatness of the above figures and makes them at first sight improbable is the enormous speed of the masses in play, a speed which we cannot approach by any known mechanical means. In the factor mV^2, the mass of one gramme is certainly very small, but the speed being immense the effects produced become equally immense. A rifle-ball falling on the skin from the height of a few centimètres produces no appreciable effect in consequence of its slight speed. As soon as this speed is increased, the effects become more and more deadly, and, with the speed of 1000 mètres per second given by the powder now employed, the

[1] I take, in this calculation, a normal goods train, comprising 40 trucks of 12½ tons, say, a weight of 500 tons, journeying at a speed of 36 kilomètres per hour on the level, and necessitating a haulage force of 6 kilogrammes per ton per second—or 3000 kilogrammes for the 500 tons. The force given out by the engine pulling this train at a speed of 36 kilomètres would amount to 400 h.p. At the rate of 1½ kilos of coal per unit and per hour, there would be consumed in 4,722 hours (duration of the journey) $4,722 \times 400 \times 1.5 = 2,830,000$ kilogrammes.

bullet will pass through very resistant obstacles. To reduce the mass of a projectile matters nothing if one arrives at a sufficient increase in speed. This is exactly the tendency of modern musketry, which constantly reduces the calibre of the bullet but endeavours to increase its speed.

Now the speeds which we can produce are absolutely nothing compared with those of the particles of dissociated matter. We can barely exceed a kilomètre per second by the means at our disposal, while the speed of radio-active particles is 100,000 times greater. Thence the magnitude of the effects produced. These differences become plain when one knows that a body having a velocity of 100,000 kilomètres per second would go from the earth to the moon in less than four seconds, while a cannon ball would take about five days.

Taking into account a part only of the energy liberated in radio-activity, and by a different method, figures inferior to those given above, but still colossal, have been arrived at. The measurements of Curie prove that one gramme of radium emits 100 calorie-grammes an hour, which would give 876,000 calories per annum. If the life of a gramme of radium is 1000 years, as is supposed, by transforming these calories into kilogrammètres at the rate of 1125 kilogrammètres per great calorie, the immensity of the figures obtained will readily appear. Necessarily, these calories, high as is their number, only represent an insignificant part of the intra-atomic energy, since the latter is expended in various radiations.

The fact of the existence of a considerable condensation of energy within the atoms only seems to jar on us because it is outside the range of things formerly taught us by experience; it should, however, be remarked that, even leaving on one side the facts revealed by radio-activity, analogous concentrations are daily observable. Is it not strikingly evident, in fact, that electricity must exist at an enormous degree of accumulation in chemical compounds, since it is found by the electrolysis of water that one gramme of hydrogen possesses an electric charge of 96,000 coulombs? One gets an idea of the degree of condensation at which the electricity existed before its liberation, from the fact that the quantity above mentioned is immensely superior to what we are able to maintain on the largest surfaces at our disposal. Elementary treatises have long since pointed out that barely a twentieth part of the above quantity would suffice to charge a globe the size of the earth to a potential of 6000 volts. The best static machines in our laboratories hardly give forth $\frac{1}{10,000}$ of a coulomb per second. They would have, consequently, to work unceasingly for a little over thirty years to give the quantity of electricity contained within the atoms of one gramme of hydrogen.[1]

As electricity exists in a state of considerable concentration in chemical compounds, it is evident that the atom might have been regarded long since as a veritable condenser of energy. To grasp thereafter the notion that the quantity of this energy must be enormous, it was only necessary to appreciate the magnitude of the attractions and repulsions which

[1] They would indeed make this output at tensions of about 50,000 volts, so that the power produced (volts × ampères) would greatly exceed, at the end of thirty years, the power generated by 96,000 coulombs under a pressure of one volt.

are produced by the electric charges before us. It is curious to note that several physicists have touched the fringe of this question without perceiving its consequences. For example, Cornu pointed out that if it were possible to concentrate a charge of one coulomb on a very small sphere, and to bring it within one centimètre of another sphere likewise having a charge of one coulomb, the force created by this repulsion would equal 9^{18} dynes, or about 9 billions of kilogrammes.[1]

Now, we have seen above that by the dissociation of water we can obtain from one gramme of hydrogen an electric charge of 96,000 coulombs. It would be enough—and this is exactly the hypothesis lately enunciated by J. J. Thomson—to dispose the electric particles at suitable distances within the atom, to obtain, through their attractions, repulsions, and rotations, extremely powerful energies in an extremely small space. The difficulty was not, therefore, in conceiving that a great deal of energy could remain within an atom. It is even surprising that a notion so evident was not formulated long since.

Our calculation of radio-active energy has been made within those limits of speed at which ex-

[1] These figures of Cornu's only give the amount of the force of repulsion between the two spheres. We can calculate the amount of power such a force as the above would yield in given conditions of time and space. If we suppose that the distance between the two spheres passes under the influence of the force in question at from 1 centimètre to 1 decimètre in 1 second, the power produced will be represented in C. G. S. units by the formula—

$$T = \int_{1}^{10} F\,ds = 9.10^{18} \int_{1}^{10} \frac{ds}{s^2} = 8.1 \times 10^{18} \text{ ergs.}$$

Converted into kilogrammètres, this formula gives 82 thousand million and a half kilogrammètres, or over one thousand millions h.p. per second.

periments show that the inertia of these particles does not sensibly vary, but it is possible that one cannot assimilate their inertia—though this is generally done—to that of material particles, and then the figures given might be different. But they would none the less be extremely high. Whatever the methods adopted and the elements of calculation employed—velocity of the particles, calories emitted, electric attractions, etc.—one arrives at figures differing from each other indeed, but all extraordinarily high. Thus, for example, Rutherford fixes the energy of the α particles of thorium at six hundred million times that of a rifle-ball. Other physicists who, since the publication of one of my papers have gone into the subject, have reached figures sometimes very much higher. Assimilating the mass of electrons to that of the material particles, Max Abraham arrives at this conclusion: "That the number of electrons sufficient to weigh one gramme carry with them an energy of 6×10^{13} joules." Reducing this figure to our ordinary unit, it will be seen to represent about 80,000,000,000 horse-power per second, about twelve times greater than the figures I found for the energy emitted by one gramme of particles with a speed of 100,000 kilomètres per second.

J. J. Thomson also has gone into estimates of the magnitude of the energy contained in the atom, starting with the hypothesis that the material atom is solely composed of electric particles. His figures, though also very high, are lower than those just given. He finds that the energy accumulated in one gramme of matter represents 1.02×10^{19} ergs, which would be about 100,000,000,000 kilogrammètres.[1] These figures only represent, according to him, "an exceedingly small fraction" of that possessed by the atoms at the beginning and gradually lost by radiation.

§ 3. *Forms under which Energy can be Condensed in Matter.*

Under what forms can intra-atomic energy exist, and how can such colossal forces have been concentrated in very small particles? The idea of such a concentration seems at first sight inexplicable, because our ordinary experience tells us that the extent of mechanical power is always associated with the dimensions of the apparatus concerned in its production. A 1000 h.p. engine is of considerable volume. By association of ideas we are therefore led to believe that the extent of mechanical energy implies the extent of the apparatus which produces it. But this is a pure illusion consequent on the weakness of our mechanical systems, and easy to dispel by very simple calculations. One of the most elementary formulas of dynamics teaches us that the energy of a body of constant size can be increased at will by simply increasing its speed. It

[1] *Electricity and Matter*, 1904. J. J. Thomson arrives at this figure by supposing the atom to be composed of negative electrons distributed within a sphere charged with a like quantity of positive electricity, and inquires the work necessary to separate them. Calling n the number of electrons in the atom (1000 for hydrogen), a the radius of the atom (10^{-8} cm. according to the kinetic theory of gases), e the charge in electro-static units of each electron (3.4×10^{-10}), N the number of atoms contained in 1 gramme ($10.2 \times 10^{7} \times \frac{n}{a}$), we obtain, for the quantity of energy contained in 1 gramme of hydrogen, the formula:

$$N \frac{(n e)^2}{a} = 1.02 \times 10^{19} \text{ ergs.}$$

is therefore possible to imagine a theoretical machine composed of the head of a pin turning round in the bezel of a ring, which, notwithstanding its smallness, should possess, thanks to its rotative force, a mechanical power equal to that of several thousands of locomotives.

To fix our ideas, let us suppose a small bronze sphere (density 8.842), with a radius of three millimètres and consequently of one gramme in weight. Let us suppose that it rotates in space round one of its diameters with an equatorial speed equal to that of the particles of dissociated matter (100,000 kilogrammes per second), and that, by some process or other, the rigidity of the metal has been made sufficient to resist this rotation. Calculating the *vis viva* of this sphere it will be seen to correspond to 203,873,000,000 kilogrammètres. This is nearly the work that 1,510 locomotives averaging 500 h.p.[1] apiece would supply in an hour. Such is

[1] I have calculated these figures in the following manner:—

The *vis viva* of an invariable solid which turns round an axis at an angular speed ω is expressed by

$$T = \frac{1}{2}\Sigma mv^2 = \frac{\omega^2}{2}\Sigma mr^2 = \frac{\omega^2}{2} I$$

The I designating the moment of inertia of the solid. In order to calculate it, the motion of the solid is brought down to a system of rectangular co-ordinates in which the axis of rotation is taken as the axis of the z. The moment of inertia I is then given by the following formula:—

$$I = \iiint m\,(x^2 + y^2)\,dx\,dy\,dz$$

In the special case under consideration of a homogeneous sphere with a radius R and a specific weight P, this integral has a value of

$$I = \frac{8}{15}\pi\frac{P}{g}R^5$$

which gives as the expression of the energy

$$T = \frac{4}{15}\pi\frac{P}{g}R^5\omega^2$$

the amount of energy that could be contained in a very small sphere animated by a rotatory movement of which the speed should be equal to that of the particles of dissociated matter. If the same little ball turned on its own centre with the velocity of light (300,000 kilogrammes per second) which represents about the speed of the β particles of radium, its *vis viva* would be nine times greater. It would exceed 1,800,000,000,000 kilogrammètres and represent the work of one hour by 13,590 locomotives, a number exceeding all the locomotives on all the French lines.[1]

It is precisely these excessively rapid movements of rotation on their axis and round a centre that the elements which constitute the atoms seem to possess, and it is their speed which is the origin of the energy they contain. We have been led to suppose the existence of these movements of rotation by various mechanical considerations much anterior to the discoveries of the present day. These last have simply confirmed former ideas and have re-trans-

[1] Previously, we simply examined the energy of a gramme of dissociated matter, animated, not with the movement of rotation we have just supposed, but with a movement of progression in a straight line such as is observed in the emission of cathode rays.

In this last case the figures were even greater than those I have just given for a sphere one gramme in weight turning on its axis with a velocity of 100,000 kilomètres per second.

The calculation shows, in fact, that the energy of a sphere in rotation represents only 2/5ths of that which would be possessed by the same sphere animated by a speed of translation equal to the equatorial velocity which was first supposed:—

$$\omega^2 \Sigma mr^2 = \frac{2}{5} \Sigma m V^2$$

This is only a consequence of the well-known fact that the square of the radius of gyration of a sphere is 2/5ths of the square of the radius of this sphere.

ferred to the elements of the atom the motion which was attributed to the atom itself at a time when it was considered indivisible. It is only, no doubt, because they possess such velocities of rotation that the elements which constitute the atoms can, when leaving their orbits under the influence of various causes, be launched at a tangent through space with the velocities observed in the emissions of particles of matter in course of dissociation.

The rotation of the elements of the atom is moreover the very condition of their stability, as it is for a top or for a gyroscope. When under the influence of any cause the speed of rotation falls below a certain critical point, the equilibrium of the particles becomes unstable, their kinetic energy increases and they may be expelled from the system, a phenomenon which is the commencement of the dissociation of the atom.

§ 4. *The Utilization of Intra-atomic Energy.*

The last objections to the doctrine of intra-atomic energy are daily disappearing, and it is now hardly contested that matter is a prodigious reservoir of energy; while the search for the means of easily liberating this energy will surely be one of the most important problems of the future. It is important to notice that, although the numbers above arrived at in various ways point out the existence in matter of immense forces—so unforeseen hitherto—they by no means imply that these forces are already at our disposal. In fact the substances which dissociate quickest, like radium, only disengage very minute quantities of energy. All those millions of kilogrammètres which a simple gramme of matter contains amount in reality to very little if, to obtain them, we have to wait millions of years. Suppose a strong box containing several thousand millions of gold dust to be closed by a mechanism which only permits the daily extraction of a milligramme of the precious metal. The owner of that strong box, notwithstanding his great wealth, would be in reality very poor, and would remain so, so long as his efforts to discover the secret of the mechanism by which he could open it were unsuccessful.

This is our position as regards the forces enclosed in matter. But, to succeed in capturing them, it was first necessary to be acquainted with their existence, and of this one had not the least idea a few years ago. It was even thought very certain that they did not exist. But shall we succeed in easily liberating the colossal power which the atoms conceal in their bosom? No one can foresee this. No more could any one say in the days of Galvani that the electrical energy which enabled him to move with difficulty the legs of frogs and to attract small scraps of paper would one day set in motion enormous railway trains. It will perhaps always be beyond our power to totally dissociate the atom, because the difficulties must increase as dissociation advances, but it would suffice if we could succeed in easily dissociating a small part of it. Whether the gramme of dissociated matter that we have supposed be taken from a ton of matter or even more, matters nothing. The result would always be the same from the point of view of the energy produced. The researches which I have essayed on these lines, and which will be set forth here, show that it is possible to largely hasten the dissociation of various substances.

The methods of dissociation are, as we shall see, numerous. The most simple is the action of light. It has further the advantage of costing nothing. In so fresh a field, with a new world opening out before us, none of our old theories should stop those who seek. "The secret of all who make discoveries," says Liebig, "is that they look upon nothing as impossible." The results that could be obtained in this order of researches are truly immense. The power to dissociate matter freely would place at our disposal an infinite source of energy, and would render unnecessary the extraction of that coal whereof the provision is rapidly becoming exhausted. The scholar who discovers the way to liberate economically the forces which matter contains will almost instantaneously change the face of the world. If an unlimited supply of energy were gratuitously placed at the disposal of man he would no longer have to procure it at the cost of arduous labour. The poor would then be on a level with the rich, and there would be an end to all social questions.

CHAPTER II.

TRANSFORMATION OF MATTER INTO ENERGY.

MODERN science formerly established a complete separation between matter and energy. The classic ideas on this scission will be found very plainly stated in the following passage of a recent work by Professor Janet:—

"The world we live in is, in reality, a double world; or, rather, it is composed of two distinct worlds: one the world of matter, the other the world of energy. Copper, iron, and coal are forms of matter, mechanical labour and heat are forms of energy. These two worlds are each ruled by one and the same law. Matter can neither be created nor destroyed. Energy can neither be created nor destroyed.

"Matter and energy can assume various forms without matter ever transforming itself into energy or energy into matter. . . . We can no more conceive energy without matter than we can conceive matter without energy."[1]

Never, in fact, as says M. Janet, has it been possible till now to transform matter into energy; or, to be more precise, matter has never appeared to manifest any energy save that which had first been supplied to it. Incapable of creating energy, it could only give it back. The fundamental principles of thermodynamics taught that a material system isolated from all external action cannot spontaneously generate energy.

[1] Janet, *Leçons d'électricité*, 2nd edition, pp. 2 and 5.

All previous scientific observations seemed to confirm this notion that no substance is able to produce energy without having first obtained it from outside. Matter may serve as a support to electricity, as in the case of a condenser; it may radiate heat as in the case of a mass of metal previously heated; it may manifest forces produced by simple changes of equilibrium as in the case of chemical transformations; but in all these circumstances the energy disengaged is but the restitution in quantity exactly equal to that first communicated to the portion of matter or employed in producing the combination. In all the cases just mentioned, as in all others of the same order, matter does no more than give back the energy which had first been given to it in some shape or other. It has created nothing, nothing has gone forth from itself.

The impossibility of transforming matter into energy seemed therefore evident, and it was rightly invoked in the works which have become classic to establish a sharp separation between the world of matter and the world of energy. For this separation to disappear, it was necessary to succeed in transforming matter into energy without external addition. Now, it is exactly this spontaneous transformation of matter into energy which is the result of all the experiments on the dissociation of matter set forth in this work. We shall see from them that matter can vanish without return, leaving behind it only the energy produced by its dissociation. The spontaneous production of energy thus established, a production so contrary to the scientific ideas of the present time, appeared at first entirely inexplicable to physicists busied in seeking outside matter and failing to find it, the origin of the energy manifested. We have shown that the explanation becomes very simple so soon as one consents to recognize that matter contains a reservoir of energy which it can lose in part, either spontaneously or by the effect of slight influences.

These slight influences act somewhat like a spark on a quantity of gunpowder—that is to say, by liberating energies far beyond those of the spark. Strictly it might be urged, doubtless, that in that case it is not matter which transforms itself into energy, but simply an intra-atomic energy which is expended; but as this matter cannot be generated without matter vanishing without return, we have a right to say that *things happen exactly as if matter were transformed into energy.*

Such a transformation becomes, moreover, very comprehensible so soon as one is thoroughly penetrated with the idea that matter is simply that form of energy endowed with stability which we have called intra-atomic energy. It results from this that when we say that matter is transformed into energy, it simply signifies that intra-atomic energy has changed its aspect to assume those divers forms to which we give the names of light, electricity, etc. And if, as we have shown above, a very small quantity of matter can produce, in the course of dissociation, a large amount of energy, it is because one of the most characteristic properties of the intra-atomic forces is their condensation, in immense quantities, within an extremely circumscribed space. For an analogous reason a gas compressed to a very high degree in a very small reservoir can give a considerable volume of gas when the tap is opened which before prevented its escape.

The preceding notions were quite new when I formulated them for the first time. Several physicists are now arriving at them by different ways, but they do not reach them without serious difficulties, because some of these new notions are extremely hard to reconcile with certain classic principles. Many scholars have as much trouble in admitting them as they experienced fifty years ago in acknowledging as exact the principle of the conservatism of energy. Nothing is more difficult than to rid oneself of the inherited ideas which unconsciously direct our thoughts.

These difficulties may be appreciated by reading a recent communication from one of the most eminent of living physicists, Lord Kelvin, at a meeting of the British Association, regarding the heat spontaneously given out by radium during its dissociation. Yet this emission is no more surprising than the continuous emission of particles having a speed of the same order as that of light, which can be obtained not only from radium, but from any substance whatever.

"It is utterly impossible," writes Lord Kelvin, "that the heat produced can proceed from the stored energy of radium. It therefore seems to me absolutely certain that if the emission of heat continues at the same rate, this heat must be supplied from outside."[1]

And Lord Kelvin falls back upon the common-place

[1] *Philosophical Magazine*, February 1904, p. 122. Lord Kelvin, however, withdrew this at the Cambridge Meeting of the British Association (1904), and admitted that the whole energy of radio-active bodies must be self-contained.—F. L.

hypothesis formed at the outset on the origin of the energy of radio-active bodies, which were attributable, as it was thought, to certain mysterious forces from the ambient medium. This supposition had no experimental support. It was simply the theoretical consequence of the idea that matter, being entirely unable to create energy, could only give back what had been supplied to it. The fundamental principles of thermodynamics which Lord Kelvin has helped so much to found, tell us, in fact, that a material system isolated from all external action cannot spontaneously generate energy. But experiment has ever been superior to principles, and when once it has spoken, those scientific laws which appeared to be the most stable are condemned to rejoin in oblivion, the used-up, out-worn dogmas and doctrines past service.

Other and bolder physicists, like Rutherford, after having admitted the principles of intra-atomic energy, remain in doubt. This is what the latter writes in a paper later than his book on radio-activity:—

> "It would be desirable to see appear some kind of chemical theory to explain the facts, and to enable us to know whether the energy is borrowed from the atom itself or from external sources."[1]

Many physicists then, like Lord Kelvin, still keep to the old principles: that is why the phenomena of radio-activity, especially the spontaneous emission of particles animated with great speed and the rise in temperature during radio-activity, seem to them utterly unexplicable, and constitute a scientific enigma, as M. Mascart has recently said. The enigma, however, is very simple with the explanation I have given.

[1] *Archives des Sciences physiques de Genève*, 1905, p. 53.

One could not hope, moreover, that ideas so opposed to classic dogmas as intra-atomic energy and the transforming of matter into energy should spread very rapidly. It is even contrary to the usual evolution of scientific ideas that they should be already widely spread, and should have produced all the discussions of which a summary will be found in the chapter devoted to the examination of objections. One can only explain this relative success by remembering that faith in certain scientific principles had already been greatly shaken by such unforeseen discoveries as those of the X rays and of radium.

The fact is that the scientific ideas which rule the minds of scholars at various epochs have all the solidity of religious dogmas. Very slow to be established, they are very slow likewise to disappear. New scientific truths have, assuredly, experience and reason as a basis, but they are only propagated by prestige—that is, when they are enunciated by scholars whose official position gives them prestige in the eyes of the scientific public. Now, it is this very category of scholars which not only does not enunciate them, but employs its authority to combat them. Truths of such capital importance as Ohm's law, which governs the whole of electricity, and the law of the conservation of energy which governs all physics, were received, on their first appearance, with indifference or contempt, and remained without effect until the day when they were enunciated anew by scholars endowed with influence.

It is only by studying the history of sciences, so little pursued at the present date, that one succeeds in understanding the genesis of beliefs and the laws governing their diffusion. I have just alluded to two discoveries which were among the most important of the past century, and which are summarized in two laws, of which one can say that they ought to have appealed to all minds by their marvellous simplicity and their imposing grandeur. Not only did they strike no one, but the most eminent scholars of the epoch did not concern themselves about them except to try to cover them with ridicule.[1]

That the simple enunciation of such doctrines should have appealed to no one shows with what difficulty a new idea is accepted when it does not fit in with former dogmas. Prestige, I repeat, and to a very slight extent experience are alone the ordinary foundation of our convictions—scientific and otherwise. Experiments—even those most convincing in

[1] When Ohm discovered the law which will immortalize his name, and on which the whole science of electricity rests, he published it in a book filled with experiments so simple and so conclusive that they might have been understood by any pupil in an elementary school. Not only did he fail to convince any one, but the most influential scholars of his time treated him in such a way that he lost the berth he occupied, and, to avoid dying of starvation, was only too glad to take a situation in a college at 1,200 francs per annum, where he remained for six years. Justice was only rendered to him at the close of his life. Robert Mayer, less fortunate, did not even obtain this tardy satisfaction. When he discovered the most important of modern scientific laws, that of the conservation of energy, he had great difficulty in finding a review which would consent to publish his memoir, but no scholar bestowed the least attention upon it; any more, in fact, than on his subsequent publications, among them the one on the mechanical equivalent of heat, published in 1850. After attempting suicide, Mayer went out of his mind, and remained for a long time unknown, to such a degree that when Helmholtz re-made the same discovery, he was not aware that he had been forestalled. Helmholtz himself did not meet with any greater encouragement at the outset, and the most important of the scientific journals of that epoch, the *Annales de Poggendorff*, declined to insert his celebrated memoir, "The Conservation of Energy," regarding it as a fanciful speculation unworthy the attention of serious readers.

appearance—have never constituted an immediately demonstrable foundation when they clashed with long since accepted ideas. Galileo learned this to his cost, when, having brought together all the philosophers of the celebrated University of Pisa, he thought to prove to them by experiment that, contrary to the then accepted ideas, bodies of different weights fell with the same velocity. Galileo's demonstration was assuredly very conclusive, since by letting fall at the same moment from the top of a tower a small leaden ball and a cannon-shot of the same metal, he showed that both bodies reached the ground together. The professors contented themselves with appealing to the authority of Aristotle, and in nowise modified their opinions.

Many years have passed away since that time, but the degree of receptivity of minds for new things has not sensibly increased.

CHAPTER III.

FORCES DERIVED FROM INTRA-ATOMIC ENERGY—MOLECULAR FORCES, ELECTRICITY, SOLAR HEAT, ETC.

§ 1. *The Origin of Molecular Forces.*

ALTHOUGH matter was formerly considered inert, and only capable of preserving and restoring the energy which had first been given to it, yet it was necessarily established that there existed within it forces sometimes considerable, such as cohesion, affinity, osmotic attractions and repulsions, which were seemingly independent of all external agents. Other forces, such as radiant heat and electricity, which also issued from matter, might be considered simple restitutions of an energy borrowed from outside.

But if the cohesion which makes a rigid block out of the dust of atoms of which bodies are formed, or if that affinity which draws apart or dashes certain elements one upon the other and creates chemical combinations, or if the osmotic attractions and repulsions which hold in dependency the most important phenomena of life, are visibly forces inherent to matter itself, it was altogether impossible with the old ideas to determine their source. The origin of these forces ceases to be mysterious when it is known that matter is a colossal reservoir of energy. Observation having long ago shown that any form of energy whatever lends itself to a large number of transformations, we easily conceive how, from intra-atomic energy may be derived all the molecular forces: cohesion, affinity, etc., hitherto so inexplicable. We are far from being acquainted with their character, but at least we see the source from which they spring.

Outside the forces plainly inherent to matter that we have just enumerated, there are two, electricity and solar heat, the origin of which has always remained unknown, and which also, as we shall see, find an easy explanation by the theory of intra-atomic energy.

§ 2. *The Origin of Electricity.*

When we approach the detailed study of the facts on which are based the theories set forth in this work, we shall find that electricity is one of the most constant manifestations of the dissociation of matter. Matter being nothing else than intra-atomic energy itself, it may be said that to dissociate matter is simply to liberate a little intra-atomic energy and to oblige it to take another form. Electricity is precisely one of these forms.

For a certain number of years the rôle of electricity has constantly grown in importance. It is at the base of all chemical reactions, which are more and more considered as electrical reactions. It appears now as a universal force, and the tendency is to connect all other forces with it. That a force of which the manifestations have this importance and universality should have been unknown for thousands of years constitutes one of the most striking facts in the history of science, and is one of those facts we must always bear in mind to understand how we may be surrounded with very powerful forces without perceiving them.

For centuries all that was known about electricity could be reduced to this: that certain resinous substances when rubbed attract light bodies. But might not other bodies enjoy the same property? By extending the friction to larger surfaces might not more intense effects still be produced? This no one thought of inquiring. Ages succeeded each other before there arose a mind penetrating enough to ask itself such questions, and inquisitive enough to verify by experiment whether a body with a large surface when rubbed would not exercise an action superior in energy to that produced by a small fragment of the same body. From this verification which now seems so simple, but which took so many years to accomplish, we saw emerge the frictional electric machine of our laboratories and the phenomena it produces. The most striking of these were the apparition of sparks and violent discharges which revealed to an astonished world a new force and put into the hands of man a power of which he thought the gods alone possessed the secret.

Electricity was then only produced very laboriously and was considered a very exceptional phenomenon. Now we find it everywhere and know that the simple contact of two heterogeneous bodies suffices to generate it. The difficulty now is not how to produce electricity, but how not to give it birth during the production of any phenomenon whatever. The falling of a drop of water, the heating of a gaseous mass by the sun, the raising of the temperature of a twisted wire, and a reaction capable of modifying the nature of a body, are all sources of electricity.

But if all chemical reactions are electrical reactions, as is now said to be the case, if the sun cannot change the temperature of a body without disengaging electricity, if a drop of water cannot fall without producing it, it is evident that its rôle in the life of all beings must be preponderant. This, in fact, is what we are beginning to admit. Not a single change takes place in the cells of the body, no vital reaction is effected in the tissues, without the intervention of electricity. M. Berthelot has recently shown the important rôle of the electric tensions to which plants are constantly subjected. The variations in the electric potential of the atmosphere are enormous, since they may oscillate between 600 and 800 volts in fine weather, and rise to 15,000 volts at the least fall of rain. This potential increases at the rate of from 20 to 30 volts per mètre in height in fine and from 400 to 500 volts in rainy weather for the same elevation. "These figures," he says, "give an idea of the potential which exists either between the upper point of a rod of which the other extremity is earthed, or between the top of a plant or a tree, and the layer of air in which that point or that top is bathed." The same scholar has proved that the effluves generated by these differences of tension can provoke numerous chemical reactions: the fixation of nitrogen on hydrates of carbon, the dissociation of carbonic acid into carbonic oxide and oxygen, etc.

After having established the phenomenon of the general dissociation of matter, I asked myself if the universal electricity, the origin of which remained unexplained, was not precisely the consequence of the universal dissociation of matter. My experiments fully verified this hypothesis, and they proved that electricity is one of the most important forms of intra-atomic energy liberated by the dematerialization of matter. I was led to this conclusion after having satisfied myself that the products which escape from a body electrified at sufficient tension are entirely identical with those given out by radioactive substances on the road to dissociation. The various methods employed to obtain electricity, notably friction, only hasten the dissociation of matter. I shall refer, for the details of this demonstration, to the chapter treating of the subject,[1] confining myself at present to pointing out summarily the different generalizations which flow from the doctrine of intra-atomic energy. It is not electricity alone, but also solar heat, which, as we shall see, may be considered one of its manifestations.

§ 3. *Origin of Solar Heat.*

As we have fathomed the study of the dissociation of matter, so has the importance of this phenomenon proportionately increased. After recognizing that electricity may be considered one of the manifestations of the dissociation of matter, I asked myself whether this dissociation and its result, the liberation of intra-atomic energy, were not also the cause, till now so unknown, of the maintenance of solar heat. The various hypotheses hitherto invoked to explain the maintenance of this heat—the supposed fall of meteorites on the sun, for example—having all seemed extremely inadequate,

[1] Pp. 198 *et seq. infra.*

it was necessary to seek others. Given the enormous quantity of energy accumulated within the atoms, it would be enough, if their dissociation were more rapid than it is on the cooled globes, to furnish the amount of heat necessary to keep up the incandescence of the stars. And there would be no need to presume, as was done when radium was supposed to be the only body capable of producing heat while dissociating, the unlikely presence of that substance in the sun, since the atoms of all bodies contain an immense store of energy.

To maintain that stars such as the sun can keep up their own temperature by the heat resulting from the dissociation of their component atoms, seems much like saying that a heated body is capable of maintaining its temperature without any contribution from outside. Now, it is well known that an incandescent body—a heated block of metal, for instance—when left to itself rapidly cools by radiation, though it be the seat of considerable atomic dissociation. But it cools, in fact, simply because the rise in temperature produced by the dissociation of its atoms during incandescence is far too slight to compensate for its loss of heat by radiation. The substances which, like radium, most rapidly dissociate, can hardly maintain their temperature at more than 3° to 4°C. above that of the ambient medium. Suppose, however, that the dissociation of any substance whatever were only one thousand times more rapid than that of radium, then the quantity of energy emitted would more than suffice to keep it in a state of incandescence.

The whole question therefore is whether, at the origin of things—that is to say, at the epoch when atoms were formed by condensations of an unknown nature, they did not possess such a quantity of energy that they have been able ever since to maintain the stars in a state of incandescence, thanks to their slow dissociation. This supposition is supported by the various calculations I have given as to the immense amount of energy contained within the atoms. The figures given are considerable, and yet J. J. Thomson, who has recently taken up the question anew, arrives at the conclusion that the energy now concentrated within the atoms is but an insignificant portion of that which they formerly contained and lost by radiation. Independently and at an earlier date, Professor Filippo Ré arrived at the same conclusion.

If, therefore, atoms formerly contained a quantity of energy far exceeding the still formidable amount they now possess, they may, by dissociation, have expended during long accumulations of ages a part of the gigantic reserve of forces piled up within them at the beginning of things. They may have been able, and consequently may still be able, to maintain at a very high temperature stars like the sun and the heavenly bodies. In the course of time, however, the store of intra-atomic energy within the atoms of certain stars has at length been reduced, and their dissociation has become slower and slower. Finally, they have acquired an increasing stability, have dissociated very slowly, and have become such as one observes them to-day in the shape of cooled stars like the earth and other planets.

If the theories formulated in this chapter be correct, the intra-atomic energy manifested during the dematerialization of matter constitutes the fundamental element whence most other forces are derived.

So that it is not only electricity which is one of its manifestations, but also solar heat, that primary source of life and of the majority of the forces at our disposal. Its study, which reveals to us matter in a totally new aspect, already permits us to throw unforeseen light on the higher mechanics of our universe.

CHAPTER IV.

THE OBJECTIONS TO THE DOCTRINE OF INTRA-ATOMIC ENERGY.

THE criticisms called forth by my researches on intra-atomic energy prove that they have interested many scholars. As a new theory can only be solidly established by discussion, I thank them for their objections, and shall endeavour to answer them.

The most important has been raised by several members of the Académie des Sciences. This is what M. Henri Poincaré, one of the most eminent, wrote to me after the publication of my researches:—

"I have read your memoir with the greatest interest. It raises a number of disturbing questions. One point to which I should like to call your attention is the opposition between your conception of the origin of solar heat and that of Helmholtz and Lord Kelvin.

"When the nebulæ condenses into a sun its original potential energy is transformed into heat subsequently dissipated by radiation.

"When the *sub-atoms* unite to form an atom this condensation stores up energy in a potential form, and it is when the atom disaggregates that this energy reappears in the form of heat (disengagement of heat by radium).

"Thus the reaction, 'nebula to sun,' is exothermic. The reaction 'isolated sub-atoms to atoms' is endothermic, but if this 'combination' is endothermic how comes it to be so extraordinarily stable?"

Another member of the Académie des Sciences,

M. Paul Painlevé, formulates the same objection, as follows:—

"Thermodynamics teaches us the modifications which must be introduced into the celebrated principle of maximum work; we know that in a chemical combination stability and exothermism are not strictly synonymous. None the less there remains the possibility that a 'combination' at the same time extraordinarily stable and extraordinarily endothermic is something contrary, not indeed to the principle of the conservation of energy, but to the whole body of facts which up to recent times have been scientifically established."[1]

M. Naquet, late Professor of Chemistry at the Faculté de Médecine of Paris, who was unacquainted with M. Poincaré's conclusions, expressed the same objection.

"There is one point, however, which I find embarrassing, especially if I adopt the most seductive of all hypotheses, that of Gustave Le Bon. . . . If the atoms disengage heat in the process of self-destruction they are endothermic, and, by analogy, should be excessively unstable. Now, on the contrary, they are the most stable things in the universe.

"Here is a troublesome contradiction. We should not, however, attach to this difficulty more importance than it possesses. Every time great systems have arisen difficulties of this kind have occurred. The authors of such systems have paid no attention to them. If Newton and his successors had allowed the perturbations they observed to stop them, the law of universal gravitation would never have been formulated."[2]

The objection of MM. Henri Poincaré, Painlevé, and Naquet is evidently sound. It would be irrefutable were it applied to ordinary chemical compounds, but the laws applicable to the chemical equilibria of molecules do not appear to apply at all to intra-atomic equilibria. The atom alone possesses

[1] *Revue Scientifique*, 27th January 1906.
[2] *Revue d'Italie*, March and April 1904.

these two contradictory properties, of being at once very stable and very instable. It is very stable, since chemical reactions leave it sufficiently untouched for our balances to find it always the same weight. It is very instable, since such slight causes as a ray of the sun, or the smallest rise in temperature suffice to begin its dissociation. This dissociation is, no doubt, slight—in relation to the enormous quantity of energy accumulated within the atom, and it no more changes its mass than a shovelful of earth withdrawn from a mountain appreciably changes the weight of the latter. Yet the change is certain. We, therefore, have to do with special phenomena to which none of the customary laws of ordinary chemistry seem to apply. To put in evidence the special laws which regulate these new facts cannot be the work of a day. To interpret a fact is sometimes more difficult than to discover it.

M. Armand Gautier, Member of the Institut and Professor of Chemistry at the Faculté de Médecine of Paris, has also taken up the question of *intra-atomic energy* in an article published[1] by him on the subject of my researches. He recognizes that it is in the form of gyratory movements that intra-atomic energy may exist. I have not wished to enter into too many details on this point here, because it is evidently only hypothetical, and have confined myself to comparing the atom to a solar system, a comparison at which several physicists have arrived by different roads. Without such movements of gyration it would be impossible to conceive a condensation of energy within the atom. With these movements it becomes easy to explain. Find the

[1] *Revue Scientifique*, February 1904, p. 213.

means, as I have pointed out above, to give to a body of any size whatever, were it even less than that of a pin's head, a sufficient speed of rotation, and you will communicate to it as considerable a provision of energy as you can desire. This is the precise condition which is realized by particles of atoms during their dissociation.

M. Despaux, an engineer, on the contrary, entirely rejects the existence of intra-atomic energy. Here are his reasons:—

"It is the dissociation of matter which, according to Gustave Le Bon, is the cause of the enormous energy manifested in radio-activity.

"This view is quite a new one, and revolutionary in the highest degree. Science admits the indestructibility of matter, and it is the fundamental dogma of chemistry; it admits the conservatism of energy, and has made it the basis of mechanics. Here are two conquests one must then abandon. Matter transforms itself into energy and conversely.

"This conception is assuredly seductive and in the highest degree philosophical. But this transformation, if it takes place, only does so by a slow process of evolution. During any given epoch, all the phenomena studied by science lead to the belief that the quantity of matter and the quantity of energy are invariable.

"Another objection arises, and a formidable one: Is it possible that so trifling an amount of matter carries in its loins so considerable a quantity of energy? Our reason refuses to believe it."[1]

Let us leave on one side the principle of the conservation of energy, which cannot evidently be discussed in a few lines, and remains, moreover, partly intact if it be recognized that the atom, by dissociation, simply gives back the energy it has stored up, at the be-

[1] *Revue Scientifique*, 2nd January 1904.

ginning of the ages, during its formation. The objections of M. Despaux reduce themselves, then, to this: reason refuses to admit that matter can conceal so considerable a quantity of energy. I simply reply that it is a question of an experimental fact, amply proved by the emission of particles endowed with a speed of the order of that of light, and by the large quantity of calories given forth by radium. The number of things that reason at first refused to recognize and yet had in the end to admit is considerable.

However, I am willing to acknowledge that this conception of the atom as an enormous source of energy, and of such energy that one gramme of *any substance* whatever contains the equivalent of several thousand million kilogrammètres, is too much opposed to received ideas to penetrate rapidly into men's minds. But this is solely due to the fact that the intellectual moulds fashioned by education do not change easily. M. A. Duclaud has put this excellently in an article on the same subject, of which this is an extract:—[1]

"The consequences of the experiments of Gustave Le Bon, which appear to rebel against the scientific dogmas of the conservation of energy and of the indestructibility of matter, have excited numerous objections. It follows that men's minds hardly lend themselves to the admission that matter can emit spontaneously (that is, by itself and without any external aid) more or less considerable quantities of energy. This arises from that very old conception of the 'duality of force and matter' which, by bringing us to consider them two distinct terms, compels us to regard matter as by itself inert. . . . One can regard matter as non-inert, as being 'a colossal reservoir of forces that it is able to expend without

[1] *Revue Scientifique*, 2nd April 1904.

borrowing anything from outside,' without on that account attacking the principle of the conservation of energy.

"But the attack which aims at the indestructibility of matter seems more serious. Still, after due reflection, I think we should only see in this a question of words.

"As a matter of fact, Gustave Le Bon presents to us four successive stages of matter . . . while showing that everything returns to ether, he allows also that everything proceeds from it. 'Worlds are born therein, and go there to die,' he tells us.

"The ponderable issues from the ether, and returns to it under manifold influences. That is to say, the ether is a reservoir, at once the receptacle and the pourer-forth of matter. Now, unless we admit that there is a loss on the part of the ether, a leakage from the reservoir in the course of this perpetual exchange between the ponderable and the imponderable, it is impossible to conclude that there is a disappearance of any quantity of matter. And the idea of a loss on the part of the ether is inadmissible, for it leads to the absurd conclusion that that which is lost must diffuse itself outside space, since, by the hypothesis, the ether fills all space."

M. Laisant, examiner at the École Polytechnique, expresses similar views in a paper on these researches:—

"A small quantity of matter, for instance, a gramme, contains, according to Gustave Le Bon's theory, an amount of energy which, if it were liberated, would represent thousands of millions of kilogrammètres. What becomes, on this conception, of the immaterial ether in which matter is about to lose itself? It is a sort of final *nirvana*, in the words of the author, an infinite and motionless nothingness, receiving everything and giving back nothing. In the stead of this eternal cemetery of the atoms, I strive to see in the ether rather the perpetual laboratory of nature. I would even go so far as to say that it is to the atom what, in biology, protoplasm is to the cell. Everything goes to and comes forth from it. It is a form of matter, at once its original and the final form."[1]

I have no reason to contradict the two authors last

[1] "L'Enseignement mathematique," 15th January 1906.

quoted on the fate of matter when it has disappeared. All I wanted to establish, in fact, was that ponderable matter vanishes without return by liberating the enormous forces it contains. Once returned to the ether, matter has irrevocably ceased to exist, so far as we are concerned. Its individuality has completely disappeared. It has become something unrecognizable and eliminated from the sphere of the world accessible to our senses. There is assuredly a much greater distance between matter and ether than there is between carbon or nitrogen and the living beings formed from their combinations. Carbon and nitrogen can, in fact, indefinitely recommence their cycle by falling again under the laws of life; while matter returned to the ether can no more become matter again—or at least can only do so by colossal accumulations of energy which demand long successions of ages for their formation, and which we could not produce without the power attributed in the Book of Genesis to the Creator.

