

popular observation seems to indicate, is becoming more and more familiar to physicists. This is why such an expression as "the life of matter," utterly meaningless twenty-five years ago, has come into common use. The study of mere matter yields ever-increasing proofs that it has properties which were formerly deemed the exclusive appanage of living beings. By taking as a basis this fact "that the most general and most delicate sign in life is the electric response," Mr. Bose has proved that this electric response "considered generally as the effect of an unknown vital force" exists in matter. And he shows by ingenious experiments "the fatigue" of metals and its disappearance after rest, and the action on these same metals of excitants, of depressants, and of poisons.

We must not be too much astonished at finding in matter properties which once seemed to belong solely to living beings, and it would be useless to seek therein a too simple explanation of the still impenetrable mystery of life. The analogies discovered are, it is likely, due to the fact that nature does not greatly vary her procedure and constructs all beings, from mineral to man, with similar materials, whence they are endowed with common properties. It always applies the fundamental principle of least action, which would suffice by itself to establish the fundamental equations of mechanics. It consists, as we know, in the enunciation, so simple and of such deep import, that of all roads which lead from one situation to another, a material molecule under the influence of a force can take but one direction, namely, the one which demands the least effort. It will probably be seen one day that this

principle is not only applicable to mechanics but also to biology. It is perhaps also the secret cause of the laws of continuity observed in many phenomena.

§ 2. *Variation of the Equilibria of Matter under the Influence of the Medium.*

Matter is, then, like all beings, strictly dependent on the medium in which it finds itself, and is modified by the slightest changes in this medium. So long as these changes do not exceed certain limits, the velocity and amplitude of the movements of the material molecules are modified without any change in their relative position. If these limits are exceeded, the equilibria of matter are destroyed or transformed. The majority of chemical reactions show us such transformations.

But in every way matter is so mobile and so sensitive that the most insignificant changes in the medium—for instance, a rise or fall in temperature of the millionth of a degree—produce modifications which our instruments allow us to note.

Matter, as we know it, only represents, as I have before said, a state of equilibrium, a relation between the internal forces it contains and the external forces which act upon them. The last cannot be modified without a similar change in the first, as one pan of a balance cannot be touched without causing the other to oscillate. It may therefore be said, in mathematical language, that the properties of matter are a function of several variable factors, especially temperature and pressure.

These various influences are capable of acting

separately, but they may also act in combination. Thus there exists a temperature—variable for each body—called critical, above which no body can exist in a liquid state. It then immediately becomes gaseous and remains so whatever pressure may be brought to bear on it. If water is heated in a closed tube, a time arrives when, suddenly, it transforms itself entirely into a gas so invisible that the tube seems totally empty. For a long time many gases could not be liquefied,<sup>1</sup> precisely because it was not known that the action of pressure was null if the gas had not been first lowered below its critical point. Carbonic acid is very easily liquefied by pressure at a temperature below  $31^{\circ}$  C. Above that temperature no pressure can bring it to a liquid state.

Matter must therefore be considered as a most mobile thing, very unstable in equilibrium, and impossible to be conceived of apart from its surroundings. It possesses no independent property beyond its inertia, from which it derives the constancy of its mass. This property is absolutely the only one which no change of surroundings, pressure, temperature, etc., can alter. Take away from matter its inertia, and one does not see how it is possible to define so changeable a thing.

Notwithstanding the extreme mobility of matter, the world, however, seems very stable. It is so, in fact, but simply because, in its present state of evolution, the medium in which it is wrapped varies within rather narrow limits. The apparent constancy of the properties of matter results solely

<sup>1</sup> Since the experiments of Sir James Dewar, even the lightest of gases, hydrogen, has been liquefied by the combined effect of intense cold and pressure. Only helium now resists.—F. L.

from the present constancy of the medium in which it is plunged.

This notion of the influence of the medium, rather neglected by the old chemists, has finally acquired great importance, since it has been proved that many reactions depend upon it, and vary in very different directions, according to the alterations, sometimes very slight, of temperature or of pressure. When the differences are considerable, many reactions are found to be entirely transformed, or to become impossible. If one could only examine substances at certain temperatures, one would consider them very different from the same substances observed at ordinary temperatures. At the temperature of liquid air, phosphorus loses its violent affinity for oxygen, and is without action upon it; sulphuric acid, which generally acts so markedly on litmus paper, no longer turns it red. At a high temperature we see, on the other hand, new affinities non-existent at ordinary temperatures come to light. Nitrogen and carbon, which combine with no other bodies at a low temperature, easily combine with several at 3000 degrees, and form bodies hitherto unknown—carbide of calcium, for example. Oxygen, which generally has no action on the diamond, acquires so energetic an affinity for this body at a high temperature that it combines with it and becomes incandescent. Magnesium has a rather mild affinity for oxygen, but at a sufficiently high temperature its affinity for it reaches such a point that, when plunged into an atmosphere of carbonic acid, it decomposes it, seizes upon its oxygen and burns continuously when lighted.

Thus, then, the elements of matter are in in-

cessant motion: a block of lead, a rock, a chain of mountains have but an apparent immobility. They are subject to all the variations of the medium and are constantly modifying their equilibria to correspond to it. Nature knows no rest. If repose exists anywhere, it is neither in the world we inhabit nor in the beings on its surface; nor is it even existent in death, which only substitutes for certain momentary equilibria of atoms other equilibria whose duration will be as ephemeral.

## CHAPTER III.

### THE VARIOUS ASPECTS OF MATTER.—GASEOUS, LIQUID, SOLID, AND CRYSTALLINE STATES.

#### § 1. *The Gaseous, Liquid, and Solid States.*

ACCORDING to the external forces to which it is subjected, matter assumes three states, which have been called the solid, liquid, and gaseous. Yet the most recent researches have clearly proved that there exists no wide separation between them. The continuity of the liquid and gaseous states has been put in evidence by the researches of Van der Waals, and the continuity of the liquid and solid states by different other experimenters. Under sufficient pressure, solids behave like liquids, their molecules slide one over the other, and a solid metal at length flows like a liquid. "The laws of hydrostatics and hydrodynamics," says Spring, "are applicable to solids subjected to strong pressures." This property of the hardest bodies of behaving like liquids under certain pressures has been utilized commercially in America for the manufacture of tools from blocks of steel subjected to sufficient pressure without the need of raising the temperature. Yet this metal may be regarded as the type of substances hardly malleable.

The crystalline state itself cannot establish a very clear separation between the solid and liquid states. There exist, as Lehmann has shown, semi-liquid crystals, and I myself have found a means of

preparing crystals of a pasty consistency.<sup>1</sup> We have seen above that liquids, while remaining liquids, can assume geometrical forms akin to the crystalline state, and certain optical processes allow us to reveal their existence.

In a general way, however, the crystalline state constitutes, as we shall see, a very peculiar stage of matter which gives it an individuality of its own, and approaches, from some points of view, that of living beings.

### § 2. *The Crystalline State of Matter—Life of Crystals.*

Among the unknown forces of which we only perceive the existence by a few of their effects, are found those which compel the molecules of bodies to take strictly geometrical forms bearing the name of crystals. All solid bodies have a tendency towards the crystalline form.<sup>2</sup> The geometrical equilibria from which these forms result, give a kind of individuality to the molecules of matter. Matter individualizes them in the same sense that the living being does—by incorporating the elements borrowed from the medium with itself.

There is nothing out of the way in this expression—the individualization of matter—when applied to its transformation into geometrical bodies. The mineral

<sup>1</sup> Simply by holding a strip of magnesium with a long pair of tongs for some minutes in boiling mercury. On cooling, the mixture assumes the form of crystalline flakes, the crystals of which have the consistency of butter, and consequently lose their shape under the pressure of the finger.

<sup>2</sup> Professor Quincke, of Heidelberg, has lately shown that all substances, on passing from the liquid to the solid state, assume what he calls a "foam structure," or become a network of cells which may enclose crystals. *Proc. Roy. Soc.*, 21st July 1906.—F. L.

being is characterized by its crystalline form as the living being is characterized by its anatomical one. The crystal also undergoes, like the animal or the plant, a progressive evolution before attaining its final form. Again, like the animal or the plant, the mutilated crystal can repair its mutilation. The crystal is in reality the final stage of a particular form of life.

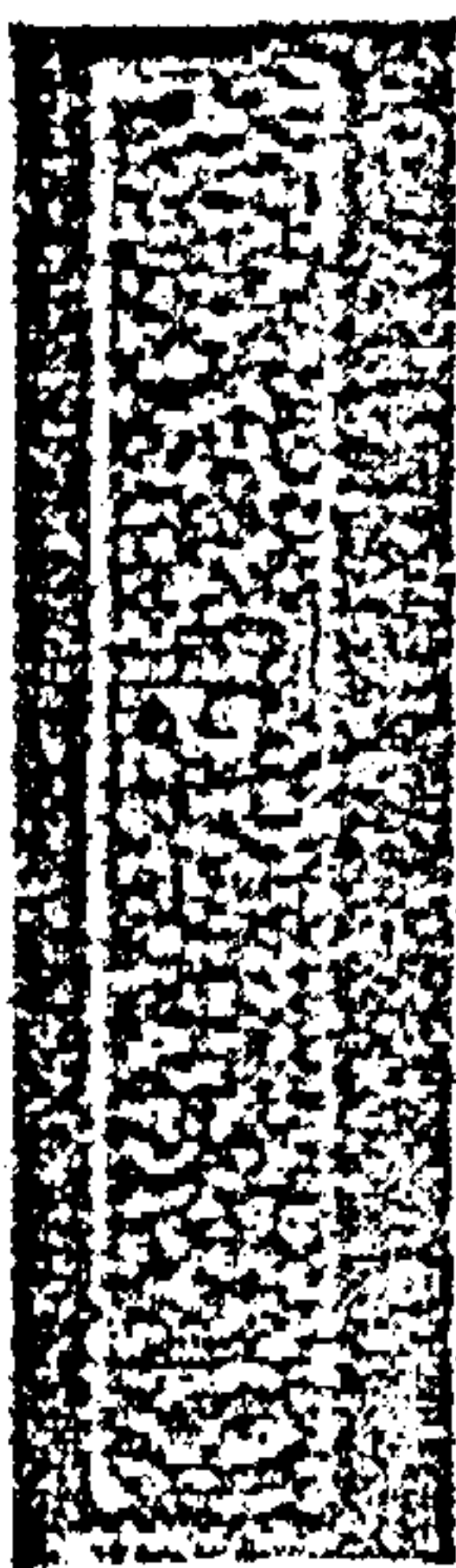


FIG. 33.

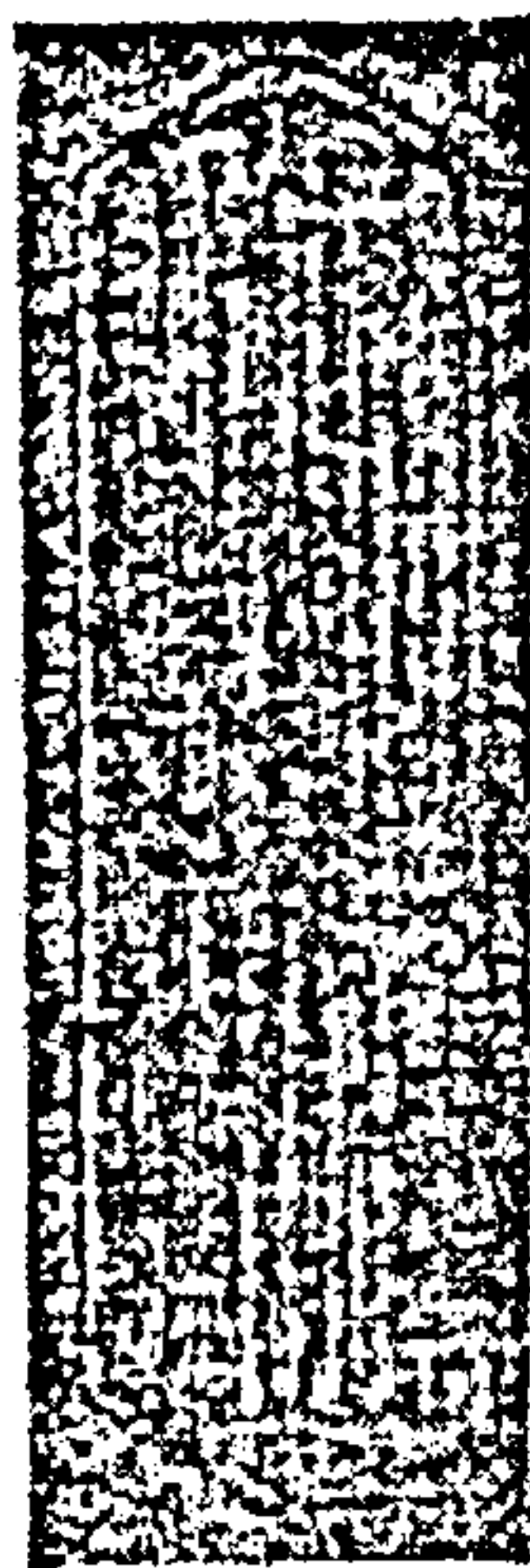


FIG. 34.

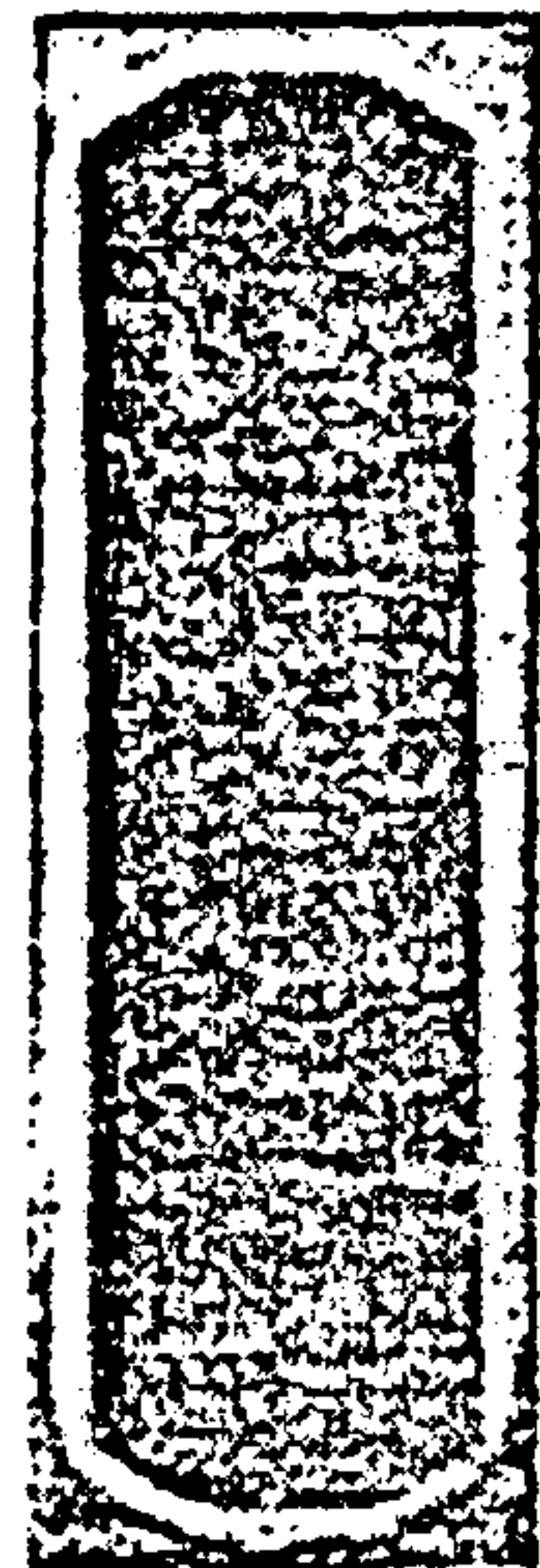


FIG. 35.

The three phases of the successive formation of a crystal.  
(From the photographs of Professor Schrön.)

Among the facts which may serve as supports to these considerations, must be especially quoted the beautiful experiments of Professor Schrön on the successive transformations which cause material molecules to assume the crystalline form. The three principal ones are—1st, a granular phase; 2nd, a fibrous phase; 3rd, a homogeneous phase. They are represented by the three photographs here reproduced, which I owe to the courtesy of the scholar in ques-



tion. In a solution about to crystallize are first formed globules, in the heart of which granulations soon appear (Fig. 33). These granulations elongate and take a fibrous aspect (Fig. 34), to which later on succeeds the homogeneous state (Fig. 35), which constitutes the definitive form of the crystal. The crystal being has then terminated its cycle.

These laws of the formation of crystals are general, and can be observed in the crystals of mineral substances as well as in those which, according to Schrön, accompany micro-organisms. Among the secretions of every microbe there always appear, according to him, crystals characteristic of every species of microbe.

These observations show that during its pre-crystalline period—that is to say, its infancy, the future crystal behaves like a living being. It represents tissue in course of evolution. It is an organized being undergoing a series of transformation of which the final stage is the crystalline form, as the oak is the final stage of the evolution of the acorn. The crystal would therefore seem to be the last phase of certain equilibria of matter unable to rise to the forms of higher life.

Researches carried out in different directions confirm the above conclusions. Thus M. Cartaud has found that metals, polished and then attacked by picric acid dissolved in acetone, exhibit “a completely closed and microscopic network of cells.” “Cells and crystals show,” he says, “an evident affiliation. Pebbles with the same crystalline orientations have the characteristic of possessing a cellular web of specific form and disposition, which permits a crystal to be regarded as an aggregate of

similar cells arranged in the same way.”<sup>1</sup> Cellular structure would therefore seem to be an embryonic phase, and crystalline structure an adult phase.

Far from being an exceptional state, the crystalline form is, in reality, the one to which all forms tend, and which they attain so soon as certain conditions of the medium are realized. Salts dissolved in an evaporating solution, and a melted metal when cooled, always tend to assume the crystalline form; and if we consider, as we do nowadays, that solutions show close analogies with gases, it may be said that the two most usual forms of nature are the gaseous and the crystalline.

There is hardly in nature anything but the crystal which possesses a truly stable and definite form. An ordinary living being is, on the other hand, something extremely mobile, always changing, and only continuing to live on the condition that it dies and is re-born unceasingly. Its form only appears definite because our senses can only perceive fragments of things. The eye is not made to see everything. It picks out of the ocean of forms that which is accessible to it, and believes this artificial limit to be the real limit. What we know of a living being is only a part of its real form. It is surrounded by the vapours it exhales, by radiations of great wave length, which it is constantly emitting by reason of its temperature. Could our eyes see everything, a living being would appear to us as a cloud with changing contours.<sup>2</sup>

<sup>1</sup> Cf. note on page 257 *sup.*—F. L.

<sup>2</sup> Our eyes are not sensitive to the infra-red radiations which living beings are unceasingly giving out, but let us imagine a being whose eyes—as may be the case perhaps with nocturnal animals—are organized so as to be able to perceive only radiations of great wave length

Whence comes the crystal which appears in a solution? What is the starting point of the transformations undergone by the molecules of this solution before becoming a crystal? Observation shows that all living beings from bacteria up to man, always proceed from an earlier being. Can it be the same with a crystal? Is it also derived by affiliation from an earlier being, or is it born spontaneously?

It seems now well proved, especially since the researches of Ostwald, that with crystals both these modes of generation exist. In certain fixed conditions of the medium—that is to say, of pressure, concentration of solutions, etc., liquids can only crystallize if they have first received a crystalline germ. The crystals thus formed may then, according to the expression of Dastre in his great work *La Vie et la Mort*, be considered as the posterity of an earlier crystal, absolutely in the same way that the bacteria developed in a solution represent the posterity of the bacteria originally introduced therein.

There exist, however, other conditions of the medium in which spontaneous crystallization may be observed without any previous introduction of germs. These different conditions being known and being producible at will, a solution may be placed either in conditions allowing it to crystallize spontaneously or in such that it will only crystallize after the introduction of suitable germs. It may therefore

and not those of the rest of the spectrum which are to us light. To a being thus organized, an animal would appear in the shape of a mist with indistinct outlines which would be rendered visible by the reflection of the infra-red radiations on the water vapour surrounding it.

be said that crystals present two very distinct modes of reproduction—spontaneous generation and generation by affiliation.

This faculty of spontaneous generation, possible to the crystal being, is, as is well known, impossible to the living being. The latter is only produced by affiliation, and never spontaneously. However, it must be admitted that before being born by affiliation, the original cells of the geological periods must have been born without parents. We are ignorant of the conditions which permitted matter to organize itself spontaneously for the first time, but nothing indicates that we shall always be thus ignorant.

We therefore see the notion accentuating that the crystal forms a being intermediate between brute and living matter, and placed nearer to the latter than to the former. It possesses in common with living beings the qualities above mentioned, and in particular something singularly resembling ancestral life. The crystalline germs we introduce into a solution in order to crystallize it seem to hint at a whole series of earlier lives. They recall the germs of living beings—that is to say, the spermatozoa which comprise the sum of the successive forms of the life of a race, and contain, notwithstanding their insignificant size, all the details of the successive transformations which the living being exhibits before arriving at the adult stage.

All the facts of this order belong to the category of unexplained phenomena of which nature is full, and which become more numerous as soon as we penetrate into unexplored regions. The complexity of things seems to increase the more they are studied.

## CHAPTER IV.

### THE UNITY OF THE COMPOSITION OF SIMPLE BODIES.

#### § I. *Are the different Simple Bodies compounded from one Element?*

WHEN we submit the various compounds existing in nature to certain chemical operations, we succeed in separating them into elements which no reaction can further decompose. These irreducible elements are termed simple bodies, or chemical elements. From their combinations are formed our globe and the beings which inhabit it.

The idea that all bodies supposed to be simple must be derived from one single element in different states of condensation or combination, comes so naturally to the mind that it was put forth directly chemistry was established. After having been abandoned for want of proof, it was reborn when the recent experiments on the dissociation of matter seemed to show that the products resulting from the dissociation of the various bodies are formed of the same elements.

Facts known at an early date already indicated that the atoms of the most dissimilar bodies possessed certain properties in common. The most important of these are the identity of the specific heat and of the electric charge when, instead of with like weights

of matter, we work with quantities proportional to the atomic weights.

Every one knows that the specific heat of bodies—that is to say, the quantity of heat, expressed in calories, which has to be communicated to them in order to raise their temperature the same number of degrees—varies with different bodies. It is thus that, with the amount of heat necessary to raise a kilogramme of water by  $3^{\circ}$ , the temperature of a kilogramme of mercury can be raised by  $97^{\circ}$ . But if, instead of comparing equal weights of the different substances, weights proportional to their atomic weight are compared, it is noted that all bodies experience the same amount of heating from the same amount of heat, while electrolysis also proves that they carry an electric charge identical for the same atomic weight. To these facts, long known, are added those resulting from the recent researches here described, which show that, by the dissociation of matter, the like products are obtained from the most different bodies. It may therefore be admitted as extremely likely that all bodies are formed of one and the same element.

But even were the demonstration of this unity of composition complete, it would only offer a slight practical interest. By chemical analysis the same elements are discovered in a painting by Rembrandt as in a public-house signboard, and it is likewise proved that the body of a dog and that of a man have the same composition. Such observations as these give us absolutely no knowledge of the structure of the bodies thus analysed. So far as atoms are concerned, what we desire to discover is the architectural laws which have enabled completely different

edifices to be created with similar materials. Nothing is more probable than the fact that the atoms of chlorine, of zinc, and of the diamond are composed of one element. But how can this element give the elements of the various substances such different properties? Of this we are so completely ignorant that we are unable even to formulate any hypothesis on the subject.

Whatever may be the nature of the equilibria existing in the elements of the atoms of the various simple bodies, it is certain that these equilibria possess, in spite of their mobility, a very great stability, since, after the most violent chemical reactions, the simple bodies are always again found unaltered. None of the transformations to which a given quantity of any element may be subjected modify either its nature or its weight. It is for this very reason that atoms have hitherto been considered indestructible.

This apparent indestructibility has always given great force to the belief in the invariability of chemical species. We shall see, however, that by looking a little closer into things, this argument loses much of its value; for, without invoking the phenomenon of the dissociation of matter, we shall prove that the same bodies may really undergo very thorough transformations of their properties, which sometimes even suggest actual transmutations.