It is, generally, mathematicians and engineers who receive my ideas with most favour. But in his inaugural discourse as President of *l'Association Française pour l'Avancement des Sciences*, M. Laisant, quoted above, produced one of my most important conclusions, and showed all the bearing it may have in the future. It is especially abroad, however, that these ideas have found most echo. Professor Filippo Ré detailed them at length in the *Rivista di Fisica*, and in a technical review exclusively designed for engineers.[1]

[1] *Bulletin de l'Association des Ingénieurs de l'École polytechnique de Bruxelles*, December 1903.

Professor Somerhausen has devoted to them a memoir from which I will give a few extracts because they show that in many thinking minds the fundamental principles of modern science have not inspired very unshakeable convictions.

"*A Revolution in Science.*—This title is apt, for the facts and hypotheses of which we are about to treat tend to do nothing less than sap two principles we have admitted as the most unshakeable foundations of the scientific edifice. . . . If one frees oneself from the tendency to arrange new facts in already known categories, one will have to admit that the remarkable facts we have examined cannot be explained by the known modes of energy, and they must necessarily be interpreted, with Gustave Le Bon, as the manifestation of an energy hitherto unsuspected.

"We have established, on the one hand, the new phenomenon of atomic dissociation, and, on the other, the production of considerable energy without any possible explanation by known means. It is evidently logical to connect the two facts, and attribute to the destruction of the atom the freeing of the new energy—of *intra-atomic energy*.

"Gustave Le Bon supposes that the dissociated atom has acquired properties intermediate between matter and ether, and between the ponderable and the imponderable. But from the point of view of the effects, nearly everything takes place as if by a direct transformation from matter into energy. . . . We therefore see matter here appearing as a direct source of energy, which vitiates all the applications of the principle of the conservation of energy. And as we have had to admit the possibility of the destruction of matter, we have to admit the possibility of the creation of energy. We now begin to discern the possibility, by combining the terms matter and energy, of arriving at a definitive equation which may be looked upon as the highest symbol of the phenomena of the universe.

"It will certainly be one of the grandest conquests of science if we succeed, after having passed the stage of the unity of matter, in joining the domain of matter with that of energy, and thus clear away the last discontinuity in the structure of the world."

Among the objections which I ought to mention there is one which must certainly have occurred to the minds of many. It was formulated by Professor Pio, in one of the four articles he published under the title "Intra-Atomic Energy," in an English scientific review.[1] I will discuss it after reproducing a few passages from these articles.

"All the new phenomena—cathode rays, emanations from radium, etc., have been explained by the doctrine of the dissociation of matter by Gustave Le Bon. . . . The phenomenon of the dissociation of matter discovered by the latter is as marvellous as it is astounding. It has not, however, excited the same attention as the discovery of radium, because the close link which connects these two discoveries has not been perceived. . . . These experiments open a perspective to inventors which surpasses all dreams. There is in Nature an immense source of forçe which we do not know. . . . Matter is no longer inert, but a prodigious store-house of energy. . . . The theory of *intra-atomic energy* leads to an entirely new conception of natural forces. . . . Till now we have only known of forces acting on atoms from without: gravitation, heat, light, affinity, etc. Now the atom appears as a generator of energy independent of all external force. All these phenomena will serve as a foundation for a new theory of energy."

The objection of the author to which I have alluded is this:

"How is it," he asks, "that particles emitted under the influence of intra-atomic energy with an enormous speed do not render incandescent by the shock the bodies they strike, and where does the energy expended go to?" The answer is: if the particles are emitted in sufficient numbers, they may, in fact, render metals incandescent by the shock, as is observed on the anti-cathode of Crookes' tube.

[1] *English Mechanic*, 21st January, 4th March, 15th April, and 13th May 1904.

With radium, and still more with ordinary substances infinitely less active, the energy is produced too slowly to generate such important effects. At the most, as is the case with radium, it may raise the temperature of the mass of the body by two or three degrees. Radium releases, according to the measurements of Curie, 100 calorie-grammes per hour, and this quantity could only raise the temperature of 100 grammes of water by one degree in an hour. It is evidently too slight to raise in any appreciable way the temperature of a metal, especially if one considers that this would cool by radiation nearly as fast as it was heated.

Certainly it would be quite different if radium or any other substance were dissociated rapidly instead of requiring centuries for the purpose. The scholar who discovers the way to dissociate instantaneously one gramme of any metal—radium, lead, or silver—will not witness the results of his experiment. The explosion produced would be so formidable that his laboratory and all the neighbouring houses, with their inhabitants, would be instantaneously pulverized. So complete a dissociation will probably never be attained, though M. de Heen attributes to explosions of this kind the sudden disappearance of certain stars. Yet there is hope that the partial dissociation of atoms may be rendered less slow. I assert this, not as the result of theory, but as of experiment, since, by the means set forth in the sequel, I have been able to render metals almost deprived of radio-activity, like tin, forty times more radio-active than an equal surface of uranium.

The preceding discussions show that the doctrine of intra-atomic energy has attracted much more notice than that of the universality of the dissociation of matter. Yet the first-named was only the consequence of the second, and it was necessary to establish the facts before looking for the consequences.

It is especially these consequences which have made an impression. One of our most important publications, the *Année Scientifique*,[1] has remarked this very clearly in a summary of which I give some extracts:—

"M. Gustave Le Bon was the first, as we should not forget, to throw some light into this dark chaos, by showing that radio-activity is not peculiar to a few rare substances, such as uranium, radium, etc., but is a general property of matter, possessed in varying degrees by all bodies.

". . . Such is, briefly and in its larger outlines, Gustave Le Bon's doctrine, which upsets all our traditional acquirements as to the conservation of energy and the indestructibility of matter. Radio-activity, a general and essential property of matter, should be the manifestation of a new mode of energy and of a force—the intra-atomic—hitherto unknown.

"We do not yet know how to liberate and master this incalculable reserve of force, of which yesterday we did not even suspect the existence. But it is evident that when man shall have found the means to make himself its master, it will be the greatest revolution ever recorded in the annals of the genius of science, a revolution of which our puny brains can hardly grasp all the consequences and the extent."

The philosophic consequences of these researches have not escaped several scholars. In an analysis of the first edition of this work published in the *Revue Philosophique* for November 1905, M. Sagaret, an engineer, has fully shown these consequences. Here are some extracts from his article:—

[1] 47th year, pp. 6, 88 and 89.

"No scientific theory has responded nor can better respond to our yearning for unity than that of Dr. Gustave Le Bon. It sets up a unity than which it would be impossible to imagine anything more complete, and it focusses our knowledge on the following principle: one substance alone exists which moves and produces all things by its movements. This is not a new conception, it is true, for the philosopher, but it has remained hitherto a purely metaphysical speculation. To-day, thanks to Dr. Gustave Le Bon, it finds a starting-point in experiment.

"The scholar has till now stopped at the atom without perceiving any link between it and the ether. The duality of the ponderable and the imponderable seemed irreducible. Now the theory of the dematerialization of matter comes to establish a link between them.

"But it realizes scientific unity in yet another way by making general the law of evolution. This law, hitherto confined to the organic world, now extends to the whole universe. The atom, like the living being, is born, develops and dies, and Dr. Gustave Le Bon shows us that the chemical species evolves like the organic species."

BOOK III.

THE WORLD OF THE IMPONDERABLE.

CHAPTER I.

THE CLASSIC SEPARATION BETWEEN THE PONDERABLE AND THE IMPONDERABLE—DOES THERE EXIST A WORLD INTERMEDIATE BETWEEN MATTER AND THE ETHER?

SCIENCE formerly divided the various phenomena of nature into two sharply separated classes, with no apparent break between them. These distinctions have existed throughout all branches of knowledge, and in physics as well as in biology.

The discovery of the laws of evolution has caused the disappearance from the natural sciences of divisions which formerly seemed impassable gulfs, and, from the protoplasm of primitive beings up to man the chain is now almost uninterrupted. The missing links are every day re-forged and we get glimpses of how the change from the simplest to the most complicated beings has operated step by step throughout time.

Physics has followed an analogous route, but has not yet arrived at unity. It has, however, rid itself of the fluids which formerly encumbered it; it has discovered the relations which exist between the different forces, and has recognized that they are but varied manifestations of one thing supposed to be indestructible: to wit, energy. It has also established permanence throughout the series of phenomena, and has shown the existence of the continuous where there formerly appeared only the discontinuous. The law of the conservation of energy is in reality only the simple verification of this continuity.

There remain, however, in physics two deep gaps to be filled before this continuity can be established everywhere. Physics, in fact, still maintains a wide separation exists between matter and energy, and another, not less considerable, between the world of the ponderable and that of the imponderable—that is to say, between matter and the ether. Matter is that which is weighed. Light, heat, electricity and all the phenomena produced in the bosom of the imponderable ether, as they add nothing to the weight of bodies, are regarded as belonging to a very different world from that of matter.

The scission of these two worlds seemed finally established. The most illustrious scholar of our times had even come to consider the demonstration of this separation as one of the greatest discoveries of all ages. This is how M. Berthelot expressed himself on the subject at the recent inauguration of the monument to Lavoisier:—

"Lavoisier established, by most exact experiments, a capital and, until his time, unrecognized distinction between the ponderable substances and the imponderable agencies, heat, light, and electricity. This fundamental distinction between ponderable matter and imponderable agencies is one of the greatest discoveries ever made; it is one of the bases of the present physical, chemical, and mechanical sciences."

A fundamental base, in fact, and one which till now has appeared unshakeable. The phenomena due to the transformations of the imponderable ether, such as light, for instance, present no appreciable analogy with those of which matter is the seat. Matter may change its form, but, in all these changes, it preserves an invariable weight. Whatever be the modification to which the imponderable agencies submit it, they do not add to it and never cause any variation in its weight.

To thoroughly grasp modern scientific thought on this point, the above quotation must be considered in connection with that relating to the separation of matter and energy, reproduced in a previous chapter.[1] They show that the science of the day is confronted not with one only, but with several very distinct dualities. They may be formulated in the following propositions:—1st. Matter is entirely distinct from energy and cannot of itself create energy; 2nd. The imponderable ether is entirely distinct from ponderable matter and has no kinship with it. The solidity of these two principles has hitherto seemed to defy the ages. We shall endeavour to show, on the contrary, that the new facts tend to utterly upset them.

So far as regards the non-existence of the classic separation between matter and energy, we need not recur to it, since we have devoted a chapter[2] to demonstrating that matter can be transformed into energy. It therefore only remains for us to inquire whether the distinction between matter and ether can equally disappear. A few scholars here and there had already remarked the jarring character of this last duality and how it rendered impossible the

[1] *Cf.* M. Janet's remarks, p. 52 and Book II., chap. ii. *supra.*—F. L.

[2] See last note.

explanation of certain phenomena. Larmor has recently employed the manifold resources of mathematical analysis in the attempt to do away with what he calls "the irreconcilable duality of matter and ether." But if this duality is destined to vanish, experience alone can show that it ought to disappear. Now, the facts recently discovered, notably those relating to the universal dissociation of matter, are sufficiently numerous to allow of an attempt to connect the two worlds till now so widely separated.

At first sight, the task seems a heavy one. It is not easy, in fact, to see how a material substance, having weight, with well-defined outlines, such as a stone or a piece of lead, can be akin to things so mobile and so subtle as a sunbeam or an electric spark. But we know, from all the observations of modern science, that it is not by bringing together the extremities of a series that the intermediate forms can be reconstructed and the analogies hidden under their dissimilarities discovered. It is not by comparing the beings who were born at the dawn of life with the higher order of animals with which our globe was afterwards peopled that the links uniting them were discovered. By proceeding in physics as we have done in biology, we shall see, on the contrary, that it is possible to bring nearer together things apparently so dissimilar as matter, electricity, and light.

The facts which enable us to prove the existence of an intermediate world between matter and ether are in reality becoming more numerous every day. They have only needed synthetizing and interpreting. To say with reason that a certain substance can be considered as intermediate between matter and ether, it must possess characteristics allowing it to be at once compared to and differentiated from both these elements. It is because characteristics of this kind have been verified among the anthropoid apes that naturalists now consider them as forming a link between the inferior animals and man. The method which we shall apply will be that of the naturalists. We shall seek out the intermediate characteristics which allow us to say that a substance, while somewhat resembling matter, is yet not matter, and while near to the ether, is yet not the ether.

Several chapters of this work will be devoted to this demonstration, of which we can only at present indicate the results. We shall endeavour to show, while throughout taking experiment for our guide, that the products of the dematerialization of matter—that is to say, the emissions produced during its dissociation—are formed from substances of which the characteristics are intermediate between those of ether and those of matter.

Of what do these substances consist? Wherein have they lost the properties of material bodies? For a number of years physicists have persisted in seeing in the emissions of radio-active bodies only fragments of matter more or less tenuous. Unable to rid themselves of the concept of material support, they have supposed that the particles emitted were merely atoms—charged with electricity, no doubt, but still, however, formed of matter. This opinion seemed confirmed by the fact that the radio-active emissions were most often accompanied by the projection of material particles. In Crookes' tube the emission of solid particles thrown off by the cathode is so considerable that it has been possible to cover with metal bodies exposed to their bombardment.

This transport (*entraînement*) of matter is, however, observed in most electrical phenomena, notably when electricity of a sufficiently high potential passes between two electrodes. The spectroscope, in fact, always reveals, in the light of the sparks, the characteristic lines of the metals of which these electrodes are composed. Yet another reason seemed to prove the material nature of these emissions. They could be deviated by a magnetic field, and were therefore charged with electricity. Now, as no one had yet seen the transport of electricity without material support, the existence of such a support was considered evident.

The sort of material dust which was thus supposed to constitute the emissions from the cathode and those from radio-active bodies presented singular characteristics for a material substance. Not only does it present the same properties whatever the body dissociated, but it has also lost all the characteristics of the matter which gives it birth. Lenard showed this clearly when he sought to verify one of his old hypotheses, according to which the effluves generated by ultra-violet light striking on the surface of metals are composed of the dust torn from those metals. Taking sodium, a body very easily dissociated by light and the smallest traces of which in the air can be recognized by the spectroscope, he found that the effluves thus emitted contained no trace of sodium. If, then, the emissions of dissociated substances are matter, it is matter which has none of the properties of the substances whence it comes.

Facts of this nature have multiplied sufficiently to prove that in the cathode radiation, as well as in radio-activity, matter transforms itself into something which can no longer be ordinary matter, since none of its properties are preserved. It is this thing of which we are about to study the characteristics, and which we shall show belongs to the intermediate world between matter and the ether.

So long as the existence of this intermediate world was ignored, science found itself confronted with facts that it could not classify. Thus it was, for example, that physicists were puzzled where to place the cathode rays which really form part of the intermediate substances between matter and the ether. This is why they placed them first in the world of matter and then in that of ether, notwithstanding that the two worlds were considered so different. Nor could they naturally class them otherwise. Since physics supposes that phenomena can only belong to one of these two worlds, what does not belong to the one necessarily belongs to the other. In reality, they belong to neither the one nor the other, but to that intermediate world between the ether and matter that we shall study in this work. It is peopled with a crowd of things entirely new, the acquaintance of which we are hardly beginning to make.

CHAPTER II.

THE IMMATERIAL BASIS OF THE UNIVERSE—THE ETHER.

THE greater part of physical phenomena—light, heat, radiant electricity, etc., are considered to have their seat in the ether. Gravitation, whence are derived the mechanics of the world and the march of the stars, seems also to be one of its manifestations. All the theoretical researches formulated on the constitution of atoms lead to the supposition that it forms the material from which they are made. Although the inmost nature of the ether is hardly suspected, its existence has forced itself upon us long since, and appears to many to be more assured than that of matter itself. Belief in its existence became necessary when the propagation of forces at a distance had to be explained. It appeared to be experimentally demonstrated when Fresnel proved that light is spread by undulations analogous to those produced by the falling of a stone into water. By the interference of luminous rays he obtained darkness by the superposition of the prominent parts of one luminous wave upon the hollow parts of another. As the propagation of light is effected by means of undulations, these undulations are necessarily produced in something. This something is what is called the ether.

Its rôle has become of capital importance, and has not ceased to increase with the progress of physics. The majority of phenomena would be inexplicable without it. Without the ether there could be neither gravity, nor light, nor electricity, nor heat, nor anything, in a word, of which we have knowledge. The universe would be silent and dead, or would reveal itself in a form which we cannot even foresee. If one could construct a glass chamber from which the ether were to be entirely eliminated, heat and light could not pass through it. It would be absolutely dark, and probably gravitation would no longer act on the bodies within it. They would then have lost their weight.

But so soon as one seeks to define the properties of the ether, enormous difficulties appear. No doubt they are due to the fact that as this immaterial element cannot be connected with any known thing, terms of comparison are entirely wanting for its definition. Before phenomena without analogy to those habitually observed, we are like a person born deaf with regard to music, or a blind man with regard to colours. No image can make them understand what is a sound or a colour.

When books on physics state in a few lines that the ether is an imponderable medium filling the universe, the first idea coming into the mind is to represent it as a sort of gas so rarefied as to be imponderable by the means at our disposal. There is no difficulty in imagining such a gas. M. Muller has calculated that if the matter of the sun and its surrounding planets were diffused through a space equal to that which divides the stars closest together, a cubic myriametre of this matter, in a gaseous state, would hardly weigh the thousandth part of a milligramme, and consequently could not be weighed in our balances. This finely-divided fluid, which perhaps represents the primitive condition of our nebula, would be a quadrillion times less dense than the vacuum of the thousandth part of an atmosphere in a Crookes' tube.[1]

Unfortunately the properties of the ether do not permit it to be in any way likened to a gas. Gases are very compressible and the ether cannot be so. If it were, in fact, it could not transmit, almost instantaneously, the vibrations of light. It is only in theoretically perfect fluids, or, better still, in solids, that distant analogies with the ether can be discovered, but then a substance with very singular qualities has to be imagined. It must possess a rigidity exceeding that of steel, or it could not transmit luminous vibrations at a velocity of 300,000 kilomètres per second. One of the most eminent of living physicists, Lord Kelvin, considers the ether to be "an elastic solid filling all space." But the elastic solid forming the ether must have very strange properties for a solid, which we never meet with in any other. Its extreme rigidity must be accompanied by an extraordinarily low density—that is to say, one small enough to prevent its retarding by its friction the movement of the stars through space. Hirn has shown that if the density of ether were but a million times less than that of the air, rarefied as it is, contained in a Crookes' tube, it would cause an alteration of half a second every hundred years in

[1] Professor Mendeléeff in his *Principles of Chemistry* gives his reasons for thinking that the ether is a gas of the argon group, incapable of combination, with an atomic weight one-millionth of that of hydrogen and a velocity of 2,250 kilomètres per second. (Eng. ed. 1905, vol. ii. p. 526.)—F. L.

the mean motion of the moon. Such a medium, notwithstanding its reduced density, would, however, very quickly expel the atmosphere from the earth. It has been calculated also that, had it the properties we attribute to gases, it would acquire, by its impact with the surface of stars deprived, like the moon, of their atmosphere, a temperature of 38,000° C. Finally, one is thrown back on the idea that the ether is a solid without density or weight, however unintelligible this may seem.

Other physicists have recently maintained that the density of the ether must, on the contrary, be very great. They found their notion on the electromagnetic theory of matter which attributes the inertia of all matter to the ether. According to this theory, the mass of a body is nothing else than the mass of the surrounding ether, held and dragged along by the lines of force which encompass the electric particles of which atoms are supposed to be formed. All the inertia of bodies—that is to say, their mass, is due to the inertia of the ether. All kinetic energy is due to the movements of the ether imprisoned by the lines of force which unite it to the atoms. J. J. Thomson, who upholds this hypothesis,[1] adds, "that it requires that the density of the ether should exceed that of all known bodies." Why, however, is not very clear.

The magnitude of the forces which the ether is able to transmit likewise constitutes a phenomenon very difficult to interpret. An electro-magnet acts across space by the intermediary of the ether. Now, as

[1] "Electricity and Matter," *Westminster*, 1904; and "On the Dynamics of an Electrified Field," *Proceedings of the Cambridge Philosophical Society*, 1903, p. 83.

Lord Kelvin has remarked, it exercises on iron at a distance a force which may extend to 110 kilogrammes per square centimètre. "How is it," this physicist writes, "that these prodigious forces are developed in the ether, an elastic solid, while ponderable bodies are yet free to move within this solid?" We do not know and cannot say if we ever shall know.

Hardly anything can be indicated concerning the constitution of the ether. Maxwell supposed it to be formed of little spheres animated by a very rapid rotatory movement, which each transmitted to its neighbour. Fresnel considered its elasticity constant, but its density variable. Other physicists believe, on the other hand, that its density is constant and its elasticity variable. For most it is not disturbed by the motions of the material systems which pass through it. Others, again, think that, on the contrary, it is carried along by them.

It is, in any case, agreed that the ether is a substance very different to matter, and is withdrawn from the laws of gravity. It has no weight, is immaterial in the usual acceptation of that word, and forms the world of the imponderable. Yet if the ether has no gravity it must have mass, since it offers resistance to movement. This mass is slight, since the speed of the propagation of light is very great. If there were no mass the propagation of light would probably be instantaneous. The question of the imponderability of the ether, so long debated, now seems definitely settled. It has been taken up again recently by Lord Kelvin,[1] and, by mathematical

[1] "On the Clustering of Gravitational Matter in any Part of the Universe," *Philosophical Magazine*, January 1902.

calculations which cannot be reproduced here, he arrives at the conclusion that the ether consists of a substance entirely outside the laws of gravitation—that is to say, imponderable. But he adds, "We have no reason to consider it as absolutely incompressible, and we may admit that a sufficient pressure would condense it."

It is probably from this condensation, effected at the beginning of the ages by a mechanism totally unknown to us, that are derived the atoms, considered by several physicists—Larmor especially—as condensation nuclei in the ether, having the form of small vortices (or whirlpools) animated with an enormous speed of rotation. "The material molecule," writes this physicist, "is entirely formed of ether and of nothing else."[1]

Such are the properties that the interpretation of the phenomena attributes to the ether. We must confine ourselves to stating, without being able to understand it, that we are living in an immaterial medium more rigid than steel, to which medium we can easily communicate, simply by burning any body whatever, movements of which the speed of propagation is 300,000 times greater than that of a cannon-ball. The ether is an agent of which we catch glimpses everywhere around us, which we can cause to vibrate, to deviate, and which we can measure at will, without being able to isolate it. Its inmost nature remains an irritating mystery.

We may sum this up by saying that if we know very little about the ether, we must, however, consider it certain that the greater part of the phenomena in the universe are the consequences of

[1] *Ether and Matter.* London, 1900.

its manifestations. It is, no doubt, the first source and the ultimate end of things, the substratum of the worlds and of all beings moving on their surface. I will endeavour to show soon how the imponderable ether can be connected with matter and thus grasp the link connecting the material with the immaterial. As a preparation for understanding their relations, we will first examine some of the equilibria it is possible to observe in the ether. We only know a small number of these, but those we are able to observe will permit us, by analogy, to foresee the nature of those unknown to us.

CHAPTER III.

THE DIFFERENT FORMS OF EQUILIBRIUM IN THE ETHER.

THE most important phenomena in nature: heat, light, electricity, etc., have, as we have just seen, their seat in the ether. They are generated by certain perturbations of this immaterial fluid on leaving or returning to equilibrium. The forces of the universe are only known to us, in reality, by disturbances of equilibrium. The state of equilibrium constitutes the limit beyond which we can no longer follow them. Light is only a change of the equilibrium of the ether, characterized by its vibrations; it ceases to exist so soon as the equilibrium is re-established. The electric spark of our laboratories, as also the lightning, are simple manifestations of the changes of the electric fluid leaving its equilibrium from one cause or another, and striving to return to it. So long as we knew not how to draw the electric fluid from its state of repose its existence was ignored.

All the modifications of equilibrium produced in the ether are very instable and do not survive the cause which gave them birth. It is just this which differentiates them from material equilibria. The various forms of equilibrium observed in matter are generally very stable—that is, they survive the cause which generates them. The world of the ether is the world of mobile equilibria, while the world of matter is that of equilibria which can be fixed.

To say that a thing is no longer in equilibrium is to state that it has undergone certain displacements. The known movements which determine the appearance of phenomena are not very numerous. They are principally attractions, repulsions, rotations, projections, vibrations and vortices, and of these different movements the best known are those which produce attractions and repulsions, as they are almost exclusively resorted to for the measurement of phenomena. The balance measures the attraction exercised on bodies by the earth, the galvanometer measures the attraction exercised on a magnet by an electric current, the thermometer, the attractions or repulsions of the molecules of a liquid submitted to the influence of heat. The osmotic equilibria which control most of the phenomena of life are revealed by the attractions and repulsions of the molecules in the bosom of liquids. The movements of various substances and the varieties of equilibrium resulting therefrom thus play a fundamental rôle in the production of phenomena. They constitute their essence, and form the only realities accessible to us.

Until the last few years, only the regular vibratory movements of the ether which produce light were studied. It might, however, have been supposed that a fluid in which, as in a liquid, regular waves could be produced, was susceptible of other movements. It is now recognized that the ether can be the seat of different movements such as projections, rotations, vortices, etc., and, among the forms of the movements in the ether lately studied, vortices appear, theoretically at least, to play a preponderant part.. Larmor[1] and other physicists consider that electrons, the supposed elements of the electric fluid—and, according to some scholars, of material atoms—are vortices or gyrostats formed within the ether. Professor de Heen[2] compares them to a rigid wire twisted into a helix, the direction of their rotations determining the attractions and repulsions. Sutherland seeks in the direction of the movements of these gyrostats the explanation of the electrical and thermal phenomena of conduction. "Electric conduction," he says, "is due to the vibration of the gyrostats in the direction of the electric force, and thermal conduction to the vibration of vortices in all directions."[3]

It was mathematical analysis alone which led physicists to attribute a fundamental rôle to the vortices in the ether, but experiments made on material fluids give to this hypothesis a precise basis, since, as we shall see, they permit the reproduction of the attractions and repulsions observed in electrical phenomena, and the constitution by vortices of material substances with geometric forms. A material vortex may be formed by any fluid, liquid or gaseous, turning round an axis, and by the fact of its rotation it describes spirals. The study of these vortices has been the object of important researches by different scholars, notably by Bjerkness and Weyher.[4] They have shown that by them can

[1] *Ether and Matter*, 1900.
[2] *Prodromes d'un Théorie de l'Electricité.* Bruxelles, 1903.
[3] "The Electric Origin of Rigidity," *Philosophical Magazine*, May 1904.
[4] *Sur les tourbillons.* 2nd edition. Paris, 1889.

be produced all the attractions and repulsions recognized in electricity, the deviations of the magnetic needle by currents, etc. These vortices are produced by the rapid rotation of a central rod furnished with pallets, or, more simply, of a sphere. Round this sphere gaseous currents are established, dissymetrical with regard to its equatorial plane, and the result is the attraction or repulsion of bodies brought near to it, according to the position given to them. It is even possible, as Weyher has proved, to compel these bodies to turn round the sphere as do the satellites of a planet without touching it.

These vortices constitute one of the forms most easily assumed by material particles, since a fluid can be caused to whirl by a simple breath. They can produce, besides, all the movements of rotation, and very stable equilibria capable of striving against the power of gravity as a top in motion remains upright on its pivot. It is the same with a bicycle, which falls laterally when it ceases to roll forward. The helices with vertical axes called helicopters used in certain processes of aviation rise in the atmosphere by screwing themselves into it so soon as they are put in rotation, and remain there so long as that rotation lasts. Directly they come to rest, being no longer able to struggle against gravity, they fall heavily to the ground. It will thus be easily conceived that it is in rotatory motion that is found the best explanation of the equilibria of atoms.

It is by whirling movements in the ether that several authors also seek to explain gravitation. Professor Armand Gautier in a notice of my memoir on intra-atomic energy gives a similar explanation. If it could be considered as definitive, it would have the advantage of explaining the way in which the imponderable may go forth from the ponderable:—

"The material atom animated by gyratory movements must transmit its gyration to the surrounding ether, and by it to the other distant material bodies which float in this ether. It follows that, when the gyration passes from one to the other, the material bodies, by virtue of their own inertia, tend, so to speak, to *screw* themselves one on to the other by the intermediary of the common vortex of ether in which they are; in a word, these material bodies must attract one another. It is sufficient thus to admit that there must be a kind of *viscosity* between the particles of the ether, or rather a kind of transport (*entraînement*) of these particles one by the other.

"But if the gyratory condition of the atomic edifices seems to be thus the cause of their mutual attraction—that is to say, of gravity, this latter must disappear wholly or in part if the energy of gyration be wholly or in part transformed into energy of translation in space. May it not likewise be the same with the *electron*—that is to say, with the atomuscule torn from the atom and launched forth from the material edifice with the velocity of the atominal light, in which atomuscule the speed of gyration has disappeared because transformed into speed of translation? These electrons thus borrowed from matter, if no longer in a state of sensible or concordant gyration, may then lose all or part of their weight while keeping their mass, and while continuing to follow the law which measures the energy transported by them by half the product of their mass multiplied by the square of their speed of translation.[1]

The experiments on whirling movements in fluids not only produce attractions, repulsions, and equilibria of all kinds: they may be associated so as to give birth to regular geometric forms as M. Benard[2] has demonstrated in a series of experiments. He has shown that a thin layer of liquid subjected to certain perturbations (convection currents bordering

[1] *Revue Scientifique*, 13th January 1904.

[2] *Revue Générale des Sciences*, 1900.

on stability) divides itself into vertical prisms with polygonal bases that can be rendered visible by certain optical processes or by simply mixing with it very fine powders. "It is," says this author, "the geometric places of neutral vortices which form the plane walls of the hexagonal prisms and the vertical axes of these prisms. The lines of the whirlpools are closed curves centred on the axis of these prisms." Metals suddenly chilled after having been fixed and cast in layers often divide in the same way and present to our observation polygonal cells.[1] These experiments show us that the molecules of a liquid can assume geometrical forms without ceasing to be liquid. These momentary forms of equilibrium do not survive the causes which gave them birth. They are analogous to those I have been able to produce and render visible by properly combining the elements of dissociated matter, as we shall see hereafter.

Although the analogies between the molecules of material fluids and those of immaterial fluids are many, they never attain identity by reason of two capital differences between material aud immaterial substances. The former are in fact subject to the action of gravity, and have very great mass. They therefore obey changes of motion, but rather slowly. The latter are free from gravity, and have very small mass, the smallness of this mass allowing them to take, under the influence of very feeble forces, rapid movements, and consequently to be extremely mobile. If, in spite of their feeble mass,

[1] According to Professor Quincke of Heidelberg, all substances on passing from the liquid to the solid state, form these cells, which he calls "foam cells."—*Proc. Roy. Soc.*, 21st July 1906 (A).

the immaterial molecules can produce fairly great mechanical effects, such as are observed, for example, in Crookes' tubes, the mirrors of which become red hot under the action of the cathodic bombardment, it is because the smallness of the mass is compensated for by their extreme speed. In the formula $T=\frac{mv^2}{2}$, without changing the result, m can be reduced at will on condition that v is increased.

By considering the important part played by the divers forms of equilibrium of which the ether is capable, it is easy to arrive at the conception that matter is nothing but a particular state of equilibrium of the ether. Consequently, when we seek in future chapters the links which unite material to immaterial things, we must especially examine the different forms of equilibrium possessed by that intermediary world of which we recognize the existence, and inquire into the analogies and dissimilarities offered by these equilibria when compared with the two worlds which we propose to unite.

BOOK IV.

THE DEMATERIALIZATION OF MATTER.

CHAPTER I.

THE VARIOUS INTERPRETATIONS OF THE EXPERIMENTS WHICH REVEAL THE DISSOCIATION OF MATTER.

§ 1. *The First Interpretations.*

THE ether and matter form the two extreme limits of the series of things. Between these limits, far as they are from each other, there exist intermediate elements, of which the existence is now revealed by observation. None of the experiments I shall set forth, however, will show us the transformation of the ether into material substances. It would require the disposal of colossal energy to effect such a condensation. But the converse transformation of matter into the ether, or into substances akin to the ether, is, on the contrary, realizable, and can be realized by the dissociation of matter. It is in the discovery first of the cathode rays and then of the X rays that are found the germs of our present theory of the dissociation of matter. This dissociation, whether spontaneous or induced, always reveals itself by the emission into space of effluves identical with the cathode and the X rays. The assimilation of these two orders of phenomena, which for several years I was alone in maintaining, is to-day universally admitted.

The discovery of the cathode and of the X rays which invariably accompany them, marks one of the most important stages of modern science. Without it, the theory of the dissociation of matter could never have been established; and without it, we should always have been ignorant that it is to this dissociation of matter that we owe phenomena long known in physics, but which had remained unexplained. Every one knows at the present time what the cathode rays are. If through a tube furnished with electrodes and exhausted to a high vacuum an electric current of sufficient tension be sent, the cathode emits rays which are projected in a straight line, which heat such bodies as they strike, and which are deviated by a magnet. The metallic cathode only serves to render the rays more abundant, since I have proved by experiment that with a Crookes' tube without cathode or any trace of metallic matter whatever, exactly the same phenomena are observed.

The cathode rays are charged with electricity, and can traverse very thin metallic plates connected with the earth without losing their charge. Every time they strike an obstacle they immediately give rise to those peculiar rays termed X rays, which differ from the cathode rays in not being deviated by a magnet, and pass through thick metallic plates capable of completely stopping the cathode rays.[1] Both cathode and X rays produce electricity in all bodies that they meet, whether they be gases or solid matter, and consequently render the air a conductor of electricity.

[1] They also differ from the cathode rays in being, according to current theories, not streams of particles at all, but irregular movements or pulses in the ether. But see p. 111 *infra*.—F. L.

The first ideas of the nature of the cathode rays which were conceived were far different from those current to-day. Crookes, who first put in evidence the properties of these rays, attributed their action to the state of extreme rarefaction of the molecules of the gas when the vacuum had been carried very far. In this "ultra-gaseous" state, the rarefied molecules represented, according to him, a peculiar state which he described as a fourth state of matter. It was characterized by the fact that, no longer hindered in their course by the impact of the other molecules, the free trajectory of the rarefied molecules lengthens to such a point that their reciprocal shocks become of no importance compared with their whole course. They can then move freely in every direction, and if their movements are directed by an external force such as the electric current of the cathode, they are projected in one direction only like grapeshot from a cannon. On meeting an obstacle they produce by their molecular bombardment the effects of phosphorescence and heat, which the experiments of the illustrious physicist put in evidence.

This conception, now recognized to be inexact, was inspired by the old kinetic theory of gases which I will thus recapitulate. The molecules of gases are formed of perfectly elastic particles, a condition necessary to prevent their losing energy by impact, and are far enough apart from each other to exercise no mutual attraction. They are animated by a speed varying with the gas, calculated at about 1,800 mètres per second in the case of hydrogen, or about double that of a cannon-ball. This speed is also purely theoretical, for, by reason of their mutual impacts, the free path of each molecule is limited to about the thousandth part of a millimètre. It is the impact of these molecules which produces the pressure exercised by a gas on the walls that enclose it. If the space enclosing the same volume of molecules be reduced to one-half, the pressure is doubled. It is tripled when the space is reduced to one-third. It is this fact which is expressed by the law of Mariotte.

In a globe exhausted to a vacuum of the millionth of an atmosphere, things, according to Crookes, happen very differently. No doubt it still contains an enormous number of gaseous molecules, but the very great reduction in their number causes them to obstruct each other reciprocally much less than under ordinary pressure, and their free path is thus considerably augmented. If, under these conditions, a part of the molecules of air remaining in the tube be electrified and projected, as I said above, by an intense electric current, they may freely traverse space, and acquire an enormous speed; while, at ordinary pressure, this speed is kept down by the molecules of air encountered.

The cathode rays, therefore, simply represented, in the original theory of Crookes, molecules of rarefied gas, electrified by contact with the cathode, and launched into the empty space within the tube at a speed they could never attain if they were obstructed, as in gases at ordinary pressure, by the impact of other molecules. They were thought to remain, however, material molecules, not dissociated, but simply spread out, which could not change their structure. No one dreamed, in fact, at this epoch that the atom was capable of dissociation.

Nothing remains of Crookes' theory since the measurement of the electric charge of the particles and of their mass has proved that they are a thousand times smaller than the atom of hydrogen, the smallest atom known. One might doubtless suppose in strictness, as was done at first, that the atom was simply subdivided into other atoms preserving the properties of the matter whence they came; but this hypothesis broke down in face of the fact that the most dissimilar gases contained in Crookes' tubes gave identical products of dissociation, in which were found none of the properties of the substances from which they had issued. It had then to be admitted that the atom was not divided, but was dissociated into elements endowed with entirely new properties which were identical in the case of all substances.

It was not, we shall see, by any means, in a day that the theory of dissociation just briefly indicated was established; in fact, it was clearly formulated only after the discovery of the radio-active substances and the experiments which helped me to prove the universality of the dissociation of matter. And it was only after several years that physicists at last recognized, conformably with my assertions, the identity of the cathode rays with the effluves of particles emitted by ordinary substances during their dissociation.

§ 2. *The Interpretations now current.*

At the time when only the cathode rays were known, the explanation by Crookes of their nature seemed to be quite sufficient. On the discovery of the X rays and of the emissions of the spontaneously radio-active bodies, such as uranium, the insufficiency of the old theory was made clear. One of the manifestations of the X rays and of the radio-active emissions which made the greatest impression on physicists and was the origin of the current explanations, was the production of electricity on all bodies both solid and gaseous struck by the new radiations. The X rays and the emissions from radio-active bodies possess, in fact, the common characteristic of producing something which renders the air and other gases conductors of electricity. With these gases thus made conducting we can, by passing them between the plates of a condenser, neutralize electric charges. It was, as a consequence, admitted that they were electrified.

This was a very unforeseen phenomenon, for all earlier experiments had without exception shown that gases were not capable of being electrified. They can be kept, in fact, indefinitely in contact with a body electrified to a very high potential without absorbing any trace of electricity. If it were otherwise, no electrified surface—the ball of an electroscope, for instance—could retain its charge, and we were, therefore, in face of an entirely new fact, much more novel even than was at first thought, since it implied, in reality, the dissociation of matter, which nobody then suspected.

So soon as an unforeseen fact is stated, one always tries to connect it with an old theory:—and since one theory alone, that of the ionization of saline solutions in electrolysis, gives an apparent explanation of the newly observed facts, haste was made to adopt it. It was therefore supposed that in a simple body there existed, as in a compound, two separable elements, the positive and negative ions, each charged with electricity of contrary sign. But the earlier theory of ionization only applied to compound bodies, and not to simple ones. The elements of compound bodies could be separated—or, as we now say, ionized,—chloride of potassium, for instance, being capable of separation into its chlorine ions and its potassium ions; but what analogy could exist between this operation and the dissociation of chloride or potassium itself, since it was considered a fundamental dogma that a simple body could not be dissociated. There was all the less analogy between the ionization of saline solutions and that of simple bodies, that, when the elements of a salt are separated by the electric current, very different bodies are extracted according to the compound dissociated. Chloride of potassium, mentioned above, gives chlorine and potassium; with sodium oxide, oxygen and sodium are obtained, and so on. When, on the other hand, we ionize a simple body, we extract from it always the same elements. Whether it be hydrogen, oxygen, nitrogen, aluminium or any other substance, the substance extracted is the same, every time. Whatever may be the body ionized, and whatever the mode of ionization, one obtains only those particles—ions or electrons—of which the electric charge is the same in all bodies. The ionization of a saline solution and that of a simple body, such as a gas, for instance, are therefore two things which present, in reality, no analogy to each other.

From the verification of the fact that from simple bodies such as oxygen, hydrogen, etc., only the same elements can be extracted, it might easily have been deduced:—first, that atoms can be dissociated; and secondly, that they are all formed of the same elements.

These conclusions are now evident, but they were a great deal too much outside the ideas then dominant for any one to dream of formulating them.

The term ionization when applied to a simple body had no great meaning, but it formed the beginning of an explanation, for which reason it was eagerly accepted. I shall likewise accept it, in order not to confuse the reader's mind, but at the same time shall take care to remark that the term ionization applied to a simple body merely means dissociation of its atoms, and not anything else.

Several physicists, it is true, and I am astonished to find Rutherford among them, think that the ionization of a gas can take place without in any way changing the structure of its atoms. One cannot see why that which is admitted to be exact in the case of a solid body should be otherwise for a gaseous one. We know that by divers means we can dissociate any simple body whatever. In the case of radium, aluminium, oxygen, or any other substance, the products of this dissociation are particles which are admitted to be exactly identical in the case of all bodies. There is therefore no foundation for saying that one has dissociated some substances and not others. To take something from an atom is always to begin its dissociation. Gases, on the other hand, are the easiest of all bodies to dissociate, because, to accomplish this, it is only necessary to pass electric discharges through them.