## § 2. *Can Simple Bodies be considered as Elements of an Unvarying Fixity?*

At the beginnings of chemistry the methods of analysis somewhat lacked refinement and the pro-

cesses of physical investigation, such as spectroscopy, were unknown. It was therefore impossible to separate, and consequently to acquire, a knowledge of any bodies save those with well defined properties. These bodies were too visibly different to be possibly confused. It was thus that arose the doctrine, analogous to that then admitted in biology, that chemical species were, like the species of living beings, invariable. Yet, after half a century of patient observation, biologists have finally abandoned the idea of the invariability of species, while chemists still defend it.

The facts discovered have shown, however, that there exist between chemical species as between living species, transitions which cannot be disputed. It has had to be recognized that a good number of simple bodies by no means present clearly defined properties which allow them to be easily differentiated. There are many, on the contrary, so near to each other—that is to say, possessing qualities so much alike—that no chemical reaction can distinguish them; and it was for this very reason that they were so long unknown. Almost a quarter of the simple bodies known—that is to say, about fifteen, so resemble each other in their chemical characteristics that without the employment of certain methods of physical investigation (spectrum rays, electrical conductivity, specific heat, etc.) they could never have been isolated. These bodies are those metals the oxides of which form what are termed the “rare earths.” “They are only distinguished,” say MM. Wyruboff and Verneuil, “with but two or three exceptions, by their physical properties and are chemically identical. So much is this the case



that no reaction has yet been found to separate them, and one is reduced, in order to obtain them in a more or less pure state, to the empirical and rude process of fractionation."

Other recently discovered facts show that the most marked chemical species, such as ordinary metals, present numerous varieties. There exists, probably, round each element, a whole series of varieties with common characteristics, which possess, however, properties sufficiently *sui generis* for them to be distinguished; as is observed in living species. Silver, as we shall presently see, is not one single metal. There exist at least five or six kinds of silver, constituting very different simple bodies. It is the same with iron and, probably, with all the other metals.

The earlier chemistry carefully noted the existence of bodies seemingly identical in nature though differing in properties. It termed "allotropic" these different states of a same body. If it did not class them, as independent simple bodies, it was because by means of various reagents they could always be brought back to a common state. Red phosphorus differs entirely from white, and the diamond differs, no less from carbon; but either white phosphorus or red can give the same compound—namely, phosphoric acid. With either coal or the diamond the same compound can also be made—namely, carbonic acid.

Without these common properties we should never have dreamed of classing together bodies so widely dissimilar as the coal and the diamond, or white and red phosphorus. White phosphorus is one of the bodies most greedy for oxygen and red phosphorus one of the least so. White phos-

phorus melts at  $44^{\circ}$  C., while red will not melt at any temperature and turns into vapour without passing through the liquid state. The first is one of the most poisonous bodies known, while the second is one of the most innocuous. Equally marked differences exist between the coal and the diamond. It is the same with certain metals which may occur in greatly differing forms. M. Coste has shown that selenium slowly cooled is a good conductor of electricity, for which reason he has given it the name of metallic selenium. Ordinary vitreous selenium obtained by rapid cooling, is, on the contrary, an insulator, and consequently no longer possesses the properties of a metal.

So long as the allotropic state was only observed in a very small number of bodies it was possible to look upon them as exceptions, but more sensitive methods of investigation have proved that what was considered exceptional constitutes, on the contrary, a very general law. The learned astronomer, Deslandres, supposes that the great differences observable in the spectrum of many bodies—carbon and nitrogen, for instance—according to the temperature at which they occur, are due to the allotropic states of these bodies.<sup>1</sup>

Without the need of invoking the hints supplied by spectrum analysis, it is easy to note that the commonest and most distinguishable bodies, such as iron and silver, display many different allotropic states which allow us to class them as different species of the same genus. There are already half a dozen different kinds of iron and silver known which have clearly defined character-

<sup>1</sup> *Comptes rendus de l'Académie des Sciences*, 14th September 1903.

istics, although they possess certain reactions in common which formerly led to their being confused. It is probable that with new methods of observation the number of these species will be greatly increased. Recent researches on colloidal metals, which we shall refer to in another chapter, even show that certain species of metals are capable of being so modified as to lose all the properties of the metal from which they are derived and to resemble organic substances rather than metals.

But without even glancing at these extreme cases of colloidal metals, and only taking the most ordinary bodies, prepared by the absolutely classic methods, it has to be acknowledged, as we shall see, that the same metal can present itself in forms impossible to be confused.

It is known that the heat absorbed or disengaged by the various simple bodies, in their combinations, is a constant quantity, represented by exact figures, and that it constitutes one of their essential characteristics. These figures, formerly considered invariable for each body, have served to found a special science—to wit, thermo-chemistry.

As soon as the allotropic forms of metals became known, these figures were taken in hand and it had to be acknowledged that, according to the mode of preparation of the metal, they might be twenty times higher or lower than the figures found for the same bodies when prepared by different methods. It therefore cannot be said, for a great number of the figures published up to now, that they are even roughly approximate. It was Berthelot himself, one of the founders of thermo-chemistry, who con-

tributed to the verification of this fact.<sup>1</sup> It is very probable that had he done so thirty years earlier, thermo-chemistry would never have been born.

From the standpoint taken by me as to the variability of chemical species, these results are of the greatest interest. From the standpoint of the ideas hitherto dominant on which thermo-chemistry was founded, they are plainly disastrous. M. Berthelot urges this by the following considerations:—

“Such inequalities of energy as these being thus established by experiment, it is clear that there cannot be accorded with certitude to ordinary metals, nor, more generally, to elements; in the discussion of their reactions, the thermo-chemical values obtained by starting from different states.

“The states of silver that I have studied do not, with one exception, answer to the figures of +7 cal. for the heat of formation of the oxide  $\text{Ag}^2\text{O}$ , which is given in thermo-chemical treatises.

“In the case of silver the thermo-chemical difference of the states of this element may rise, for one atom of silver, to 2 calories, which makes, for the formation of oxide, with 2 atoms of silver ( $\text{Ag O}$ ), a difference of +4 calories.”

The figures given in the books would then be, in

<sup>1</sup> Here, moreover, are the figures obtained for silver by M. Berthelot, according to the kind of metal employed (see the *Comptes rendus*, 4th February 1901). These figures represent the heat of the solution of an equal weight of substance in mercury:—

1st, Silver in thin leaves: +2.03 cal.

2nd, Silver produced by the transformation of the above metal heated for 20 hours at 500-550° C. in a current of oxygen: +.47 cal.

3rd, Silver crystallized in needles, obtained by electrolysis from nitrate of silver dissolved in 10 parts of water: +.10 cal.

4th, Silver precipitated from its nitrate by copper; washed and dried partly at the normal temperature: +1.10 cal.

5th, The above silver dried at 120° C.: +.76 cal.

6th, The above silver heated to a dark red: +.08 cal.

the above case, wrong by nearly fifty per cent. The same author then asks himself whether it might not be the same with iron, of which so many allotropic forms occur. The observation is probably applicable, not only to iron, but to all other bodies. What therefore is there left of all the figures which thermo-chemistry formerly displayed as so infallible?

There will probably remain very little, for even if we start from metals prepared in the same way, there is no certainty of starting from an identical body, since its simple dessication temperature permits its heat of combination to vary, and it is sufficient to very slightly change its physical state to also change its thermal properties. Faraday remarked, a long time ago, that silver, deposited on a plate of glass by chemical means, had a great refracting power and a very feeble transparency. If we heat the glass plate to from  $250^{\circ}$  to  $300^{\circ}$  C., the silver loses the greater part of its refracting power and acquires a great transparency. Faraday concluded from this that silver, in these two cases, must represent very different forms, and this prediction has been fully confirmed by experiment.

At the time when the figures of thermo-chemistry were established, chemists could not have reasoned other than they did, since they were not then able to differentiate bodies except by reactions incapable of bringing to light certain dissimilarities which were, however, fundamental. Silver, whatever its origin, when treated by nitric acid, invariably yielded nitrate of silver of the same composition per cent., and one could always extract from it the same quantity of metallic silver. How, then, was it possible to suspect

that there existed, in reality, metals differing from each other, although presenting the same appearance and known by the name of silver ?

We nowadays know this because our methods of investigation have been perfected. When they are still more perfect, it is probable, as I have said before, that the number of chemical species derived from the same body will further increase.

The foregoing facts establish this important general law: that simple bodies are by no means composed of determined elements invariable in structure, but of elements which can be varied within rather wide limits. Every simple body only represents a type from which greatly different varieties are derived. By adopting for the classification of metals that employed for living beings, it might be said that a metal like silver or iron constitutes a genus which includes several species. All the species of the same genus, the genus iron and the genus silver, for example, are absolutely distinct though possessing common characteristics. And if we consider that in the mineral world species are modified with some ease, since, for instance, the white phosphorus species may become the red phosphorus species, or that the silver species, capable of disengaging many calories in its combinations, may become a species which disengages a smaller number, it is allowable to affirm that chemical species are much more easily transformable than animal species. It is not a matter for wonder, since the organization of the latter is much more complicated than that of the former.

Chemical species, then, are subject to variability. We know, on the other hand, that, given certain

appropriate actions, atoms may undergo the beginning of dissociation. Is the variability of simple bodies limited? May we hope, on the contrary, to succeed in totally transforming a simple body? This is the problem which we will now proceed to examine.

## CHAPTER V.

### THE VARIABILITY OF CHEMICAL SPECIES.

#### § 1. *Variability of Simple Bodies.*

“It is very rare,” wrote more than sixty years ago the celebrated chemist Dumas, “that one succeeds in comprehending the laws of a whole class of phenomena, by studying those whose action is displayed with the greatest intensity. It is generally the contrary which is observed, and it is nearly always by the patient analysis of a slight or slow phenomenon that one succeeds in discovering the laws of those which at first escaped analysis.”

The whole history of science confirms this view. It was by attentively examining the oscillations of a hanging lamp that Galileo discovered the most important of the laws of mechanics. It was by a lengthened study of the shadow of a hair that Fresnel built up the theories which transformed the science of optics. It was by analyzing, with rudimentary apparatus, minute electric phenomena that Volta, Ampère, and Faraday<sup>1</sup> called forth from the void a science which was shortly to become one of the most important factors of our civilization.

“It is certain that in the future as in the past,” writes M. Lucien Poincaré, “the most profound dis-

<sup>1</sup> The home-made appearance of the apparatus of Faraday, now exhibited at the Royal Institution, must strike every visitor.—F. L.



coveries, those which will suddenly reveal regions entirely unknown, and open up perfectly fresh horizons, will be made by a few men of genius who will pursue in solitary meditation their stubborn labour, and who, to verify their boldest conceptions, will doubtless require only the most simple and least costly methods of experiment."

Considerations such as these should always be borne in mind by independent seekers when they find themselves stopped from want of means, or by the indifference or hostility which most often requites their labours. There exists, perhaps, no physical phenomena which, studied with patience in all its aspects, will not finally reveal, thanks to very simple means of investigation, totally unexpected facts. It was thus that the attentive study of the effluves generated by light on the bit of metal struck by it was the origin of all the researches noted in this work, and finally led me to demonstrate how little foundation there was for the century-old dogma of the indestructibility of matter.

The great interest of such researches, when stubbornly followed up, consists in constantly seeing new facts appear, and in never knowing into what unknown region one will be led. I have noticed this more than once during the many years devoted to my experiments. Undertaken with quite another object, they led me to study experimentally the question of the variability of chemical species; and if I give the preceding explanations, it is somewhat to excuse myself for having treated of a subject which would seem, at first sight, outside the scope of my researches.

From the philosophical point of view, the problem

of the variability of chemical species is of the same order as that of the variability of the species of living organisms, which has for so long agitated science. Energetically denied at first, this variability of species has at last been accepted. The principal argument which led to its adoption is the extent of the variations to which beings can be subjected, although no one has ever succeeded in experimentally obtaining the transformation of a single species. If, therefore, we succeed in obtaining very great variations of some chemical species, the possibility of their transformation may be admitted for reasons of the same order as those which have appeared convincing to biologists.

The variability of chemical species, put in evidence in the preceding chapter by the simple statement of facts already known, needed to be first discussed in order to prepare the reader for the interpretation of the experiments I will now detail.