This ionization of simple bodies—that is to say, the possibility of extracting from them positive and negative ions bearing electric charges of opposite signs—once admitted, presented a number of difficulties, which were studiously passed over in silence, because it is really impossible to find their explanation. For these electric ions, or this ionic electricity, if I may use the expression, differs singularly in its properties from the ordinary electricity which a century of researches has made known to us. A few comparisons will suffice to show this. On any insulated body whatever we can fix only a very small quantity of electricity if it is a solid, and none at all if it is a gas. Ionic electricity, on the other hand, must necessarily be condensed in immense quantities on infinitely small particles. Ordinary electricity, even though it has the intensity of lightning, can never pass through a metallic plate connected with the earth, as Faraday showed long ago. On this classic property there has even been founded the manufacture of clothes from light metallic gauze which affords the workmen in factories, where electricity at a high potential is produced, protection from even the most violent discharges. Ionic electricity, on the other hand, easily traverses metallic enclosures. Ordinary electricity goes along wire conductors with the rapidity of light, but cannot be led like a gas into a hollow tube bent back upon itself. Ionic electricity, on the other hand, acts like a vapour, and can circulate slowly through a tube. And finally, ionic electricity has the property of giving birth to the X rays whenever the ions animated by a certain speed happen to touch any body whatever.

No doubt it can be urged that electricity generated by the ionization of matter which has assumed the special form of electrical atoms, must possess in this form properties very different to ordinary electricity. But then, if the properties of the atom called electrical are absolutely different to electricity, why call it electrical? In the experiments I shall set forth, electricity will most often appear to us as an effect and not a cause. It is to this unknown cause what electricity is to the heat or to the friction which generates it. When a rifle-ball or a jet of steam produces electricity by its impact, we do not say that this bullet or this jet of steam are electricity, nor even that they are charged with it. The idea would never enter any one's head of confounding effect with cause as some persist in doing in the case of the radio-active emissions.

The phenomena observed in the dissociation of matter, such as the emission of particles having a speed of the order of light and the property of generating X rays, are evidently characteristics possessed by none of the known forms of electricity, and ought to have led physicists to suppose, as I did, that they are certainly the consequence of an entirely new form of energy. But the imperious mental need of seeking for analogies, of comparing the unknown with the known, has led to the connecting of these phenomena with electricity, under the pretext that among the effects observed one of the most constant was the final production of electricity.

It is plain, however, that several physicists are very near arriving by different roads at the conception that all these radio-active emissions which it is sought to connect with electricity by the theory of ionization, represent manifestations of intra-atomic energy—that is to say, of an energy which has no relation to anything known; and the facts proving that electricity is only one of the forms of this energy are multiplying daily.

One of the most important of these is the discovery due to Rutherford, of which I shall soon have to speak, namely, that the greatest part of the particles emitted during radio-activity proceed from an emanation *possessing absolutely no electric charge*, though capable of giving birth to bodies able to produce electricity. Emanations, ions, electrons, X rays, electricity, etc., are really, as we shall see, only different phases of the dematerialization of matter—that is to say, of the transformation of intra-atomic energy.

"It seems," wrote Professor de Heen with regard to my experiments, "that we find ourselves confronted by conditions which remove themselves from matter by successive stages of cathode and X ray emissions and approach the substance which has been designated the ether. The ulterior researches of Gustave Le Bon have fully justified his first assertions that all these effects depend upon a new mode of energy. This new force is as yet as little known as was electricity before Volta. We simply know that it exists."

But whatever may be the interpretations given to the facts revealing the dissociation of matter, these facts are incontestable, and it is only the demonstration of them which is at present of importance.

On these facts there is almost complete agreement at the present time, and it is the same with the identity of the products of the dissociation of matter, whatever be the cause of this dissociation. Whether they are generated by the cathode of Crookes' tube, by the radiation of a metal under the action of light, or by the radiation of spontaneously radio-active bodies, such as uranium, thorium, and radium, etc., the effluves are of the same nature. They are subject to the same magnetic deviation, the relation of their charge to their mass is the same. Their speed alone varies, but it is always immense.

We can, then, when we wish to study the dissociation of matter, choose the bodies in which the phenomenon manifests itself most intensely—either, for example, the Crookes' tube, in which a metallic cathode is excited by the electric current of an induction coil, or, more simply, very radio-active bodies such as the salts of thorium or of radium. Any bodies whatever dissociated by light or otherwise give, besides, the same results, but the dissociation being much weaker, the observation of the phenomena is more difficult.

CHAPTER II.

THE PRODUCTS OF THE DEMATERIALIZATION OF MATTER (IONS, ELECTRONS, CATHODE RAYS, ETC).

§ 1. *Classification of the Products of the Dematerialization of Matter.*

I HAVE set forth in the preceding chapter the genesis of the current ideas on the interpretation of the facts relating to the dissociation of matter. We will now study the characteristics of the products of this dissociation. Not to complicate a subject already very obscure, I will accept, without discussion, the theories at present admitted, and will confine myself to the attempt to state them with more precision, and to bring together things which resemble one another, but which are often called by different names.

I have said that, whatever the body dissociated and the mode of dissociation employed, the products of this dissociation are always of the same nature. Whether it be the emissions of radium, of those of any metal under the influence of light, of those produced by chemical reaction or by combustion, or of those proceeding from an electrified point, etc., the products will, as already said, be identical, although their quantity and their speed of emission may be very different.

This generalization has taken a long time to establish. It was, consequently, natural that things recognized later on as similar after having first been considered as different, should have been designated by particular terms. It is therefore clearly important to define first of all the exact value of the various terms employed. Without exact definitions no generalization is possible. The necessity of such definitions makes itself all the more felt that the greatest confusion exists in the meaning of the terms generally in use. It is easy to see, moreover, why this should be so. A new science always gives birth to a new terminology. The science is not even constituted until its language has been fixed. The recently discovered phenomena necessarily compelled the formation of special expressions indicating both the facts and the theories inspired by those facts. But, these phenomena having been examined by various inquirers, the same words have sometimes received very different meanings.

Often words of old standing and possessing a well-defined meaning, have been used to designate things newly discovered. Thus, for instance, the same word *ion* is used to designate the elements separated in a saline solution and those derived from the dissociation of simple bodies. Some physicists, like Lorentz, use indifferently the terms ions and electrons, which to others imply very distinct things. J. J. Thomson calls corpuscles[1] the electric atoms which Larmor and other authors call electrons, etc.

By only taking into account facts revealed by experiment and without troubling about the theories from which the definitions are derived, we find that the

[1] The corpuscles of Professor J. J. Thomson are, of course, the *negative* electrons only.—F. L.

different products of the dissociation of matter now known may be arranged in the six following classes:—1st, Emanations; 2nd, Negative Ions; 3rd, Positive Ions; 4th, Electrons; 5th, Cathode rays; 6th, X rays and analogous radiations.

§ 2. *Characteristics of the Elements furnished by the Dissociation of Matter.*

The Emanation.—This product, which we shall examine at greater length in the chapter devoted to the study of spontaneously radio-active matter, is a semi-material substance having some of the characteristics of a gas, but is capable of spontaneously disappearing into electric particles. It was discovered by Rutherford in thorium and by Dorn in radium, and according to the researches of J. J. Thomson[1] it exists in the majority of ordinary bodies: water, sand, stone, clay, etc. It may, then, be considered as one of the usual stages of the dissociation of matter.

If we have just styled a semi-material substance "the emanation," it is because it possesses at once the properties of material bodies and those of bodies which are not material or which have ceased to be so. It can be condensed, like a gas, at the temperature of liquid air, when, thanks to its phosphorescence, its behaviour can be watched. It can be kept for some time in a sealed glass tube, but it soon escapes by transforming itself into electric particles[2] and then

[1] See the *Cambridge Philosophical Society's Proceedings* for April 1904, pp. 391 *et seq.*, Professor Thomson there suggests that the emanation in the substances examined by him may be due to the presence of some radio-active impurity.—F. L.

[2] According to Mr. Soddy (*Radio-activity*, p. 163), there is some reason to think that the disappearance of the helium is caused by the projected α particles burying themselves in the glass.—F. L.

ceases to be material. These electric particles comprise positive ions (Rutherford's α rays), to which, after a certain time, succeed electrons (the same author's β rays) and X rays (γ rays). These various elements will be studied later on.

Although the "emanation" can produce electric particles by its dissociation, it is not charged with electricity.

Positive Ions and Negative Ions.—Let us recall to mind, for the understanding of what is to follow, that, according to a theory already old, which has, however, taken a great extension in these days, all atoms contain electric particles of ascertained size, called electrons. Let us now suppose that a body of some kind, a gas, for example, is dissociated—that is to say, ionized, as it is called. According to present ideas, there would be formed within it positive ions and negative ions by a process comprising the three following operations:—

1st. The atom, originally neutral—that is to say, composed of elements which neutralize each other—loses some of its negative electrons. 2nd. These electrons surround themselves, by electrostatic attraction, with some of the neutral molecules of the gases around them in the same way that electrified bodies attract neighbouring ones. This aggregate of electrons and neutral particles form the *negative ion*. 3rd. The atom, thus deprived of part of its electrons, then possesses an excess of positive charge, and in its turn surrounds itself with a retinue of neutral particles, thus forming the *positive ion*. Such is—reduced to its essential points—the present theory which the researches of numerous experimenters, especially J. J. Thomson, have succeeded in getting adopted, notwithstanding all the objections raised against it.

Things, however, only happen in the manner described in a gas at ordinary pressure. In a vacuum, electrons do not surround themselves with a retinue of material molecules; they remain in the state of electrons and can acquire a great speed, so that the formation of negative ions is not observed in a vacuum. Nor does the positive ion in a vacuum surround itself with neutral particles, but, as it is composed of all that is left of the atom, it is still voluminous, which is why its speed is comparatively feeble.

It may happen, however, and this is the case with the emission from radio-active bodies, that the negative electrons are expelled from the atom into the atmosphere, at the ordinary pressure, with too great a speed for their attraction on the neutral molecules to be capable of exercise. They do not then transform themselves into ions, but remain in the state of electrons and circulate as rapidly as those emitted *in vacuo*. It is they that form the β rays of Rutherford.

The positive ions, notwithstanding their volume, are likewise capable of acquiring a very high speed in the case of the emission from the radio-active substances. At least, such is the result of the researches of Rutherford, who supposes that the α rays—which constitute 99 per cent. of the emission of radium—are formed of positive ions launched with a speed equal to one-tenth that of light. This point demands elucidation by further researches.

When the factors of pressure and speed do not intervene, and the negative and positive ions are formed at atmospheric pressure, they have about the same bulk. It is only when they are generated *in vacuo* or are emitted with a very high speed that their dimensions vary considerably. *In vacuo*, in fact, the electron, as the nucleus of the negative ion, does not, as mentioned above, surround itself with material molecules, and remains in the state of electron. Its mass, according to several measurements of which I shall have to speak elsewhere, does not exceed the thousandth part of that of an atom of hydrogen. What remains of the atom deprived of a part of its electrons—that is to say, the positive ion—possesses a mass equal to and sometimes greater than that of an atom of hydrogen, and consequently at least a thousand times greater than that of the electron.

It is therefore necessary, when treating of the properties of ions, to distinguish—1st, whether they were formed in a gas at ordinary pressure; 2nd, if they were generated *in vacuo*; 3rd, if, by any cause whatever, they were launched into space at a great speed at the moment of their formation. Their properties naturally vary according to these different cases, as we shall see in other parts of this work. But, in all these different cases, the general structure of the ions remains the same. Their fundamental nucleus is always formed of electrons—that is, of electric atoms.

It is natural to suppose that the dimensions and properties of the ions formed in a gas at ordinary pressure differ notably from those of the electrons, since these latter are supposed to be free from all admixture of matter. But it seems difficult, on the current theory, to explain some of the properties of the ions, especially those which can be observed with simple gases, bodies which are easy to ionize by many different means. It is noted that they then form in the aggregate an entirely special fluid of which the properties are akin to those of a gas, without, however, possessing its stability. It can circulate, for some time, before being destroyed, through a worm of metal connected with the earth, which electricity could never do. It possesses a marked inertia, as its slight mobility proves. Such a fluid has properties too peculiar not to have a name given to it, for which reason I propose to call it the *ionic fluid*. We shall see that, owing to its inertia, we can transform it into very regular geometrical figures.

As ions are charged with electricity, they can be attracted by electrified bodies. This is, in fact, as we shall see later, the means of measuring their charges. When an ionized gas is enclosed between two metal plates, one of which bears a positive and the other a negative charge, the first-named attracts the negative and the last the positive ions. If the voltage of these plates is weak, part of the ions combine with one another, and become neutral, especially when their number is considerable. To extract them from the gaseous medium before they combine, it is necessary to raise the voltage of the containing vessel until the current produced by the circulation of the ions no longer increases—which maximum current is called the "saturation current."

We shall likewise see, in the part of this work devoted to experiments, that if ions possess common properties, which allow them to be classed in the same family, they also possess certain properties which permit them to be sharply differentiated.

Electrons.—The electrons, or electric atoms—called "corpuscles" by J. J. Thomson—are, as we have seen, the nucleus of the negative ion. They are obtained, disengaged from any foreign element, by means either of Crookes' tubes (when they take the name of cathode rays) or of radio-active bodies (when they are termed β rays). But, in spite of these differences of origin, they appear to possess similar qualities.

One of the most striking properties of electrons—apart from that of generating X rays—is that of passing through metallic plates without losing their electric charge, which, I repeat, is contrary to a fundamental property of electricity. The most violent discharges are, as is well known, incapable of passing through a metallic plate, however thin, connected with the earth.

These electrons, presumed to be atoms of pure electricity, have a definite size (and probably also a considerable rigidity). They have, whatever their origin, an identical electric charge, or can, at least, produce the neutralization of an amount of electricity which is always the same. But we possess no means of studying them in repose; and they are only known to us by the effects they produce when animated by great speed.

Their apparent mass—that is to say, their inertia—is, as we shall see in another chapter, a function of their speed. It becomes very great, and even infinite, when this speed approaches that of light. Their real mass, if they have one in repose, would therefore be only a fraction of the mass they possess when in motion.

The measurements of the inertia of electrons have only been made with the negative electrons, the only ones which have yet been completely isolated from matter. They have not been effective with the positive ions. Being inseparable at present from matter, these last must possess its essential property—that is to say, a constant mass independent of speed.

Electrons in motion behave like an electric current, since they are deviated by a magnetic field, and their structure is much more complex, in reality, than the above summary would seem to indicate. Without going into details, I shall confine myself to saying that they are supposed to be constituted by vortices of ether analogous to gyroscopes. In repose, they are surrounded by rectilinear rays of lines of force. In motion, they surround themselves with other lines of force—circular, not rectilinear—from which result their magnetic properties. If they are slowed down or stopped in their course they radiate Hertzian waves, light, etc. I shall recur to these properties in summing up in another chapter the current ideas on electricity.

The Cathode Rays.—As has been said in a preceding chapter, physicists have greatly altered their views as to the nature of the cathode rays. They are now considered to be composed of electrons—that is to say, of atoms of pure electricity disengaged from all material elements. They are obtained by various processes, notably by means of radio-active substances. The simplest way to produce them in large quantities is to send an induction current through a glass bulb furnished with electrodes and exhausted to the millionth of an atmosphere. As soon as the coil begins to work, there issues from the cathode a sheaf of rays, termed cathodic, which can be deviated by a magnet.

The bombardment produced by these rays has as its consequence very energetic effects, such as the fusion of metals struck by it. From their action on the diamond, the temperature they generate has been calculated at 3,500° C. Their power of penetration is rather weak, whereas that of the X rays, which are derived from them, is, on the contrary, very great. Lenard, who was the first to bring the cathode rays outside a Crookes' tube, employed to close the orifice in the tube, a plate of aluminium only a few thousands of a millimètre in thickness.

A portion of the electric particles constituting the cathode rays is charged with negative electricity; the other—that produced in the most central part of the tube—is composed of positive ions. These last have been called "Canal rays." The cathode rays and the canal rays of Crookes' tubes are of the same composition as the α and β radiations emitted by radio-active bodies such as radium and thorium.

Cathode rays possess the property of rendering air a conductor of electricity and of transforming themselves into X rays so soon as they meet an obstacle. In the air they diffuse very speedily, differing in this from the X rays, which have a strictly rectilinear progress. When Lenard brought the cathode rays out of a Crookes' tube through a plate of thin metal, he noted that they formed a widely-spread fan which did not extend farther than a few centimètres. In very rarefied gases it is possible, on the other hand, by means of a diaphragm, to confine them to a cone free from diffusion for the length of a mètre.

Whatever the gas introduced into a Crookes' tube before creating the vacuum—a very relative vacuum since there still remain in it thousands of millions of molecules, even when the pressure is reduced to the millionth of an atmosphere—it is noted that the cathode rays which are formed have the same properties and the same electric charges. J. J. Thomson has concluded from this that the atoms of the most different bodies contain the same elements. If, instead of a Crookes' tube, a very radio-active matter, thorium or radium, is used, the majority of the proceeding phenomena are found with simply quantitative variations. For example, more rays charged with negative electricity are found in the Crookes' tube than in those emanations of radium which are especially charged with positive electricity; but the nature of the phenomena observed in the two cases remains the same.

Speed and Charge of the Cathode and Radio-active Particles.—The measurement of the speed and of the electric charge of the particles of which both bodies are found, has proved, as has just been said, the cathode rays and the emission from radio-active their identity. It would take long to set forth the divers methods which have settled these points. Details will be found in the memoirs of J. J. Thomson, Rutherford, Wilson, etc. I will only here indicate very briefly the principle of the methods used.

So far as the speed, which is of the same order as that of light, is concerned, it may seem very difficult to measure the velocity of bodies moving so quickly;

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yet it is very simple. A narrow pencil of cathodic radiations obtained by any means—for example, from a Crookes' tube or a radio-active body—is directed on to a screen capable of phosphorescence, and on striking it a small luminous spot is produced. This sheaf of particles being electrified can be deviated by a magnetic field. It can therefore be deflected by means of a magnet so disposed that its lines of force are at right angles to the direction of the particles. The displacement of the luminous spot on the phosphorescent screen indicates the deviation which the particles undergo in a magnetic field of known intensity. As the force necessary to deviate to a given extent a projectile of known mass enables us to determine its speed, it will be conceived that it is possible to deduce from the extent of their deviation the velocity of the cathodic particles. It is seldom less than one-tenth of that of light, or say 30,000 kilomètres per second, and sometimes rises to nine-tenths. When the pencil of radiations contains particles of different speed, they trace a line more or less long on the phosphorescent screen instead of a simple point, and thus the speed of each can be calculated.

To ascertain the number, the mass, and the electric charge—or at least the ratio $\frac{e}{m}$ of the charge to the mass—of the cathode particles, the procedure is as follows:—The first thing is to ascertain the electric charge of an unknown number of particles contained in a known volume of gas. A given quantity of gas containing the radio-active particles is then enclosed between two parallel metallic plates, the one insulated and the other positively charged. The positive particles are repelled towards the insulated plate, while the negative particles are attracted, and their charge can be measured by the electrometer. From this total charge, the charge of each particle can evidently be deduced if the number of particles can be ascertained.

There are several modes of arriving at this number. The most simple, first used by J. J. Thomson, is based on the fact that when cathode particles are introduced into a reservoir containing water-vapour, each particle acts as a condensation nucleus for the vapour and forms a drop. The result is a cloud of small drops. These latter are far too small to be counted, but their number may be deduced from the time they take to fall through the recipient containing them, the fall being rendered very slow owing to the viscosity of the air. When one knows the number of these small drops, and consequently the number of cathode particles contained in a given volume of water-vapour, and also the electric charge of all the particles, a simple sum in division gives the electric charge of each particle.

It is by working in this way that it has been possible to demonstrate that the electric charge of the cathode particles was constant whatever their origin (particles of radio-active bodies, of ordinary metals struck by light, etc.). Their electric charge is represented by about 10^8 electro-magnetic units. The value of $\frac{e}{m}$ of the ion of hydrogen in the electrolysis of liquids being only equal to 10^5, it follows that the mass of the negative ion in dissociated bodies is the thousandth part of the atom of hydrogen, the smallest atom known.

The preceding figures only apply to negative ions. They are the only ones of which the size is constant for all substances. As to the positive ions which contain the greater part of the undissociated atom, their charge naturally varies according to the substance. Their dimensions are never less than those of the atom of hydrogen.

The X rays.—When the cathode rays—that is to say, the electrons emitted by a Crookes' tube or by a radio-active body, meet an obstacle, they give birth to special radiations called X rays when they come from a Crookes' tube, and γ rays when emitted by a radio-active body. These radiations travel in a straight line, and can pass through dense obstacles. They are not reflected, refracted, nor polarized, and this absolutely differentiates them from light. They are not deviated by a magnet, and this separates them sharply from the cathode rays, whose power of penetration is, besides, infinitely more feeble. The X or γ rays possess the property of rendering air a conductor of electricity, and consequently of dissipating electric charges. They render phosphorescent various substances, and impress photographic plates.

When the X rays strike any substances whatever, they cause the formation of what are called secondary rays, identical with the cathode rays;[1] this simply means that X rays derived from the dissociation of matter have the property of producing a further dissociation of matter when they come into contact with it, a property which luminous radiations,

[1] According to Professor Sagnac, only a part of the secondary rays are deviable in a magnetic field, and this part varies according to the metal or other substance by which they are emitted. (*Comptes rendus du 1st Congrès International pour la Radiologie.* Bruxelles, 1905, pp. 146 *et seq.*)—F. L.

notably those of the ultra-violet region, likewise possess.[1]

Notwithstanding the researches of hundreds of physicists ever since their discovery, our knowledge concerning the X rays is almost solely confined to the notice of the attributes described; and as they have no relation to anything known, they can be assimilated to nothing.[2]

It has been sought, however, to connect them with ultra-violet light, from which they would only differ by the extreme smallness of their wave-length. This hypothesis seems to have but small grounds for support. Without going into the speed which the cathode rays must possess to impart to the ether vibrations corresponding to those of light, and leaving on one side the absence of polarization and of refraction which would be justified by the smallness of the supposed waves, it is curious to observe that the more one advances into the ultra-violet region, and the nearer one consequently gets to the supposed wave-length of the X rays, the less penetrating do the radiations become. In the extreme limit of the spectrum they end by being no longer able to overcome the slightest obstacle. For the extreme violet spectrum in the neighbourhood of $.160\mu$ to $.100\mu$, so lately studied by Schumann and Lenard, two centimètres of air are as opaque as lead, as is a sheet of mica the hundredth part of a millimètre in thickness.

[1] For further particulars of this analogy see C. Sagnac, *L'Optique des Rayons X*, p. 140; Paris, 1900.—F. L.

[2] Professor Soddy compares them to light, both being, according to him, pulses in the ether, and attributes the impossibility of their polarization, etc., to the fact that, unlike light, they are "sudden pulses very rapidly dying away" instead of regular successive undulations. Cf. *Radio-Activity*, p. 8.—F. L.

Now, the X rays, supposed to be so near to this extreme region of the ultra-violet, pass, on the contrary, through all obstacles, thick metallic plates included. If they did not produce fluorescence and photographic action, no one would have dreamed of comparing them to ultra-violet light.

The impossibility of giving to the X rays that deviation by a magnetic field which the cathode rays undergo, has caused them to be looked upon as no longer possessing any electricity, but this conclusion may easily be contested. Suppose, in fact, that the X rays are constituted of electric atoms still more minute than the ordinary negative electrons, and that their speed of propagation borders on that of light.[1] According to the researches to be presently mentioned, electrons having such a velocity would have an infinite mass. Their resistance to motion being infinite, it is evident that they could not be deviated by a magnetic field, though composed of electric elements.

What seems now to be most evident is that there is no more reason to connect the X rays with electricity than with light. Assimilations such as these are the offspring of that habit of mind which induces us to connect new things with those previously known. The X rays simply represent one of the manifestations of intra-atomic energy liberated by the dissociation of matter. They constitute one of the stages of the vanishing of matter, a form of energy having its own characteristics, which must be defined solely by these characteristics

[1] The Austrian physicist, Professor Marx, claims to have measured their speed, and to have ascertained that it is the same as that of light. (*Annalen der Physik*, 1905).—F. L.

without endeavouring to fit it into previously arranged categories. The universe is full of unknown forces which, like the X rays of to-day, and the electricity of a century ago, were discovered only when we possessed reagents capable of revealing them. Had phosphorescent bodies and photographic plates been unknown, the existence of X rays could not have been verified. Physicists handled Crookes' tubes, which yield these rays in abundance, for a quarter of a century without discovering them.

If it is probable that the X rays have their seat in the ether, it seems certain that they are not constituted by vibrations similar to those of light. To me, they represent the extreme limit of material things, one of the last stages of the vanishing of matter before its return to the ether.

Having sufficiently described, according to present ideas, the supposed constitution of the products given off by matter during its dissociation, we will now study the various forms of this dissociation, and show that we shall everywhere meet again the elements just enumerated.

CHAPTER III.

THE DEMATERIALIZATION OF VERY RADIO-ACTIVE SUBSTANCES—URANIUM, THORIUM, RADIUM, ETC.

§ 1. *The Products of the Dematerialization of very Radio-active Substances.*

We are about to relate, in this chapter, the researches which have been effected on very radio-active substances—that is to say, upon substances which dissociate spontaneously and rapidly. Among the products of their dematerialization we shall again meet with those which are given off by any substance dissociated by any means, but the products emitted will be much greater in quantity. Under different names we shall still find the emanation, ions, electrons, and X rays.

It must not be thought that these substances represent all the stages of the dematerialization of matter. Those of which the existence is known are only parts of what is probably a very long series. If we always meet with the same elements in the products of all bodies subjected to dissociation, it is because the reagents actually in use, being only sensitive to certain substances, are naturally unable to reveal others. When we discover other reagents, we shall certainly note the existence of other elements.

The very great interest of the spontaneously radio-active substances consists in their emitting, in considerable quantity, elements which other bodies only produce in much smaller quantity. By thus enlarging a general phenomenon, they permit of its being studied more in detail.

In this chapter we shall simply set forth the researches on eminently radio-active bodies, thorium and radium in particular. It is as yet a very new subject, and for that reason the results obtained will offer many contradictions and uncertainties. Their importance is, however, paramount.

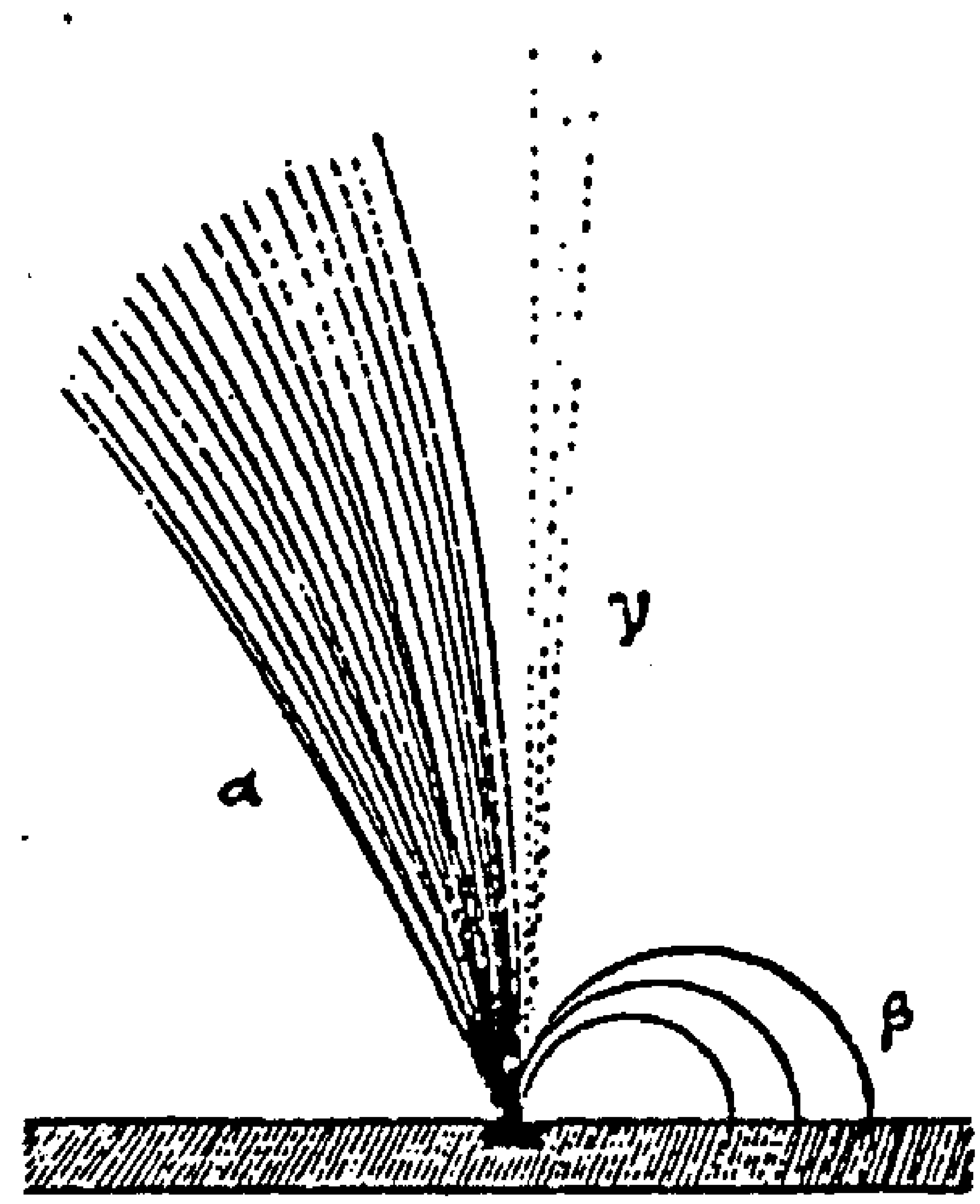


FIG. 3.

The three orders of radiations emitted by a radio-active body and separated by a magnetic field.

On the left are seen the α radiations (or positive ions), which form 99% of the total radiations; on the right the β radiations (or negative electrons); and in the centre, undeviated by the magnetic field, the γ or X rays. This mode of representation has been borrowed from Rutherford and Curie, but the relation between the various radiations has been modified, so as to show plainly that the α rays form the greatest part of the radiations. The diagrams hitherto published show precisely the contrary.

Rutherford, who has studied the radio-active substances with great success, and has, with Curie, discovered nearly all the facts concerning them, has designated their radiations by the letters α, β, and γ, which are now generally adopted. But under these new appellations are found exactly the products we have described. The α radiations are composed of positive ions, the β radiations of electrons identical with those constituting the cathode rays, while the γ radiations are similar to the X rays. These three kinds of radiations are very clearly indicated in the diagram given in Fig. 3.

To these several radiations is joined, as a primary phenomenon, according to Rutherford, the emission of a semi-material substance, which he terms "emanation." It possesses no electric charge, but would appear to undergo subsequent stages of dissociation, which change it into α and β particles. We will now examine the properties of the products we have just enumerated. For the most part, we shall only have to repeat or complete what has been said in a previous chapter.

§ 2. α *Rays, or Positive Ions.*

The α rays are formed of positive ions. They are deviated by an intense magnetic field, but in a contrary direction to the β rays. The radius of curvature of their deviation is 1000 times greater than that of the β particles. They form 99% of the total radio-activity of radium. They render air a conductor of electricity. Their action on a photographic plate is much less than that of the β rays, and their force of penetration very slight, since they are stopped by a sheet of paper. This weak power of penetration enables them to be easily differentiated from the other radiations to which paper is no obstacle. Of all the emissions of radio-active bodies it is the α rays especially which make the air a conductor of electricity, and it is the β rays which produce photographic impressions. When a radio-active body is enclosed in a glass tube nearly all the α particles are stopped by the glass walls.

It is supposed, from various calculations, that the α particles must have a mass equal or superior to that of the hydrogen atom and a like charge. Their speed, as calculated from the extent of their deviation by a magnetic field of given intensity, is one-tenth that of light. Their quantity varies according to the substance. For uranium and thorium it is, for one gramme, 70,000 per second, and for radium a hundred thousand millions. This emission may last without interruption for more than a hundred years.

The emission of the α particles, otherwise positive ions, is, together with the production of the emanation, the fundamental phenomenon of radio-activity. The emission of β particles and that of the γ rays, which together form hardly one per cent. of the total emission, should represent a further stage in the dissociation of radio-active atoms.

On striking phosphorescent bodies the α particles render them luminous. It is on this property that is based the spinthariscope, an instrument which renders visible the permanent dissociation of matter. It simply consists of a screen of sulphide of zinc, above which is placed a small metal rod, the end of which has been dipped in a solution of chloride of radium. On examining the screen through a magnifying-glass, there can be seen spurting out without cessation a shower of small sparks produced by the impact of the α particles, and this emission may last for centuries, which shows the extreme smallness of the particles coming from the disaggregation of atoms. If this emission is visible, it is, as Crookes says, because "each particle is made apparent solely through the enormous degree of lateral perturbation produced by its shock on the sensitive surface, in the same way that raindrops falling into the water produce ripples which exceed their diameter." I have succeeded, by using certain varieties of phosphorescent sulphide, in making screens allowing the phenomenon of dissociation to be observed, not only with salts of radium, but also with divers substances, notably thorium and uranium.[1]

The high speed of the α particles seems very difficult to explain. This speed is intelligible enough in the case of the β rays, which, being composed of atoms of pure electricity, and having, no doubt, a very small inertia, can acquire a very high speed under the influence of very minute forces; but for the α particles, whose dimensions would appear to be identical with that of the hydrogen atom, a velocity of 30,000 kilomètres per second seems to be very difficult to explain, and I think that, on this point, the experiments of Rutherford and his pupils should be taken up anew.[2]

It is hardly to be supposed, moreover, that these

[1] The phosphorescent sulphide is spread in a layer, so thin as to be transparent, on a strip of glass first covered with varnish. The side coated with phosphorescent matter is then placed on the substance it is desired to examine, and the other face of the glass is observed through a magnifying-glass. All uranium and thorium minerals, and even an ordinary incandescent mantle, give out a luminescent scintillation indicating a dissociation of matter; but, in order to see this, it is necessary that the eye be rendered sensitive by previously remaining in the dark for a quarter of an hour.

[2] It seems possible that this high speed can be explained by supposing that, although the α particles are being constantly emitted, it is only when they reach a certain velocity that their existence can be recognized by us. Thus, the Hon. R. J. Strutt, in reviewing Professor Rutherford's *Radio-Activity* (2nd ed.), says: "Ordinary matter may be emitting as many or more α particles than uranium, if only their velocity is less than that minimum velocity which has been found necessary to produce the characteristic phenomenon." (*Nature*, 25th January 1906.)—F. L.

velocities are produced instantaneously; they are only comprehensible on the hypothesis that the particles of atoms can be compared to small planetary systems animated with enormous velocities. They would preserve their speed on leaving their orbits as does a stone launched from a sling. The invisible speed of rotation of the elements of the atom would therefore be simply transformed into a speed of projection visible or in any case perceptible by our instruments.

§ 3. *The β Rays or Negative Electrons.*

β rays are considered to be composed of electrons identical with those of the cathode rays. They should, therefore, be formed of negative electric atoms, freed from all matter. Their mass should be, like that of the cathode particles, the thousandth part of that of the hydrogen atom. Their velocity should vary between 33% and 96% of that of light.

They are emitted in a much smaller proportion than that of the α particles, since they hardly form 1% of the total radiation. It is these rays which produce photographic impressions.

Their penetrating power is considerable. While the α rays are arrested by a sheet of ordinary paper, the β rays will traverse several millimètres of aluminium. It is probably by reason of their great speed that they are much more penetrating than the cathode rays of a Crookes' tube, which can only pass through sheets of aluminium of a thickness of some thousandths of a millimètre.

They immediately render luminous by impact bodies capable of phosphorescence, even when separated from them by a thin plate of aluminium. The phosphorescence is very bright in platino-cyanide of barium and those kind of diamonds—rather rare, by-the-by—which are capable of phosphorescence.[1]

The β particles seem to be somewhat complex, as is proved by the different speeds of their composing elements. This inequality of speed is easily recognized by the extent of the photographic impression they produce when submitted to the action of a magnetic field.[2] It is likewise noticed, by covering the photographic plate with screens of varying thicknesses, that different α and β particles possess different powers of penetration.[3] It is therefore very probable that they represent well marked

[1] It is this very property which I have taken as a basis for the measurement of the intensity of the various samples of radium I have had occasion to examine. When the tube containing a salt of radium renders a diamond phosphorescent through a thin strip of aluminium, this salt may be regarded as very active. Brazilian diamonds alone—Cape diamonds never—are utilizable for this experiment. The first, in fact, are capable of phosphorescence by light and the second are not so. I have proved this by experiments extending to many hundreds of samples, details of which are given in my memoir on phosphorescence.

[2] Professor J. J. Thomson has also shown this by a very elaborate series of experiments, which he sums up by saying that "the radio-active substances, Radium and Polonium, emit when cold slowly-moving negatively electrified corpuscles." Later, he has shown that this property is possessed by the alkali-metals, and thinks that "with more delicate apparatus . . . it is probable that this property might be detected in all substances." (See *Phil. Mag.* for November 1905, p. 587.)—F. L.

[3] This fact, which was asserted some time since by Professor Rutherford (*Phil. Mag.* for May 1904), was for a long time denied by M. Henri Becquerel. Later experiments have, however, convinced him that Professor Rutherford is right. (See *Comptes Rendus de l'Académie des Sciences*, 12th February 1906.)—F. L.

stages of the dissociation of matter which we are not at present able to distinguish.

§ 4. *The γ or X rays.*

Together with the α and β rays, the first charged with positive, and the second with negative electricity, radio-active bodies emit an extremely slight proportion (less than one per cent.) of γ rays, entirely analogous, as to their properties, to the X rays, but possessing a higher power of penetration, since they can traverse several centimètres of steel. This property enables them to be easily distinguished from the α and β rays, which are stopped by a lead plate a few millimètres thick. Their nature is otherwise but little known, and if they are said to be analogous to the X rays, it is solely because they are not deviated by a magnetic field and possess great penetrating power.

What complicates to a singular degree the study of the above emissions (α, β and γ) is that none of them can touch a gaseous or a solid body without immediately causing—no doubt through the disturbance produced by their enormous velocity—a dissociation resulting in the production of rays called secondary, which are similar in their properties to the primary rays, but less intense. These secondary radiations also impress photographic plates, render the air a conductor of electricity, and are deviated by a magnetic field. They are able to produce, by their impact, tertiary rays having the same properties and so on. It is the secondary rays produced by the γ rays which are the most active. A photographic impression through a metallic plate is sometimes intensified by the interposition of that plate, because the action of the secondary rays is then superposed on that of the primary rays.

§ 5. *Semi-material Emanation proceeding from the Radio-active Substances.*

One of the most curious properties of the radio-active, and, moreover, of all substances, is that of incessantly emitting a non-electrified product, designated by Rutherford as the emanation. This emanation represents the first stages of the dissociation of matter, and, by its disaggregation, generates emissions of the particles studied in the preceding paragraph. To this emanation is also due the property possessed by radium of rendering radio-active all bodies placed in its neighbourhood.

The emanation has been especially studied in the case of radium and of thorium. Uranium does not give enough of it to be revealed by reagents. It is, however, very probable that, contrary to the opinion of Rutherford, it does disengage an emanation, since, according to the researches of J. J. Thomson, the majority of bodies in nature, water, sand, etc., produce one also.

The emanation can be drawn from any radio-active bodies, either by dissolving them in any liquid placed in a receiver communicating with a closed tube, or by bringing them to a red heat in a similar apparatus. The emanation drawn into the tube renders it phosphorescent by its presence, which fact allows of its behaviour being examined. It can be condensed by the cold produced by liquid air. This condensation is revealed by the localization of the phosphorescence, but no substance capable of being measured by the balance appears. As the emanation of thorium condenses at 120° C., and that of radium at 150° C., it seems very likely that the emanations of different bodies, some resemblances notwithstanding, display various properties.

At the ordinary temperature radio-active bodies in a solid state emit the emanation, but only a hundredth part of the quantity emitted in the state of solution. By introducing sulphide of zinc into a bulb containing a solution of chloride of radium, the disengagement of the emanation renders the sulphide phosphorescent. Radium, when heated, loses the greater part of its activity by reason of the quantity of emanation it gives off, but it regains it entirely in twenty days or so. The same loss occurs when a solution of this salt is heated to boiling.

When solid chloride of radium has been brought to a red heat, or a solution of it has been boiled for some time, it still preserves a quarter of its primary activity, but this latter is then solely due to the α particles, as can be noted by the weak penetrating power of the rays emitted, which can no longer pass through a sheet of paper. It is only after a certain lapse of time that the appearance of the β rays, capable of passing through metals, again takes place. The activity of the emanation is lost rather quickly. The rapidity of this loss varies according to the substance. That of actinium is destroyed in a few seconds, that of thorium in a few minutes, that of radium only at the end of three weeks, but it is already reduced by one-half in four days.

According to Rutherford, radium and thorium produce different kinds of emanations, that is, of dissociations which begin with the emission of the emanations. He has already counted five or six belonging to this last. The first engenders the second, and so on. They no doubt represent successive stages of the dematerialization of matter.

To the emanation are due three-fourths of the heat incessantly produced by radium, which maintains its temperature at 3° or 4°C. above the ambient medium. If, in fact, radium be deprived of its emanation by heating, it gives out no more than a quarter of the heat it emitted at first. Almost all the rise in temperature is due to the α particles.

It results, as I have already remarked, from the experiments of Ramsay, that if some emanation of radium is left for some days in a tube, there can be observed the spectral lines of helium which were not there in the first instance.

Before drawing too many conclusions from this transformation, it must be first remarked that helium is a gas which accompanies all radio-active minerals. It was even from these bodies that it was first obtained. This gas enters into no chemical combination,[1] while it is the only substance hitherto found impossible to liquefy and can be kept for an indefinite time in the tubes in which it is enclosed.