To obtain the transformation of certain bodies we shall require no energetic means, such as high temperatures, great electric potential, or the like. I have already shown that matter, very resistant to mighty agencies, is sensitive, on the contrary, to slight excitants on condition that they are appropriate. It is precisely for this reason that, notwithstanding its stability, it can be dissociated under the influence of slight causes, such as a feeble ray of light.

I have already pointed out the very important part played by traces of a foreign substance when added to certain bodies. Its importance struck me as soon as I saw such curious properties as phosphorescence and such capital ones as radio-activity produced by the influence of such admixtures. If such import-

ant phenomena can be created by such very simple means, may it not be possible, by proceeding in an analogous manner, to succeed in modifying all the fundamental properties of certain elements?

By fundamental properties we understand those apparently irreducible ones upon which chemists rely for their classification. Thus, the property possessed by aluminium of not decomposing water when cold and of not being oxidized at the ordinary temperature constitutes one of the fundamental characteristics of this metal. If it can be compelled to oxidize when cold and to decompose water by simply adding to it traces of certain bodies, we shall evidently have the right to say that its fundamental properties have been modified.

As these experiments are merely accessory, since they go beyond the scope of my researches, I have only brought them to bear on three metals—namely, aluminium, magnesium, and mercury. And as, although very simple, they necessitate certain technical explanations, I refer the reader for their detailed description to the purely experimental part of this work. It will there be seen that by putting the first two of these metals in the presence of traces of various substances—for example, distilled water which has served to wash out an empty flask previously containing mercury—it becomes possible so to modify their characteristics that, if classified according to their new properties, their places in the list of elements would have to be altered. Thereafter, these metals, which are generally without any action on water, decompose it violently; the aluminium instantaneously becomes oxidized in air, becoming covered with thick tufts which grow under one's

eyes, and which give to a plate of polished aluminium the look of a jungle.<sup>1</sup>

Several hypotheses were put forward to explain these facts when presented in my name to the Académie des Sciences. M. Berthelot pointed out that two metals in the presence of each other might form an electric couple which might be the origin of the phenomena noticed, and that therefore it would not be the properties of metals which were under observation but those of their couples. This is evidently a very insufficient explanation.

Other scholars have compared the metals thus transformed to alloys which, according to certain ideas now in vogue, are constituted by combinations in defined proportions, dissolved in the excess of one of the metals in question. But in alloys, the changes obtained, such as hardness, fusibility, etc., are especially of the physical order, and in none of them are observed chemical transformations similar to those I have obtained.

By extending these researches, a large number of facts of the same order will certainly be discovered. Chemistry already possesses a certain number of them. There are, perhaps, as I have said, no bodies more dissimilar than white and red phosphorus. In certain of their fundamental chemical properties, amongst them their capacity for oxidation, they differ from each other almost as much as sodium from iron. Yet it is sufficient to add to

<sup>1</sup> In Europe this experiment seems to have passed almost unnoticed. Dr. Parodi of Cairo says, however, that he has repeated it with perfect success, and, apparently, much to his own astonishment. (See *Bulletin de l'Institut Egyptien*, Sec. 4, No. 4 (9th November 1904) pp. 464 et seq.)—F. L.

white phosphorus traces of iodine or of selenium to transform it into red phosphorus.

The instances of iron and steel and of pure and ordinary iron are no less typical. It is known that steel, so dissimilar to iron in hardness and in appearance, only differs from it chemically by the presence of a few thousandth parts of carbon. It is also known that the properties of pure iron are absolutely different from those of ordinary iron. This last, in fact, does not oxidize in dry air. Pure iron obtained by reducing sesqui-oxide of iron by means of heated hydrogen is so oxidizable that it spontaneously ignites in air, whence the name of pyrophoric iron given to it.

It might even be well, in the presence of such facts, to inquire whether the classic properties of several ordinary metals may not be solely due to some infinitesimal quantity of other bodies, the presence of which is often hidden from us, and which we call impurities when they are revealed to us by analysis. We shall see that the diastases, the most important compounds of organic chemistry, lose all their properties when deprived of the traces of certain metals whose existence was formerly not even suspected.

The facts put in evidence by my researches and by those of the same order which I have brought together seem therefore to prove that simple bodies have not the invariability attributed to them. To admit that they are not invariable is to say that it may become possible to transform them, and to come back to the old problem of the transmutation of substances which so exercised the alchemists of the middle ages, and which modern science has finally judged to be as unworthy of its researches as the

squaring of the circle or perpetual motion. Long considered as chimerical, it nowadays comes again to the front and occupies the minds of the most eminent chemists.<sup>1</sup>

“The great modern discovery to be realized to-day,” wrote M. Moissan, a few years back, “would not therefore be to increase by a single unit the number of our elements, but, on the contrary, to diminish it by passing in methodical fashion from one simple body to another. . . . Shall we finally attain that transformation of simple bodies into one another which would play in chemistry as important a part as the idea of combustion when grasped by the acute mind of Lavoisier? . . . Great questions here stand for solution. And this mineral chemistry, which we thought to be exhausted, is yet only at its dawn.” In reality, on the modern theory of electrolytic dissociation, chemists are obliged to admit, as everyday occurrences, transmutations quite as singular as those dreamed of by the alchemists, since it suffices to dissolve a salt in water to entirely transform its atoms.

It is known that, according to the theory even then old but greatly developed a few years ago by Arrhenius, in an aqueous solution of a salt—chloride of potassium, for example—the atoms of the chloride and of the potassium separate and remain present in the bosom of the liquid. Chloride of potassium is dissociated by the sole fact of its solution into chlorine and potassium. But, as potassium is a metal which cannot remain in water without violently decomposing it, nor find itself in pres-

<sup>1</sup> Cf. Sir William Ramsay's article in the *Athenium* of 10th March 1906.—F. L.

ence of chlorine without energetically combining with it, it must perforce be admitted that the chlorine and the potassium of this solution have acquired new properties bearing no analogy to their ordinary properties. It follows from this that their atoms have been entirely transformed. This is acknowledged, moreover, since the phenomenon is interpreted by the assertion that the differences noted are due to the fact that, in the solution, the atoms of chlorine and the atoms of potassium are formed of ions bearing electric charges of opposite signs, which would neutralize each other in ordinary chlorine and potassium. There must therefore exist two very different kinds of potassium, the potassium of the laboratory with all the properties we observe in it, and the ionized potassium without any relationship to the first; and the case is the same with chlorine. This theory has been accepted because it facilitates calculations, but it will be evident that it would lead us to consider the atom as the easiest thing in the world to transform, since it would suffice to dissolve a body in water in order to obtain a radical transformation of its characteristic elements.

Several chemists, moreover, formerly went some length in this direction. H. Sainte-Claire Deville declared to his pupils that he did not believe in the persistence of elements in compounds. W. Ostwald, Professor of Chemistry at the University of Leipsic, likewise affirms that the elements cannot continue to subsist in chemical combinations. "It is," according to him, "contrary to all evidence to allow that matter in a chemical reaction does not disappear and make room for another matter endowed with different properties." Oxide of iron, for instance, would nowise

contain iron and oxygen. When oxygen is made to act on iron, a complete transformation is effected of the oxygen and the iron, and if, from the oxide thus formed, oxygen and iron are subsequently extracted, it is only by performing the converse transformation. "Is it not nonsense," writes M. Ostwald, "to claim that a definite substance can continue to exist without possessing any of its [original] properties? In point of fact, this purely formal hypothesis has only one object—that is, to make the general facts of chemistry agree with the utterly arbitrary notion of an unalterable matter."

It certainly seems to result from what has been said above that the equilibria of the elements constituting the atoms can be easily modified, but it is indisputable also that they have an invincible tendency to return to certain forms of equilibrium special to each; since, after every possible modification, they are always able to return to their primary form of equilibrium. It may therefore be said that, in the present state of science, the variability of chemical species is proved, but that with the means at our disposal it is only realizable within certain limits.

### § 2. *Variability of Compound Bodies.*

What I have just said of the variability of simple bodies and of the means which allow it to be effected applies equally to compound chemical bodies. There exists at the present day a very important industry—that of the manufacture of incandescent lamps—founded on nothing but the principle of the transformation of certain properties of compound bodies in the presence of slight quantities of other bodies. When the mantles of these lamps are soaked in pure



oxide of thorium, they do not become luminous on heating, or only very slightly so; but if to the oxide of thorium one per cent. of oxide of cerium be added, this mixture gives to the mantle that brilliant luminosity we all know. With an increase or a diminution in the quantity of oxide of cerium added, the incandescence diminishes at once. This was a very unforeseen phenomenon, and is the reason why the creation of this mode of illumination required lengthy researches.

But it is, perhaps, in the chemical phenomena which occur in the interior of living beings that this same principle can be more frequently verified. Divers diastases<sup>1</sup> entirely lose their properties if they are stripped of the traces of mineral substances they contain, especially manganese. It is probable that bodies like arsenic, which is now extracted in infinitesimal doses from many tissues, exercise an important influence unsuspected by the earlier chemistry.

It is probably to the actions exercised by the presence of bodies in very small quantities that are due the differences observed in compounds formerly considered identical, which, however, would seem to vary with their origin. In former times well-defined radicals, such as sugar, chlorophyll, hæmoglobin, nicotine, the volatile essences, etc., were considered as identical, no matter from what living being they came. But Armand Gautier has established that this is an error: "Though still appertaining to the same chemical family, these radicals, when isolated and closely studied, are modified from one vegetable race to another by isomerization, sub-

<sup>1</sup> Substances which cause diastasis or separation. The saliva, which converts starch into sugar, is a familiar example.—F. L.

stitution, and oxidation; *they have become, in short, other definite chemical species. . . .* It is the same with the animal kingdom. There is not one hæmoglobin, but several hæmoglobins, each proper to its own species.”

In noting these differences between bodies similar to each other, but of different origin, Armand Gautier does not give their causes. It is by analogy that I have supposed the said differences to be produced by traces of various substances, and by variations in their quantity. I have already pointed out that organic ferments lose their properties the moment they are deprived of the small proportion of metallic matter they always contain. Hæmoglobin, which seems to act as a catalytic ferment, contains quantities of iron varying greatly with the animal species.

This principle of the transformation of the properties of a substance by the addition of a very small quantity of another body has thus plainly a general importance.<sup>1</sup> Yet it is only the enunciation of

<sup>1</sup> The interest of these considerations has not escaped the attention of all chemists. I find a proof of this in a note of M. Duboin, Professor of Chemistry at the Faculté des Sciences of Grenoble, published in the *Revue Scientifique*, 2nd January 1904, from which I extract the following passage:—

“The perusal of the recent memoirs of Gustave Le Bon has led me to a new theory on the constitution of bodies presenting several allotropic states. . . .

“I think that of the three known varieties of phosphorus—white, red, and violet—one only would be a simple substance, the other two being combinations of the first, with some element of extremely low atomic weight . . . analogous to particles emanated from radio-active bodies. . . .

“When oxygen slowly oxidizes white phosphorus, it may take away this element and combine with it to form ozone, which would thus be a combination of oxygen with this unknown element.

“This is, no doubt, a hypothesis; but, if verified by experiments, it would amount to an incursion into that world of chemistry without balance, of which you were the first to point out the extent.”

empirical observations, of which the secret causes still remain hidden. The particular combinations thus formed, to which we shall return in a subsequent chapter, altogether escape the fundamental laws of chemistry.

The various applications I have made of this principle have proved to me that it will be fruitful and of practical use, not only in chemistry and physiology, but also in therapeutics. I base this assertion on some studies which I undertook several years ago on the totally new properties caffeine assumes when associated under certain conditions with very small doses of theobromine (an alkaloid which, when isolated, only acts on the organism in very large doses). From experiments made with registering instruments on various patients, several of which have been repeated in one of the laboratories of the Sorbonne by Professor Charles Henry, theobromized caffeine would seem to be the most energetic muscular stimulant known. Observations made on a certain number of artists and writers have likewise proved its singular power on intellectual activity.