This derivative of radium must be a very special helium since it appears to possess the property of spontaneously vanishing. Its sole resemblance to ordinary helium would seem to consist in the momentary presence of some spectral rays. It

[1] This can now hardly be said. Dr. Ternent Cooke has shown that helium in certain circumstances forms an unstable compound with cadmium. (See *Proc. Roy. Soc.*, 8th February 1906.)—F. L.

therefore seems very difficult to admit the transformation of radium into helium.

Rutherford considers the emanation as a material gas, because it can be diffused and condensed in the manner of gases. No doubt the emanation has some properties in common with material bodies, but does it not curiously differ from these last by its property of vanishing in a few days, even when enclosed in a sealed tube, by transforming itself into electric particles? Here, especially, is shown the utility of the notion we have endeavoured to establish, of an intermediary between the material and the immaterial—that is to say, between matter and the ether.

The emanation of the radio-active bodies represents, according to me, one of these intermediate substances. It is partly material, since it can be condensed and dissolved in certain acids and recovered by evaporation. But it is only incompletely material, since it ends by entirely disappearing and transforming itself into electric particles. This transformation, which takes place even in a sealed glass tube, has been proved by the experiments of Rutherford. He has shown that in disappearing the emanation at first gives birth to α particles and only later to β particles and γ radiations.

To prove that the emanation of radium or of thorium only generate at first positive or α particles, it is placed in a brass cylinder .05 mm. thick, which retains all the α particles, but allows the β particles and γ rays to pass through. By noting at regular intervals by means of an electroscope the external radiation of the cylinder, it can be seen that it is only at the end of three or four hours that the β particles appear. The α particles, on the contrary, show themselves at once, as is proved by their action on an electroscope connected with the interior of the cylinder.

Rutherford concludes from his experiments that "the emanation" at first emits only α rays, then β and γ rays by deposition on the walls of the containing cylinder. It is difficult to conceive, from all we know of electricity, an emission of solely positive particles without a similar negative charge being produced at the same time.

However that may be, if the above theory be correct, the emanation in disappearing first produces positive ions relatively voluminous, then negative electrons, a thousand times less so, and finally γ radiations.

Rutherford considers the emanation to be a sort of gas capable of spontaneously dissociating into electric particles expelled with immense velocity. In the course of dissociation this supposed gas would emit three million times the amount of energy produced by the explosion of an equal volume of hydrogen and oxygen mixed in the proportions required for the formation of water. This last reaction is, however, as is well known, that which produces most heat.

Is this emanation, which produces so large a quantity of electric particles, itself electrified? In no way. Rutherford asserts this positively, but this important point has been very clearly demonstrated by the researches of Professor MacClelland. "The fact," he says, "that the emanation is not charged has an important significance from the point of view of our conception of the manner in which the radium atom destroys itself. The radium atom assuredly produces α particles charged positively. But the particles of the emanation cannot be what remains of the atom after the emission of the α particles, for, in that case, they would be charged negatively." There results from these experiments and the observations previously made by me that everything relating to the α particles, which form 99% of the emission of radio-active bodies, requires to be entirely re-examined.

§ 6. *Induced Radio-activity.*

It is the emanation which, by freeing itself and by projecting its disaggregated particles on to the surface of other bodies, produces the so-called induced radio-activity. This phenomenon consists in all substances placed in the neighbourhood of a radio-active compound becoming momentarily radio-active. They do not become so if the active salt is enclosed in a glass tube. The β and γ rays are alone capable of producing induced radio-activity. The α particles do not seem to possess this power. Radio-activity, artificially provoked in any substance, disappears only after a fairly long time.

All gases or metals placed close to a radio-active substance or on which is blown, by means of a long tube, the emanation which it disengages, become momentarily radio-active. If it be admitted that this radio-activity is generated by the freeing of electric particles, it must be supposed that these particles are capable of being carried along by the air and of attaching themselves like dust to other bodies, and possess properties singularly different from those of ordinary electricity. Rutherford has verified the fact that the emanations of thorium can pass through water and sulphuric acid without losing their activity. If a metallic wire charged with negative electricity be exposed to the emanations of thorium, it becomes radio-active; if this wire be treated with sulphuric acid and the residuum then evaporated, it will be found that this latter is still radio-active. One really does not see how electricity could bear such treatment.

The induced radio-activity communicated to an inactive substance may be much more intense than that of the radio-active substance from which it emanates. When, in an enclosed vessel, containing some emanation from a radio-active body—thorium, for example—a metal plate charged with negative electricity at a high potential is introduced, all the particles emitted by the thorium concentrate themselves upon it, and, according to Rutherford, this plate becomes ten thousand times more active, surface for surface, than the thorium itself. These facts are not, any more than the preceding ones, explicable by the current theory.

If a metal, rendered artificially radio-active, be brought to a white heat, it loses its radio-activity, which spreads itself over the bodies in its neighbourhood. Here, again, we see the so-called electric atoms behave in a very strange manner.

The phenomenon of induced radio-activity is, then, quite inexplicable with the current ideas as to electric particles. It cannot be admitted that such particles deposited on a metal can remain for weeks in the state of electric atoms and be carried along by reagents. It would seem, from M. Curie's experiments, that bismuth, plunged into a solution of bromide of radium and carefully washed immediately, remains radio-active for at least three years. This radio-activity would even seem to persist after energetic chemical treatment. Can it be considered likely that electric particles act in such a manner? And, since they act so differently from electricity, how is it possible, as I have so often repeated, to persist in applying to them the term "electric" atoms?

I must remark with respect to induced radioactivity, that certain forms of energy can be stored in bodies for a great length of time and expend themselves very slowly. In my former experiments on phosphorescence I noted that sulphide of calcium, exposed to the sun for a few seconds, radiates invisible light for eighteen months, as is proved by the possibility of photographing the insolated object in the dark room or in the most complete darkness. At the end of eighteen months it no longer gives any radiation, but still preserves a residual charge which persists for an indefinite period, and can be made visible by causing invisible infra-red rays to fall on the surface of the insolated body.

A radio-active body has been compared to a magnet which keeps its magnetism for ever, and can, without losing its power, magnetize other bodies. There is little foundation for this comparison, for the magnet is not the seat of a constant emission of particles into space.[1] It might, however,

[1] M. Villard's experiments, however, have given him some reason to think that an electro-magnet may, under certain conditions, actually emit particles of magnetism which he calls "magnetons." (See *Revue Générale des Sciences*, 15th May 1905.)—F. L.

be employed to explain roughly the phenomenon of induced radio-activity, which could be reduced to the fact that a radio-active body imparts its properties to a neighbouring body, as the loadstone gives magnetization to fragments of iron near it. If the molecules of the air were magnetic—and they are so in a slight degree—a loadstone would magnetize them, and they themselves might magnetize others. If they preserved their magnetism, we should have a gas, which, like the emanation of radio-active bodies, would be able to circulate in tubes and remain persistently on the surface of a metal without losing its properties.

From all that has been set forth above one general consideration emerges, and this confirms what has been said at the commencement of this chapter—namely, that the stages of the dissociation of matter must be extremely numerous and that but few of them are yet known to us. Without being able to isolate them, we are, at least, certain that they exist, since the unequal deviation of the β particles by a magnet proves clearly that these are composed of different elements. We equally know that, in the semi-material product designated under the general name of emanation, already four or five very different stages of the dissociation of matter may be noted.

The same experiments equally confirm this other view—that matter, in dissociating, emits products, more and more subtle, more and more dematerialized, which progressively lead to the ether. The positive ion is still largely charged with matter. The negative electrons are nearer to the ether. They themselves represent varied stages of dissociation, since their unequal deviation by the same magnetic field proves that they are composed of different elements. Finally, we come to the γ radiations, which are no longer stayed by any obstacle, which no magnetic attraction can deviate, and which seem to constitute one of the last phases of the dissociation of matter before its final return to the ether.

CHAPTER IV.

THE DEMATERIALIZATION OF ORDINARY BODIES.

§ 1. *Divers Causes of the Dematerialization of Matter. Methods employed to verify it.*

MANY years have elapsed since I proved that the dissociation of matter observed in the substances called radio-active, such as uranium and radium, was, contrary to the ideas then accepted, a property belonging to all bodies in nature, and capable of manifesting itself under the influence of the most varied causes and even spontaneously. The spontaneous radio-activity of certain substances, such as uranium and thorium, which has so taken physicists by surprise, is in reality a universal phenomenon and a fundamental property of matter.

In a recent study,[1] Professor J. J. Thomson has again taken up this question, and has succeeded in showing the existence of radio-activity in most bodies —water, sand, clay, brick, etc. He has drawn from them an "emanation" which is produced in a continuous manner, similar to that extracted by Rutherford from radium and having the same properties of radio-activity.[2]

[1] On the Presence of Radio-active Matter in Ordinary Substances (*Proceedings of the Cambridge Philosophical Society*, April 1904, p. 391).

[2] It should be noted that in the memoir referred to, Professor J. J. Thomson mentions that the "capriciousness" of the emanations obtained indicates "that they are due to minute traces of a radio-active

These experiments confirm all those I had already published on the spontaneous dissociation of matter, but they in no way prove, as Elster and Geitel would believe, that there is radium everywhere.[1] It was the only explanation to which the last partisans of the indestructibility of matter could attach themselves. To admit that the atoms of two or three exceptional bodies can be dissociated is less embarrassing than to acknowledge that there is here a question of an absolutely general phenomenon.

My experiments, moreover, take away all verisimilitude from such explanations. When we succeed in varying enormously the radio-activity of a body by certain chemical reactions, when we render greatly radio-active, by admixture, substances such as tin and mercury, which apart are not so, is it really possible to imagine that radium can have anything to do with the radio-activity then observed?

impurity." This has not been confirmed, so far as I am aware, by subsequent experiments, and it is coupled with the observation that "there is, I think, a considerable amount of evidence that most, if not all, bodies are continually emitting radiation which, like the Röntgen rays, can ionize a gas through which it is passed." M. Blondlot, the well-known professor of Nancy, on the other hand, has since made experiments that go to show that an emanation capable of increasing the light of a phosphorescent screen, which can be deviated by a magnetic or electric field or a draught of air, is emitted at ordinary temperatures by copper, silver, zinc, damped cardboard, all liquids, odorous substances such as camphor and musk, and the human body. (See *Comptes Rendus de l'Acad. des Sci.*, 13th and 27th June, 4th and 25th July 1904.)—F. L.

[1] This does not seem to be Professors Elster and Geitel's present opinion. Their most recent utterance on the subject is that the spontaneous ionization of the atmosphere is due to a very penetrating radiation resembling that emitted by uranium and present all over the earth's surface. They found it able to penetrate 20 cm. of lead, but that it is subject to a large loss of power in passing through rock-salt. (See *Physikalische Zeitschrift*, 15th January 1906.)—F. L.

It was only thanks to long and minute experiments that I was able to establish the universality of the dissociation of matter. Some of these will be set forth in the second part of this work. Here only a summary of the results obtained will be given.

What phenomena now can be relied upon for the demonstration of the dissociation of ordinary matter? Exactly those which prove the dissociation of the particularly radio-active substances, such as radium and thorium—that is to say, the production of particles emitted at an immense speed, capable of rendering the air a conductor of electricity and of being deviated by a magnetic field.

There exist other accessory characteristics: photographic impressions, production of phosphorescence and fluorescence, etc., by the emitted particles, but they are of secondary importance. Besides which, 99 per cent. of the emission of radium is composed of particles having no action on photographic plates, and there exist radio-active substances such as polonium which only emit rays such as these.[1]

The most important among the characteristics above enumerated is the emission of particles able to render the air a conductor of electricity and consequently capable of discharging an electroscope at a distance. It has been exclusively made use of in the separation of radium. It is therefore the one to which we shall principally have recourse.

The possibility of deviating these particles by a magnetic field constitutes the next most characteristic

[1] Since this was written, successful attempts have been made to impress a photographic plate with the β rays from polonium or, what is the same thing, radio-tellurium. Cf. *Proc. Roy. Soc.*, 21st July 1906 (Professor Huff's experiments).—F. L.

phenomenon. It has permitted the identity of the particles emitted by substances endowed with radio-activity, whether spontaneous or excited, with the cathode rays of Crookes' tubes to be indisputably established. It is the degree of deviation of these particles by a magnetic field which has enabled their speed to be measured.

§ 2. *Dissociation of Matter by Light.*

It was by attentively studying the action of light on metals and noting the analogy of the effluves emitted with the cathode rays that I was led to the discovery of the universality of the dissociation of matter.

It will be seen in the experimental part of this work that the *technique* of the experiments demonstrating the dissociation of bodies under the influence of light is pretty simple, since it amounts to throwing on to a positively charged electroscope the effluves of dissociated matter emitted by a metallic plate struck by light. These effluves are not produced by metals alone, but by the majority of substances. In some, the emission, surface for surface, may be forty times more considerable than that produced by certain spontaneously radio-active substances, such as thorium and uranium.

For a long time the composition of these effluves which I asserted to be of the nature of cathode rays, and of the radiations emitted by radio-active bodies, was contested, but at the present day no physicist denies this identity.

The effiuves produced under the action of light, like the cathode rays, render the air a conductor of electricity, and they are also deviated by a magnet. The electric charge of these component particles, as measured by J. J. Thomson, has been found equal to that of the cathode particles.

I shall show in the experimental part of this work that the different parts of the spectrum possess very different powers of dissociation, and that the resistance of various bodies to dissociation by light is very unequal. The ultra-violet is the most active region. In the extreme regions of the ultra-violet produced by electric sparks—regions which do not exist in the solar spectrum, because they are absorbed by the atmosphere,—it may be noted that all bodies dissociate with far greater rapidity than in ordinary light. In this part of the spectrum, substances which, like gold and steel, are not sensibly affected by solar light, emit effluves in quantities sufficiently abundant to discharge the electroscope almost instantaneously. If the earth were not protected from the extreme solar ultra-violet rays by its atmosphere, life on its surface, under existing circumstances, would probably be impossible.

Solar light does not possess the property of dissociating the molecules of gases. These can only be dissociated by the absolutely extreme ultra-violet radiations. If, as is probable, these radiations exist in the solar spectrum before their absorption by the atmospheric envelope, an energetic dissociation of the aerial gases must take place on the confines of our air. This cause must have contributed, in the course of ages, to deprive certain stars, like the moon, of their atmosphere.

§ 3. *Dissociation of Matter by Chemical Reactions.*

We now arrive at one of the most curious and unexpected parts of my researches. Convinced of the general character of the phenomena I had noted, I asked myself whether chemical reactions might not generate effluves similar to those produced from substances by light, and which would still possess the common characteristic of dissipating electric charges. Experiment has fully confirmed this hypothesis.

Here was a fact hitherto absolutely unsuspected. It had long been known, since the observation goes back as far as Laplace and Lavoisier, that hydrogen, prepared by the action of iron on sulphuric acid, was electrified. This fact ought to have impressed physicists the more that the direct electrification of a gas is impossible. A gas left for an indefinite period in contact with a metallic plate charged with electricity never becomes electrified. If the air could be electrified it would no longer be an insulator, an electroscope could no longer keep its charge, and the majority of electrical phenomena would still be unknown to us. But this fact, so important, since it contained the proof, then concealed, that matter is not indestructible, remained totally unnoticed.

The most striking phenomena hardly attract our attention except when light is thrown upon them by other phenomena, or when some great generalization capable of explaining them forces us to examine them more closely. If, in Lavoisier's experiments just alluded to, hydrogen was found to be electrified, it was only because the atoms of this substance had undergone the commencement of dissociation. It is curious to note that the first experiment from which it could be deduced that matter is perishable had for its author the illustrious savant whose greatest claim to glory is that of endeavouring to prove that matter is indestructible.

The experiments collected at the end of this work prove that a large number of chemical reactions, whether accompanied or unaccompanied by the disengagement of gas, produce effluves similar to the cathode rays, and therefore reveal a destruction of matter without return during the reactions.

Among these reactions I shall only mention: the decomposition of water by zinc and sulphuric acid or merely by the sodium amalgam, the formation of acetylene by carbide of calcium, the formation of oxygen by the decomposition of oxygenated water by means of dioxide of manganese, and the hydration of sulphate of quinine.

As regards sulphate of quinine, it presents highly curious phenomena. This body, as it has long been known, becomes phosphorescent by the action of heat, but what was not known is that after having lost its phosphorescence, if sufficiently heated it becomes highly luminous and radio-active on refrigeration. After seeking the cause of its phosphorescence on cooling, and proving it to be due to a very slight hydration, I noted that by reason of this hydration the substance became radio-active for a few minutes. It was the first instance I discovered of the dissociation of matter—that is to say, of radio-activity—by chemical reactions, and it led me to the discovery of many more.

Since then, Dr. Kalähne, Professor of Physics at the University of Heidelberg, has taken up again the same subject in an important study. "My observations," he says, "absolutely confirm that the chemical phenomena pointed out by Gustave Le Bon is the cause of the radiation."[1]

Rutherford also had my results relating to sulphate of quinine verified by one of his pupils, who devoted a paper to the subject.[2] This work was skilfully performed, and published in the *Physical Review*. Rutherford has adopted and reproduced the conclusions in his great work on radio-activity.[3]

The author has noted, as I did, that the air became a conductor of electricity, and that the phenomenon was duly produced, as I had said, by the hydration of sulphate of quinine, but he thinks that the radio-activity is due to a chemical reaction or "to a kind of ultra-violet light," generated by the phosphorescence.

That the radio-activity was due to chemical reaction is exactly what I wished to demonstrate, and this Professor Kalähne has confirmed; that it was due to ultra-violet light is impossible,[4] for the reason that the phosphorescence persists longer than the radio-activity, a thing which would not happen if

[1] *Ann. der Physik*, 1905, p. 450. "This memoir," says the author at the outset, "contains the results of my researches on the radiation of sulphate of quinine as discovered by Gustave Le Bon." The same subject had been previously examined by a different method by Miss Gates.

[2] Miss Gates. (See *Physical Review*, vol. xviii.—1904—p. 144.) She came to the conclusion that while Dr. Le Bon is right as to the cause of the radiations, they differ from those of the radio-active substances in several particulars. But see Kalähne, *Ann. der Physik*, 1905, p. 457.—F. L.

[3] *Radio-Activity*, 1st ed., p. 9.

[4] This Miss Gates has since admitted. (See *Physical Review*, 1906, p. 46.)—F. L.

the latter were the consequence of the light produced by the phosphorescence.

Rutherford thinks that the radiations thus produced differ from those of the radio-active substances because, he says, they have little penetrating power. He is not unaware, however, that this penetration proves nothing, since, according to him, 99 per cent. of the emission of radium is stopped by a thin sheet of paper, and certain very radio-active substances, such as polonium, only emit radiations having no penetration.[1] I think that in writing the above the eminent physicist was still under the influence of the idea, very widespread at the outset, that radio-activity was the exclusive appanage of a small number of exceptional bodies.

§ 4. *Dissociation of Matter by Electric Action.*

Certain very intense electric actions—for instance, induction sparks fifty centimètres long between which is placed the body to be experimented on—do exercise a slight action—that is to say, render the bodies submitted to their influence slightly radio-active; but the effect is much weaker than that produced by a simple ray of light or by heat.

This is not very astonishing. Electricity, as I shall show farther on, is a product of the dissociation of matter. It can certainly generate, like the cathode rays or radio-active emissions, secondary radiations in the substances struck by it, but the ions

[1] The last experiments go to show that polonium emits β rays which are as penetrating as those of radium. *Cf.* Professor Giesel in *Berichte*, 1906 (Bd. xxxix.), p. 780. They lack confirmation, but are probably correct.—F. L.

to which it gives birth in the air have too low a speed to produce much effect.

No doubt it is known, from the experiments of Elster and Geitel, that a wire electrified to a high potential acquires a temporary radio-activity; but it may be supposed in that case that the wire, by reason of its electrification, only attracts the ions which are always present in the atmosphere.

It was by pursuing the study of radio-activity excited by electricity that I was led to effect the experiment which will be mentioned later, and to compel particles of dissociated matter to traverse, visibly, and without deviation, thin plates of glass or ebonite.

§ 5. *Dissociation of Matter by Combustion.*

If slight chemical reactions, such as simple hydration, can provoke the dissociation of matter, it will be conceived that the phenomena of combustion, which constitute powerful chemical reactions, must realize the maximum of dissociation. This is, in fact, what is observed. A burning body is an intense source of cathode rays similar to those emitted by a radio-active body, but possessing, by reason of their low speed, no great penetration.

For at least a century it has been known that the gases arising from flames discharge electrified bodies. Branly has shown that, even when cooled, gases preserve this property. All these facts remained uninterpreted, and it was hardly suspected that within them dwelt one of the proofs of the dissociation of matter.

This was, however, a conclusion to which one was bound to come. It has been clearly confirmed by the recent researches of J. J. Thomson. He has shown that a simple metal wire or thread of carbon brought to a white heat—the carbon thread of an incandescent lamp, for example—is a powerful and almost unlimited source of electrons and ions—that is to say, of particles identical with those of radio-active bodies. He has proved it by showing that the relation of their charge to their mass was the same. "We are therefore brought to this conclusion," he says, "that from an incandescent metal or a heated thread of carbon electrons are projected." Their quantity is enormous, he points out; for the quantity of electricity which these particles can neutralize corresponds to many ampères per square centimètre of surface. No radio-active body could produce electrons in such proportion. If it be considered that the solar spectrum indicates the presence of much carbon in its photosphere, it follows that the sun must emit an enormous mass of electrons, which, on striking the upper layers of our atmosphere, perhaps produce the aurora borealis through their property of rendering rarefied gases phosphorescent. This observation squares perfectly with my theory of the maintenance of the sun's heat by the dissociation of the matter of which it is composed.

§ 6. *Dissociation of Matter by Heat.*

Heat much inferior to that produced by combustion—that is to say, not exceeding 300° C.—is sufficient to provoke the dissociation of matter. But in this case the phenomenon is rather complicated, and its explanation has required very lengthy researches.

The reason is that, in reality, heat does not in this case appear to act directly as the agent of dissociation. I shall show in the chapter devoted to my experiments that it acts as if the metal contained a limited provision of a substance similar to the emanation of radio-active matter, which it gives out under the influence of heat, and then only recuperates by repose. It is for this reason that, after a metal has been rendered radio-active by a slight heat, it soon loses all trace of radio-activity, and regains it only after several days. It is, too, in this way that radio-active substances really behave, but in consequence of their activity being much superior to that of ordinary substances, whatever they lose from time to time is again formed simultaneously, unless they are brought to a red heat. In this last case the loss is only made up after a certain lapse of time.

When I published these experiments, J. J. Thomson had not yet made known his researches which proved that nearly all substances contain an emanation[1] comparable with that of radio-active bodies, such as radium and thorium. His observations fully confirm my own.

§ 7. *Spontaneous Dissociation of Matter.*

The experiments alluded to above prove that most substances contain a provision of radio-active matter which can be expelled by a slight heat and spontaneously formed anew; these substances are therefore, like ordinary radio-active substances, subject to

[1] See note on p. 148.—F. L.

spontaneous dissociation. It is, however, extremely slow.

In the foregoing experiments this spontaneous dissociation has only been made evident by means of slight heat. It is possible, however, by the help of various artifices—for instance, by folding the metal over itself so as to form a closed cylinder—to allow radio-active products to form therein, the presence of which is verified by the electroscope. The substance thus experimented on, however, soon ceases to be active. It has not on that account used up all its provision of radio-activity; it has simply lost all that it can emit at the temperature under which the operation is effected. But, as with phosphorescent substances or radio-active matter, it suffices to heat it a little for it to produce an increased quantity of active effluves.

The researches I have just summarized prove that all substances in nature are radio-active, and that this radio-activity is in no way a property peculiar to a few bodies. All matter, then, tends spontaneously towards dissociation. This latter is most often very small, because it is hindered by the action of antagonistic forces. It is only exceptionally, and under different influences, such as light, combustion, chemical reaction, etc., capable of striving against these forces, that dissociation reaches a certain intensity.

Having proved by the experiments just summarized, of which the details will be found at the end of this volume, that the dissociation of matter is a general phenomenon, I am entitled to say that the doctrine of the invariability of the weight of atoms, on which all modern chemistry is based, is only an illusion resulting entirely from lack of sensitiveness in our balances. Were they sufficiently sensitive, all our chemical laws would be considered as merely approximations. With exact instruments we should note in many circumstances, and particularly in chemical reactions, that the atom loses a part of its weight. I may, then, be allowed to affirm that, contrary to the principle laid down as the basis of chemistry by Lavoisier, *we do not recover in a chemical combination the total weight of the substances employed to bring about this combination.*

§ 8. *The Part taken by the Dissociation of Matter in Natural Phenomena.*

We have just seen that very different causes acting in a continuous manner, such as light, can dissociate matter and finally transform it into elements which no longer possess any material properties, and cannot again become matter.

This dissociation, which has gone on since the beginning of the ages, must have played a great part in natural phenomena. It is probably the origin of atmospheric electricity, and no doubt that of the clouds, and consequently of the rainfall which exercises so great an influence on climate. One of the characteristic properties of radio-active emissions is that of condensing the vapour of water, a property which also belongs to all kinds of dust, and is demonstrated by an experiment of long standing.[1] A globe full of water in ebullition is placed in com-

[1] See, for further details, Mr. John Aitken on "Dust, Fog, and Clouds" (*Trans. Roy. Soc. Edin.*, vol. xxx. (1883) pp. 337 *et seq.*). *Cf.* C. T. R. Wilson on "Condensation Nuclei," *Phil. Trans.*, vol. cxcii. pp. 403 *et seq.*).—F. L.

munication with two other globes, one filled with ordinary air from a room, the other filled with the same air cleared of dust by simple filtration through cotton-wool. It can then be seen that the steam coming into the globe containing the unfiltered air immediately condenses into a thick fog, while that in the globe containing pure air does not condense.

We see how the importance of the phenomenon of the dissociation of matter increases with the study of it. Its universality spreads daily, and the hour is not far distant, I believe, when it will be considered as the source of a great number of the phenomena observed on the surface of our planet.

But these are not the most important of the phenomena due to the dissociation of matter. We have already shown it to be the source of solar heat, and we shall see presently that it is the origin of electricity.

CHAPTER V.

ARTIFICIAL EQUILIBRIA OF THE ELEMENTS ARISING FROM THE DISSOCIATION OF MATTER.

WE shall see in a later chapter that the particles which escape from an electrified point connected with one of the poles of an electrical machine in motion are composed of ions and electrons of the same composition as the particles of dissociated matter emitted by the radio-active substances or by a Crookes' tube. They, too, render the air a conductor of electricity, and are deviated by a magnetic field. If, therefore, we wish to study the equilibria of which the elements of dissociated matter are capable, we may replace a radio-active body by a point electrified by being connected with one of the poles of an electrical machine in action.

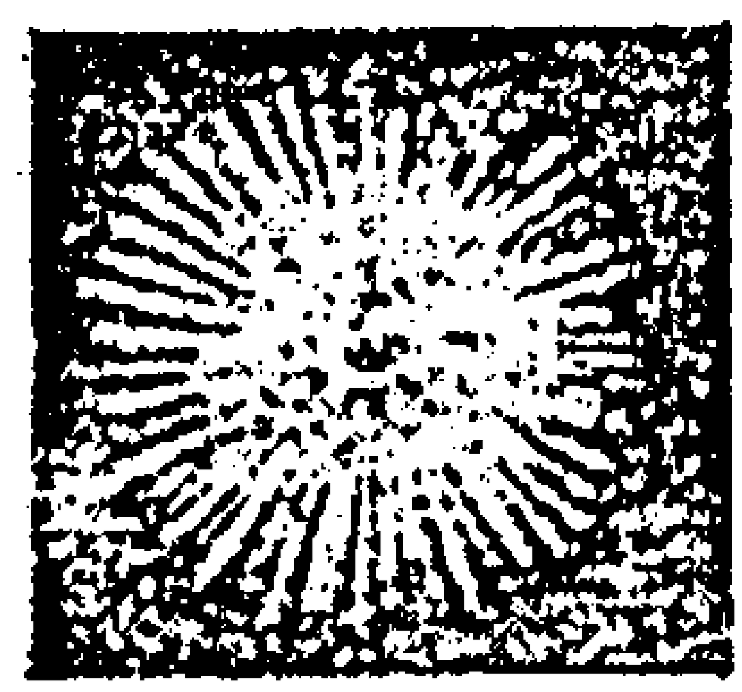


FIG. 4.—Radiation of particles of dissociated matter not subjected to attractions or repulsions. — [*Instantaneous photograph.*]

FIG. 5.—Attractions of particles of dissociated matter charged with position and negative electricity. — [*Instantaneous photograph.*]

These particles are subject to the laws of attractions and repulsions which govern all electric phenomena. By utilizing these laws we can obtain at will the most varied equilibria.

Such equilibria can only be maintained for a moment. If we were able to isolate and fix them for good—that is to say, so that they would survive their generating cause—we should have succeeded in creating with immaterial particles something singularly resembling matter. The enormous quantity of energy condensed within the atom shows the impossibility of realizing such an experiment.

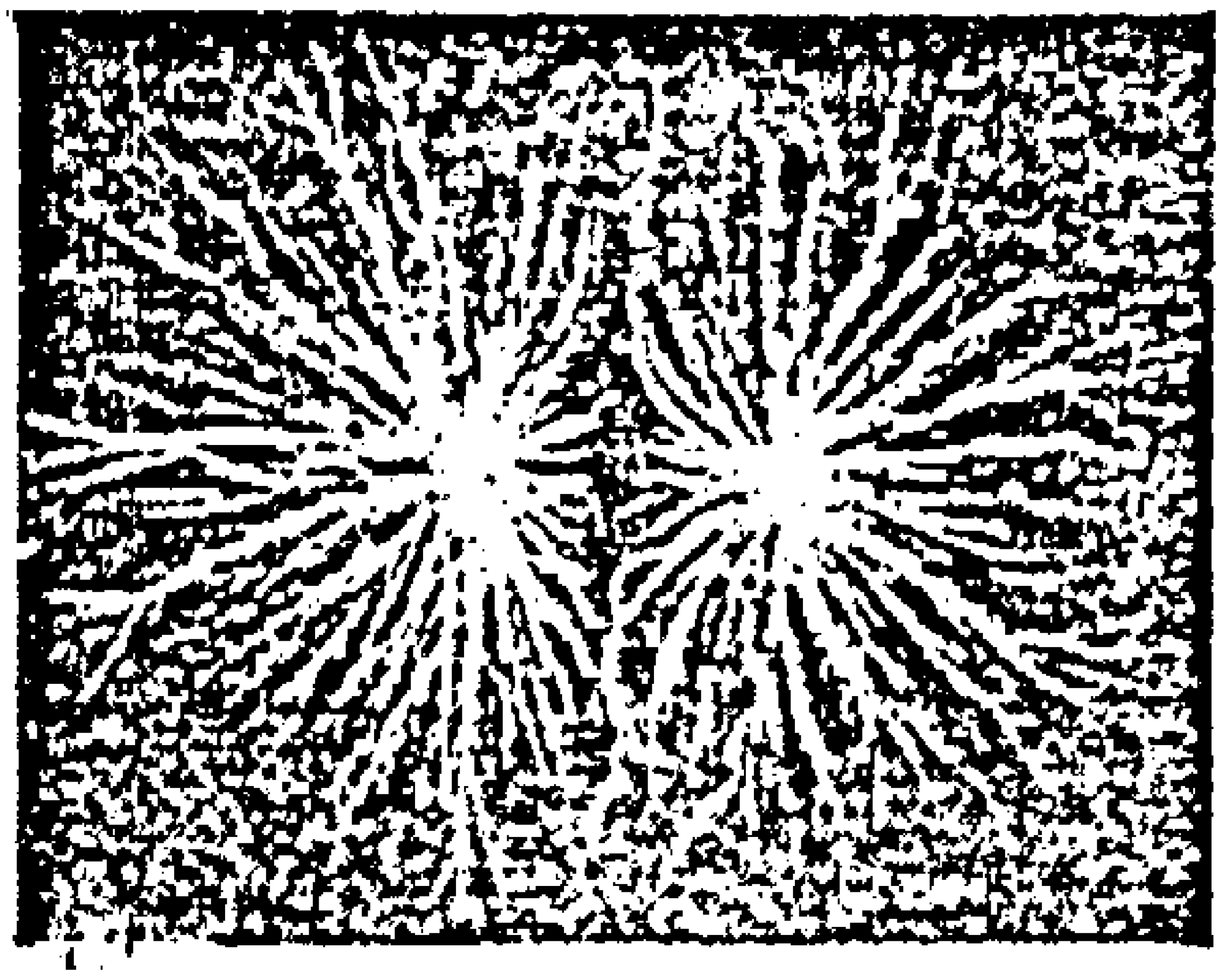


FIG. 6.—Repulsion of particles of dissociated matter emitted by two points and moving in the direction of the lines of force.—[*Instantaneous photograph.*]

But, if we cannot with immaterial things effect equilibria able to survive the cause which gave them birth, we can at least maintain them for a sufficiently long time to photograph them, and thus create a kind of momentary materialization.

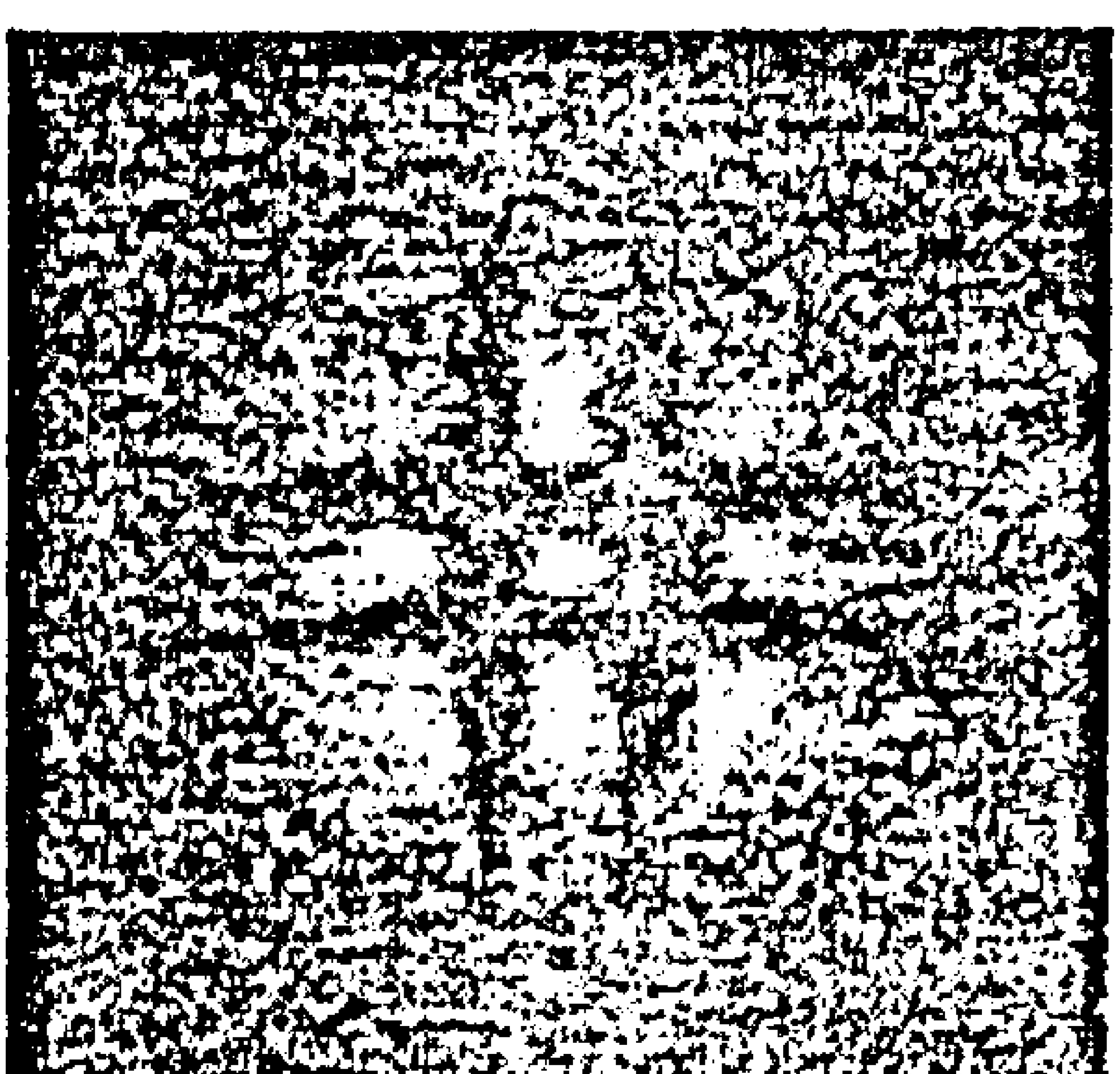


FIG. 7.—Repulsion of particles of dissociated matter emitted by several points.—[*Instantaneous photograph.*]

By utilizing nothing but the laws mentioned above I have succeeded in grouping the particles of dissociated matter, so as to give to this grouping every possible form—straight and curved lines, prisms, cells, etc., which were then made permanent by photography.

In Figs. 8 to 11 we see straight and curved figures produced by the mutual repulsions of particles of dissociated matter having electrical charges of

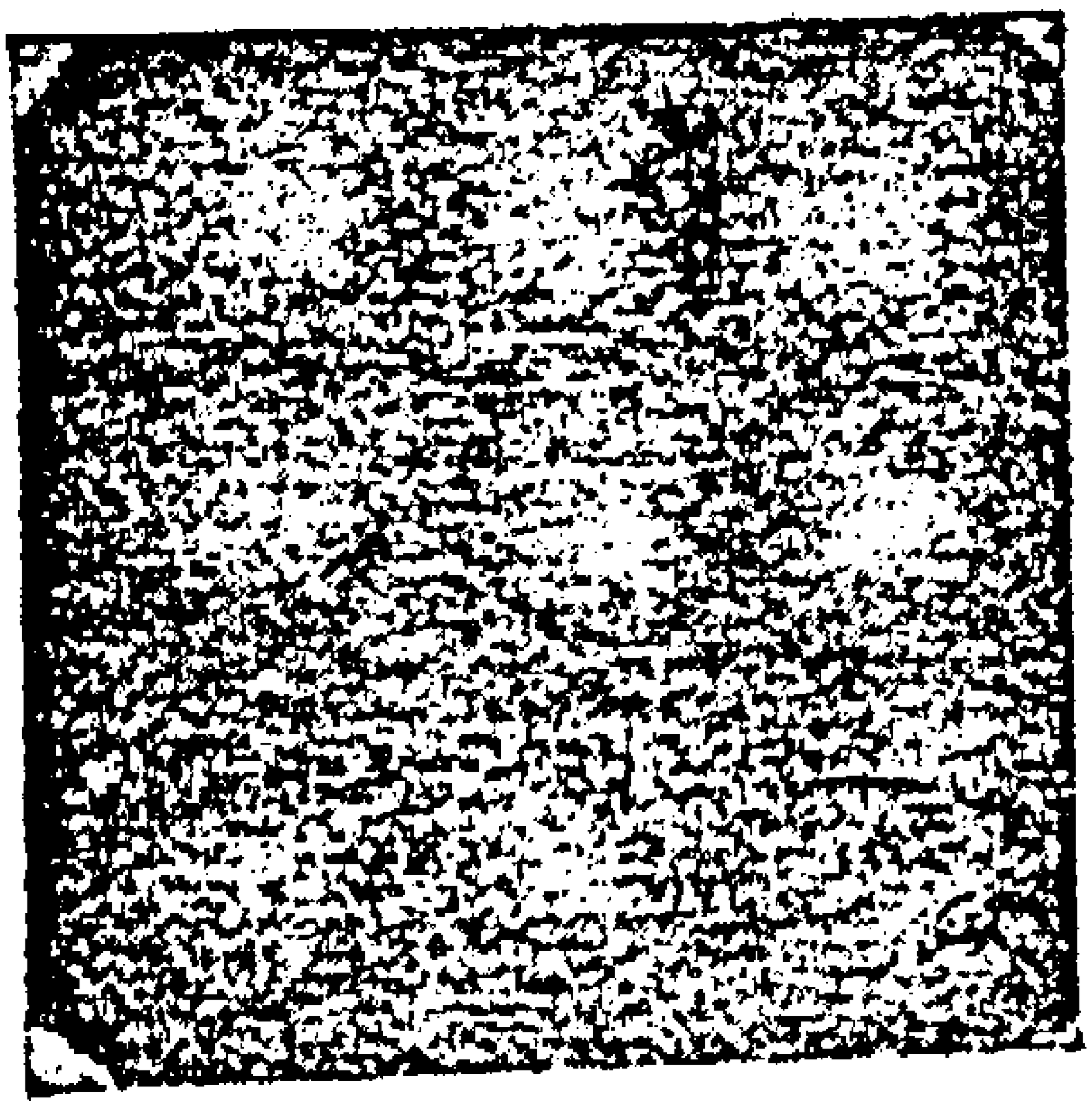


FIG. 8.