Experiments on the variability of compound chemical species have evidently not the same importance as those relating to the variability of simple bodies, since chemistry has for a long time known how to modify compound bodies by various reactions. If I have detailed them, it is to show that the principle of the method which permits the properties of simple bodies to be varied is applicable to many compound bodies, and to draw attention to its consequences in advance. In the early mineral chemistry, any compound bodies—nitrate of silver, for instance

—were considered as sharply defined substances formed by the combination of certain elements in strictly constant proportion. They are probably nothing of the kind. The law of definite proportions is no doubt only an approximate law like the law of Mariotte, and only owes its apparent correctness to the insufficiency of our methods of observation.

In so far as the variability of simple bodies is concerned, it should be pointed out that a very serious reason, deduced from my researches, will no doubt always be opposed to the subjection of the atom to complete transformations of equilibrium. I have shown that it is a reservoir of colossal energy. It seems therefore probable that to transform it entirely would require quantities of energy far superior to those at our command.

But experiment proves that, without being able to definitely destroy the atomic equilibria, we are allowed to modify them. We know, also, that, by very simple means, we can provoke the dissociation of matter, and consequently liberate a part of its energy. If, therefore, it is found impossible to add enough energy to the atom to transform it, we may at least hope to deprive it of a part of its energy—that is to say, to cause it to go down a step which it cannot retrace in the scale of its successive states. The atom deprived of a certain amount of energy can no longer be in the same state as before it lost it. Then it is, no doubt, that a veritable transmutation would appear.

Bringing together the facts above demonstrated we arrive at this conclusion. Matter, from which our experiments have banished immortality, has no longer the fixity attributed to it. It follows

further that all the ideas still dominant on the invariability of chemical species seem sentenced to disappear. When we see how profound are the so-called allotropic transformations, the transformation of bodies in electrolytic solutions and the complete transformations of several metals in presence of small quantities of certain substances; when, too, we see the facility with which bodies dissociate and reduce themselves to the same elements, we are naturally led to the renunciation of classical ideas and to the formulation of the following principle:—

*Chemical species are not invariable, any more than are living species.*

## CHAPTER VI.

### THE CHEMICAL EQUILIBRIA OF MATERIAL ELEMENTS.

#### § I. *The Chemical Equilibria of Mineral Substances.*

THE various elements may, by combination, give birth to bodies of an increasing complexity, from the minerals composing our globe up to the compounds forming the tissues of living beings.

For a long time chemistry has been studying these combinations. It might therefore be supposed that we are about to enter a very well-known field. A very short stay there will show that, on the contrary, it constitutes a world full of utterly unknown quarters.

As the mineral world was the only one accessible to the early methods of chemistry, it was naturally its first object of study. This was comparatively easy, and for this reason chemistry seemed at first a simple and precise science.

Mineral substances are, in fact, generally formed by combinations of a very small number of elements—oxygen, hydrogen, sulphur, etc. These combinations possess a constant composition and represent molecular edifices of small complexity in structure. It is only when we reach the compounds elaborated within the tissues of living beings that the phenomena become difficult to interpret. The molecular

edifices then possess an excessive complication and a very great instability necessitated by the rapid production of energy requisite for the maintenance of life. The elementary edifice of the mineral world, composed of only a few stones, has become a town. The structure of organic substances sometimes reaches such a degree of complication that it very often escapes us altogether.

But however simple mineral edifices may appear, we are far from discerning the nature of the equilibria capable of giving them birth. It is solely the effects produced by these equilibria which are accessible to us. It is impossible for us to know wherein an atom of sulphur differs from an atom of oxygen or from any other atom, and equally impossible to understand the cause of the different properties in the compounds formed by their combinations. All that can be said is, that the relative position of the atoms seems to determine the properties of bodies much more than the attributes supposed to be inherent in these atoms. There are hardly any properties of elements which one cannot manage to transform by modifying the structure of the molecular edifices in which they are united. What properties of the rigid diamond are found in the gaseous carbonic acid resulting from the combination of the diamond with oxygen? What properties of the suffocating chlorine, of the alterable sodium are met with in the sea salt formed by their association? Cacodyl and arsenic are very poisonous bodies, potassium a very caustic one; while cacodylate of potassium, which contains 42% of arsenic, is a body in no wise caustic and utterly inoffensive.

The properties of the elements then are capable of

being entirely transformed by changes in the position of the atoms which enter into their structure. In chemistry, as in architecture, the shape of the edifice has a far greater importance than that of the materials which compose it.

It is principally in isomeric bodies—that is, bodies possessing the same percentage of component parts though manifesting different properties<sup>1</sup>—that is shown the importance of the structure of molecular edifices. In the isomeric bodies termed metameric<sup>2</sup> there is not only the same proportional composition, but often the same number of atoms per molecule. The identity appears complete, but the difference in properties show that it cannot be so.

In bodies termed polymeric the percentage composition likewise remains identical, but the molecular weight varies either by condensation or by the splitting in two of the molecules. Such at least is the explanation given. If we could create polymeric elements from the metals we know we should probably succeed in creating new bodies, just as, by polymerizing acetylene by simply heating it, we transform it into benzene. By the simple fact that three molecules of acetylene  $C^2 H^2$  unite with each other, they form an entirely different body—tri-acetylene or benzene  $3 (C^2 H^2) = C^6 H^6$ .

So long as chemistry had to handle only the very simple compounds of the mineral world—water, acids, mineral salts, etc., of which the composition

<sup>1</sup> Or the quality which enables certain simple and compound bodies to change their properties without changing their composition. Ozone, which though identical with oxygen in other respects, yet possesses perfectly different properties, is a good instance.—F. L.

<sup>2</sup> The term used for those bodies whose isomerism comes from the association of compounds.—F. L.



was well known—it succeeded, by methodically varying their composition, in transforming their properties and in creating new bodies at will.

Take, for instance, as a combination with very little complication, the case of marsh gas or formene [*i.e.* methane] which is composed of carbon and hydrogen ( $\text{CH}^4$ ). One can, by successively replacing an atom of hydrogen by an atom of chlorine, obtain very different products, such as monochlorinated formene or chloride of methyl ( $\text{CH}^3, \text{Cl}$ ), bichlorinated formene ( $\text{CH}^2, \text{Cl}^2$ ), and trichlorinated formene or chloroform ( $\text{CH}, \text{Cl}^3$ ). If the last atom of hydrogen be taken from the combination, it becomes perchloride of carbon ( $\text{CCl}^4$ ).

All these reactions, being very simple, can be expressed by very simple formulas. Had chemistry stopped at this phase, it might have been considered as a perfectly constituted science. The study of the chemical equilibria of organic substances has shown the insufficiency of the early notions.

## § 2. *The Chemical Equilibria of Organic Substances.*

As soon as chemistry passed the bounds of the mineral world and penetrated into the study of the organic world, its phenomena became more and more complex. It was quickly noted that there existed equilibria independent of the percentage composition of bodies, and that, consequently, the customary formulas could not express them without giving the same formulas to very dissimilar bodies. It was necessary, therefore, to discard the early methods, and have recourse to geometrical figures, in order to approximately represent the structures coming to

light. It was at first supposed—against all likelihood, however—that atoms ranged themselves on one plane according to geometrical lines, of which the hexagon was the type. Then it was at length understood that they were perforce disposed according to the three dimensions of space, and they then came to be represented by solid figures typified by the tetrahedron. Thus was born stereo-chemistry, which, without certainly telling us anything of the inaccessible architecture of atoms, permitted certain known facts to be put together and others to be discovered. But these diagrammatic structures, without any relationship to reality, in the long run showed themselves very insufficient. We were then led to suppose that the elements of bodies were not in static but in dynamic equilibrium. From this came a new chemistry, still in course of formation, which might be called *kinematic chemistry*. In its formulas atoms are represented by little circles, round which are drawn arrows indicating the supposed direction of their rotation. The idea that atoms and their component elements are in perpetual motion in bodies is quite in conformity with the notions I have set forth, but to interpret by diagrams such complicated movements is evidently beyond our powers.

The most striking feature in the current conception is that chemical compounds appear more and more as mobile equilibria, varying with the external conditions, such as temperature and pressure, to which they are subjected.

The reactions indicated by chemical equations owe their apparent rigidity only to the fact that the medium in which they are realized does not noticeably vary. When these conditions are much modified,

the reactions immediately change and the usual equations are no longer applicable. What is called in chemistry the phase law was established through this fact being noticed. Any chemical combination ought always to be regarded as a state of equilibrium between the external forces which surround a body and the interior forces which it contains.

So long as chemistry had only to study very simple mineral or organic compounds elementary laws were sufficient, but closer examination showed that substances existed to which none of the known laws of chemistry could be applied, and these substances are just those which play a preponderating part in the phenomena of life. A living being is made up of an aggregate of chemical compounds formed by the combination of a small number of elements so associated as to compose molecular edifices of very great mobility. This mobility, necessary for the rapid production of a great quantity of energy, is one of the very conditions of existence. Life is bound up in the constant construction and destruction of very complicated and very unstable molecular edifices. Death, on the contrary, is characterized by the return to less complicated molecular edifices of very great stability of equilibrium.

A great number of the chemical compounds of which the aggregate constitutes a living being, possess a structure and properties to which none of the old laws of chemistry are applicable. In this structure is found a whole series of bodies—diastases, toxins, anti-toxins, alexins, etc., of which the existence has only, in most cases, been revealed by physiological characteristics. No formula can express their composition, and no theory explains their properties.

On them depend the majority of the phenomena of life, and they possess the mysterious quality of producing very great effects without any apparent change in their composition and simply by their presence.

It is thus that the protoplasm which is the fundamental substance of the cells, never appears to change, although by its presence it determines the most complicated chemical reactions, notably those which result in the transformation of bodies containing energy at low potential into bodies whose potential is higher. The plant is able to manufacture, with compounds of small complication, such as water and carbonic acid, very complicated oxidizable molecular edifices, which are charged with energy. From the energy at a low tension which surrounds it, it consequently manufactures energy at a high tension. It compresses the spring which other beings will relax to utilize its force.

The chemical edifices, which humble cells are able to form, comprise operations, not only the most skilful in our laboratories—namely, etherification, oxidation, reduction, polymerization, etc., but many more skilful still which we are unable to imitate. By means which we do not even suspect, the vital cells are able to construct those complicated and varied compounds—albuminoids, cellulose, fats, starch, etc., necessary for the support of life. They are able to decompose the most stable bodies, such as chloride of sodium, to extract the nitrogen from ammoniacal salts, the phosphorus from phosphates, etc.

All these operations, so precise, so admirably adapted to one purpose, are directed by forces of which we have no conception, which act exactly as

if they possessed a power of clairvoyance very superior to reason. What they accomplish every moment of our existence is far above what can be realized by the most advanced science.

A living being is an aggregate of cellular lives. So long as we are unable to comprehend the phenomena which take place in the bosom of an isolated cell, and have not discovered the forces which direct them, it will be of no use to build philosophical systems to explain life. Chemistry has, at least, achieved this much progress that it puts us face to face with a world of totally unknown reactions. For the former certainties of a too young science, it has finally substituted the uncertainties with which a more advanced science is ever burthened. They should not, however, be made too prominent, for the length of the journey before us would paralyze all efforts. Happily, those who enter upon these studies do not see how little advanced they are, and very often their teachers do not see it either. There is no dearth of learned formulas to conceal our ignorance.

What part may intra-atomic energy play in the reactions as yet so little known to us, which take place in the bosom of the cells? This is the point into which we will now inquire.

## CHAPTER VII.

### INTRA-ATOMIC CHEMISTRY AND THE UNKNOWN EQUILIBRIA OF MATTER.

#### § I. *Intra-atomic Chemistry.*

I HAVE just briefly demonstrated the existence of chemical actions which reveal certain equilibria of matter hitherto completely unknown. Without claiming to be able to determine the nature of these equilibria, will it not now be possible to more or less foreshadow their origin? It seems extremely probable that a large number of the inexplicable reactions we have mentioned, instead of only affecting molecular edifices, affect atomic edifices also, and bring into play the important forces of which we have proved the existence within them. Ordinary chemistry can displace the materials of which compounds are formed, but has not hitherto thought of dealing with these materials which it has considered to be indestructible.

Whatever interpretation may be given to the facts to follow, it is certain that they prove the existence of equilibria of matter which none of the early theories of chemistry could explain. We see in them important actions produced by reactions so slight that our balances cannot detect them, and phenomena which none of the doctrines of chemistry have foreseen, and which for the most part contradict

them. We are on the threshold of a new science where our ordinary reagents and balances can be no help, since it is a question of reactions whose effects are enormous, notwithstanding that but infinitely small quantities of matter are brought into play.