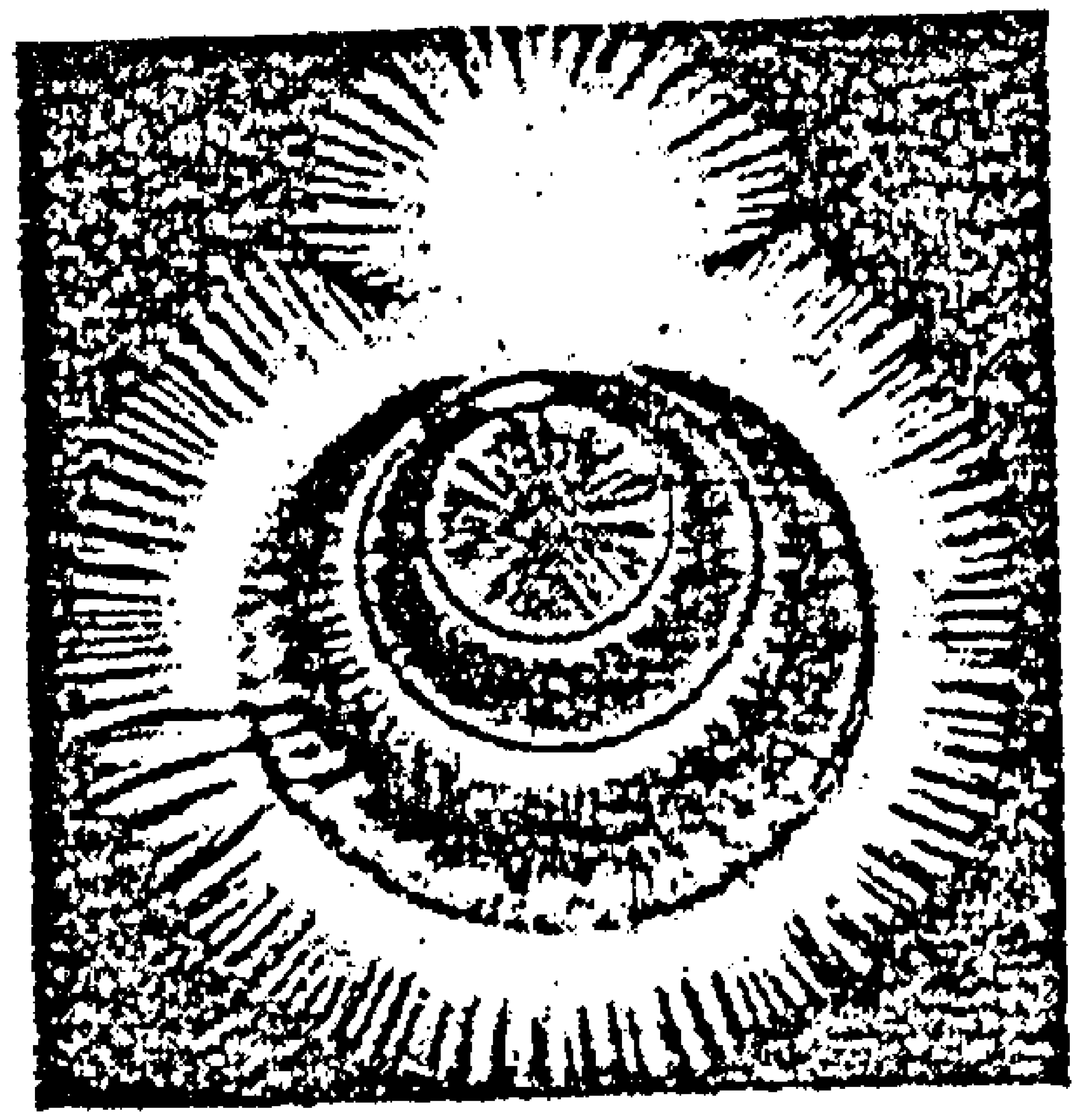


FIG. 9.

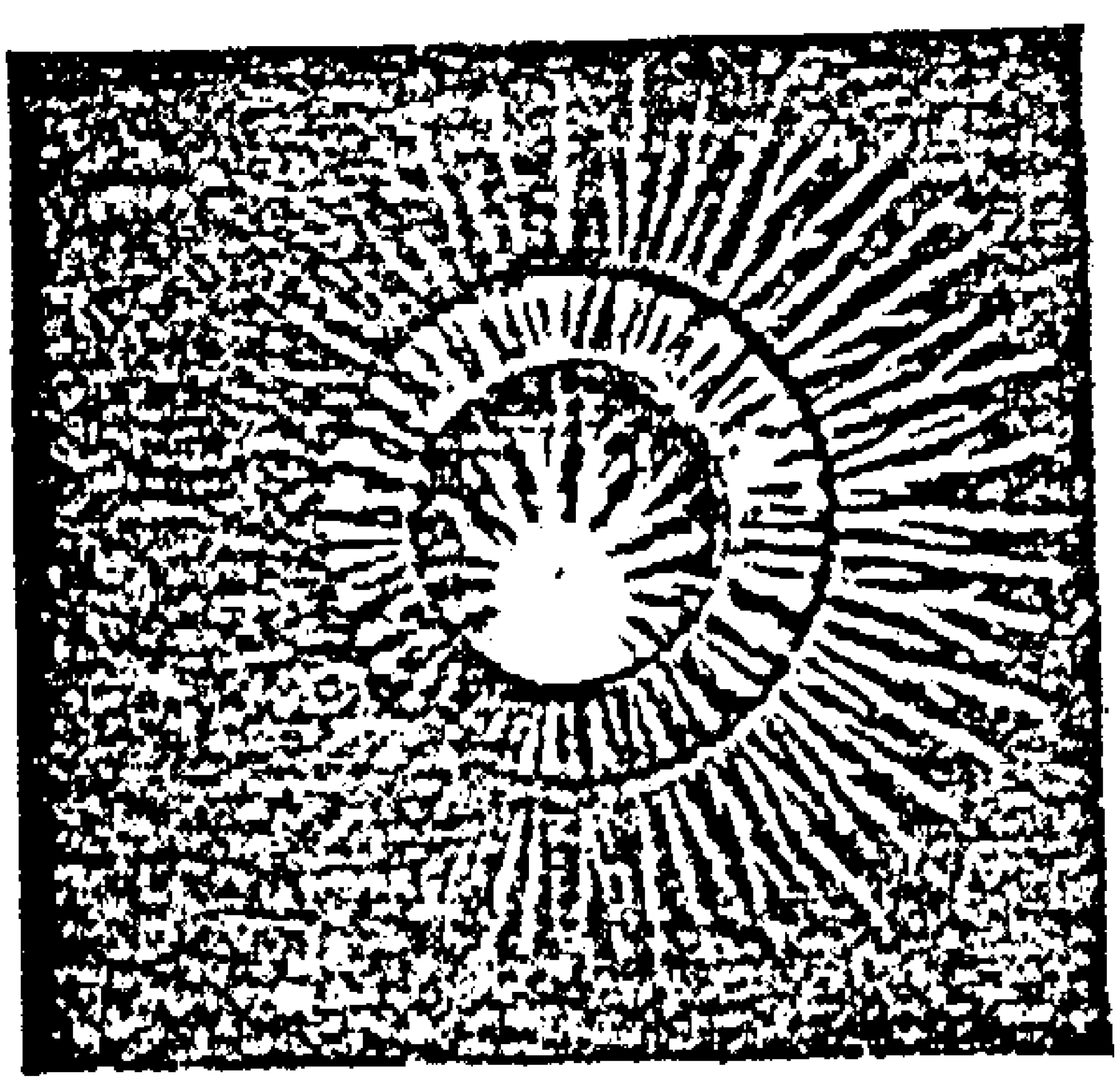


FIG. 10.

FIG. 11.

Several figures obtained by compelling particles of dissociated matter to move and repel each other in certain directions.

the same sign. So soon as the particles are brought near enough to each other, they repel one another and do not succeed in touching, as can be seen by the dark lines separating them and the considerable shortening of the radiation on the side where the particles are. By multiplying the discharges, by means of an arrangement of fine needles, the regular forms of Figs. 12 to 15 are obtained.

The polygonal forms, represented in some of the photographs, are not, of course, reproductions of plane surfaces, but of forms really possessing three dimensions, of which photography can only give the projection. They are, therefore, really figures in space which I have obtained by maintaining for a moment in the equilibrium forced upon them particles of dissociated matter.

The particles which form the model of the images here produced, are not composed entirely of electrons. According to current ideas, they should be regarded as electric atoms surrounded by a retinue of material particles. They are therefore composed of those ions which we studied in a former chapter. But the nucleus of these latter is constituted of those electric atoms which are produced by the dematerialization of matter.

Among the forms of different equilibrium that we can cause particles of dissociated matter to assume, there is one—the globular form—of which the theory has not yet been established, attraction and repulsion not sufficing for its explanation. It is probable that the electric atoms must here be in a special state of whirling equilibrium. This equilibrium, though still momentary, is much more stable than those in the preceding experiments.

Electricity in this form has more than once been observed during storms, but rarely enough for its existence to have been long denied. In such cases, it occurs in the form of brilliant globes which may attain the size of a child's head. They revolve slowly, and finally burst with a noise like a shell, causing great damage. The energy enclosed in them is therefore considerable, and I willingly appeal to this example for the comprehension of what may

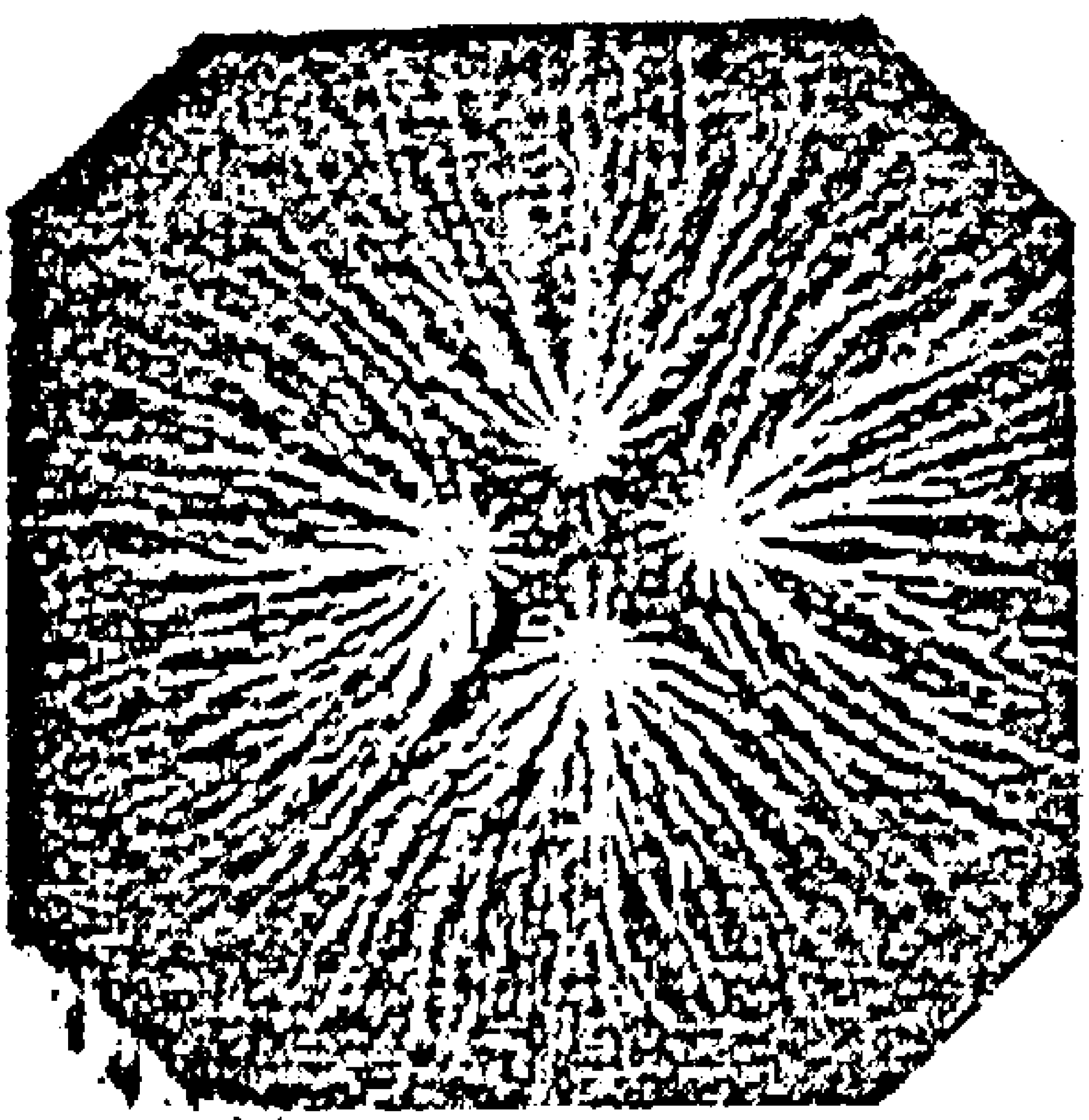


FIG. 12.

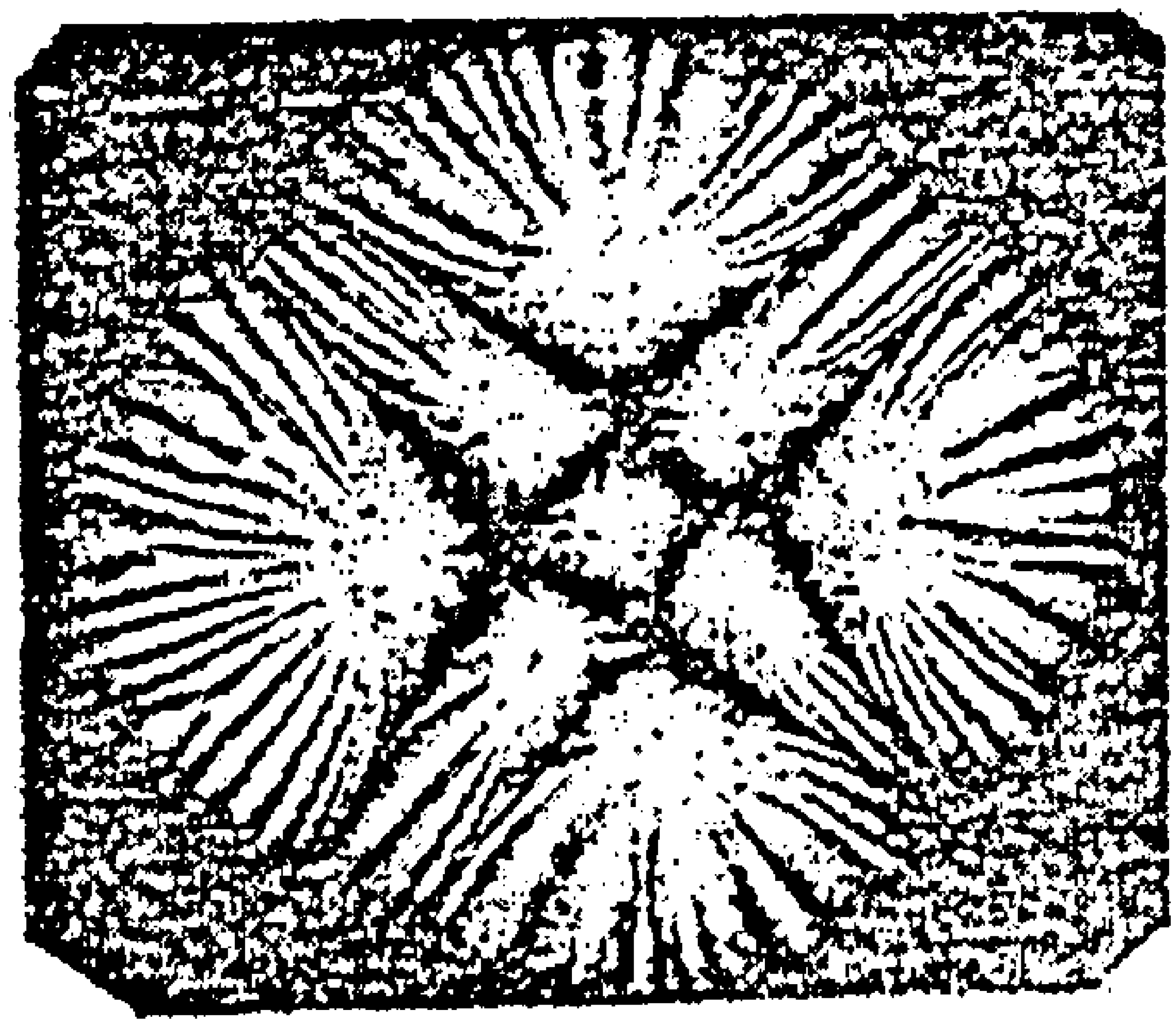


FIG. 13.

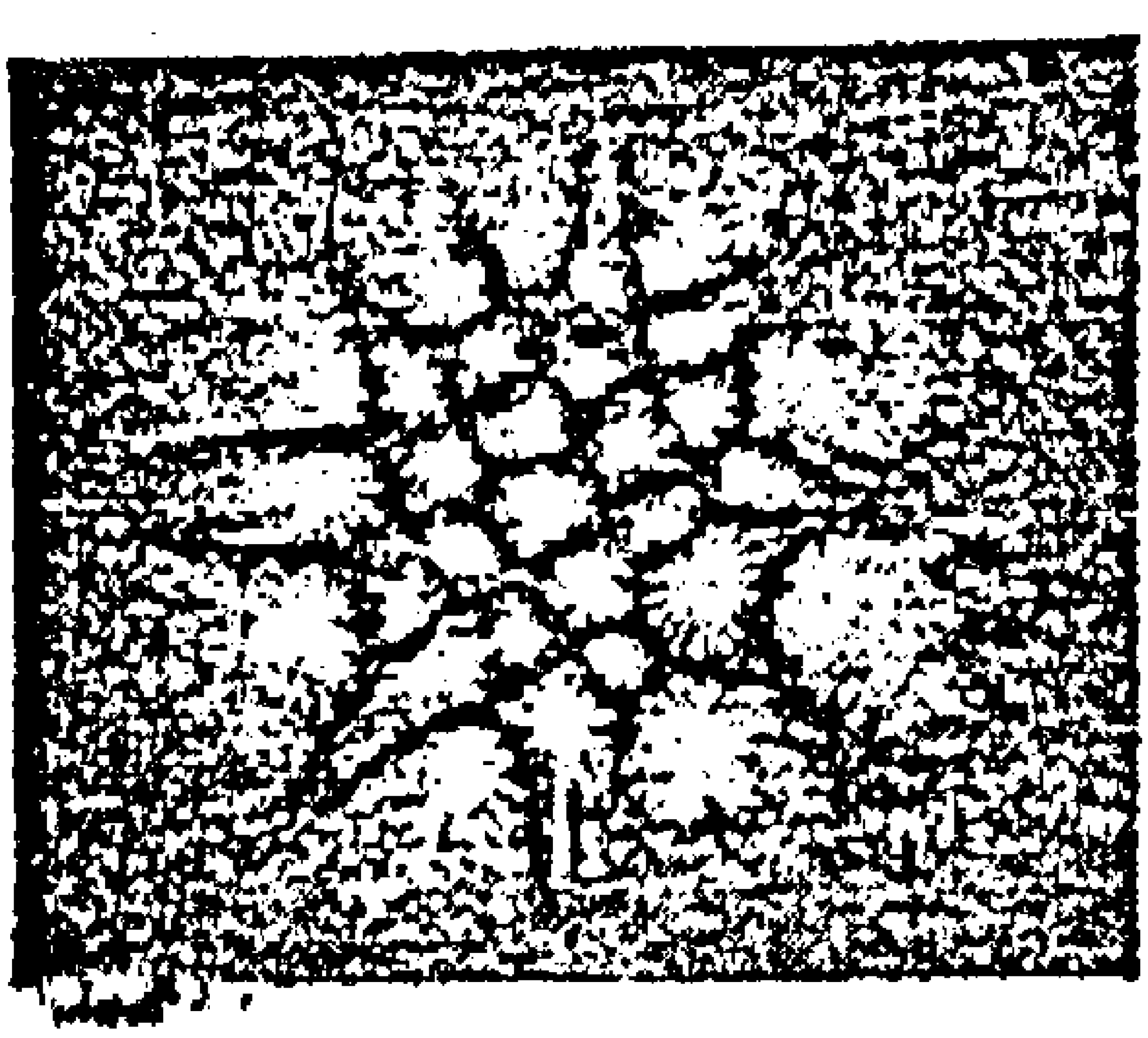


FIG. 14.

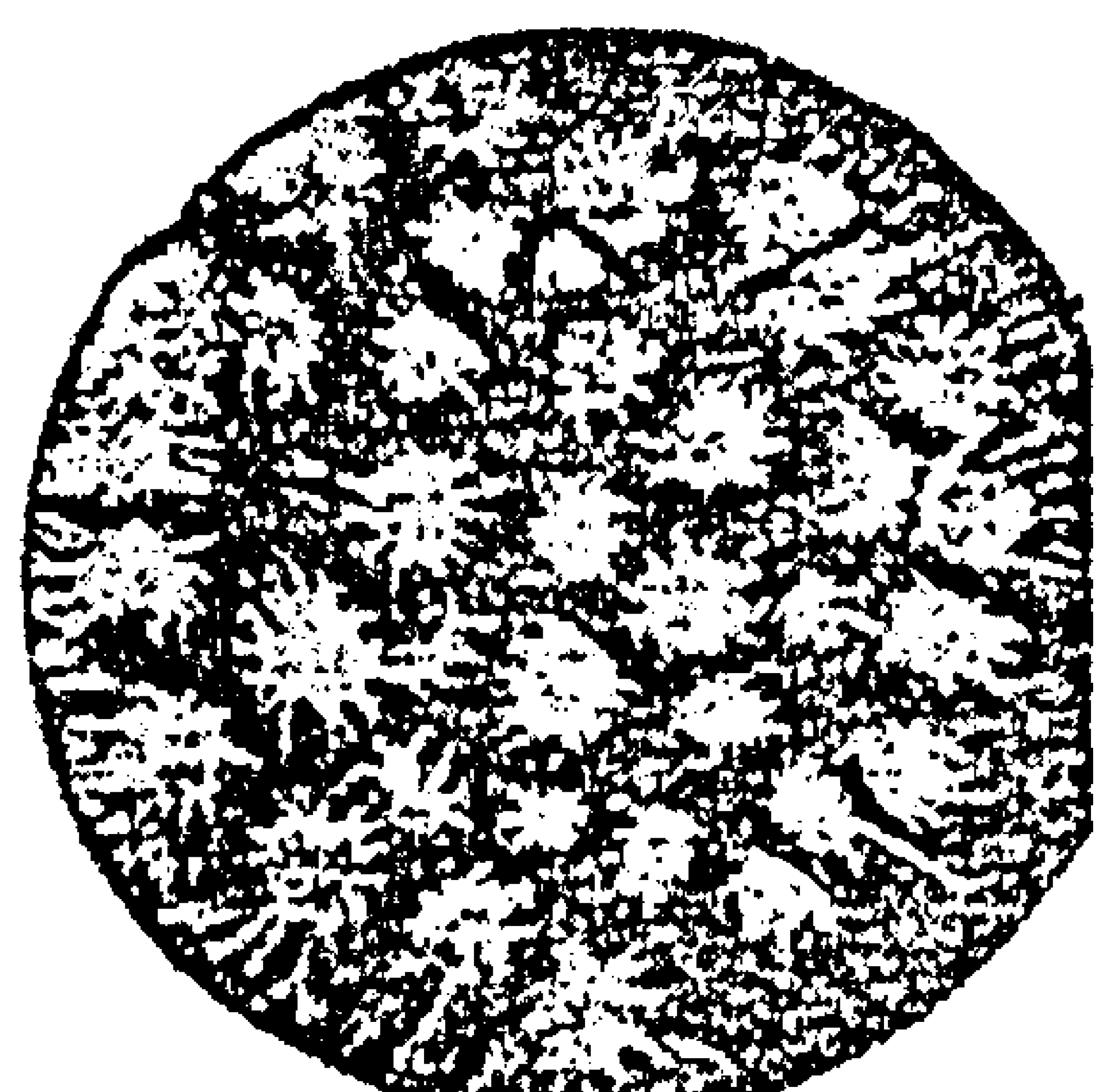


FIG. 15.

Apparent materializations produced in space by utilizing the repulsions of dissociated matter.—In Fig. 12 will be seen how repulsions are effected between particles issuing from four neighbouring electrified points. In Figs. 13, 14, and 15, the number of points has been multiplied, and we have succeeded in creating in space the figures which are represented in the photographs. Some of these remind us, by their forms, of the cells of living beings.

be done with condensed energy in a state of equilibrium of at least momentary stability.

We cannot hope to generate in our laboratories phenomena of such intensity, but we can reproduce them on a small scale. Small luminous spheres imitating globular thunderbolts[1] can be produced by various methods. That of M. Stephane Leduc permits them to be very easily formed. It suffices to place on a photographic plate, at a few centimètres from each other, two very thin rods connected with the different poles of a static machine. There soon issues from the rod connected with the negative pole small luminous spheres, apparently about one millimètre in diameter, which very slowly make for the other rod, and vanish as soon as they touch it.

But, with this mode of operation, one may always suppose a particular form of effluve to exist between the two poles. I have therefore tried to obtain this globular electricity with a single pole, and I have succeeded in doing so by a very simple process. A rod, about half a centimètre in diameter, terminated by a needle of which the point is placed on a plate covered with gelatino-bromide of silver, is connected with the negative pole of a Wimshurst machine, and the other pole is earthed. When the machine is in motion, one sees issue from the point of the needle one or several luminous globes, which advance slowly and disappear abruptly after a few centimètres, leaving on the plate the trace of their trajectory.

If, instead of employing a thick rod terminated by a needle, a thin rod were used, the formation of luminous spheres would not take place. The pheno-

[1] *I.e.* St. Elmo's fire or corposants.—F. L.

menon seems to act—though probably it is produced quite otherwise—as if the electricity of the thick rod accumulated at the point of the needle after the fashion of a drop of liquid.

It is difficult to state precisely the part taken in these experiments by the gelatino-bromide of the photographic plate. Its presence facilitates the result, but is it indispensable? Some authors claim to have obtained globular electricity with simple plates of glass or mica, but I have not succeeded in thus producing them.

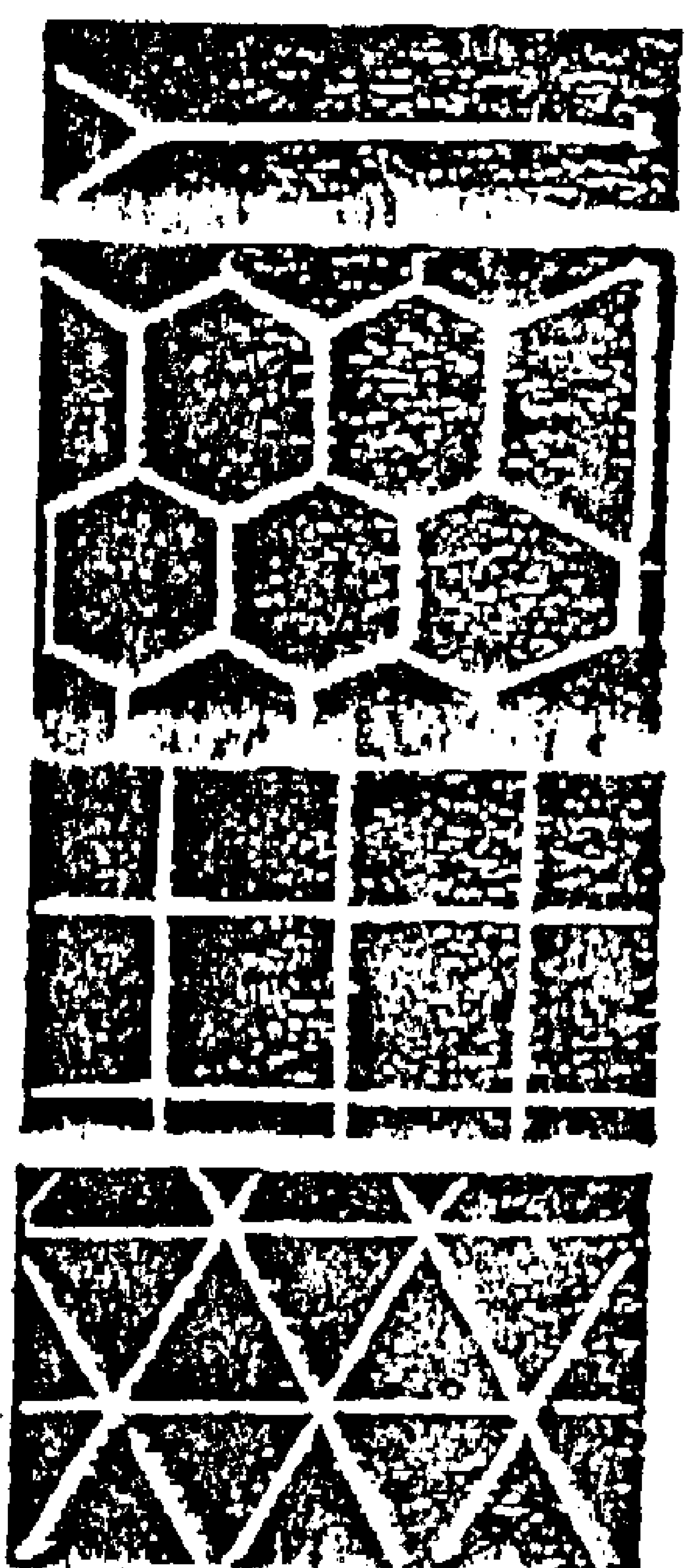
However that may be, the luminous spheres formed by one of the processes just indicated, possess very singular properties, notably a considerable stability. They can be touched and displaced with a strip of metal without being discharged.[1] A magnetic field —at all events the one of rather weak intensity at my disposal—has no action on them. If these spheres only consist of agglomerated ions, these last must be in a very special state. Their stability can only proceed from extremely rapid whirling movements, similar to those of the gyroscope, which, as is well known, simply owes its equilibrium to the rotary motion which animates it.

In the preceding experiments we have realized,

[1] In a case of globular lightning observed at Autun, and quoted in the *Comptes Rendus de l'Académie des Sciences*, 29th August 1904, M. Roche reports that the globe of fire after travelling 500 mètres, in which it carried away doors, and swept off three large chimney-stacks, created a great perturbation at the Sous-Prefecture, which was provided with a lightning-rod. The author draws this conclusion: "It would therefore seem that a lightning-rod has no action on globular lightning." This last fact can be connected with the impossibility noticed in my experiments of discharging an electric globule by touching it with a metallic body.

with particles of dissociated matter, geometrical figures of a momentary stability which hardly survive the causes producing them. But it is possible to maintain for a fairly long time and on one surface certain forms of the electric fluid and to cause it to take the form of geometric plane figures with concise outlines.

In speaking of the properties of ionized gases, I have called by the name of ionic fluid, that fluid which the ionized particles make up by their aggregation. Thanks to its inertia, it is easy, by following the method pointed out by Professor de Heen, to transform this into regular geometric figures possessing a certain permanence. The experiment is very simple. Take a large square plate of resin from 30 to 40 centimètres in diameter, and electrify it by passing its surface over one of the poles of an electrical machine in motion. Then expose for several seconds the electrified face of this plate to two sources of ionization—for instance, two Bunsen burners at a distance of 5 to 6 centimètres from each other. The ions starting from these sources come into contact with the plate, repel the electricity, and then, when face to face with each other, they halt and form a straight line (Fig. 16). This



FIGS. 16 TO 19.—Photographs of geometrical figures obtained by confining the ionic fluid to plates of resin.

invisible line is rendered visible by dusting powdered sulphur on the plate by means of a sieve. After slightly shaking the plate, there will only remain on its surface the straight line traced by the ionic fluid.

If, instead of two Bunsen burners, a certain number are placed so as to form the outlines of geometrical figures, you obtain on the plate varied images: triangles, hexagons, etc., as regularly as if they had been traced with a ruler (Figs. 17 to 19). It is evident that with an ordinary gas, you could produce nothing like this, since it would escape from the plate by diffusing through the atmosphere.

In the different experiments above mentioned, we have materialized, crystallized as it were, for an instant the fluid, so immaterial in appearance, composed of the union of the elements proceeding from the dissociation of matter. We now begin to see how, with more complicated equilibria and above all with the colossal forces she has at command, Nature has been able to create those stable elements which constitute material atoms. While in evolution towards the state of matter, the ether must, no doubt, have passed through intermediate phases of equilibrium similar to those indicated in this chapter, and also through various forms the history of which is unknown to us.

CHAPTER VI.

HOW, NOTWITHSTANDING ITS STABILITY, MATTER CAN DISSOCIATE.

§ 1. *Causes capable of Modifying Molecular and Atomic Structures.*

THE first objection which occurs to the mind of the chemist to whom one sets forth the theory of the dissociation of matter, is the following:—How can bodies so stable as atoms—which appear to withstand the most violent reactions, since their weight is always recognized as invariable—dissociate either spontaneously or under such slight causes as rays of light hardly capable of influencing a thermometer?

To say, as I maintain, that matter is a large reservoir of forces, simply means that there is no need to look outside it for the origin of the energy expended during dissociation, but this in no way explains how intra-atomic energy condensed under an evidently very stable form can free itself from the bonds which hold it. The doctrine of intra-atomic energy therefore supplies no solution to the question just put. It is unable to say why the atom, which is to all appearance the most stable of all things in the universe, can, under certain conditions, lose its stability to the extent of easily disaggregating.

If we wish to discover the solution of this problem, it will first be necessary to show, by various examples, that in order to produce in matter very great changes of equilibrium, it is not always the magnitude of the effort which counts, but rather the quality of that effort. Every equilibrium in Nature is only sensitive to the appropriate excitant, and it is this excitant which must be discovered in order to obtain the effect sought. Once discovered, it can be seen that very slight causes can easily modify the equilibrium of atoms and bring about, like a spark in a mass of gunpowder, effects whose intensity greatly exceeds that of the exciting cause.

A well-known acoustic analogy allows this difference between the intensity and the quality of the effort to be clearly shown from the point of view of the effects produced. The most violent thunderclap or the most deafening explosion may be powerless to cause the vibration of a tuning-fork, while a sound, very slight but of suitable period, will suffice to set it in motion. When a tuning-fork starts vibrating by reason of the production near it of a sound identical with its own, it is said to vibrate by resonance. The part played by resonance in acoustics as well as in optics is now well known; it gives the best explanation of the phenomena of opacity and transparency. It can help to explain, with all the facts I am about to state, that insignificant causes can produce great transformations in matter.

Although our means of observing the internal variations of bodies are very insufficient, facts, already numerous, prove that it is easy to profoundly change molecular and atomic equilibria, when they are acted upon by the proper agents. I shall confine myself to recalling a few of them.

A simple ray of light, though its energy is very slight, by falling on the surface of substances, such as selenium, sulphide of silver, oxide of copper, platinum black, etc., modifies their electric resistance to a considerable extent. So, too, several dielectrics become birefringent when electrified. Boracite, again, which is birefringent at ordinary temperatures, becomes unirefringent when heated. Certain alloys of iron and nickel also become instantaneously magnetic by heat and lose their magnetism on cooling. Finally, if a transparent body placed in a magnetic field has a luminous ray passed through it, the rotation of the plane of polarization can be observed.

All these changes in physical properties necessarily imply changes of molecular equilibria. Slight causes suffice to bring about these changes because the molecular equilibria are sensitive to these causes. Forces far greater, but not appropriate, would, on the contrary, have no effect. Take any salt—chloride of potassium, for instance. It can be ground, pulverized by the most powerful machinery without it ever being possible to separate the molecules of which it is composed. And yet, to dissociate these molecules, to separate what are called ions—that is to say, chlorine and potassium—it suffices, according to modern theories on electrolysis, to dissolve the substance in a liquid so that the solution is sufficiently diluted.

Many similar examples can be given. To force apart the molecules of a steel bar it would have to be submitted to enormous mechanical strains; yet it suffices to heat it slightly, if only by placing the hand upon it, for it to elongate. This elongation of a bar by the contact of the hand can even be made visible, as Tyndall showed, to a whole audience by means of a lever and a mirror suitably arranged. A similar phenomenon is observed in water. It is almost incompressible under the very strongest pressure, and yet its temperature has only to be slightly lowered for it to contract.

We can produce in a metal far more thorough molecular displacements than those effected by heat, for there are some which imply a complete change in the direction of the molecules. No mechanical force could cause such transformations; yet they are instantaneously effected by bringing a bar of iron near a magnet, when all its molecules instantly change their direction.

The recent employment of high temperatures, formerly impossible of attainment, as well as the introduction of the high electrical potentials which have permitted new chemical combinations to be produced, naturally leads us to think that it would be especially by means of these enormous forces that certain transformations will be possible. No doubt, by these new means, it has been possible to create certain chemical equilibria hitherto unknown, but to modify instable matter there is no need of these gigantic efforts. This is proved when we see certain luminous rays of a fixed wave-length producing instantaneously in various substances the chemical reactions which generate phosphorescence, and radiations of shorter wave-length giving birth to converse reactions which no less instantaneously destroy this phosphorescence.

A further proof is afforded when we note that the Hertzian waves produced by electric sparks transform, at a distance of 500 kilomètres, the molecular structure of metal filings;[1] or, again, when we observe that the neighbourhood of a simple magnet immediately changes, in spite of all intervening obstacles, the direction of the molecules of an iron bar.

In the dissociation of matter similar facts are observed. Metals, highly radio-active under the influence of luminous radiations of a certain wavelength, are hardly so at all under the influence of radiations of one but slightly different. The same thing seems to occur here as in the phenomenon of resonance. It is possible, as I remarked above, to cause a tuning-fork or even a heavy bell to vibrate by producing close to them a note of a certain vibratory period, when the most violent noises may leave them insensitive. When we become better acquainted with the causes capable of slightly dissociating the aggregate of energy condensed in the atom, we shall certainly arrive at a more complete dissociation and be able to utilize it for industrial purposes.

The whole of the preceding facts justifies my assertion that, in order to obtain important transformations of molecular equilibrium, it is not a question of the intensity but of the quality of the effort. These considerations enable it to be under-

[1] Is this the effect of the Hertzian waves? The different theories as to the manner in which the coherer operates are set out by M. Turpain (*Les Ondes Electriques*, pp. 237 *et seq.* Paris, 1902) with the remark that none are entirely satisfactory. Cf. the researches of M. A. Blanc on "Cohération," *Revue Scientifique*, 30th June 1906.—F. L.

stood how structures so stable as atoms can be dissociated under the influence of such slight causes as a ray of light. If invisible ultra-violet radiations can dissociate the atoms of a steel block on which all the forces of mechanics would have no effect, it is because they form a stimulant to which matter is sensitive. The component parts of the retina are not sensitive to this stimulant, and this is why the ultra-violet light, capable of dissociating steel, has no action on the eye, which does not even perceive its presence.

Matter, insensitive to actions of importance, can therefore be, I repeat, sensitive to very minute ones. Under appropriate influences, a very stable body may become unstable. We shall see soon that sometimes imponderable traces of substances may at times powerfully modify the equilibria of other bodies and act in consequence as those excitants, light but appropriate, which matter obeys.

§ 2. *Mechanism of the Dissociation of Matter.*

According to the ideas now current on the constitution of atoms, every atom may be considered as a small solar system comprising a central part round which turn with immense speed at least a thousand particles, and sometimes many more. These particles therefore possess a great kinetic energy. Let some appropriate cause come to disturb their trajectory or let their speed of rotation become sufficient for the centrifugal force which results from it to exceed the force of attraction which keeps them in their orbits, and the particles of the periphery will escape into space by following the tangent of the curve they formerly trod. By this emission they will give birth to the phenomena of radio-activity. Such, in any case, is one of the hypotheses which may be provisionally formulated.

When it was recognized that radio-activity was an exceptional property appertaining to only a very few bodies, such as uranium and radium, it was thought—and many physicists still think—that the instability of these bodies was a consequence of the magnitude of their atomic weight. This explanation vanishes before the fact shown by my researches that it is just those metals whose atomic weight is feeblest, such as magnesium and aluminium, which become most easily radio-active under the influence of light; while, on the contrary, it is bodies possessing a high atomic weight, like gold, platinum, and lead, which have the weakest radio-activity. Radio-activity is therefore independent of atomic weight, and probably very often due, as I shall explain later on, to certain chemical reactions of an unknown nature. Two bodies not radio-active sometimes become so when combined. Mercury and tin may be placed among bodies of which the dissociation, under the action of light, is the weakest: I have shown, however, that mercury became extraordinarily radio-active under this same influence, so soon as traces of tin are added to it.

All the interpretations which precede contain assuredly only the outlines of an explanation. The mechanism of the dissociation of matter is unknown to us. But what physical phenomenon is there whose ultimate causes are not equally hidden from our view?

§ 3. *Causes capable of Producing the Dissociation of very Radio-active Substances.*

We have seen that various causes may produce the dissociation of ordinary matter. But in the dissociation of substances spontaneously very radio-active—radium and thorium, for instance—no external cause seems to bring about the phenomenon. How, then, can it be explained?

Contrary to the opinions expressed at the commencement of researches into radio-activity, I have always maintained that the phenomena observed in radium arose from certain special chemical reactions, similar to those produced in the case of phosphorescence. These reactions take place between substances of which one is in infinitesimal proportion to the other. I only published these considerations after I had discovered bodies becoming radio-active in such conditions. Salts of quinine, for instance, are not radio-active. By letting them be slightly hydrated after desiccation, they become so, and remain phosphorescent while hydration lasts. Mercury and tin show no perceptible signs of radio-activity under the influence of light; but add to the former a trace of the latter, and its radio-activity at once becomes intense. These experiments even led me thereafter to modify entirely the properties of certain simple bodies by the addition of minute quantities of foreign bodies.

The disintegration of matter necessarily implies a change of equilibrium in the disposition of the elements which compose the atom. It is only by passing into other forms of equilibrium that it can lose part of its energy, and, in consequence, can radiate anything.

The changes of which it is then the seat differ from those known to chemistry in this fundamental point, that they are intra-atomic, while the usual reactions affecting merely the structure of the groupings of atoms are extra-atomic. Ordinary chemistry can only vary the disposition of the stones destined to the building of an edifice. In the dissociation of atoms, the very materials with which the edifice is constructed are transformed.

The mechanism of this atomic disaggregation is unknown, but it is quite evident that it allows of conditions of a peculiar order, very different from those hitherto studied by chemistry. The quantities of matter put in play are infinitely small and the energies liberated extraordinarily large, which is the opposite of that which we get in our ordinary reactions.

Another characteristic of the intra-atomic reactions which produce radio-activity is that they seem to occur, as I said before, between bodies of which one is extremely small in quantity with regard to the other. These particular reactions, to which we will revert in another chapter, are mainly observed during phosphorescence. Pure bodies such as sulphide of calcium, sulphide of strontium, etc., are never phosphorescent. They only become so on being mixed with very small quantities of other bodies; and they then form mobile combinations, capable of being destroyed and regenerated with the greatest ease, which are accompanied by phosphorescence or the disappearance of phosphorescence. Other clearly defined reactions, such as a slight hydration, can likewise produce at the same time both phosphorescence and radio-activity.

This conception that radio-activity had its origin in a special chemical process, has at last secured the favour of several physicists. It has, notably, been adopted and defended by Rutherford and Soddy.

"Radio-activity," say these, "is accompanied by a succession of chemical changes in which new types of radio-active matter are being continuously produced. It is a process of equilibrium where the amount of new radio-activity is balanced by the loss of the radio-activity already produced. Radio-activity is maintained by the continual production of new quantities of matter possessing temporary radio-activity."[1]

A radio-active body is, in fact, a body in course of transformation. Radio-activity is the expression of its never-ceasing leakage. Its change is necessarily an atomic disaggregation. Atoms which have lost anything are, from that very fact, new atoms.

One might consider as singular—at all events, as little in accord with the observations in our laboratories—the existence of chemical reactions continuing almost indefinitely. But we also find in phosphorescence reactions capable of taking effect with extreme slowness. I have shown by my experiments on invisible luminescence that phosphorescent bodies are capable of retaining in the dark, and for two years after exposure to sunlight, the property of radiating, in a continuous manner, an invisible light capable of impressing photographic plates. Since chemical reactions can destroy phosphorescence, and continue to act for two years, it will be understood that other reactions, such as those

[1] *Philosophical Magazine*, September 1902.

capable of producing radio-activity, might last for very much longer.

Though the amount of energy radiated by atoms during their disaggregation is very large, the loss of material substance which occurs is extremely slight, by reason of the enormous condensation of energy contained in the atom. M. Becquerel estimates the duration of one gramme of radium at a thousand million years. M. Curie contents himself with a million years. More modest still, Mr. Rutherford speaks only of a thousand years, and Sir William Crookes of a hundred years, for the dissociation of a gramme of radium. These figures, of which the first are quite fantastic, become more and more reduced as the experiments become more exact. Dr. Heydweiler,[1] after direct weighings, estimates the loss in five grammes of radium at .02 milligrammes in 24 hours. If the loss continued at the same rate, then five grammes of radium would lose one gramme of their weight in 137 years. We are already astonishingly far from the thousand million years imagined by M. Becquerel. Even Heydweiler's figures, from certain of my experiments, are still too high. He has put in a tube the body experimented on in bulk, while I have noted that the radio-activity of a same body increases considerably if the substance is spread over a large surface, which can be obtained by leaving to dry the paper used to filter a solution of it. We thus reach the conclusion that five grammes of radium lose probably the fifth of their weight in twenty years and consequently that a gramme would last one hundred

[1] *Physikalische Zeitschrift*, 15th October 1903.

years, which are exactly the figures given by Sir William Crookes. In reality it is only repeated experiments which will finally settle this point.

But even if we accepted the figures of a thousand years given by Mr. Rutherford for the duration of the existence of one gramme of radium, it would be sufficient to prove that if spontaneously radio-active bodies, such as radium, existed in the geological epochs, they would have vanished long since, and would consequently no longer exist. And this again goes to support my theory, according to which rapid and spontaneous radio-activity only made its appearance since the bodies in question have been engaged in certain peculiar chemical combinations capable of affecting the stability of their atoms, which combinations we may perhaps some day succeed in reproducing.

§ 4. *Can the Existence of Radium be Affirmed with Certainty?*

If radio-activity be the consequence of certain chemical reactions, it would appear that an absolutely pure body cannot be radio-active. It was on this reasoning, supported by various experiments, that I based my assertion a few years ago that the existence of the metal radium was very problematical. In fact, although the operation of separating a metal from its combinations is very easy, it has never been possible to separate radium.

What one obtains at the present day under the name of radium is in nowise a metal, but a bromide or a chloride of this supposed metal. I consider it very probable that if radium exists and it is ever successfully isolated, it will have lost all the properties which render its combinations so interesting. But for a long time[1] and for divers reasons I have predicted that radium will never be isolated, and, as the supposed process of isolation would be too simple not to have been tried by the possessors of sufficiently large quantities of radium, the complete silence observed upon these attempts is a strong presumption in favour of my hypothesis. The separation of barium from its salts is so easy that this was one of the first metals isolated by Davy.

The preparation of the salts of radium enables us to guess the manner in which were possibly formed the unknown combinations which have given birth to radio-activity. One knows how salts of radium were discovered. M. Curie having noticed that certain uranium ores acted on the electroscope with more force than uranium itself, was naturally induced to endeavour to isolate the substance to which this special activity was due. The property registered by the electroscope of rendering air more or less a conductor of electricity being the only available means of investigation, it was the action on the electroscope which alone served as guide in these researches. It was through it alone, in fact, that one could ascertain in which part of the precipitates the most active substances were to be found. After dissolving the ore in various solvents and precipitating the products contained in these solvents by fitting reagents, the most active parts were, by means of the electroscope, set aside, re-dissolved and

[1] Cf. *Revue Scientifique*, 5th May 1900.

separated anew by precipitation, and these manipulations were repeated a great number of times. The operation terminated with fractional crystallization, and finally a small quantity of a very active salt was obtained. It is to the metal, not isolated yet, of the salt thus obtained that the name of radium was given.

The chemical properties of salts of radium are identical with those of the combinations of barium. Radio-activity apart, they only differ by certain rays in their spectra. The supposed atomic weight of radium, calculated from a very small quantity of salts of radium, varies so much with the different observers that nothing can be deduced from it as to the existence of this metal.

Without being able to pronounce positively, I repeat that I believe the existence of radium to be very disputable. It is, at any rate, certain that it has not been possible to isolate it. I should much more willingly admit the existence of an unknown compound of barium capable of giving this metal radio-active properties. Radio-active chloride of radium seems to bear the same relation to inactive chloride of barium that sulphide of barium, impure but phosphorescent, bears to sulphide of barium pure, and for that reason, non-phosphorescent. It suffices, as I have noted above, for traces of foreign bodies to be added to certain sulphides—those of calcium, barium, strontium, etc.—for them to acquire the marvellous property of becoming phosphorescent under the action of light. This phosphorescence, which may be produced by radiation acting for no more than one-tenth of a second and destroyed, as I have shown, by other radiations of equally short period, proves the existence of chemical combinations of extreme mobility. Phosphorescence is a phenomenon which hardly astonishes us because it has so long been known; but on reflection, it must be acknowledged that it is quite as singular as radio-activity and still less explicable.

I will add that by operating with salts of radium but slightly active—that is to say, still mingled with foreign bodies—the rôle of the chemical reactions is very clearly apparent. Thus, for instance, the phosphorescence of these salts is lost by the action of heat and only reappears after the lapse of a few days. Humidity destroys it altogether.

Whether, then, we take ordinary phosphorescence or radio-active properties, they both seem to be produced by chemical reactions the nature of which is totally unknown to us, but in which it seems one of the combining bodies is always in very small quantity compared to the other.

Doubtless, the law of definite proportions tells us that substances can only combine in certain relative quantities. This merely proves that bodies only form stable equilibria—which are the only ones accessible to chemistry—when combined in certain proportions. The number of combinations that two or more bodies can form is perhaps infinite, but as they are not stable, we can only suspect their existence when they are unaccompanied by marked physical phenomena. The combinations accompanied by radio-activity or phosphorescence are most probably instable combinations of this nature.

However this may be, the above theory greatly assisted me in my researches. It is owing to this theory that I was led to discover the radio-activity which accompanies certain chemical reactions, and to find combinations capable of enormously increasing the dissociation of a body under the influence of light, and, finally, to fundamentally modify the properties of certain simple substances.

BOOK V.

THE INTERMEDIATE WORLD BETWEEN MATTER AND THE ETHER.

CHAPTER I.

PROPERTIES OF THE SUBSTANCES INTERMEDIATE BETWEEN MATTER AND THE ETHER.

All the substances we have studied in the shape of products of the dissociation of matter, have presented characteristics visibly intermediate between those of matter and those of the ether. Sometimes they possess material qualities, as the emanations from thorium and radium, which can be condensed like a gas and enclosed in a tube. They equally present certain of the qualities of immaterial things, like the last-named emanation which, in certain phases of its evolution, vanishes by transforming itself into electric particles. Here, then, is a complete transformation of a material body into an immaterial substance. But it is possible to go further.

What are the characteristics which allow us to assert that a substance is no longer altogether matter without yet being ether, and that it constitutes something intermediate between these two substances?

It is only if we see matter lose one of its irreducible characteristics—that is to say, one of those of which it cannot be deprived by any other means whatever—that we are authorized to say that it has lost its quality of matter.

We have already seen that these irreducible characteristics are not numerous, since up to the present only one has been discovered. All the usual properties of matter—solidity, form, colour, etc.—are destructible. A mass of rock can, by heat, be transformed into vapour. One property alone, the mass measured by the weight, remains invariable through all the transformations of bodies and allows them to be followed and re-discovered, notwithstanding the frequency of their changes. It is on this invariability of the mass that the sciences of chemistry and mechanics have been built.

Mass, as is well known, is simply the measure of inertia—that is to say, of that property of unknown essence which enables matter to resist motion or the changes of motion. Its magnitude, which can be represented by a weight, is an absolutely invariable quantity for any given body, whatever be the conditions in which it can be placed. We are therefore led to consider a substance of which the inertia, and consequently the mass, can by any means be rendered variable as something very different from matter.

Now, it is just this variability of the mass—that is to say, of the inertia—which is noted in the electric particles emitted by radio-active bodies during their disaggregation. The variability of this fundamental property will allow us to state that the elements resulting from the dissociation of bodies, elements which besides differ so by their general properties from material substances, form a substance intermediate between matter and the ether.

Long before the current theories as to the structure of the electric fluid, now supposed to be formed by the conjunction of particular atoms, it was noticed that it possessed inertia—that is to say, resistance to motion or to change of motion, but only quite lately has the measurement of this inertia been arrived at. The oscillating discharge of a Leyden jar was one of the first phenomena which revealed the inertia of the electric fluid. This oscillating discharge can be compared to the movements, similarly due to its inertia, which a liquid poured into a U tube makes before reaching its position of equilibrium. It is likewise through inertia that the phenomena of self-induction are produced.

So long as the inertia of electric particles could not be measured, it was allowable to suppose it to be identical with that of matter; as soon as it was possible to calculate their velocity from the intensity of the magnetic force necessary to deviate them from their trajectory, it became possible to measure their mass. It was then seen to vary with their speed.

The first experiments on this point are due to Kaufmann and Abraham. By observing on a photographic plate the deviation under the influence of two superposed magnetic and electric fields, they noted that the relation of the electric charge *e*, carried by a radio-active particle, to the mass *m* of this particle, varied with its velocity. As it cannot be supposed that in this relation the charge changes, it is evident that it is the mass which varies.

The variation of the mass of the particles with their speed is besides in agreement with the electro-magnetic theory of light, and had already been pointed out by various authors, Larmor amongst them. This variation of the mass would suffice to prove that substances which exhibit such a property are no longer matter. It is thus that Kaufmann deduces

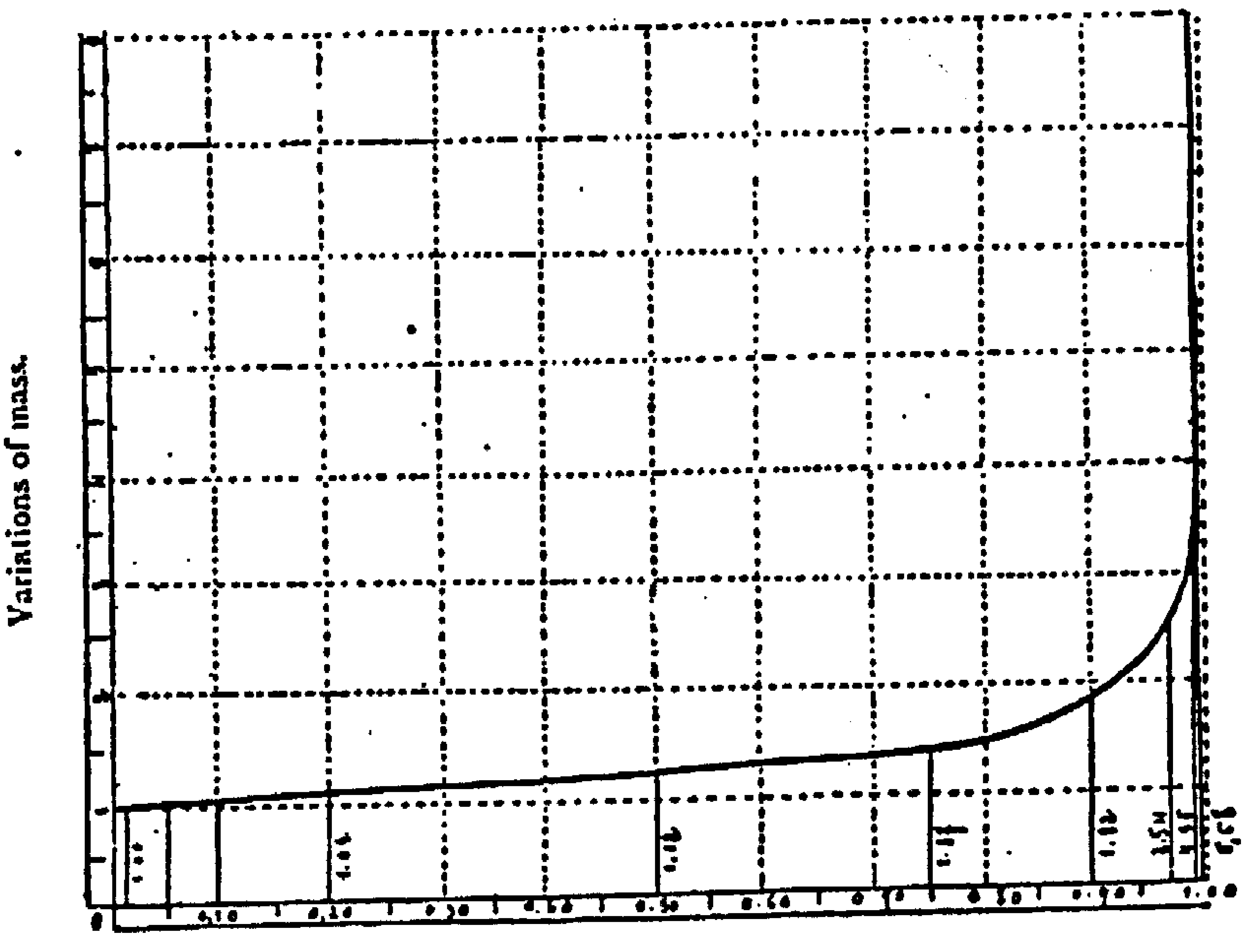


FIG. 20.—*Curve showing one of the fundamental properties of the substance intermediate between penderable matter and the imponderable ether.*—The mass, instead of being constant in magnitude, like that of matter, varies with the speed.

from his observations that the electron, of which certain radio-active emissions are composed, "is nothing but an electric charge distributed over a volume or a surface of very small dimensions."

By putting Abraham's equation into the form of a curve, it is easy to see the manner in which the mass of the elements of dissociated matter vary with their speed. Constant at first even for very great velocities, it increases abruptly and quickly tends to become infinite as it approaches the velocity of light.[1]

So long as the mass has not attained a speed equal to 20 per cent. of that of light—that is to say, not exceeding 60,000 kilomètres per second, its magnitude, represented by 1 at the beginning, remains about the same (1.012). When the speed reaches half that of light—that is, 150,000 kilomètres per

[1] To express these variations Max Abraham has given the following equation:—

$$\mu = \mu_0 \frac{3}{4} \psi(\beta)$$

in which μ_0 represents the value of the electric mass for slight speeds, $\beta = \frac{q}{c}$, the ratio of the speed q of this mass to that c of light and

$$\psi(\beta) = \frac{1}{\beta^2}\left[\frac{1 + \beta^2}{2\beta} \log \frac{1 + \beta}{1 - \beta} - 1\right]$$

In order to obtain a graphic representation of the variation of the mass acting as a function of its speed, I have set forth the above equation in a form in which the ratio $\frac{\mu}{\mu_0}$ appears as an explicit function of the ratio $\beta = \frac{q}{c}$; we take as abscissæ the values of the ratio $\beta = x$ and as ordinates the values of the ratio $\frac{\mu}{\mu_0} = y$.

The equation of the curve becomes then

$$y = \frac{3}{4x^2}\left[\frac{1 + x^2}{2x} \log \frac{1 + x}{1 - x} - 1\right]$$

The horizontal $y = 1$ corresponds to $\frac{\mu}{\mu_0} = 1$ and represents the constant magnitude of the mechanical mass. In order to detach the curve more quickly I have adopted a scale of ordinates equal to ten times that of the abscissæ. The excessive reduction of the curve rendered necessary by the size of this volume has made the numbers hardly legible. I have calculated the figures which express the variations of the mass as a function of the speed to 8 places of decimals. The most interesting of these are given in the text.

second—the mass has still only increased by one-tenth (1.119). When the speed equals three-fourths that of light, the increase of the mass is still very slight (1.369). When the speed equals nine-tenths that of light, the mass has not yet quite doubled (1.82); but as soon as the speed reaches .999 that of light, the mass increases sixfold (6.678).

We are here very close to the speed of light, and the mass has as yet only increased sixfold; but it is now that the figures deduced from the equation begin to increase singularly. For the mass of the electric atom to become twenty times greater (20.49), its speed will only have to differ from that of light by the fraction of a millimètre. For its mass to become a hundred times greater, its velocity would have to differ from that of light by the fraction of a millimètre comprising fifty-eight figures. Finally, if the speed of the electric atom became exactly equal to that of light, its mass would be theoretically infinite.

These last results cannot be verified by any experiment, and are evidently only an extrapolation.[1] We must not, however, consider as *à priori* absurd the existence of a substance of which the mass would increase in immense proportions, while its already very great speed would only vary by the minute fraction of a millimètre. The considerable increase of an effect under the influence of a very small variation in the cause is observed in many physical laws which can be translated by asymptotic curves. The immense variations in size of the image of an object for a very slight displacement

[1] The word used by mathematicians for the process of finding new terms outside a series.—F. L.

of that object when very close to the principal focus of a lens, furnish an example of this. Suppose an object placed at one-tenth of a millimètre from the focus of a lens with a focus of ten centimètres. The general equation of lenses shows that its image will be magnified a thousand times. If the object is brought nearer by one-hundredth of a millimètre, its image will, theoretically, be magnified a hundred thousand times. If, lastly, the object is placed in the very focus itself, its image will, theoretically, be infinite. Every time a physical law can be translated by curves similar to the above, the slightest variation in the variable produces extremely important variations of the function in the neighbourhood of the limit.[1]

Leaving these theoretical considerations and coming back to the results of experiments, we may say this: the particles produced during the dissociation of matter possess a property resembling inertia, and in this they are akin to matter; but this inertia, instead of being constant in magnitude, varies with the speed, and on this point particles of dissociated matter are sharply differentiated from material atoms.

The study of the properties of the inertia of these elements leads, as will be seen, to their being considered something which, issuing from matter, possesses properties somewhat similar to, but yet

[1] I must point out, by the way—and this observation will explain many historical events—that it is not only physical, but many social phenomena which can be likewise defined by curves possessing the properties we have just stated, and in which, consequently, very small changes in a cause may produce very great effects. This is owing to the fact that when a cause acts for a length of time in a same direction, its effects increase in geometrical progression, while the cause varies simply in arithmetical progression. *Causes are the logarithms of effects.*

notably different from, those of material atoms. Representing one of the phases of the dematerialization of matter, they are only able to retain a part of the properties of this last. We shall see in another chapter that the electric fluid likewise possesses properties intermediate between those of matter and those of ether.

Some physicists have supposed—without, however, being able to furnish any proofs—that the inertia of matter is due to the electric particles of which it should be composed, and consequently that all the inertia of material substances is entirely of electromagnetic origin.[1] There is nothing to indicate that material inertia can be identified with that of the particles of dissociated matter. The mass of these last is only, in reality, an apparent mass resulting simply from its condition as an electrified body in motion. They appear, besides, to have a longitudinal mass (that which measures the opposition to acceleration in the direction of the motion), different from the transversal mass (that perpendicular to the direction of the motion). In every way it is evident that the properties of an element of dissociated matter differ considerably from those of a material atom.[2]

[1] *Cf.* Professor J. J. Thomson in his Yale Lectures:—"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." (*Electricity and Matter*, pp. 50-51.)—F. L.

[2] The vicious circle of the argument attacked in this paragraph is thus well set forth by Professor H. A. Wilson:—"It is now suggested that all matter is composed of electrons, so that all inertia is electro-

Of what, then, are constituted these atoms which are supposed to be electric, and are emitted by all bodies during their dissociation? The answer to this question supplies the link required between the ponderable and the imponderable. It is impossible, in the present state of science, to give a definition of a so-called electric particle, but we can at least say this: Substances neither solid, liquid, nor gaseous, which pass through obstacles, and have no property common to matter, except a certain inertia, and even then an inertia varying with their speed, are very clearly differentiated from matter. They are likewise differentiated from the ether, of which they do not possess the attributes. They therefore form a transition between the two.

Thus, then, the effluves emanating from spontaneously radio-active bodies, or from bodies capable of becoming so under the influence of the numerous causes we have enumerated, form a link between matter and the ether. And, since we know that these effluves cannot be produced without the

magnetic. Density, according to this view, is simply the number of electrons per unit volume. Electro-magnetic inertia—that is, all inertia—is due to the energy of the magnetic field produced by the moving charges of electricity. The energy of this magnetic field resides in the ether. According to Maxwell's dynamical theory, the electro-magnetic energy of the ether is due to motion of parts of the ether, these parts possessing motion. But the only kind of inertia which we really know is the inertia of matter, which is due to the electro-magnetic action of the electrons of which matter is made up. If inertia is due to electrons, then if we ascribe to parts of the ether the property of inertia, we ought to say that the ether contains so many electrons per unit volume. But the free ether is not supposed to contain any electrons; in fact, if we explain inertia by the energy of the magnetic fields produced by moving charges, then evidently to explain this energy by inertia in the ether is merely to argue in a circle." (*Nature*, 22nd June 1905.)—F. L.

definitive loss of matter, we have a right to say that the *dissociation of matter realizes indisputably the transformation of the ponderable into the imponderable.*

This transformation, so contrary to all the ideas bequeathed to us by science, is yet one of the most frequent phenomena in nature. It is daily produced before our eyes; but as formerly there existed no reagent to show it, it was not seen.

CHAPTER II.

ELECTRICITY CONSIDERED AS A SEMI-MATERIAL SUBSTANCE GENERATED BY THE DEMATERIALIZATION OF MATTER.

§ 1. *Radio-active and Electrical Phenomena.*

By pursuing our researches on the dissociation of matter, we have been progressively led, by the concatenation of experiments, to recognize that electricity, of which the origin is so entirely unknown, represents one of the most important products of the dissociation of matter, and in consequence can be considered as a manifestation of the intra-atomic energy liberated by the dissociation of atoms.

We have seen in the last chapter that the particles issuing from the radio-active substances constitute a substance derived from matter and possessing properties intermediate between matter and the ether. We shall now see that the products of the dissociation of matter are identical with those disengaged by the electrical machines in our laboratories. This generalization duly established, electricity in its entirety, and not simply in some of its forms, will appear to us as the connecting link between the world of matter and that of the ether.

We know that the products of the dissociation of all bodies are identical, and only differ by the extent of the power of penetration belonging to them and resulting from their difference of speed. We have established that they are composed—(1st) of positive ions of some volume at all pressures, and always comprising in their structure some material parts; (2nd) of negative ions formed of electric atoms termed electrons, which can surround themselves in the atmosphere with material neutral particles; (3rd) of electrons disengaged from all material components, and able, when their speed is sufficient, to create by their impact X rays.

These various elements are generated by all bodies which are dissociated, and especially by spontaneously radio-active substances. They are also found with identical properties in the products obtained from Crookes' tubes—that is to say, tubes through which, after exhaustion, electric discharges are sent. The only difference which exists between a Crookes' tube in action and a radio-active body in course of dissociation is, as we have already seen, that the second produces spontaneously—that is to say, under the influence of actions unknown to us—that which the first produces only under the influence of electric discharges.

Thus, then, electricity under various forms is always met with as the ultimate product of the dissociation of matter, whatever the process employed for its dissociation. It is this experimental fact which induced me to inquire if in a general way the electricity generated by any means—a static machine, for instance—might not be one of the forms of the dissociation of matter.

But, if the analogy between a Crookes' tube and a radio-active body has at length become so evident that it is no longer disputed, it was less easy to establish an analogy between the phenomena taking place in that tube and electrical discharges in the air at ordinary pressure. Yet they are two identical things, though they differ in aspect. I will now demonstrate this.

When two rods of metal connected with the poles of a generator of electricity are placed at a short distance from each other, the two electric fluids of contrary signs with which they are charged tend to recombine by virtue of their attractions. As soon as the electric tension becomes sufficiently strong to overcome the resistance of the air, they recombine violently, producing loud sparks.

Air, by reason of its insulating qualities, offers great resistance to the passage of electricity; but if we do away with this resistance by introducing the two electrodes in question into an exhausted receiver, the phenomena will be very different. Yet, in reality, nothing has been created in the tube. All that is found there, both ions and electrons, were already in the electricity which has been brought into it. At the most there could have been formed there new electrons arising from the impact of those derived from the source of electricity against the particles of rarefied gas still left in the tube.

If the effects obtained by a discharge in a vacuum tube are greatly different from those produced by the same discharge in a tube filled with air, the reason is that in the vacuum the electric particles are not impeded by molecules of air obstructing their course. In a vacuum alone can electrons obtain the speed necessary for the production of X rays when they strike against the walls of the tube.

In no case, I repeat, are ions and electrons formed in the vacuum tube; they are brought there from outside. They are elements produced by the generator of electricity. *It is not in a Crookes' tube that matter is dissociated; it is taken there already dissociated.*

If this be actually so, we ought to be able to meet, in the electric discharges produced in the air by an electric machine, with the various elements—ions and electrons—of which we have noted the existence in the Crookes' tube, and which we know to be likewise generated by radio-active bodies.

Let us, then, examine the electricity furnished by the little static machines of our laboratories. We might take as a typical generator of electricity the most simple of all, a rod of glass or resin giving out electricity at a tension of from two or three thousand volts, but its use would be inconvenient for many experiments. The majority of electrical machines for laboratory use, however, only differ from this elementary apparatus by the greater surface presented by the body receiving friction, and because it is possible by the help of various artifices to collect separately the positive and negative electricity at two different extremities called poles.

The electricity issuing from a static machine possesses, however, a considerable advantage from the point of view which interests us. Its output is very small, but the electricity issues from it at an extremely high tension, which may easily exceed 50,000 volts. It is just this circumstance which will enable us to demonstrate in the electric particles shot forth by the insulated poles of a static machine a strict analogy with the particles emitted by radio-active bodies. The electricity of a battery is evidently identical with that of static machines, but as it is turned out at the tension of a few volts only, it cannot produce the same effects of projection.

It is probable also that the friction on which the construction of the static machines is based constitutes one means of dissociation of the atom, and consequently brings intra-atomic energy into play. This, doubtless, does not act in the molecular dissociation of compound bodies on which the battery is based, and this is probably why electricity is produced, in great quantity but at a very low tension, which in the best type of battery hardly exceeds two volts. If the output of a static machine could attain that of a small ordinary battery, it would constitute an exceedingly powerful agent capable of producing an enormous amount of industrial work. Suppose an electric machine worked by hand and giving out electricity at a tension of 50,000 volts had an output of only two ampères—that is to say, the output of the very smallest battery—its yield would represent work to the extent of 100,000 watts, or 136 horse-power per second. Given that a considerable liberation of energy results from the dissociation of a very slight quantity of matter, the creation, in the future, of such a machine—that is to say, of an apparatus giving forth a power extremely superior to that expended in setting it in motion—can be considered possible. It

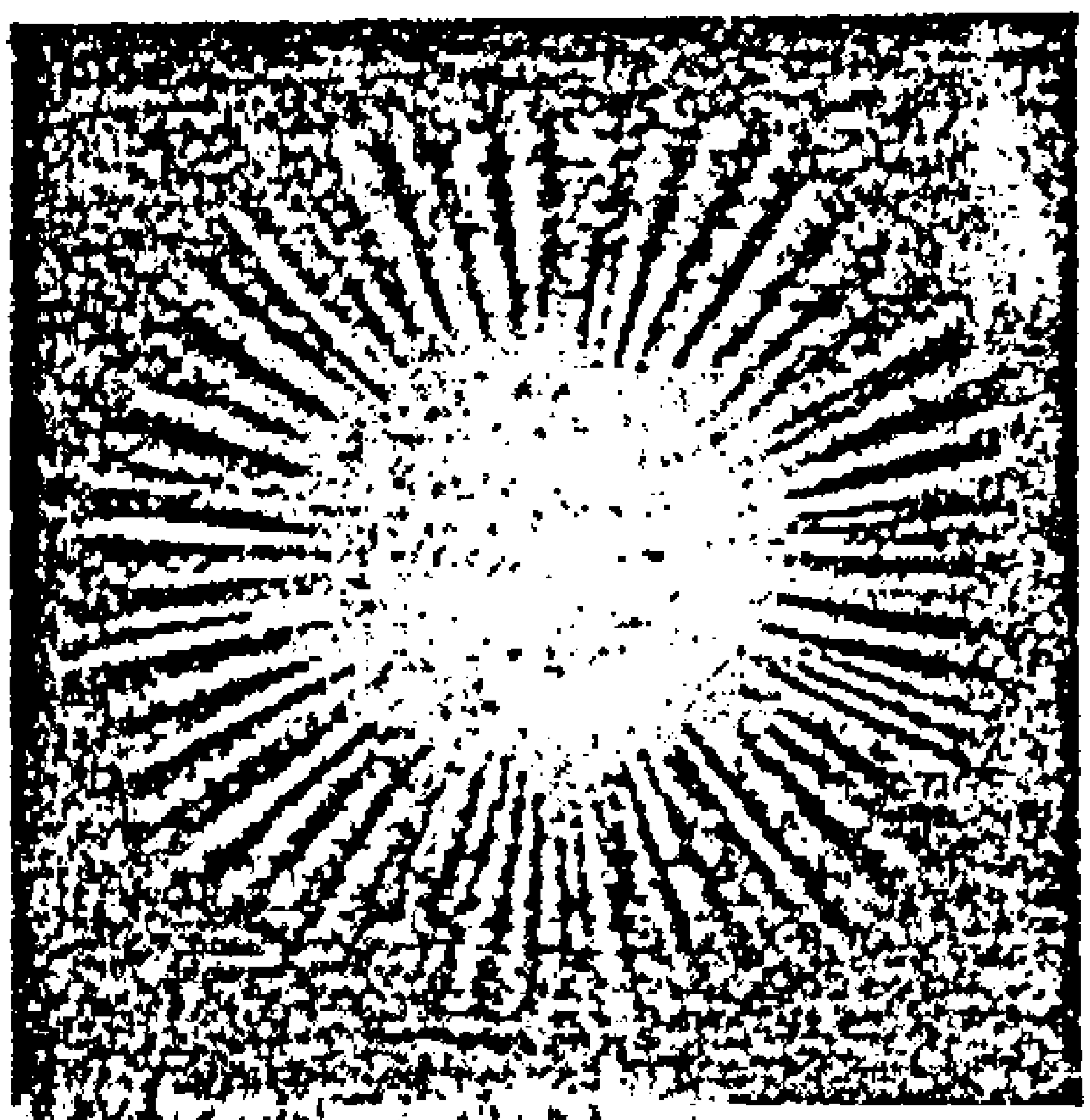


FIG. 21.—Radiation of the electric particles from a single pole. [*Instantaneous photograph.*]

is a problem of which the enunciation would have seemed altogether absurd some ten years ago. To solve it, it would be enough to find the means of placing matter in a state in which it can be easily dissociated. Now, we shall see that a simple ray of sunlight is a model agent of dissociation. It is probable that many others will be discovered.

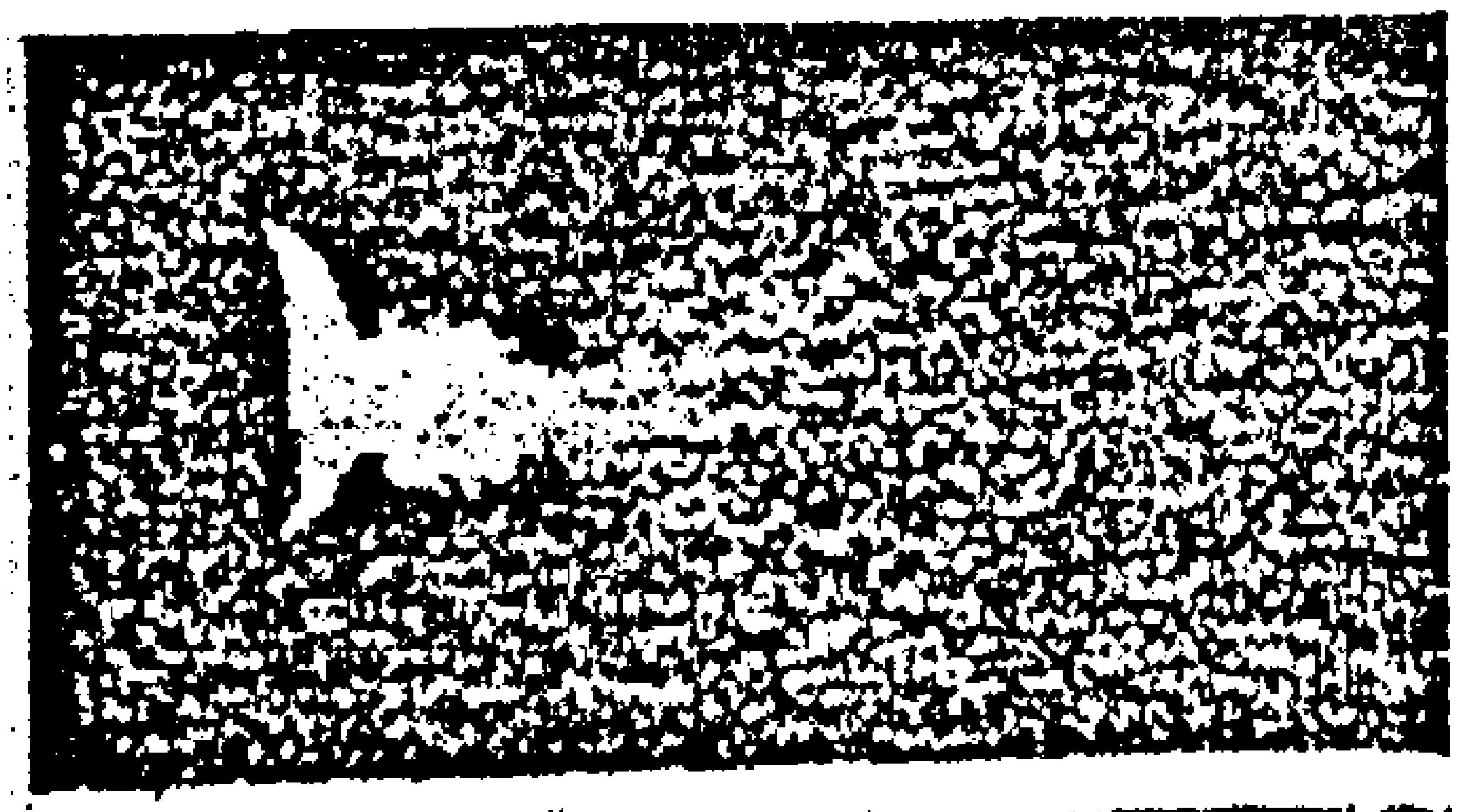


Fig. 22.

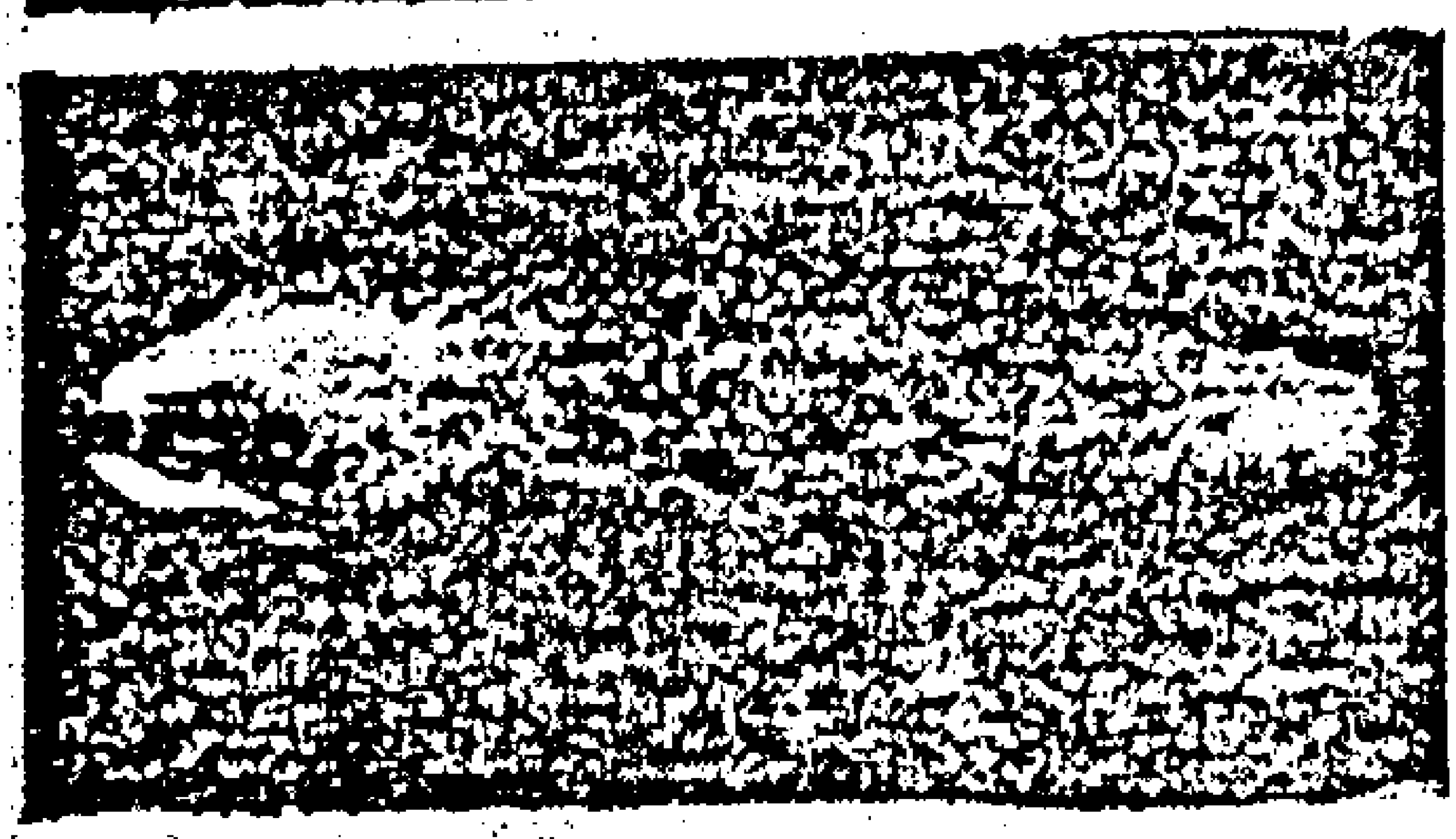


Fig. 23.