The fundamental phenomena which reveal the dissociation of matter having been referred to elsewhere, it would be useless to go into the subject anew. The facts I am about to enumerate prove, in my opinion, that this dissociation has an important bearing on many phenomena hitherto unexplained.

These facts cannot be classed in any methodical fashion, since we have to do with a science yet unborn. I shall therefore confine myself to describing them in a series of paragraphs, without endeavouring to present them in the orderly manner which their fragmentary character does not allow.

### § 2. *Colloid Metals.*

One of the best types of substances which elude the ordinary laws of chemistry is represented by the colloid metals. One of the methods of preparing them should alone suffice to indicate, apart from their very special properties, that their atoms must be partly dissociated. We have seen that, from the metallic poles of a static machine in motion there issue, as the result of the dissociation of matter, electrons and ions. Instead of a static machine let us take for the convenience of the experiment, an induction coil, the poles of which terminate in rods of the metal we wish to dissociate—gold or platinum, for instance—which are plunged in distilled water. By making sparks pass between the two rods, as described by Bredig, a cloud will be seen to form

round the electrodes. After a certain time, the liquid becomes coloured and contains, in addition to the metallic particles torn from the electrodes and separable by filtration, something unknown and proceeding from the dissociation of the metal. It is to this unknown thing that the name of colloid metal has been given.<sup>1</sup> If the operation be long continued the colloid ceases to form, as if the liquid were saturated.

The properties of metals in a colloidal state are absolutely different from those of the body from which they emanate. In the prodigiously small proportion of  $\frac{1}{300}$ th of a milligramme per litre, the colloid metal exercises the very energetic action which we will demonstrate later on.

The liquid in which the colloid metal is found is coloured, but it is impossible to separate anything from it by filtration, or to perceive in it with the microscope any particles in suspension, and this shows that these particles, if they exist, are inferior in size to the wave lengths of light.

The ionic theory being applicable to most phenomena, it has naturally been applied to the colloids. A colloidal solution is to-day considered as containing granules bearing electric charges—some positive, the others negative. But whatever this rather too simple doctrine be worth, it is evident that a colloid metal has retained no traces of the same metal in the ordinary state. Its atoms have probably undergone a commencement of dissociation,

<sup>1</sup> There are chemical methods of preparing metals, notably silver, in the state called colloidal, but it is nowise proved that these metals are identical with the bodies obtained by the electric spark, in the manner just described.



and it is for this very reason that they no longer possess any of their former properties. Colloidal platinum or gold are certainly no longer either gold or platinum, though made from these metals.

The properties of colloid metals have, in fact, no analogy with those of a salt of the same metal in solution. By certain of their actions they resemble far more some organic compounds, notably the oxydases, than mineral salts. They present the greatest analogies with the toxins and the ferments, whence the name of inorganic ferments sometimes applied to them. Colloidal platinum decomposes oxygenated water as do certain ferments of the blood; it transforms alcohol by oxidation into acetic acid in the same way as does the *mycoderma aceti*. Colloidal iridium decomposes formiate of lime into carbonate of lime, carbonic acid, and hydrogen after the manner of certain bacteria. More curious still, bodies, which like prussic acid, iodine, etc., poison organic ferments, paralyze or destroy in the same manner the action of colloid metals.

The properties, at once so special and so energetic, of these metals led perforce to the study of their action on the organism, which is very intense. It is to their presence in various mineral waters that Professor Garrigou attributes several properties of these waters—that of abolishing the phenomena of intoxication, for example. M. Robin has employed colloid metals as a remedy for sundry affections, notably typhoid fever and pneumonia, by injecting from 5 to 10 cubic centimètres of a solution containing 10 milligrammes of metal per litre. The result was a considerable increase of the organic exchanges, and of the oxidation of the elimination

products as revealed by an over-production of urea and uric acid. These solutions being, unfortunately, very rapidly alterable, their practical use is very difficult.

There is, it will be seen, no relationship, close or distant, between the colloid metals and those from which they are derived. No chemical reaction can explain the properties they possess. Their mode of preparation authorizes the supposition that they contain, as I have said, certain elements of dissociated matter. I have, however, not observed in them any phenomena of radio-activity, but it will be readily understood that if these phenomena arise during the dissociation of matter, there is no reason for their appearance when matter is already dissociated.

Besides metals, many substances can exist in the state termed colloidal, and there is now a tendency to ascribe to this unknown form of the material equilibria a preponderant part in physiology. Protoplasm, for instance, would thus be only a mixture of colloidal substances—a fact, however, which throws very little light on its marvellous properties.

### § 3. *The Diastases, the Enzymes, the Toxins, and Actions by Presence.*

To the colloid metals obtained by the dissociation of various simple bodies must be compared the compounds classed under the name of diastases, toxins, enzymes, etc., whose reactions are near akin to those of the colloid metals. Their chemical constitution is utterly unknown. They act almost exclusively by their presence and are sometimes extremely poisonous in almost imponderable doses.

According to Armand Gautier, two drops of the toxin of tetanus containing 99% of water, and 1% only of the active substance—which would hardly represent a milligramme—is sufficient to kill a horse.<sup>1</sup> A gramme of this substance would suffice, he says, to kill 75,000 men. Such energies as these make one think of those which very slight atomic dissociations might manifest.

At the time when bacteria were believed to constitute the active agent of intoxications, it was possible to explain by their rapid multiplication the intensity observed in their effects, but it is now known that the toxins remain just as active after the bacteria have been separated by filtration. The living substance called yeast transforms glucose into alcohol and carbonic acid, but after having killed this yeast by heating it to a certain temperature, a substance can be extracted from it deprived of all organisms and called zymase, as capable of producing fermentation as the living yeast itself. The phenomena attributed a few years ago to micro-organisms are therefore due to non-living chemical substances fabricated by them.

The part played by the various substances just mentioned in the phenomena of life is a very preponderant one. Most often it is only physiological reactions which reveal their existence and allow them to be isolated. All we know of them is that

<sup>1</sup> Insignificant traces of various substances are sufficient to paralyze the action of the diastases. There are poisons with poisons of their own. They resist certain energetic reagents and are influenced by traces of seemingly very inoffensive substances. Such violent products as prussic acid, corrosive sublimate and nitrate of silver have no effect on the venom of the cobra, while traces of an alkaline salt prevent it from acting.

they lose their properties if deprived of the infinitely small quantities of mineral matters that they contain under a form that we suppose to border on the colloidal state.

Most of the above bodies—colloid metals, diastases, ferments, etc.—possess the property, very inexplicable as yet—of acting, at least in appearance, by their presence alone. They do not appear in the products of the reactions which they excite. These actions of presence, also called catalytic, have been observed for a long time in chemistry. It was known, for example, that oxygen and sulphurous acid, though without action one on the other, unite to form sulphuric acid in presence of platinum black without this latter taking part in the reaction. So nitrate of ammonia, though ordinarily unalterable, also gives a continual disengagement of nitrogen in presence of platinum black. This latter body does not combine with oxygen, but it can absorb 800 times its own volume of it. It is supposed—but this is evidently only an hypothesis—that it generally acts by borrowing oxygen from the air and conveying it to the substances with which it is in contact.

Among the substances of which one might strictly say that they act only by their presence is found the vapour of water, which, in extremely small doses, plays an important part in various reactions. Perfectly dry acetylene is without action on hydride of potassium, but in presence of a trace of humidity the two bodies react one on the other with such violence that the mixture becomes incandescent. Well-dried carbonic acid is also without action on hydride of potassium, but in presence of a slight quantity of steam it produces a formiate. It is the same with

many other bodies—ammoniacal gas and hydrochloric gas, for example, which ordinarily combine with the emission of thick white fumes, but no longer do so after having been carefully dried. It will be remembered that I noted that by adding to dried salts of quinine traces of water vapour they become phosphorescent and radio-active.

Although catalytic actions were early known, it is only in the last few years that they have been proved to play a preponderant part in the chemistry of living beings. It is now admitted that the diastases and various ferments whose rôle is so important act only by their presence.

On closely examining the rôle of bodies acting by their mere presence, we note that they behave as if energy were transported from the catalyzing body to that catalyzed. This fact can hardly be explained, in my idea, unless by the catalyzing body undergoing the commencement of atomic dissociation. We know that, by reason of the enormous velocity possessed by particles of matter during its dissociation, considerable quantities of energy can be produced by the dissociation of a quantity of matter so imponderable as to elude all attempts to weigh it. *The catalyzing substances should therefore be simply liberators of energy.*

If this be really the case, we ought to be able to note that the catalyzing body at length undergoes a certain alteration. Now, this is exactly what is verified by observation. Platinum black and the colloid metals are in the long run worn out—that is to say, by use they lose a great part of their catalyzing action.

#### § 4. *Oscillating Chemical Equilibria.*

All the reactions above indicated are, I repeat, inexplicable by current ideas. They are even contrary to the most important laws of chemistry, such as those of definite and of multiple proportions. We see, in fact, some bodies transform themselves under the influence of imponderable doses of certain substances, while others excite intense reactions by their mere presence, etc.

The study of early chemistry left on the mind the notion of very stable products, of well-defined and constant composition, and incapable of modification except by violent means such as high temperatures. Later on arose the notion of compounds less fixed, capable of receiving a whole series of modifications connected with the variations of the medium or of the temperature and of the pressure to which they are subjected. Of late years the notion has gradually arisen that any body whatever simply represents a state of equilibrium between the internal elements of which it is formed and the external elements acting upon it. If this connection is not plainly apparent in some bodies, it is because they are so constituted that their equilibria maintain themselves without perceptible changes within the limits of fairly large variations of the medium. Water can remain liquid in variations of temperature ranging from 0° to 100° C., and most metals do not appear to change their state within still wider limits.

It is now necessary to proceed farther and admit that outside the only factors till now regarded by chemistry—mass, pressure, and temperature—there

are others in which occur the elements resulting from the dissociation of atoms. These elements should be capable of giving to bodies equilibria of such mobility that these equilibria could be destroyed or regenerated in a very short time under very slight external influences.

This succession of changes would be accompanied by the liberation of a certain quantity of the intra-atomic energy contained in matter. The actions by mere presence which are of such importance in the phenomena of life, may perhaps find an explanation in this theory. It was my studies on phosphorescence which led me to this hypothesis. It will be recollected that pure substances, various sulphides, phosphates of lime, etc., are never phosphorescent normally, and only become so when brought to a red heat for a length of time with traces of other various bodies—such as bismuth, manganese, etc. I have shown, on the other hand, that this elevation of temperature always provokes a dissociation of matter. It is therefore permissible to suppose that the elements proceeding from this dissociation have an active part in the unknown compounds then formed, which gives to such bodies the capacity for phosphorescence.

The combinations thus obtained have precisely the characteristic pointed out above as belonging to extreme mobility—that is to say, of destroying and regenerating themselves very rapidly. A ray of blue light falling on a screen of sulphide of zinc, illuminates it in the tenth of a second, and a ray of red light falling on the same screen, destroys the phosphorescence in the same space of time—that is to say, it brings the screen back to its primitive state. These

two contrary operations, necessarily implying two converse reactions, may be indefinitely repeated.

However this may be, the facts enumerated in this chapter show us that chemistry is on the threshold of entirely new phenomena, characterized very probably by intra-atomic reactions accompanied by a liberation of energy. By reason of the enormous quantity of intra-atomic energy contained in matter, a loss of substance too small to be detected by our balances may be accompanied by a very great liberation of energy.

In endeavouring to bring the phenomenon of the dissociation of atoms into the explanation of unexplained chemical reactions, I have evidently only framed an hypothesis whose justification is not yet strong enough. It has at least the advantage of explaining facts hitherto without interpretation. It is certain that a phenomenon so important and frequent as that of the dissociation of matter must play a predominant part in many reactions. Intra-atomic chemistry is a science of which we barely see only the dawn. In this new science the old material of chemists, their balances and their reagents, will probably find their occupation gone.



## CHAPTER VIII.

### THE BIRTH, EVOLUTION, AND END OF MATTER.

#### § I. *Genesis and Evolution of Atoms.*

BARELY forty years ago it would have been impossible to write, on the subject I am now treating, a single line deduced from a scientific observation, and one might have thought that thick darkness would always envelop the history of the origin and development of atoms. How could they, moreover, be supposed to evolve? Was it not universally admitted that they were indestructible? Everything in the world changed and was ephemeral. Beings succeeded beings by assuming always new forms; stars were finally extinguished; but the atom alone did not submit to the action of time, and seemed eternal. The doctrine of its immutability reigned for two thousand years, and nothing allowed us to suppose that it might one day be shaken.

We have run through the experiments which have at last ruined this old belief. We now know that matter vanishes slowly, and consequently is not destined to last for ever. But if the atoms are likewise condemned to a relatively ephemeral existence, it is natural to suppose they were not always what they are at the present day, and that they must have evolved during the succession of the ages. Through what successive phases have they passed?

What forms have they step by step assumed? What were formerly the different substances we see around us—stone, lead, iron, in a word, all bodies? Astronomy alone could give some answer to such questions. Able to penetrate by spectrum analysis into the structure of the stars of various ages which illumine our nights, it has revealed to us the transformations to which matter is subject when it commences to grow old. We know that spectrum analysis proves an incandescent body to have a spectrum reaching further towards the ultra-violet as its temperature rises. The same spectrum, moreover, has a maximum brilliancy which likewise moves towards the ultra-violet when the temperature of the luminous source rises, and towards the red when it diminishes. We know, on the other hand, that the spectral rays of a metal vary with its temperature. Wetteville has even shown that if potassium be introduced into a flame, its spectrum changes according as the metal is in the more or less heated regions of this flame. The spectroscope gives us, then, the means of knowing from what elements the stars are composed, and how they vary with the temperature. In this manner it has been possible to follow their evolution.

The nebulae which show only the spectra of permanent gases like hydrogen, or products derived from carbon, must constitute, according to several astronomers, the first phase of the evolution of celestial bodies. By condensing they must form new stages of matter which end in the formation of stars. These latter represent very varying periods of evolution.

The whitest stars, which are also the hottest, as is

proved by the prolongation of their spectrum into the ultra-violet, are composed of only a very small number of chemical elements. Sirius and  $\alpha$  Lyrae, for instance, contain almost exclusively incandescent hydrogen. In the red and yellow stars, stars less heated, which are beginning to cool and are therefore of greater age, other chemical elements appear. First, magnesium, calcium, silicium, etc. Certain bodies are observed only in the coldest stars. It is therefore with the lowering of the temperature that the elements of atoms undergo new phases of evolution, the result of which is the formation of certain simple bodies.

It is probable that the solid elements we observe—gold, silver, platinum, etc.—are bodies which have lost different quantities of their intra-atomic energy. Simple bodies in a gaseous state—nitrogen, hydrogen, oxygen—are the least numerous on our globe. To pass into a solid state, which they can only do at an extremely low temperature, they must first lose a very great amount of energy.

It seems very doubtful if heat is the sole cause of the sidereal evolution of the atoms. Other forces most probably have acted in it. We know that variations in pressure may, as Deslandres has shown, cause considerable variations in the rays of the spectrum; "under increasing pressures new series are seen to arise which only existed in germ at lower pressures."

To sum up, the observation of the stars shows us the evolution of the atoms and the formation of the various simple bodies under the influence of this evolution.

We are ignorant of the nature and the mode of

action of the forces capable of condensing a part of the ether which fills the universe into atoms of gas, such as hydrogen or helium, and then of transforming this gas into substances such as sodium, lead, or gold. But the changes observed in the stars are a proof that forces capable of effecting such transformations exist, that they have acted in the past, and that they continue to act in the present.

In the system of the world unfolded by Laplace, the sun and the planets were at first a great nebula, in the centre of which was formed a nucleus animated by a rotatory motion from which were successively detached rings which later on formed the earth and the other planets. Gaseous at first, these masses progressively cooled, and the space at first filled by the nebula was no longer occupied save by a small number of globes revolving on their own axes and round the sun. It is allowable to suppose that the atoms were not formed otherwise. We have seen that each of them may be considered as a little solar system comprising one or several central parts, round which revolve at immense speed thousands of particles. It is from the union of these miniature solar systems that matter is composed.

Our nebula, like all those still shining by night, must perforce have come from something. In the present state of science there is only, as far as we can see, the ether which can have constituted this cosmic starting point; and this is why all investigations always bring us back to consider it as the fundamental element of the universe. Worlds are born there and return thither to die.

We cannot say how the atom was constituted nor why it at length slowly vanishes; but at least we

know that an evolution similar to this pursues its way without halt, since we observe worlds in every phase of evolution from the nebula to the cooled planet, starting from suns still incandescent like our own. The transformations of the inorganic world now appear as certain as those of organized beings. The atom, and consequently matter, do not escape that sovereign law which causes the beings which surround us and the innumerable stars with which the firmament is peopled, to be born, to grow, and to die.

### § 2. *The End of Matter.*

I have attempted in this work to determine the nature of the products of the dematerialization of matter, and to show that they constitute by their properties substances intermediate between matter and the ether.

The ultimate term of the dematerialization of matter seems to be the ether in the bosom of which it is plunged. How does it return to it? What forms of equilibrium does it assume to affect this return? Here we are evidently on the extreme limit of the things our intelligence can comprehend, and are inevitably compelled to form hypotheses; but they will not be vain if it be possible to give them precise facts and analogies for a support.

When studying the origin of electricity we saw that it might be regarded as one of the most general forms of the dematerialization of matter. We recognized, moreover, that the final products of the dissociation of the radio-active bodies were formed of atoms of electricity. These last should therefore

represent one of the last phases of the existence of material substances.

What is the fate of the atom of electricity after the dissociation of matter? Is it eternal while matter is not? If it possesses any individuality, how long does it keep it? And if it does not keep it, what becomes of the atom?

That the electric atom should be destined to have no end is very unlikely. It is on the extreme limit of things. If the existence of those elements had continued to exist, since their formation, under the influence of the various causes which produce the slow dissociation of matter, they would finally have accumulated to the extent of forming a new universe, or, at least, a kind of nebula. It is therefore likely that they at length lose their individual existence. But in what way, then, do they disappear? Are we to suppose that their destiny is that of those blocks of ice which float in the Polar regions, and which preserve an individual existence so long as the sole cause of destruction which can annihilate them—a rise in temperature—does not attack them? So soon as they are overtaken by this cause of destruction, they vanish into the ocean and disappear. Such, doubtless, is the final lot of the electric atom. Once it has radiated away all its energy, it vanishes into the ether and is no more.

Experiment furnishes a certain support to this hypothesis. I demonstrated with regard to the elements of dissociated matter emitted by the machines in our laboratories, that electric atoms in motion are always accompanied by vibrations of the ether. Such vibrations have received the names of Hertzian waves, radiant heat, visible light,

invisible ultra-violet light, etc., according to the effect on our senses or on our instruments; but we know that their nature is the same. They may be compared to the waves of the ocean, which differ only by their size.

These vibrations of the ether, ever the companions of the electric atoms, most likely represent the form under which these vanish by the radiation of all their energy. The electric particle with an individuality of its own, of a defined and constant magnitude, would thus constitute the last stage but one of the disappearance of matter. The last of all would be represented by the vibrations of the ether, vibrations which possess no more durable individuality than do the waves formed in water when a stone is thrown into it, and which soon disappear.

How can the electric atoms proceeding from the dematerialization of matter preserve their individuality and transform themselves into vibrations of the ether?

All modern research leads us to consider these particles as constituted by whirls, analogous to gyroscopes, formed in the bosom of ether and connected with it by their lines of force. The question, therefore, reduces itself to this: how can a vortex formed in a fluid disappear into this fluid by causing vibrations in it?

Stated in this form, the solution of the problem presents no serious difficulties. It can be easily seen, in fact, how a vortex generated at the expense of a liquid can, when its equilibrium is disturbed, vanish by radiating away the energy it contains under the form of vibrations of the medium in which it is

plunged. In this way, for example, a waterspout formed by a whirl of liquid loses its individuality and disappears in the ocean.

It is, no doubt, the same with the vibrations of the ether. They represent the last stage of the dematerialization of matter, the one preceding its final disappearance. After these ephemeral vibrations the ether returns to its repose, and matter has definitely disappeared. It has returned to the primitive ether from which hundreds of millions of ages and forces unknown to us can alone cause it to emerge, as it emerged in the far-off ages when the first traces of our universe were outlined on the chaos. The beginning of things was, doubtless, nothing else than a re-beginning. Nothing leads to the belief that they had a real beginning, or that they can have an end.

If the views set forth in this work be correct, matter must have successively passed through very different stages of existence.

The first of these carries us back to the very origin of the worlds, and escapes all the data of experiment. It is the chaos epoch of ancient legends. What was to be one day the universe was then only constituted of shapeless clouds of ether.

By becoming polarized and condensed under the influences of forces unknown to us, which acted through age piled upon age, this ether was finally organized in the form of atoms: and it is from the aggregation of these last that matter as it exists in our globe or as we can observe it in the stars at various stages of their evolution, is composed.

During this period of progressive formation, the atoms have stored up the provision of energy they



have to expend in various forms—heat, electricity, etc.—in the course of time. While thenceforth slowly losing the energy first stored up by them, they have undergone various evolutions and have consequently assumed varying aspects. Once they have radiated away all their store of energy in the form of luminous, calorific, or other vibrations, they return by the very fact of these consecutive radiations, to their dissociation—to the primitive ether whence they came. This last, therefore, represents the final nirvana to which all things return after a more or less ephemeral existence.

The evolution of the worlds would therefore, in the last analysis, comprise two very different phases—one the condensation of energy into the atom, the other, the expending of this energy.

These brief sketches on the beginning of our universe and on its end evidently constitute only faint gleams projected into the deep darkness which envelops our past and veils our future. They are doubtless very insufficient explanations, but science can as yet offer no others. It has not yet any glimpse of the time when it may discover the true first cause of things nor even arrive at the real causes of a single phenomenon. It must therefore leave to religions and to philosophies the care of imagining systems capable of satisfying our longing to know. All these systems represent the synthesis of our ignorance and of our hopes, and are consequently only pure illusions; but these creations of our dreams have always been more seductive than realities, for which reason man has never ceased to choose them as guides.

### § 3. *Conclusions.*

The experiments analyzed in this work have allowed us to follow the atom from its birth to its decline. We have seen that matter, hitherto considered as indestructible, slowly vanishes through the dissociation of its component elements. This matter, formerly regarded as inert and as having only the power of giving back the energy which had been communicated to it, has, on the contrary, shown itself to us as an immense reservoir of forces. And from these forces are derived the majority of known modes of energy; molecular attractions, solar heat, and electricity in particular.

We have seen that matter can be dissociated under the influence of manifold causes, and that the products of its successive dematerializations constitute substances intermediate by their properties between matter and the ether. The result of this is that the ancient dichotomy between the world of the ponderable and that of the imponderable, formerly so widely separate, must disappear. And the study of the successive phases of the existence of matter has led us to the conclusion that the final term of its evolution is the return into the ether.

In thus endeavouring to catch a glimpse of the origins of matter, of its evolution and of its end, we have step by step arrived at the extreme limits of those semi-certitudes to which science can attain, and beyond which there is nothing but the darkness of the unknown.

My work is therefore finished. It represents the synthesis of laborious investigations carried on during many years. Starting with the attentive observation

of the effects produced by light on a fragment of metal, I have been successively led by the concatenation of phenomena to explore very different fields of physics and to sketch in outline a synthesis of the universe.

Without doubt, experiment has always been my principal guide; but to interpret the results obtained and to discover others, I have had to set up more than one hypothesis. As soon as the obscure regions of science are entered, it is impossible to proceed otherwise. If you refuse to take hypothesis as a guide you must resign yourself to chance for your teacher. "The rôle of the hypothesis," says Poincaré, "is one which no mathematician can afford to ignore, any more than can an experimentalist." To make hypotheses, to verify them by experiments, then to attempt to connect, by the aid of generalizations, the facts discovered, represents the stages necessary for the building up of all our knowledge.

In no other way have the great edifices of science been constructed. Imposing as they are, they still contain a large number of unverified theories, and it is often the least verifiable which play the greatest part in the direction of the researches of every epoch.