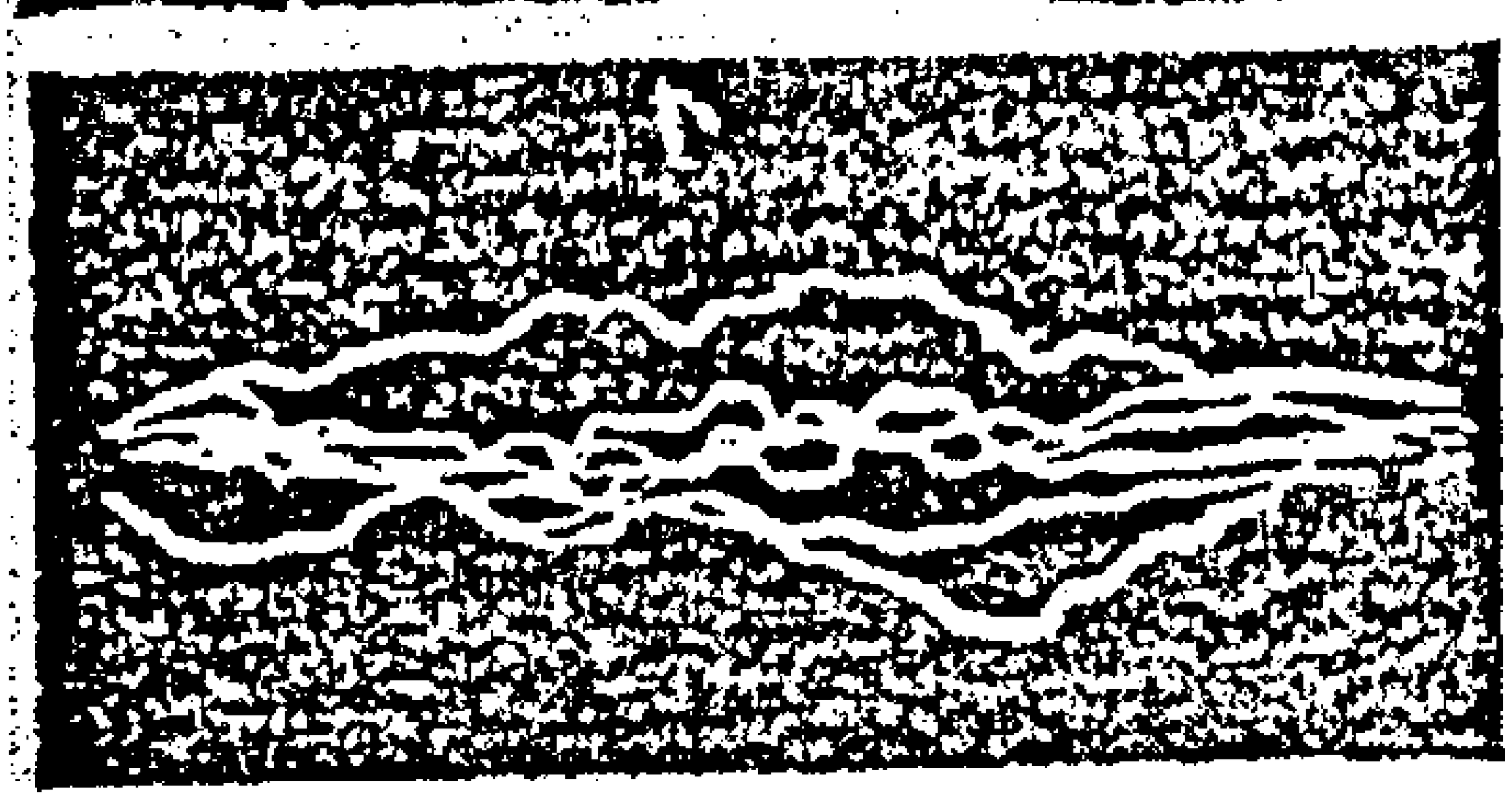


Fig. 24.

Fig. 22.—Photograph of the aigrettes produced by the particles emitted by one of the poles of a static machine.

Fig. 23.—Positive and negative electric particles, which are formed at the two poles and attract each other.

Fig. 24.—Concentration of the electric particles into a few lines from which results a discharge in the shape of sparks.

Let us now examine our ordinary electric machine at work and inquire what is disengaged by it.

If the terminal rods forming the poles are very wide apart, there will be seen at their extremities sheaves of tiny sparks named aigrettes (Figs. 21 and 22), which are disengaged with a characteristic crackling noise. In the production of these elements dwells the fundamental phenomenon. It is by examining their composition that one notes the analogies which exist between the products of radio-active bodies and Crookes' tubes, and those of an electrical machine.

The effects obtained with the elements which issue from the poles vary according to the disposition of these poles, and it is important to remember this first of all.

If we connect the two poles by a wire of any length, in the circuit of which we intercalate a galvanometer, the deviation of its magnetic needle will reveal to us the silent and invisible production called an electric current. It is identical with that which traverses our telegraph lines, and is constituted of a fluid formed, according to current ideas, by the conjunction of electric particles called electrons, which the machine constantly generates.

Instead of connecting the poles by a wire, let us bring them a little closer, keeping, however, a certain distance between them. The electric elements of contrary signs attracting one another, the aigrettes we have noticed elongate considerably, and with a fairly powerful machine they can be observed to form in the dark a cloud of luminous particles connecting the two poles (Fig. 23).

If we bring the poles still closer to one another, or if, without bringing them closer, we increase the tension of the electricity by means of a condenser, the attractions between the electric particles of contrary signs become much more energetic. These particles now condense over a smaller number of lines or over one line only, and the recombination of the two electric fluids takes place under the form of contracted, noisy, and luminous sparks (Fig. 24). But they are still constituted of the same elements as before, for the distance between the poles or the elevation of the tension are the only factors we have made to vary.

The various effects we have just described are, naturally, very different from those we observe when the discharge occurs in a globe in which the air has been more or less rarefied. The absence of the air produces these differences, but this gas exercises no action on the electric elements disengaged by generators of electricity. Of what do these elements consist?

§ 2. *Composition and properties of the elements emitted by the poles of an electric machine. Their analogy with the emissions of radio-active bodies.*

To analyse these elements, they must be studied before the recombination of the electric particles—that is to say, when the poles are far apart and during the production of the aigrettes mentioned above.

We shall meet in them with the fundamental properties of the emissions of radio-active bodies, notably those of rendering air a conductor of electricity and of being themselves deviated by a magnetic field. From the positive pole of the machine start positive ions: from the magnetic pole start those atoms of pure electricity of defined magnitude termed electrons. But in opposition to what happens in a vacuum, these electrons immediately become the centre of attraction for gaseous particles and transform themselves into negative ions identical with those produced by the ionization of gases and in all forms of ionization.

These emissions of ions are accompanied by secondary phenomena, heat, light, etc., which we will examine later on. They are also accompanied by a projection of metallic dust torn from the poles, the speed of which, according to J. J. Thomson, can attain 1800 mètres per second—that is to say, about double the speed of a cannon ball.

The speed of projection of the ions which together form the aigrettes of the poles of a static machine, depends, naturally, on the electric tension. By raising it to several hundred thousand volts with a high frequency resonator, I have succeeded in compelling the electric particles of the aigrettes to pass through, visibly (Figs. 25 and 26), and without deviation, plates of insulating bodies half a millimètre in thickness. This is an experiment made some time back with the collaboration of Dr. Oudin which I have already published with confirmatory photographs. In the experimental part of this book will be found the technical directions necessary for repeating it. Notwithstanding its importance[1] it made very little impression on physicists, though it was the first time that any one had succeeded in visibly transpiercing matter by electric atoms. By placing a glass plate between the barely separated poles of an induction coil, it can, as has long been known, be easily pierced; but this is a simple mechanical action. The aigrettes in our experiment go through bodies without in any way affecting them, just as does light. The direction of the charge proves that they are composed of positive ions.

[1] So far as I know it has been noticed only by a distinguished English electrician, Professor Fleming, who, in one of his lectures on Electric Oscillations (*Cantor Lectures*, 1900), describes it as "striking."

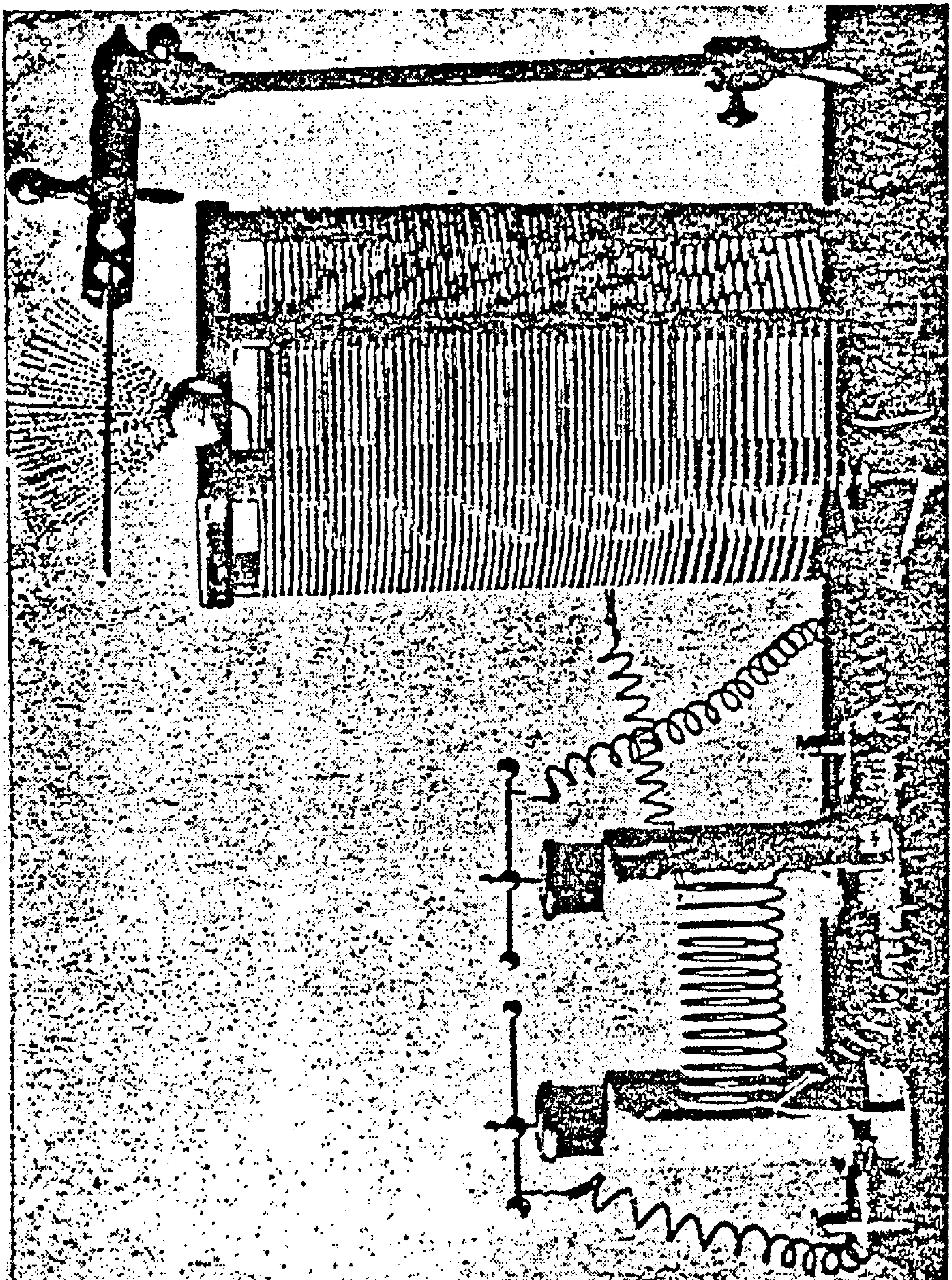


FIG. 25.—*The visible passage through a material obstacle formed of a plate of glass or ebonite.* The effluves have been outlined in dots as they appear to the eye. The next diagram represents the photograph of the phenomenon. The dots have disappeared, through the enforced prolongation of the exposure.

The emission by the poles of an electric machine of electrons afterwards transformed into ions is accompanied by various phenomena which are met with in radio-active bodies under hardly different forms. To study them it is preferable to have points at the end of the poles of the machine. It is then easily verified that *what issues from an electrified point is identical with that which issues from a radio-active body.*

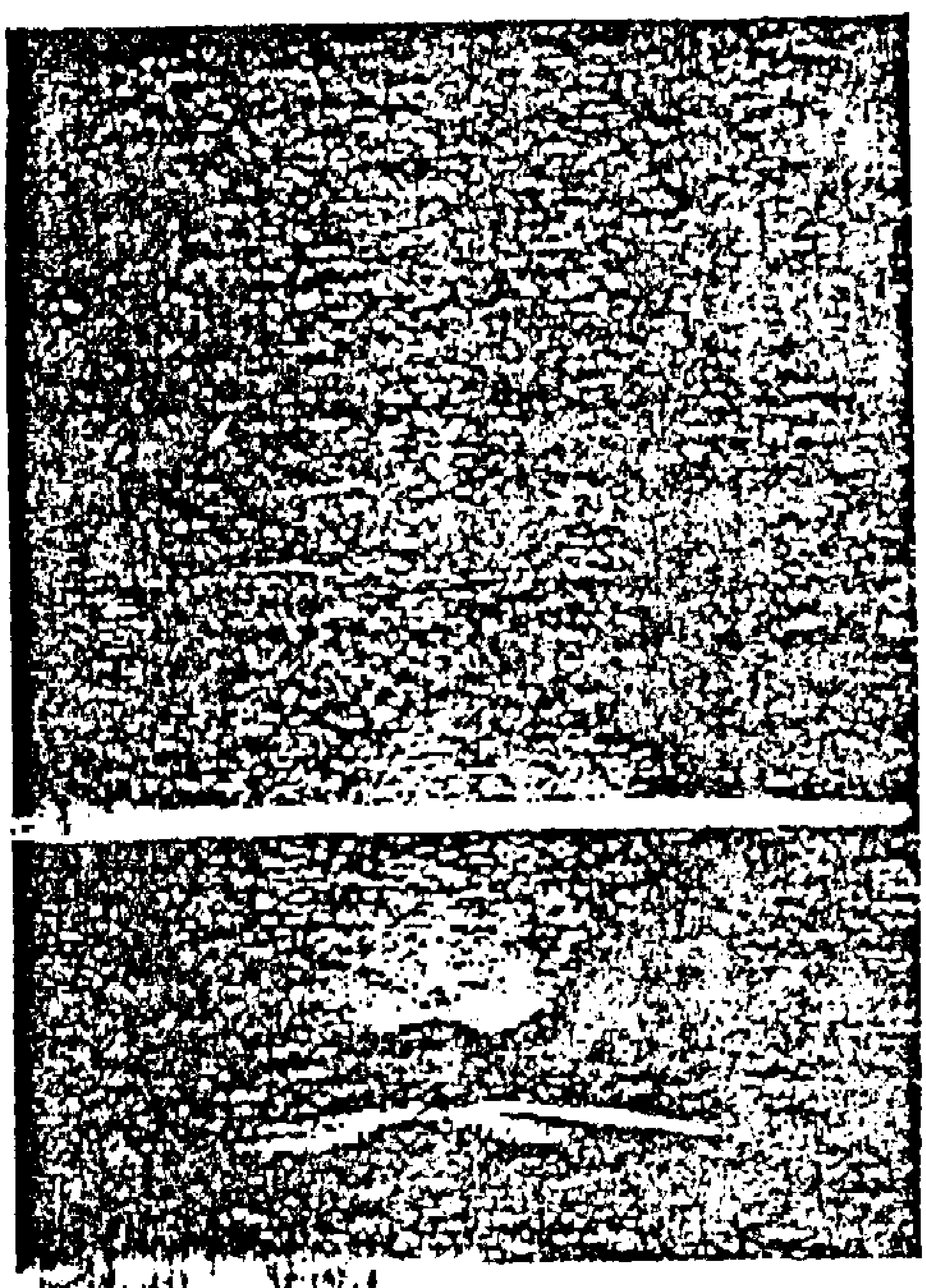


FIG. 26.—Photograph of the effluves proceeding from the dematerialization of matter during their passage through a material obstacle such as a plate of glass or of ebonite.

The only actual difference is that the point does not at ordinary pressure produce X rays. When it is desired to observe these latter, the point must be connected with a conductor allowing the discharge to take place in an exhausted globe. In this case, the production of X rays is abundant enough, even though only one pole be used, to render visible, on a screen of platino-cyanide of barium, the bones of the hand.

The non-production of X rays is otherwise in accordance with the theory. The X rays are only generated by the impact of electrons having a great speed. Now, electrons formed in a gaseous medium at atmospheric pressure immediately change into ions by the addition of a retinue of neutral particles, and in consequence of this surcharge cannot keep up the speed necessary to generate X rays.

Besides this property of generating X rays, which, moreover, is not common to all radio-active bodies, the particles which disengage themselves from an electrified point are, I repeat, in every way comparable to those resulting from the dissociation of the atoms of all bodies. They render, in fact, air a conductor of electricity, as Branly showed long since, and are, as J. J. Thomson proved, deviated by a magnetic field.

The projection of particles of dissociated matter—that is to say, of ions—against the air molecules produces what is called the electric wind, by which a lamp can be extinguished and a whirl made to revolve, etc. It is in nowise due, as is constantly stated in all treatises on physics, to the electrification of the particles of the air, for a gas cannot be electrified by any process, save when it is decomposed. It is the kinetic energy of the ions transmitted to the molecules of the air which causes the displacement of these last.

The ions emitted by the points with which we have equipped the poles of an electric machine can produce fluorescent effects very similar to those observed with radium. They allow us to imitate the effects of the spinthariscope, which renders the dissociation of matter visible. One has only, according to M. Leduc, to bring within a few centimètres of a screen of platino-cyanide of barium in the dark a rod terminating in a very fine point connected with one of the poles—the positive one for choice—of a static machine, the other pole being earthed. If the screen be then examined with a magnifying-glass, exactly the same shower of sparks as in the spinthariscope will be observed, and the cause is probably identical.

The ions which issue from the poles of a static machine are not, as a rule, very penetrating—no more so, in fact, than the ions which form 99 per cent. of

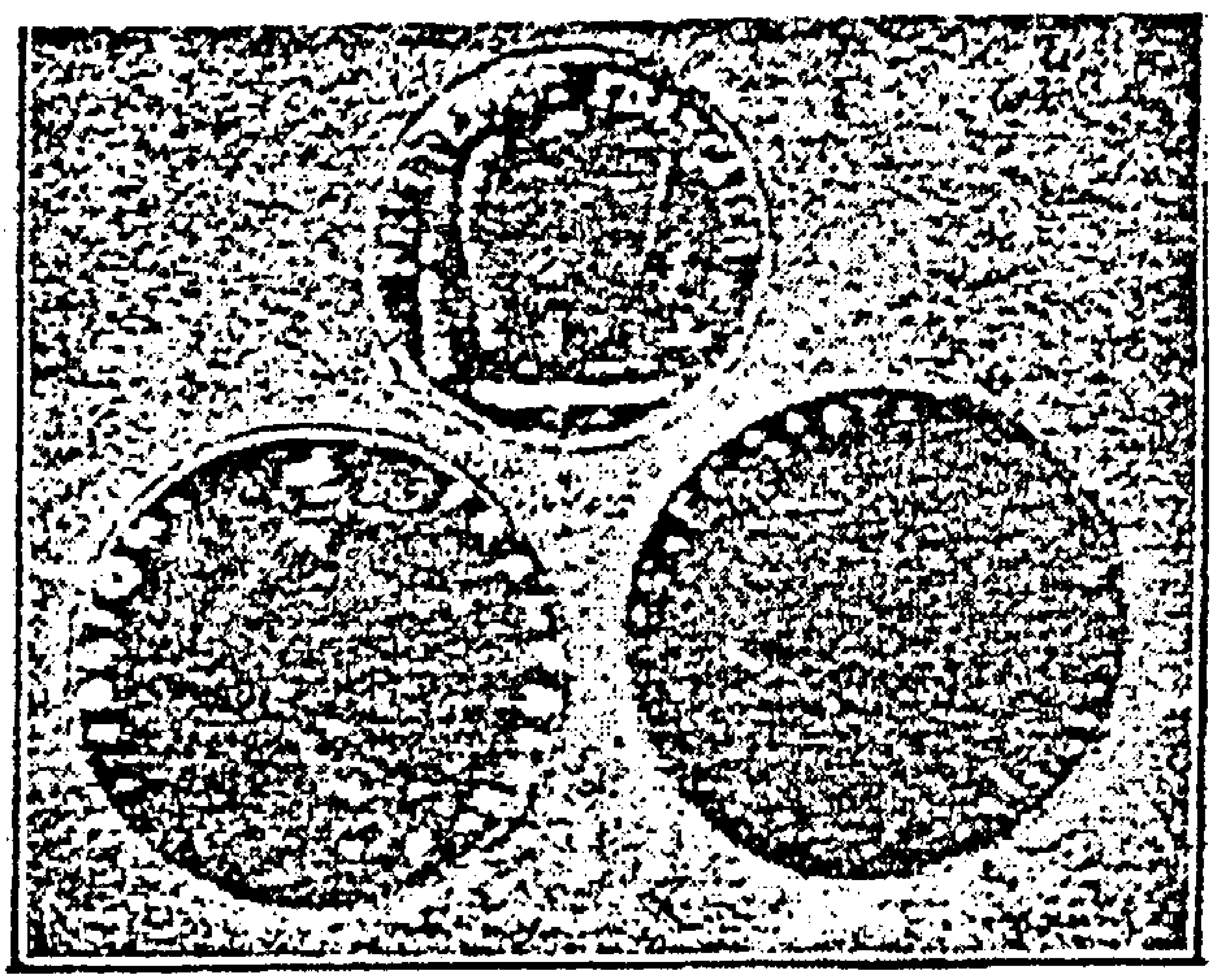


FIG. 27.—Impressions produced by ions issuing from an electrified point through a sheet of black paper.

the emission of radium. However, I have been able to obtain very clear photographic impressions through a sheet of black paper by raising the electric tension sufficiently (Fig. 27).

It is sufficient to place the object to be reproduced—a medal, for instance—over a photographic plate placed on a sheet of metal connected with one of the poles, while above the metal is fixed a rod communicating with the other pole. A few small sparks suffice. The reproduction thus obtained cannot be attributed to the ultra-violet light produced by the discharge, seeing that the medal is separated from the plate by a sheet of black paper, and that under these conditions it is evident no light, visible or invisible, would succeed in producing an impression of the details of the medal. This phenomenon is, however, rather complex, and its thorough discussion would carry us too far. Hence I do not insist on the point.

The ions emitted by electrified points are most often accompanied by the emission of light, a phenomenon likewise observed in certain radio-active bodies. The spectrum of this light is singularly spread out. It varies, in fact, according to my researches, from Hertzian waves not more than two or three millimètres long up to ultra-violet rays, of which the length is *under* $\lambda = .230\mu$. If a solar diffraction spectrum be reckoned at one centimètre in length, the spectrum of the electrified points would be on the same scale about thirty mètres long. The production of ultra-violet light in the spectrum of electric sparks has long been known and utilized, but it is, I think, M. Leduc who first pointed out its presence in the aigrettes from points.

Yet there remained in my mind a doubt as to its existence. In the whole region round an electrified point there exists an intense electric field capable of illuminating at some distance a Geissler tube, and perhaps also capable of illuminating fluorescent bodies. It was therefore necessary to eliminate its action.

To separate the action of the ultra-violet light from that which might be due to the electric field, I made use of the large 12-plate machine of Dr. Oudin, whose action is so powerful that the aigrettes produced will illuminate a screen of platino-cyanide of barium or a Geissler tube at a distance of several mètres.

The separation of the action of the electric field from that of the ultra-violet light has been realized in the most categorical manner by the following experiment effected with the co-operation of Dr. Oudin:—

Within a wooden cage enveloped in metallic gauze connected with the earth—so as to obviate all electric action—are placed Geissler tubes and metal plates, on which are traced letters with powdered platino-cyanide of barium dissolved in gum arabic. It is then found that the Geissler tubes, which outside the cage shine brightly, entirely cease to be luminous as soon as they are placed within it; while, on the contrary, the letters traced with the platino-cyanide and enclosed in the metallic cage continue to shine. The illumination of these latter is therefore solely due to the ultra-violet light.

It results, then, from what precedes that the formation of electric aigrettes is accompanied by an enormous production of invisible light. With a high frequency resonator the quantity is so great that illumination of the platino-cyanide can be produced up to a distance of more than five mètres.

It is not for me to inquire here how ultra-violet light acts on fluorescent bodies. It is admitted, since the days of Stokes, that fluorescence comes from the transformation of invisible ultra-violet waves into larger and, for that reason, visible waves. But I must remark, by the way, that it would perhaps be simpler to suppose that fluorescence is due to the production—under the influence of ultra-violet light, the energetic ionizing action of which is well known—of slight atomic electric discharges from bodies which their structure renders capable of fluorescence.

In order to determine the limits of the ultra-violet produced in the foregoing experiments, I made use of various screens placed on the platino-cyanide screen, having first ascertained their transparency by means of the spectrograph used in former researches. The active part of the ultra-violet—that is to say, that which is capable of producing fluorescence—extends up to about $\lambda = .230\mu$.

But an electrified point in discharge is not only a source of ultra-violet light; it also emits Hertzian waves, a fact totally unknown before my researches. I have indicated, in the experimental part of this work, the means employed to reveal them. By reason of their slight length, which, probably, does not exceed two millimètres, they hardly propel themselves farther than forty to fifty centimètres.[1]

[1] The Hertzian wave which always accompanies electric sparks is no longer electricity but is a phenomenon of vibration of the ether, and only appears to differ from light in length of wave. Though it has gone forth from electricity, it is able to re-assume the ordinary electric form whenever it touches any substance. It then communicates to the latter a charge verifiable by the electroscope, and can produce sparks.

Between the Hertzian wave and electricity there is a difference of the same order as that which exists between radiant heat and heat by conduction, which were formerly confounded. They are two very different phenomena, since one occurs with matter, the other in the ether. They can, however, transform themselves one into the other. A substance when heated emits waves in the ether analogous to those produced by a stone thrown into water. These waves on striking a material substance become absorbed by it and are transformed into heat. So soon as the material substance is heated it at once radiates calorific waves into the ether in the same way as the Hertzian wave electrifies a substance when it touches it and imparts to it the faculty of emitting in turn other Hertzian waves.

This production of Hertzian waves, visible light and invisible ultra-violet light, the constant companions of all emissions of electric particles, must be borne in mind, for it will furnish us later on with the key to the final process of the transformation of matter into vibrations of the ether when we take up this question in another chapter.

To sum up the foregoing, we may say that a body electrified by any means, notably friction, is simply a body whose atoms have undergone the commencement of dissociation. If the products of this dissociation be emitted in a vacuum, they are identical with those generated by the radio-active substances. If emitted in the air, they possess properties which only differ from those of radio-active emissions, from their speed being less.

Looked at from this point of view, electricity appears to us as one of the most important phases of the dematerialization of matter, and, consequently, as a particular form of intra-atomic energy. It constitutes, by reason of its properties, a semi-material substance intermediate between matter and the ether.

CHAPTER III.

COMPARISON OF THE PROPERTIES OF THE ELECTRIC AND THE MATERIAL FLUIDS.

I HAVE shown that the electric particles and the fluid they form by their conjunction possess an inertia of a special nature differing from that of matter, which, joined to other properties, allows us to consider electricity in all its forms as composing an intermediate world between matter and the ether.

We shall again meet with the properties of this intermediate world when we compare the laws of the flow of material fluids with those which regulate the distribution of the electric fluid. The differences between these different fluids are too visible for it to be necessary to indicate them at length. The electric fluid possesses a mobility which allows it to circulate in a metallic wire with the speed of light, which would be impossible for any material substance. It escapes the laws of gravitation while the equilibria of material fluids are governed by these laws alone, etc.

The differences are therefore very great, but the analogies are so likewise. The most remarkable of them is formed by the identity of the laws governing the flow of the material fluids and of the electric fluid. When one knows the former one knows the latter. This identity, which has taken some long time to establish, has now become classic. The most elementary treatises lay stress at every page on the assimilation which can be established between the distribution of electricity and that of liquids. They are careful, nevertheless, to point out that this assimilation is symbolical, and does not apply in every case. On looking a little closer into the matter, it has to be acknowledged, however, that it is in nowise a question of a simple assimilation. In a recent work[1] the learned mathematician Bjerkness has shown that we have only to employ a certain system of electrical units for "the electric and magnetic formulas to become *identical* with the hydro-dynamic formulas."

A few examples will at once make evident the resemblance of these laws. To give them more authority I borrow them from a work of Cornu, published a few years ago.[2]

It must first be remarked that the fundamental law of electricity, that of Ohm $\left(i=\frac{e}{r}\right)$, might have been deduced from that movement of liquids in conduit pipes the properties of which have long been known to engineers.

Here is, however, for the most important cases, the comparison of the laws governing these various phenomena. One of the two columns applies to material fluids, the other to the electric fluid.

The outflow of a liquid per unit of time, through a communication tube, is proportional to the difference of level and in inverse ratio to the resistance of the tube.	The intensity of a current in a given wire is proportional to the difference of potential existing between the two extremities, and in inverse ratio to the resistance.

[1] Bjerkness, *Les actions hydrodynamiques à distance.*

[2] Cornu, *Corrélation des phénomènes d'électricité statique et dynamique.*

In the fall of a liquid through a communication pipe from one given level to another likewise fixed, the work at our disposal is equal to the product of the quantity of liquid by the difference in the levels.	In the passage of electricity through a wire from one given potential to another likewise fixed, the available work of the electric forces is equal to the product of the quantity of electricity by the difference of potential (fall) of electricity.
The height of the level in a vessel increases in proportion to the quantity of liquid poured into it, and in inverse ratio to the section of the vessel.	The electric potential of a conductor increases in proportion to the quantity of electricity yielded (charge), and in inverse ratio to the capacity of the conductor.
Two vessels filled with liquid placed in suitable communication with each other are in a state of hydrostatic equilibrium when their levels are the same.	Two electrified conductors put in connection with each other are in a state of electrostatic equilibrium when their potentials are the same.
The total quantity of liquid is then divided in proportion to the capacities of the vessels.	The total electric charge is then divided in proportion to the capacities of the conductors.

Cornu, who has carried these analogies much further than I have here done, is careful to remind us that these are assimilations of everyday use in practice, "an electric canalisation must be treated like a distribution of water: at every point on the system one must make certain of the pressure necessary for the output."

All the foregoing phenomena observed with the electric fluid as with the material fluids are the result of the disturbances of equilibrium of a fluid which obeys certain laws in regaining its equilibrium. Disturbances of equilibrium producing electric phenomena manifest themselves whenever by any means—friction, for instance—a separation is made between the two elements positive and negative, of which the electric fluid is supposed to be formed. The re-establishment of the equilibrium is characterized by the recombination of these two elements.

It is only, as I have already said, the phenomena resulting from disturbances of equilibrium which are accessible to us. The neutral electric fluid—that is to say, the electric fluid which has not undergone any change of equilibrium—is a thing we may assume to exist, but no reagent reveals it. But it is natural to believe that it has an existence as real as that of water enclosed in different reservoirs, between which there is no alteration of level capable of producing a mechanical effect which would reveal the pressure of the liquid. What we call electricity proceeds solely from phenomena resulting from the displacement of the so-called electric fluid or of its elements.

We have just shown that electricity in motion acts like a material fluid, but why should these two substances, evidently so different, obey the same laws? Can the analogy of effects indicate the analogy of causes?

We know that this can nowise be. Gravity has no appreciable action on electricity, while it is the sole reason of the laws governing the flow of liquids. If a liquid passes from a higher to a lower level, it is because it obeys gravitation, which is not at all the case with electricity. The potential of a fall of water—that is to say, the difference in height between its starting-point and its destination—is entirely due to gravity; and if water stored at a certain height represents energy, it is because it is attracted towards the centre of the earth—an attraction which the walls that imprison it alone prevent its obeying. When, by tapping the reservoir, the water is allowed to flow, its fall produces, by reason of the earth's attraction, a force corresponding to that used in raising it. Once on the level of the ground, it can no longer produce work.

If the gravitation which governs the flow of liquids is totally foreign to the phenomena noted in the circulation of the electric fluid, what is the cause of this last? We know that this cause acts exactly like gravitation, but that, perforce, it differs from it. Although its inmost nature is unknown to us, we can imagine it, for observation teaches us that the electric fluid, by virtue of the reciprocal repulsion of its molecules, presents a tendency to expansion which is termed tension. This tendency to expansion is also observed in gases, but it there differs from that of the electric fluid. This last may, in fact, be retained on the surface of any insulated body, while gases diffuse immediately unless confined by the walls of a hermetically sealed vessel. All modes of energy, whether appearing in the form of quantity or of tension, obey the same general laws.

Thus we see continually occurring analogies—sometimes close, sometimes distant—between material things and things no longer material. It is precisely to the nature of the analogies between the ether and matter that are due the differences and the resemblances we have noted.

CHAPTER IV.

THE MOVEMENTS OF ELECTRIC PARTICLES—THE MODERN THEORY OF ELECTRICITY.

We have just shown the analogies of the electric and material fluids, and have noted that the laws of their distribution are identical.

These analogies become very slight, and even finally disappear when, instead of examining electricity in a fluid state, we study the properties of the elements which appear to form this fluid. We know that, according to current ideas, it is composed of particles called electrons. This conception of a discontinuous—that is to say, granular—structure of electricity, which goes back to Faraday and Helmholtz, has been greatly strengthened by recent discoveries. Suitably interpreted, it will enable us to bring together in a bird's-eye view not only the phenomena called radio-active, but also those previously known in electricity and optics, such as the voltaic current, magnetism, and light. The majority of these phenomena may be produced by simple changes of equilibrium and movement of electric particles—that is to say, by displacements of the same thing. This we shall now demonstrate.

Instead of taking a hypothetical body such as an electric atom or an electron, we will take in its stead, in the majority of cases, a small electrified metal sphere. This simple substitution, which does not modify the theory, has the advantage of making experimental verifications possible.

According to whether this sphere is at rest, or in motion, or stopped when in motion, it will, as we shall see, produce the whole series of electrical and luminous phenomena.

Let us take, then, a little metallic sphere, insulate it by any of the ordinary means, and begin by electrifying it. Nothing can be more simple, since it has only to be placed in contact with a heterogeneous substance. Two different metals separated after contact, remain, as is well known, charged with electricity. Electrification by friction, on which the old machines were based, only represents one particular case of electrification by contact. Friction, in fact, only multiplies and renews the heterogeneous surfaces present.

This settled, let us remove our sphere to a little distance from the body with which it has first been put in contact. We then discover, by various means, that it is bound to this last by lines called lines of force, to which J. J. Thomson attributes a fibrous structure. These lines tend to bring together the bodies between which they exist, and have the property of repelling each other.[1] Faraday compared them to springs stretched between the bodies. It is the extremities of these springs which constitute electric charges.

Let us now remove our sphere to a great distance from the substance which served to electrify it by its contact. The lines of force which connect the two bodies remain attached to each of

[1] See the photographs of these repulsions of lines of force, or, rather, of particles going in the direction of lines of force, Fig. 6, p. 164.

them and radiate in straight lines into space.[1] It is to them as a whole that the name of electric field is given.

If our sphere thus electrified and surrounded by radiating lines of force be well insulated, it will preserve its electric charge and produce all the phenomena observed in static electricity: attraction of light bodies, production of sparks, etc.

In this state of repose the electrified sphere possesses no magnetic action, as is proved by its absence of effect on a magnetized needle. It can only acquire this property after it has been set in motion. Let us, then, put it in motion and suppose its speed to be uniform. Our electrified sphere will acquire, from the mere fact of this motion, all the properties of an ordinary voltaic current—that is to say, the current which circulates along the telegraph wires. It is even supposed, by the present theory, that there can be no other current than that produced by the movement of electrons.

But since our electrified sphere in motion acts in the same manner as a voltaic current, it ought to possess all its properties, and consequently its magnetic action. As a fact, it is surrounded, by its very motion, by circular lines of force constituting a magnetic field. These lines envelop the trajectory of the electrified body, and are superposed on its electro-static field, composed, as we have said, of radiating straight lines.

This magnetic field which surrounds an electrified body in motion is not at all a merely theoretical view, but an experimental fact revealed by the deviation

[1] See p. 163, Fig. 4, for a photograph representing, fairly correctly, the lines of force of a body electrified in a state of repose.

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imparted to a magnetized needle placed near it.[1] The existence of these circular lines of force surrounding a current can be easily shown by passing it through a straight rod of metal piercing, at right angles to its plane, a sheet of cardboard sprinkled with metal filings. These filings, attracted by the magnetic field of the current, arrange themselves in circles round the rod. So that by the mere fact of being set in motion an electrified body acquires the properties of an electric current and of a magnet. This is equivalent to saying that any variation of an electric field produces a magnetic field.

But this is not all. We have supposed the speed of our electrified sphere in motion to be uniform. Let us now vary this motion, either by moderating it or by accelerating it, and new phenomena very different to the above will appear.

The change of speed of the electrified body has for its consequence, by reason of the inertia of the electric particles, the production of the phenomena called phenomena of induction—that is to say, the birth of a new electric force which makes itself felt

[1] Rowland was the first to prove, by a memorable experiment (the origin of all the current theories), that an electrified body in motion possesses all the properties of an electric current which follows the direction of the movement, and is consequently surrounded by a magnetic field. An insulating disc covered with metallic sectors charged with electricity, when set in motion, will cause a magnetic needle placed immediately above it to deviate exactly in the same way as would an ordinary voltaic current. Some few years ago a student in M. Lippmann's laboratory thought he was able to dispute this fundamental experiment, but a learned physicist, M. Pender, compelled him to acknowledge his error by pointing out that if he failed to obtain this deviation which proved the existence of a current, it was simply because he had had the unlucky idea of covering the metallic sectors with an insulating varnish which absorbed the electricity.

in a direction perpendicular to that of the magnetic lines, and consequently in the direction of the current. The variation of a magnetic field, therefore, has the effect of producing an electric field. It is on this phenomenon that are based many machines for the commercial production of electricity.

Another result of the superposition of this new force on the magnetic field of the electrified body whose movement has been modified, is the apparition in the ether of vibrations which propagate themselves therein with the speed of light. It is waves of this kind that are made use of in wireless telegraphy. In the electro-magnetic theory of light accepted by all modern physicists, it is even supposed that these vibrations are the sole cause of light as soon as they are rapid enough to be perceived by the retina.

All through the foregoing we have supposed that the electrified body in motion is displaced in the air or in a gas at ordinary pressure. If it be made to move in a very rarefied medium, still new phenomena of a very different kind appear. These are the cathode rays, in which the electric atom seems to be entirely disengaged from all material support, and the X rays generated by the impact of these electric atoms against an obstacle. Here, evidently we can no longer have recourse to our picture of an electrified sphere of metal. We must consider the electric charge alone, freed from the material sphere which carried it.

Thus, then, as we said at the first, it is sufficient to modify the movement and the equilibrium of certain particles to obtain all the phenomena of electricity and light.

The above theory is verified, in most cases, by experiments. It is even, in reality, only a theoretical translation of experiment. So far as the phenomena of light are concerned, it had, however, prior to the researches of Zeeman, received no experimental confirmation. It was only by hypothesis that it was supposed to be the atoms of electricity, and not matter, which entered into vibration in incandescent bodies. It was thought that a flame contained electrons in motion round a position of equilibrium at a speed sufficient to give birth to electro-magnetic waves capable of propagating themselves in the ether, and of producing when rapid enough the sensation of light on the eye.

To justify this hypothesis it was necessary to be able to deviate the electrons of flames by a magnetic field, since an electrified body in motion is deviable by a magnet. It is this deviation that Zeeman succeeded in producing by causing a powerful electro-magnet to act on a flame. He then noticed that, on examining this flame with the spectroscope, the rays of the spectrum were deviated and doubled. From the distance between the spectrum lines thus separated, Zeeman was able to deduce the ratio $\frac{e}{m}$ existing between the electric charge e of the electron in the flame and its mass m. This ratio was found to be exactly equal to that of the cathode particles in the Crookes tube. This measurement helps to prove the analogy of an ordinary flame with the cathode rays and radio-active bodies.

One here sees the fundamental part played by electrons in current ideas. A great number of physicists consider that they form the sole element of the electric fluid. "A body positively electrified," says one of them, "is simply a body which has lost part of its electrons. The carrying of electricity from one point to another is realized by the transport of electrons from the place where there is an excess of positive electricity to the place where there is an excess of negative electricity." The aptness of elements to enter into chemical compounds should depend on the aptness of their atoms to acquire a charge of electrons. Their instability should result from the loss or excess of their electrons.

The theory of electrons allows us to explain many phenomena in a very simple manner, but it leaves many uncertainties still existing. By what mechanism does the propagation of electrons take place so rapidly in conducting bodies—a telegraph wire, for instance? How is it that electrons pass through metals while these last form an absolute obstacle to the most violent electric sparks? Why is it that electrons which can pass through metals are unable to cross an interval of 1 millimètre of vacuum, as is proved by bringing together the two electrodes of an induction coil in a tube in which a complete vacuum has been made (Hittorf tube)? Even with a coil giving a spark of 50 centimètres—that is to say, one able to pass through 50 centimètres of air, the electricity is powerless to overcome 1 millimètre of vacuum.[1]

[1] By substituting fine needles for the electrodes I have sometimes obtained the passage of the current, but I draw no conclusions from the experiment, not being positive as to whether the vacuum in the tube was complete. But Cooper Hewitt has shown that the electric particles can be compelled to traverse a complete vacuum by first producing between the electrodes a short circuit.

The electron has become at the present day a sort of fetish for many physicists, by means of which they think to explain all phenomena. There has been transferred to it the properties formerly attributed to the atom, and many consider it the fundamental element of matter, which would thus be only an aggregation of electrons.

Of its inmost structure we can say nothing. It is not giving a very certain explanation to assure us that it is constituted by a vortex of the ether comparable to a gyrostat. Its dimensions in any case should be extraordinarily small, but can it be considered indivisible, which would imply that it possessed an infinite rigidity? May it not be itself of a structure as complicated as that now attributed to the atom, and may it not, like the latter, form a veritable planetary system? In the infinity of worlds, magnitude and minuteness have only a relative value.

What appears to us most likely in the present state of our knowledge is that under the name of electricity are confused extremely different things, having the one common quality of finally producing certain electric phenomena. This is an idea I have already several times dwelt on. But we have no more right to call electricity everything which produces electricity than we have to call heat all causes capable of generating heat.

BOOK VI.

THE WORLD OF PONDERABILITY.—BIRTH, EVOLUTION, AND END OF MATTER.

CHAPTER I.

THE CONSTITUTION OF MATTER.—THE FORCES WHICH UPHOLD MATERIAL EDIFICES.

§ 1. *Former Ideas on the Structure of Atoms.*

BEFORE setting forth the current ideas relating to the constitution of matter, I will briefly refer to those on which science has lived till now.

According to ideas which are still classical, matter is composed of small indivisible elements termed atoms. As these appear to persist in spite of all the transformations of bodies, it is supposed that they are indestructible. The molecules of bodies, the smallest particles subsisting which exhibit the properties of these bodies, are composed of a small number of atoms.

This fundamental notion has existed for over 2000 years. The great Roman poet, Lucretius, has set it forth in the following terms, which modern books do little more than reproduce:—

"Bodies are not annihilated when they disappear from our view. Nature forms new beings with their remains. It is only by the death of some that it grants life to others. *The elements are unalterable and indestructible.* . . . The principles of matter, the elements of the great whole are solid and eternal: no foreign action can change them. The atom is the smallest body in nature . . . it represents the last term of division. There therefore exist in nature corpuscules of unchangeable essence. . . . Their various combinations change the essence of bodies."

Down to the last few years nothing had been added to the above except a few hypotheses on the structure of atoms. Newton regarded them as hard bodies incapable of deformation. Lord Kelvin (when Sir W. Thomson), harking back to the ideas of Descartes, supposed them to be constituted by vortices analogous to those which can be formed by striking the bottom of a rectangular box filled with smoke, the upper side of which is pierced with a hole. This causes vortices to issue in the form of a ring composed of gaseous threads revolving round the meridians of the ring. The ring is displaced as a whole and is not destroyed by the contact of other rings. All these vortices offer permanent oscillations and vibrations, the intensity and frequency of which are modifiable by various influences such as that of heat.

It was largely on the old hypothesis of atoms that the theory termed atomic was founded during the last century. It was first supposed that all bodies brought to the gaseous state contain the same number of molecules in the same volume. Their weight, volume for volume, being supposed to be proportional to that of their atoms, it is possible, by simply weighing the body in a state of vapour, to ascertain what is called its molecular weight, from which is deduced, by a process of analysis that there is no need to show here, what is conventionally designated by the name of its atomic weight. It is compared with that of hydrogen taken as unity.

§ 2. *Current Ideas on the Constitution of Matter.*

It is very difficult to set forth the current ideas on the constitution of matter, for they are still in course of formation. We are in the midst of a period of anarchy, where we see the former theories vanishing and those springing up which will serve to build up the science of to-morrow.

The scholars who follow, in the reviews and scientific memoirs published abroad, the experiments and discussions to which are appended the names of the most eminent physicists, witness a curious spectacle. They see disappearing, day by day, fundamental conceptions of science which seemed established solidly enough to last for ever. It is a regular revolution which is now in course of accomplishment.

The interpretations which flow from the facts recently discovered entirely upset the very bases of physics and chemistry, and seem destined to change all our conceptions of the universe. Our highest official teaching is, in France, too exclusively busy in seeing that the examination manuals are duly conned and is too hostile to general ideas to concern itself about this prodigious movement. The new philosophy of the sciences now coming to light has no interest for it.

The scientific revolution now going on seems rapid, but this rapidity is much more apparent than real. The transformation of present ideas on the constitution of matter, which seems to have taken only a few years, was prepared, in reality, by a century of researches.

Scientific ideas, in fact, only change with extreme slowness, and when they seem to be abruptly modified, it is always noted that this transformation is the consequence of a subterranean evolution which has taken long years to accomplish.

Five fundamental discoveries form the bases on which have been slowly built up the new ideas relating to the constitution of matter. They are—1st, the facts revealed by the study of electrolytic dissociation; 2nd, the discovery of the cathode rays; 3rd, that of the X rays; 4th, that of the bodies called radio-active, such as uranium and radium; 5th, the demonstration that radio-activity does not belong exclusively to certain bodies and constitutes a general property of matter.

The oldest of these discoveries, since, in fact, it goes back to Davy—that is to say, to the beginning of the last century—is that of the dissociation of chemical compounds by an electric current. Various physicists, notably Faraday, later completed its study. It has led in succession to the theory of atomic electricity and to the preponderating influence which the electric elements have in chemical reactions and the properties of bodies.

The second of the discoveries mentioned above gave a glimmering idea that there might perhaps exist a condition of matter different to those already known; but this idea remained without any influence till Roentgen, examining more closely those Crookes' tubes which physicists had been handling for twenty years without seeing anything in them, remarked that they gave out peculiar rays absolutely different to everything known, to which he gave the name of X rays. An unforeseen fact, absolutely new, and without any kind of analogy to known phenomena, thus burst into science.

The discovery of the radio-activity of uranium, later of that of radium, and finally of the universal radio-activity of matter, very closely followed that of the X rays. The link which connected all these phenomena, apparently so dissimilar, was not at first seen. It was established by my researches that they formed but one thing.

Long before these last discoveries, it was well known that electricity played an important part in chemical reactions, but it was believed to be simply superposed on the material molecules. By the discovery of electrolysis, Faraday had shown that the molecules of compound bodies carry a charge of neutral electricity of a definite and constant amount which is dissociated when solutions of metallic salts are traversed by an electric current. The molecules of bodies then came to be considered as composed of two elements, a material particle and an electric charge combined with it or superposed upon it.

The ideas most commonly accepted before the recent discoveries are well expressed in the following passage from a work published a few years ago by

Dr. Nernst, Professor of Chemistry at the University of Göttingen:—

"The ions are a kind of chemical combination between the elements or radicals and electric charges . . . the combination between matter and electricity is subject to the same laws as the combinations between different matters (laws of definite proportions, laws of multiple proportions). . . . If we suppose the electric fluid to be continuous, the laws of electro-chemistry seem inexplicable; if, on the contrary, we suppose the quantity of electricity to be composed of particles of invariable size, the foregoing laws are evidently a consequence thereof. *In the chemical theory of electricity, over and above the known elements there should be two others: the positive and the negative electrons.*"

In this phase of the evolution of ideas, the positive electron and the negative electron were simply two new substances to be added to the list of simple bodies and capable of combining with them. The old idea of a material atom still persisted.

In the present period of evolution there is a tendency to go much farther. After asking themselves whether this material support of the electron was really necessary, several physicists have arrived at the conclusion that it is not so at all. They reject it entirely, and consider the atom to be solely constituted by an aggregate of electric particles without other elements. These particles can be dissociated into positive and negative ions, according to the mechanism explained above.

This was a gigantic step, and it is far from being one which all physicists have yet taken. A great uncertainty still dominates their ideas and their language. For the majority of them the material support remains necessary, and electric particles—that is to say, electrons—are mingled with or superposed upon material atoms. These electrons, still according to them, circulate through conducting bodies, such as metals, with a velocity of the same order as that of light, by some mechanism totally unknown.

To the partisans of the exclusively electrical structure of matter the atom is composed solely of electric vortices. Round a small number of positive elements there are supposed to revolve negative electrons, not less than a thousand in number, and often more. Together they form the atom, which would thus be a kind of miniature solar system. "The atom of matter," writes Larmor, "is composed of electrons, and nothing else."[1]

In its ordinary form the atom would be electrically neutral. It would become positive or negative only when freed from electrons of the contrary sign, as is done in electrolysis. All chemical actions would be due to the loss or gain of electrons. If, instead of being in a state of rapid motion, the electrons were in repose, they would precipitate themselves on each other, but the velocity by which they are animated causes their centrifugal force to balance their reciprocal attraction. When the speed of rotation is reduced from any cause whatever, such as a loss of kinetic energy due to the radiation of electrons into the ether, the attraction may gain the upper hand, and the electrons tend to unite; if it is, on the other hand, the centrifugal force which gains the day, they

[1] *Æther and Matter*, p. 337.—F. L.

escape into space, as is verified in radio-active phenomena.

The atom, and consequently matter, is therefore in stable equilibrium, thanks only to the movements of the elements which compose it. These elements may be compared to a top, which fights against gravity as long as the kinetic energy due to its rotation exceeds a certain value. If it falls below this value, the top loses its equilibrium and falls to the ground. But the movements of atomic elements are far more complicated than those which have just been supposed. Not only are they dependent on one another, but they are also connected with the ether by their lines of force, and in reality only seem to be nuclei of condensation in the ether.

Such is, in broad outline, the current state of the ideas in course of formation as to the constitution of the atoms of which matter is formed. These ideas can very well be reconciled with those I have endeavoured to establish in this work, according to which the atom is a colossal reservoir of energy condensed in the form already explained.

Whatever may be the future of these theories it may already be positively asserted that the ancient chemical atom, formerly considered so simple, is complicated in the extreme. It appears more and more as a sort of sidereal system having one or more suns and planets gravitating round it with immense velocity. From the structure of this system are derived the properties of the various atoms, but their fundamental elements seem to be identical.

§ 3. *Magnitude of the Elements of which Matter is Composed.*

The molecules of bodies, and *a fortiori*, the atoms, are extremely small. The most minute microbes are enormous colossi compared with the primitive elements of matter: yet various considerations have enabled their size to be estimated. They give figures which no longer appeal to the mind for the reason that infinitely small figures are as difficult to picture to oneself as infinitely large ones. But it is owing to the extreme smallness of the elements of which atoms are formed that matter in course of dissociation can emit in permanent fashion and without appreciably losing weight, a veritable cloud of particles.

I have spoken in a former chapter of the millions of corpuscles per second which one gramme of a radio-active body can emit for centuries. Such figures always provoke a certain amount of mistrust because we cannot succeed in representing to ourselves the extraordinary minuteness of the elements of matter. The mistrust disappears when one notes that very ordinary substances are capable, without undergoing any dissociation, of being for years the seat of an emission of abundant particles easily verified by the sense of smell, without this emission being discoverable by the most sensitive balances.

M. Berthelot has made on this subject some interesting researches.[1] He has endeavoured to determine the loss of weight undergone by very

[1] *Comptes Rendus de l'Académie des Sciences*, 21st May 1904.

odoriferous though slightly volatile bodies. The sense of smell is infinitely superior in sensitiveness to that of the balance, since in the case of certain substances such as iodoform, the presence, according to M. Berthelot, of the hundredth of a millionth of a milligramme can be easily revealed by it.

His researches have been made with this substance, and he has arrived at the conclusion that one gramme of iodoform only loses the hundredth of a milligramme of its weight in a year—that is to say, one milligramme in a hundred years, though continuously emitting a flood of odoriferous particles in all directions. M. Berthelot adds, that if, instead of iodoform, musk were used, the weight lost would be very much smaller, "a thousand times perhaps," which would make 100,000 years for the loss of one milligramme. The same scholar also remarks, in a later work, "that there is hardly any metallic or other body which does not manifest, especially on friction, odours of its own," which is simply saying that all bodies slowly evaporate.

These experiments give us an idea of the immensity of the number of particles which may be contained in an infinitesimal quantity of matter.[1]

[1] Various considerations earlier than the current theories long since led to the attribution of an extreme smallness to the molecules of bodies. It has been calculated that it required 600 to 700 millions of bacteria to make up the weight of 1 milligramme. Certain of these bacteria give birth in 24 hours to 16 million germs. Professor M'Kendrick points out that an organic germ necessarily contains an immense number of molecules since it must comprise the hereditary characteristics of a long line of ancestors. He mentions spores which are $\frac{1}{10000}$ of a millimètre in diameter, and there are probably some still less which we are unable to see, as the action of filtered solutions in which the microscope reveals nothing would tend to prove.

From various experiments, of which the most recent authors, Rutherford, Thomson, etc., have accepted the results, 1 cubic millimètre of hydrogen would contain 36,000 billions of molecules. These are figures the magnitude of which can only be understood by transforming them into units easy to interpret. An idea of their enormous magnitude will be obtained by finding out the dimensions of a reservoir capable of containing a similar number of cubic grains of sand having each a face or side of one millimètre. The above quantity of grains of sand could only be enclosed in a parallelepipedal reservoir with a base of 100 mètres on each of its faces and a height of 3,600 mètres. These last figures would have to be much increased if we wished to represent the quantity of particles which one cubic millimètre of hydrogen would yield on the dissociation of its atoms.

§ 4. *The Forces which maintain the Molecular Edifices.*

We have seen that matter is constituted by the union of very complicated structural elements termed molecules and atoms. We are compelled to suppose that these elements are not in contact; otherwise bodies could neither dilate, nor contract, nor change their state. We are likewise obliged to suppose that those particles are animated by permanent gyratory movements. The variation of these movements can alone explain, in fact, the absorption

According to Wismann, a blood corpuscle with a dimension of about $\frac{7}{1000}$ of a millimètre, would contain 3,625 millions of particles. The head of a spermatozoon, sufficient for the fecundation of an egg and with a diameter of $\frac{1}{25}$ of a millimètre, would contain 25,000 million "organic molecules," each composed of several atoms.

and the expenditure of energy which are noticed in the building up and the destruction of chemical compounds.

We ought, therefore, to picture to ourselves any body whatever, such as a block of steel or a rigid fragment of rock, as being composed of isolated elements in motion but never in contact. The atoms of which each molecule is formed themselves contain thousands of elements which describe round one or more centres, curves as regular as those of the celestial bodies.

What are the forces which keep together the particles of which matter is formed and prevent it from falling into dust? The existence of these forces is evident, but their nature remains totally unknown. The terms cohesion and affinity which are applied to them tell us nothing. Observation only reveals that the elements of matter exercise attraction and repulsion. We can, however, add to this brief statement that the atom being an enormous reservoir of forces, it may be supposed, as I have already remarked in another chapter, that cohesion and affinity are manifestations of intra-atomic energy.

The stability of the molecular edifices bound together by cohesion is generally fairly great. It is, however, not enough to prevent chemistry from modifying or destroying it by various means, notably by heat. That is why it is possible to liquefy bodies, to reduce them to vapour, and to decompose them. The stability of the atomic edifices, of which the molecules are formed, is, on the contrary, so great that it was deemed right to declare, after the experience of centuries, that the atom was unchangeable and indestructible.

The cohesion which keeps together the elements of bodies manifests itself by the mutual attraction and repulsion of the molecules; and the magnitude of the forces producing cohesion is measured by the effort we are compelled to make in order to change the form of a body. It resumes its primitive state when the action on it ceases, which fact proves the existence in the bosom of matter of forces of attraction. It resists the attempt to compress it, which demonstrates the existence of forces of repulsion when the molecules come within a certain distance of each other.

The attractions and repulsions by which cohesion is manifested are intense, but their radius of activity is extremely restricted. They cannot exercise any action at a distance, as does, for instance, gravitation. To nullify them we only require to separate the molecules of the bodies by heat. If the force of cohesion is abolished, the most rigid body is instantly transformed into liquid or vapour.

Outside the attractions and repulsions which operate between the particles of the same body, there are others produced between the particles of different bodies which vary according to their nature. We describe them under the general term of affinity; and it is they which determine the majority of chemical reactions.

The attractions and repulsions resulting from affinity engage the atoms in new combinations, or allow us to separate them from those combinations. Chemical reactions are only the destructions and restorations of equilibrium due to the affinities of the bodies present. One knows; by the effects of explosives, the power of the actions that affinity can produce when certain equilibria are disturbed.

It is from the manner in which the atoms are grouped by the energy of affinity that the molecular edifices result. They may be very unstable, and then the least stimulus, a shock or even the touch of a feather, suffice to destroy them. Such is the case with fulminate of mercury, iodide of nitrogen, and several other explosives. The edifice may, on the other hand, be so solid that it is destroyed with difficulty. Such are those organic salts of arsenic, like cacodylate of soda, wherein the molecule is so stable that no reagent can discover the quantity, enormous though it be, of atoms of arsenic which it contains. Aqua regia, fuming nitric acid, and chromic acid are without action on the molecular edifice; it is a strongly built fortress.

§ 5. *The Attractions and Repulsions of Isolated Material Molecules and the Forms of Equilibrium resulting from them.*

The energies of affinity and cohesion are therefore manifested by attractions and repulsions. We have already seen that it is by these two forms of movement—whether in the case of material or of electric particles—that phenomena generally manifest themselves. This is why the study of them has always held a preponderating place in science; and many physicists still reduce the phenomena of the universe to the study of the attractions and repulsions of molecules subjected to the laws of mechanics. "All terrestrial phenomena," said Laplace, "depend on molecular attractions, as celestial phenomena depend on universal gravitation." Nowadays, however, it seems probable that the affairs of nature are more complicated. If attractions and repulsions appear to play so great a part, it is because of all the effects which forces can produce, these movements are the most easily accessible to us.

The equilibria determined by the attractions and repulsions which are born in the bosom of solid bodies, are discernible with difficulty, but we can render them visible by isolating their particles. The method is easy, since it only consists in dissolving the solids in some suitable liquid. The molecules are then nearly as free as if the body were transformed into gas, and it is easy to observe the effects of their mutual attractions and repulsions. It is well known, moreover, that the molecules of a dissolved body move within the solvent and develop there the same pressure as if they were converted into gas in the same space.

Such attractions exercised by molecules in a free state are of daily observation. To them are due the forms taken by a drop of liquid when it clings to the extremity of a glass rod. They are the origin of what has been called the surface tension of liquids, a tension in virtue of which a surface behaves as if it were composed of a stretched membrane. All attractions and repulsions can act only at a certain distance. As is known, the name of field of force is given to the space in which they are exercised, and that of lines of force to the directions in which are produced the attracting and repelling effects.

It is in the phenomena called osmotic that molecular attractions and repulsions are most clearly shown. When water is gently poured into an aqueous solution of a salt such as sulphate of copper, we notice by the simple difference of colour that the liquids are at first separate, but we soon see the molecules of the dissolved salt diffuse themselves through the supervening liquid. There consequently exists in them a force which enables them to overcome the force of gravity. This force of diffusion is the consequence of the reciprocal attraction of the particles of water and of the dissolved salt. It has received the name of osmotic pressure or tension.

FIG. 28.[1]

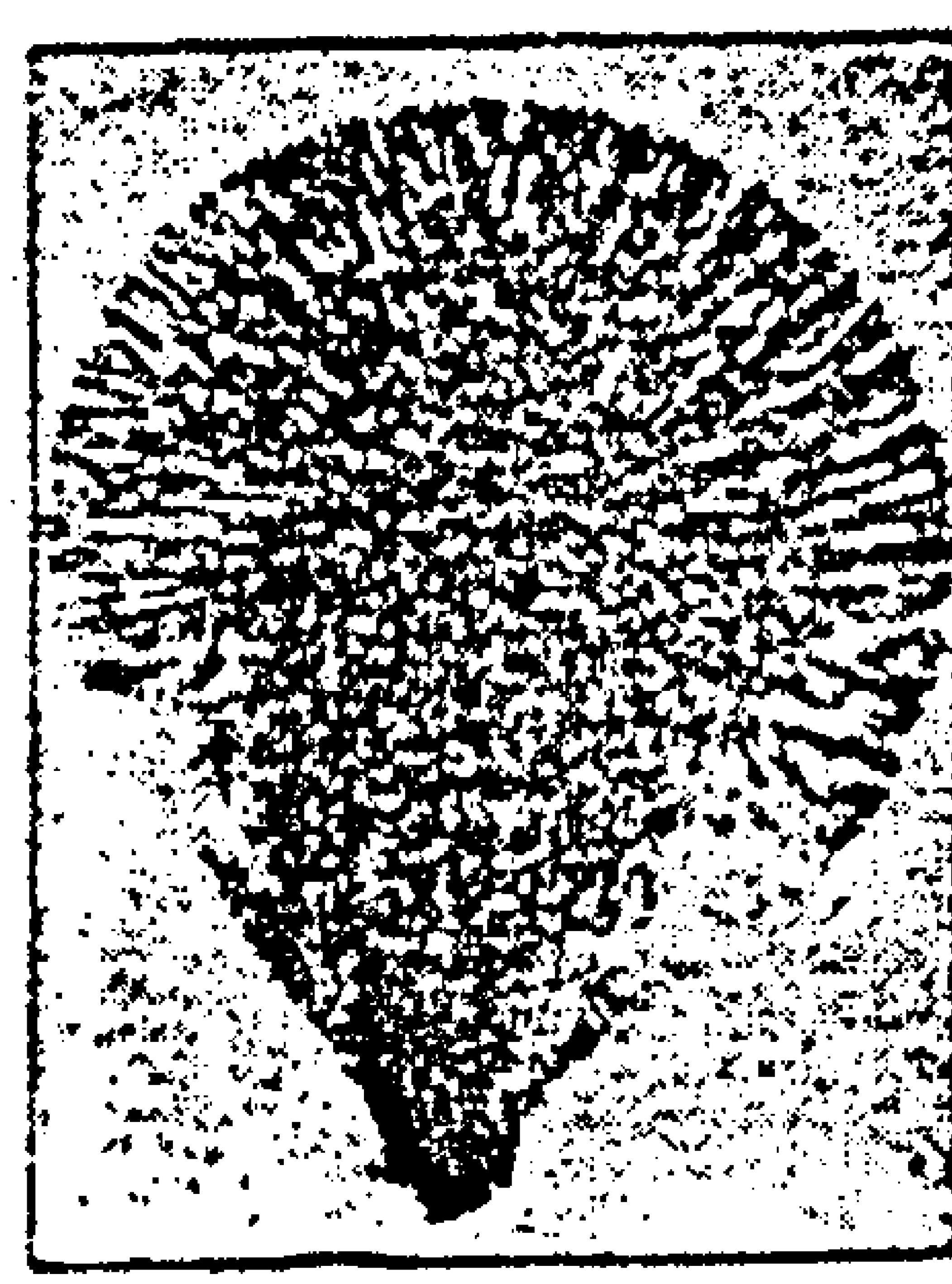

FIG. 29.

Repulsions and attractions of molecules in a liquid.

All substances which possess the property of dissolving in a liquid attract the solvent, and conversely are attracted by it. Lime placed in a vessel rapidly attracts the vapour of water in the atmosphere, and increases in volume to the extent of breaking the vessel.

Osmotic attractions are very energetic. In the cells of plants they can make equilibrium to pres-

[1] The photographs 28 to 32 were taken by Professor Stéphane Leduc.

sures of 160 atmospheres, and even more according to some authors. They are rarely less than ten atmospheres.

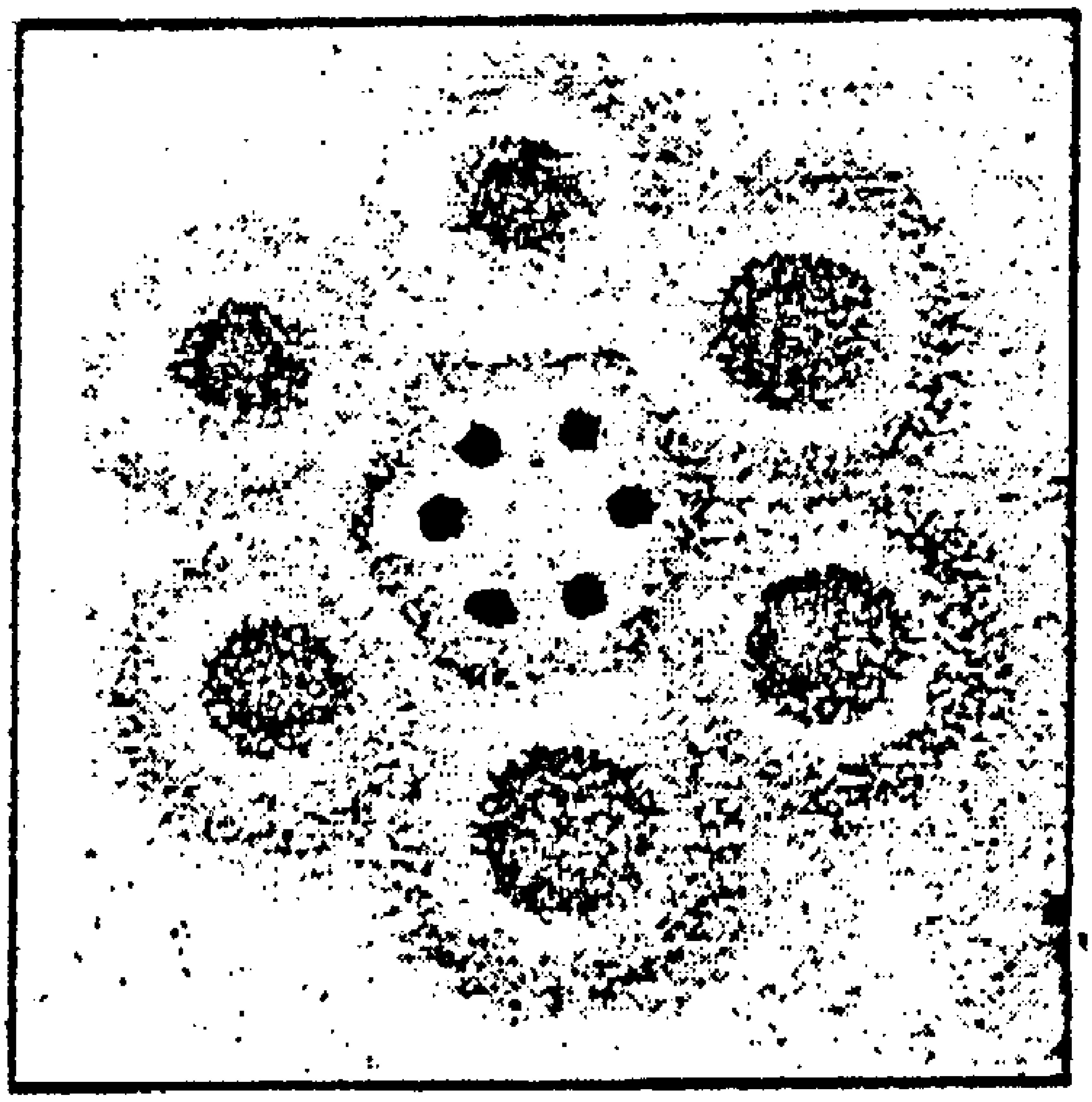

FIG. 30.

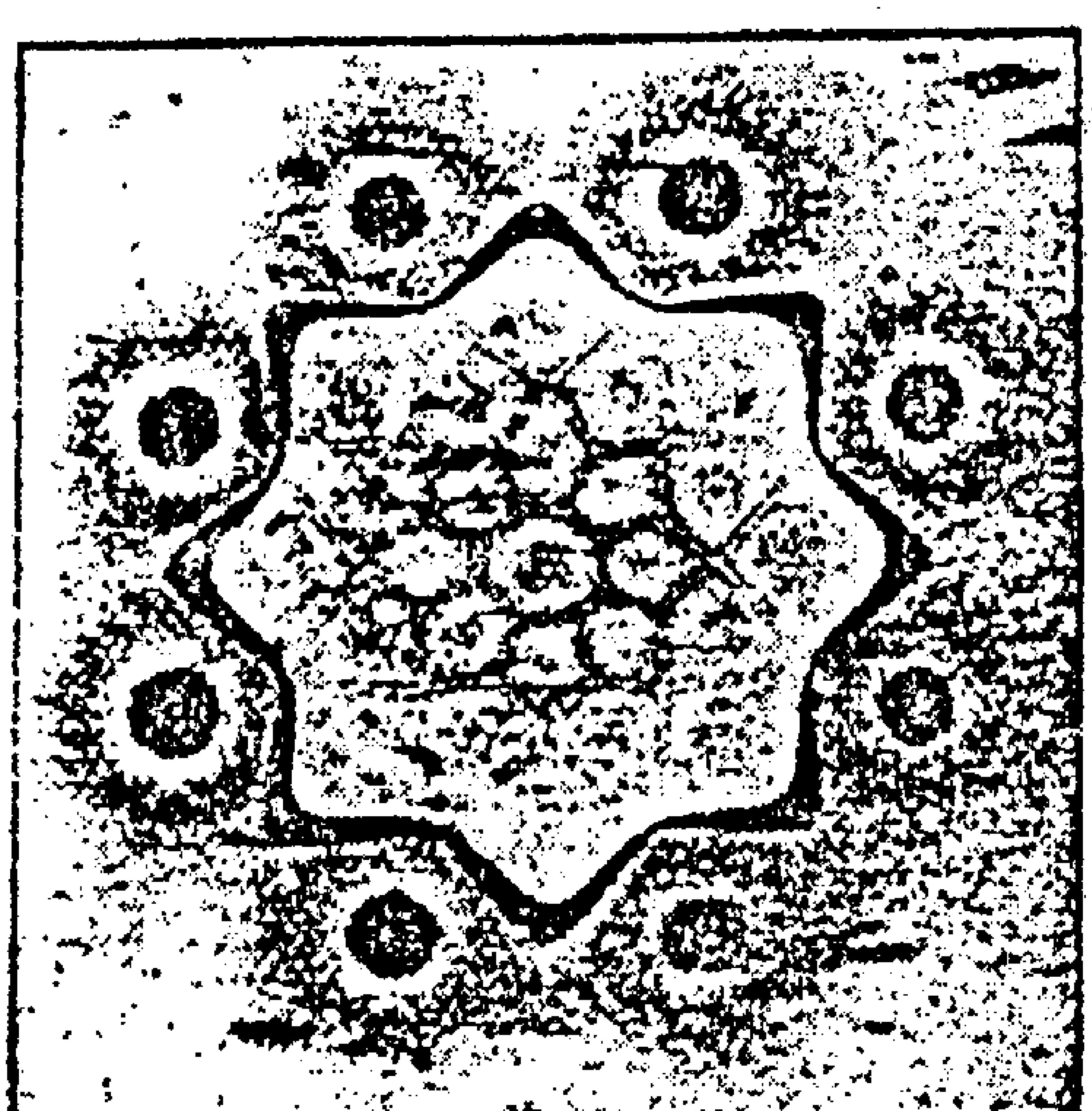

FIG. 31.

Photographs of artificial cells resulting from molecular attractions and repulsions in a liquid.

Although the magnitude of osmotic pressure is considerable, 342 grammes of sugar dissolved in a litre of water exercising a pressure of 22 atmospheres, this pressure does not manifest itself on the walls of the vessel, because the solvent opposes resistance to the movement of the molecules. To measure it, the substances present must be separated by a partition

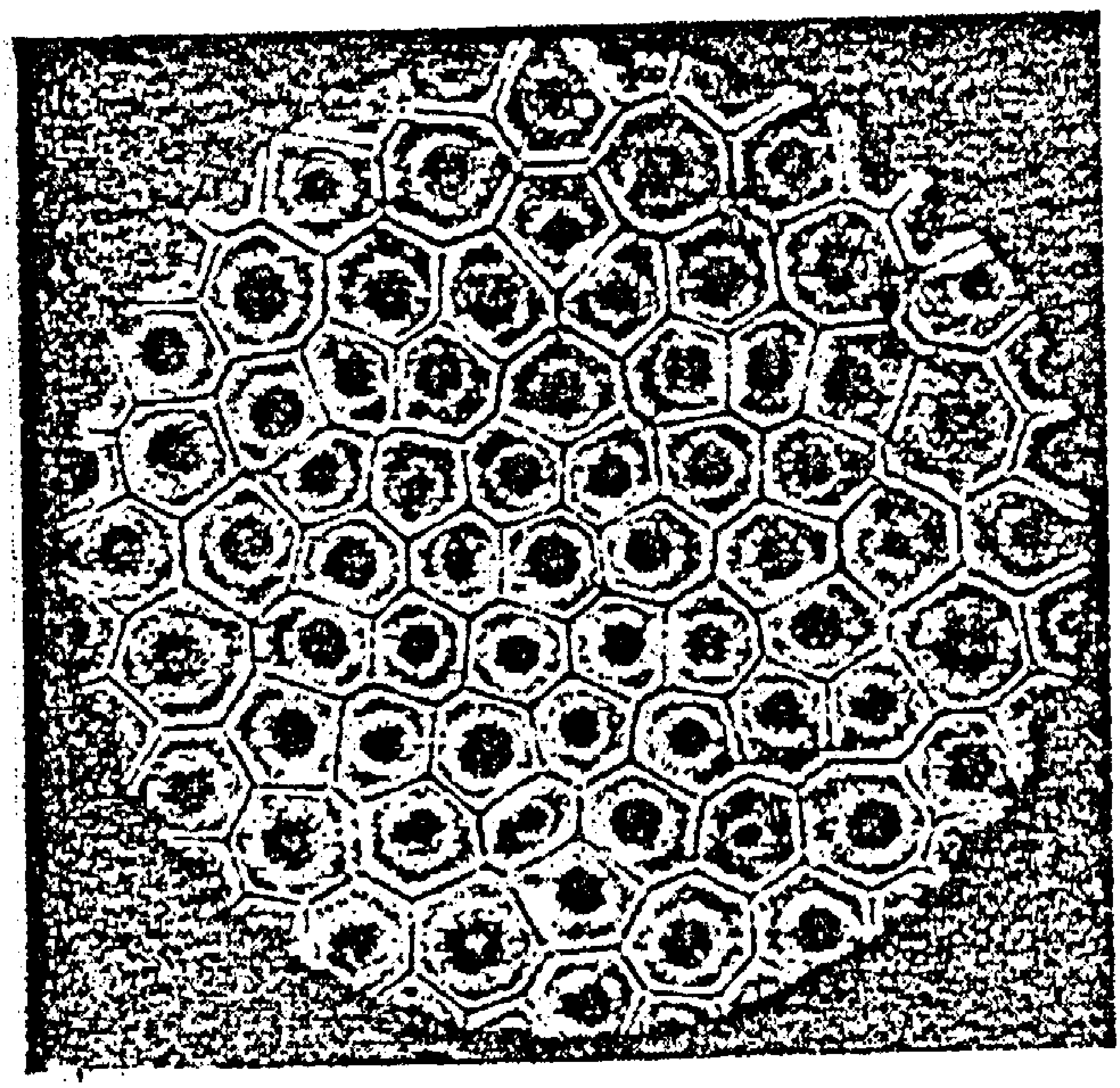

FIG. 32.—Photograph of artificial cells obtained by diffusion.

impermeable to one of them. Such partitions are called for this reason semi-permeable. It might be more correct, perhaps, to say unequally permeable. In the case of plant cells these partitions are formed by the walls of the cells.

In osmotic phenomena there are always produced two currents in a converse direction, called exosmose and endosmose, of which one may overcome the other. These simple molecular attractions and repulsions acting in the bosom of liquids govern a great number of vital phenomena, and are, perhaps, one of the most important causes of the formation of living beings. "Osmotic pressure," says Van't Hoff, "is a fundamental factor in the various vital functions of animals and vegetables. According to Vriès, it is this which regulates the growth of plants; and, according to Massart, it governs the life of pathogenic germs."

As the molecules existing in the midst of a liquid are able to attract or repel each other at a distance, they are necessarily surrounded by a field of force—that is, a region in which their action is exercised. By utilizing the attractions and repulsions of the free molecules in a liquid, M. Leduc has succeeded in creating geometrical forms quite analogous to those of the cells of living beings. According to the mixtures employed, he has been able to bring before us particles which attract and repel each other, like electric atoms. By spreading over a glass plate a solution of nitrate of potassium, on which are poured, at two centimètres from each other, two drops of Indian ink, two poles are obtained whose lines of force repel each other. To obtain two poles of contrary sign, whose lines of force, consequently, attract each other, a crystal of nitrate of potassium and a drop of defibrinated blood are placed at a distance of two centimètres from each other in a dilute solution of the salt mentioned above. By uniting several drops able to produce poles of the same sign, polyhedra are obtained with the appearance of the cells of living beings (Fig. 32). If, finally, a salt be crystallized in a colloidal solution—gelatine, for instance—the field of force of crystallization being able to act in the contrary direction to the osmotic attractions, the form of the crystal becomes altered. These researches cast a strong light on the origin of the fundamental phenomena of life.

The above ideas on the constitution of matter may be summed up as follows:—As soon as we lift the veil of appearances, matter, so inert in its outward aspect, is seen to possess an extremely complicated organization and an intense life. Its primary element, the atom, is a miniature solar system composed of particles revolving round one another without touching and incessantly pursuing their eternal course under the influence of the forces which direct them. Were these forces to cease for a single minute, the world and all its inhabitants would be instantly reduced to an invisible dust.

On these prodigiously complicated equilibria of intra-atomic life are superposed, by reason of the association of atoms, other equilibria which complicate them further. Mysterious laws known solely by some of their effects, intervene to build with the atoms, the material edifices of which worlds are formed. Relatively very simple throughout the mineral kingdom, these edifices gradually become complicated, as we shall now show, and have finally, after the slow accumulations of ages, generated those extremely mobile chemical associations which constitute living beings.

CHAPTER II.

MOBILITY AND SENSIBILITY OF MATTER.—VARIATIONS OF THE EQUILIBRIA OF MATTER UNDER THE INFLUENCE OF THE SURROUNDINGS.

§ 1. *Mobility and Sensibility of Matter.*

WE have now arrived at that phase of the history of atoms where, under the influence of unknown causes of which we can only note the effects, the atoms have finally formed the different compounds which constitute our globe and the living beings upon it. Matter is born and will persist for a long succession of ages.

It persists with different characteristics of which the most distinctly apparent is the stability of its elements. They serve to construct the chemical edifices of which the form readily varies but of which the mass remains practically invariable throughout all changes. These chemical edifices formed by atomic combinations, appear to be firmly fixed, but are, in reality, of very great mobility. The least variations of the medium—temperature, pressure, etc.—instantaneously modify the movements of the component elements of matter.

The fact is, that a body as rigid in appearance as a block of steel, represents simply a state of equilibrium between its own internal energy and the external energies, heat, pressure, etc., which surround it. Matter yields to the influence of these last as an elastic thread obeys the pull exercised upon it, but regains its form—if the pull has not been too great—as soon as it ceases.

The mobility of the elements of matter is one of its most easily observed characteristics, since it suffices to bring the hand near the bulb of a thermometer to see the column of liquid immediately displaced. Its molecules consequently are separated by the influence of slight heat. When we place our hand near a block of metal, the movement of its molecules are likewise modified, but so slightly that it is not perceptible to our senses, and this is why matter appears to us to possess but little mobility.

The general belief in its stability seems to be confirmed, moreover, by observing that in order to subject a body to considerable modifications, to melt it or change it into vapour, for instance, very powerful means are required. Sufficiently exact methods of investigation show, on the contrary, that not only is matter of an extreme mobility, but is further endowed with an unconscious sensibility which cannot be approached by the conscious sensibility of any living being.

It is known that physiologists measure the sensibility of a being by the degree of excitement necessary to produce in it a reaction. It is considered very sensitive when it reacts under very slight excitants. Applying to mere matter a similar means of procedure, we note that the substance most rigid and least sensitive in appearance is, on the contrary, of an unexpected sensibility. The matter of the bolometer, reduced by final analysis to a thin platinum wire, is so sensitive that it reacts—by a variation of electric conductivity—when struck by a ray of light of such feeble intensity as to produce a rise in temperature of only the hundred millionth of a degree.

With recent progress in the means of examination this extreme sensitiveness of nature becomes more and more manifest. Mr. H. Steele has found that it is sufficient to touch an iron wire slightly with the finger for it to become immediately the seat of an electric current. It is known that hundreds of miles away the Hertzian waves greatly modify the state of the metals with which they come in contact, since they change in enormous proportion their electric conductivity. It is on this phenomenon that wireless telegraphy is based.

The extraordinary sensibility of matter which has enabled the bolometer to be created and wireless telegraphy to be discovered, is utilized in other instruments employed in industry; such as, for instance, the telegraphone of Poulsen, which enables spoken words to be preserved and reproduced by the changes of magnetism brought about in the surface of a steel band moving between the poles of an electro-magnet to which a microphone is attached. When you speak into the membrane of this last, the minute fluctuations of the current in the microphonic circuit cause variations of magnetism in the molecules of the steel ribbon of which the metal retains the trace. These variations permit us to reproduce the speech at will by passing the same band between the poles of an electro-magnet put in circuit with a telephone.

This sensibility of matter, so contrary to what