It is rightly said that science is the daughter of experiment, but it is very rare that experiment has not hypothesis for its guide. This last is the magic wand which evokes the known from the unknown, the real from the unreal, and gives a body to the most shadowy chimeras. From the heroic ages down to modern times, hypothesis has always been one of the mainsprings of the man's activity. It is by religious hypotheses that the most imposing

civilizations have been founded, and it is with scientific hypotheses that the greatest modern discoveries have been accomplished. Modern science accepts them no less than did our forefathers—and their rôle is, in reality, much greater now than ever it was, and no science could progress without their aid.

Hypotheses above all serve to found those sovereign dogmas which occupy, in science, as preponderant a part as in religions and philosophies. The learned just as much as the ignorant man, has need of faith to give direction to his researches and to guide his thoughts. He can create nothing if not animated by some faith, but must not remain too long unmoved in that faith. Dogmas become dangerous so soon as they commence to grow old.

It matters little that hypotheses and the beliefs they generate be insufficient; it is enough that they are fruitful, and they become so as soon as they provoke research. Strictly verifiable hypotheses do not exist. Neither do absolutely positive laws. The most important of the principles on which all the sciences rely are only truths approximately true within certain limits, but which, outside those limits, lose all exactitude.

Science lives on facts, but it has always been great generalizations which have given them birth. A fundamental theory cannot be modified without the direction of scientific researches at once changing. From the single fact that ideas on the constitution and invariability of atoms are in course of transformation, the doctrines which once formed a basis for the foundations of physics, of chemistry, and of mechanics, together with the direction of research, will have to change likewise. This new orientation

in investigation will necessarily bring with it an outburst of new and unexpected facts.

No one could dream of studying the world of atoms at the still recent time when they were thought to be formed of simple, irreducible, inaccessible, and indestructible elements. To-day we know that science is able to attack these elements, and that each one of them is a small universe of an extraordinarily complicated structure, a repository of forces formerly unknown, the magnitude whereof exceeds enormously all those hitherto known. That which chemistry and physics believed they knew best was in reality what they knew least.

It is in these atomic universes, whose nature was so long misunderstood, that must be sought the explanation of most of the mysteries which surround us. The atom, which is not eternal as the ancient creeds asserted, is far more powerful than if it were indestructible and therefore incapable of change. It is no longer a thing inert, the blind sport of all the forces of the universe. These forces, on the contrary, are its own creation. It is the very soul of things. It stores up the energies which are the mainspring of the world and the beings which animate it. Notwithstanding its infinite minuteness, the atom perhaps contains all the secrets of the infinite greatness.

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## SECOND PART.

### EXPERIMENTAL RESEARCHES.

ALL the theories set out in the preceding pages rest on a long series of experiments. The scientific or philosophical doctrine which has not experience for its basis is deprived of interest and constitutes only a literary dissertation without meaning.

I can only give in the following pages a brief summary of the experiments published by me during the last ten years. The memoirs in which they are described take up about 400 columns of the *Revue Scientifique*, and I could not dream of republishing them here. Some of them, such as those on phosphorescence, Hertzian waves, the infra-red, etc., I have had to omit entirely.

In all that follows I have especially endeavoured to give very simple experiments, and consequently easy to repeat. Naturally, I do not recapitulate those which have already been described, when this could be done without going into too many technical details in the first part.

Much of the apparatus and a great part of the methods described in the following pages have no longer more than an historical interest. Both the one and the other have been brought considerably nearer to perfection by the physicists who have entered upon the path I marked out. There is always use, however, in knowing the apparatus employed at the outset of new researches, and for this reason I have described without alteration the instruments and methods which I have used.

## CHAPTER I.

### GENERAL METHODS OF OBSERVATION FOR VERIFYING THE DISSOCIATION OF MATTER.

I HAVE explained in a former chapter the principles of the methods employed in studying the dissociation of matter—that is to say, its dematerialization. Before describing them in detail I will recall in a few lines what I have said.

All the means employed for verifying the dissociation of a body, whether radium or any sort of metal, are identical. The characteristic phenomenon to be studied is always the emission of particles animated by an immense speed, deviable by a magnetic field, and capable of rendering the air a conductor of electricity. It is this last feature alone which was used to isolate radium.

There are other accessory characteristics, such as photographic impressions and the production of phosphorescence and of fluorescence by the particles emitted, but they are of secondary importance. Besides, 99% of the emission from radium and the radio-active bodies is composed of particles without effect on the photographic plate, and there exist radio-active bodies, such as polonium, which only emit such radiations.<sup>1</sup>

The possibility of deviating these particles by a

<sup>1</sup> But see Wigger [of Göttingen]s researches [*Jahrbuch der Radioaktivität und Elektronik*, II.], for the fact that polonium and kindred substances do emit negative electrons or  $\beta$  rays, though these last are so slow-moving as to have hitherto escaped detection. This agrees with the latest researches of Rutherford and J. J. Thomson.—F. L.



magnetic field constitutes the most important phenomenon next to the aptitude for rendering the air a conductor of electricity. It has enabled the identity between the particles emitted by radio-active bodies and the cathode rays of Crookes' tube to be settled beyond dispute, and it is the degree of deviation of these particles by a magnetic field which has rendered the measurement of their speed possible.

As the measurement of the magnetic deviation of radio-active particles requires very delicate and costly apparatus, it is impossible to include it among easily performed experiments. These last being the only ones I wish to give here, I shall confine myself to the fundamental property possessed by particles of dissociated matter of rendering the air a conductor of electricity.

*The Way to prove that the Air has been Rendered a Conductor of Electricity by Radio-active Bodies.*—The

classic process employed to prove that a body emits particles of dissociated atoms capable of rendering the air a conductor of electricity is exceedingly simple. It requires, in fact, no other instrument than a graduated electro-scope. The substance X, supposed to be capable of

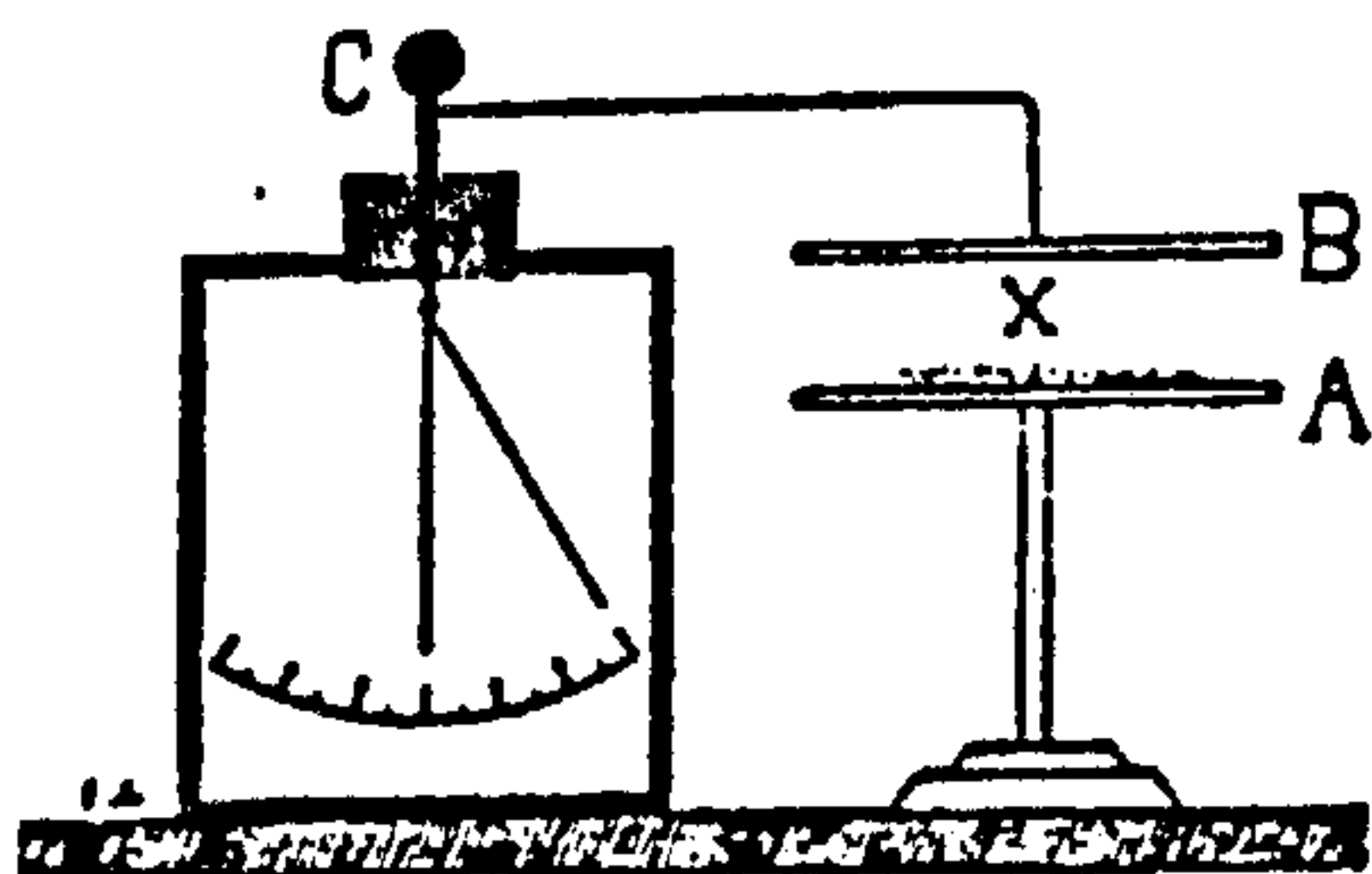


FIG. 36.—Classic method used to measure the radio-activity of bodies.

dissociation, is placed on a plate A (Fig. 36). Above it is arranged a plate of metal B connected with a charged electro-scope C. If conducting particles—ions or electrons—are emitted by the body X, the air becomes a conductor between the two plates and the electro-scope is discharged. The rate of fall of the leaves is pro-

portionate to the intensity of the emission of the particles by the dissociation. Or, the same results can be obtained by placing the bodies to be studied in a metal capsule placed directly on the electroscope. This is the means I generally employ.

It must not be thought that the electroscope constitutes a rough and ready mode of examination incapable of yielding exact measurements. Rutherford, who has studied it at great length, shows, on the contrary, that it is a very exact instrument, far superior, for most experiments, to the quadrant electrometer, and when well constructed much more sensitive than the best galvanometer. The capacity  $c$  of a system with gold-leaf 4 cm. long is, according to him, about one electrostatic unit. If we call  $v$  the fall of potential of the leaves in seconds  $t$ , the intensity of the current  $i$  through

the gas is given by the formula  $i = \frac{c v}{t}$ . In this way a current of  $2 \times 10^{-15}$  ampères can be measured, which cannot be done with any galvanometer. But, for ordinary experiments, such a degree of sensitiveness is absolutely useless, and in the majority of cases it suffices to use an electroscope surmounted by a plate above or on which, as the case may be, the matter to be experimented on is placed. It is only necessary, though this point is indispensable, that the dielectric through which the rod supporting the gold leaves passes should be a perfect insulator.

This last and very essential condition is, unfortunately, not realizable in any of the electroscopes manufactured in Paris. Only those of which the insulator is made with pure sulphur are really serviceable,<sup>1</sup> and they are not found in commerce. One must therefore make the instrument oneself. Supports made

<sup>1</sup> Amber, which has a high dielectric strength, and is less fragile than sulphur, is now generally employed in England.—F. L.

of paraffin, or of a mixture of sulphur and paraffin, do not long remain insulated, and the gold-leaf loses its charge. If forced to make use of them, the insulator must be cleaned, at least once a day, with a sheet of emery paper, an operation all the more necessary from the fact that the surface of the dielectric in time becomes charged with electricity. An electroscope can only be used for this kind of research when it does not give a loss greater than one angular degree in an hour after being covered with its cap.

Instead of the two classic gold leaves, it is better to use only one with a rigid central strip of oxidized copper. The angular deflection

of the gold-leaf is then very sensibly proportionate to the potential. With the electroscope I use, a deflection of the gold-leaf of  $90^\circ$  corresponds to a charge of 1,300 volts, or about 14 volts per angular degree. By

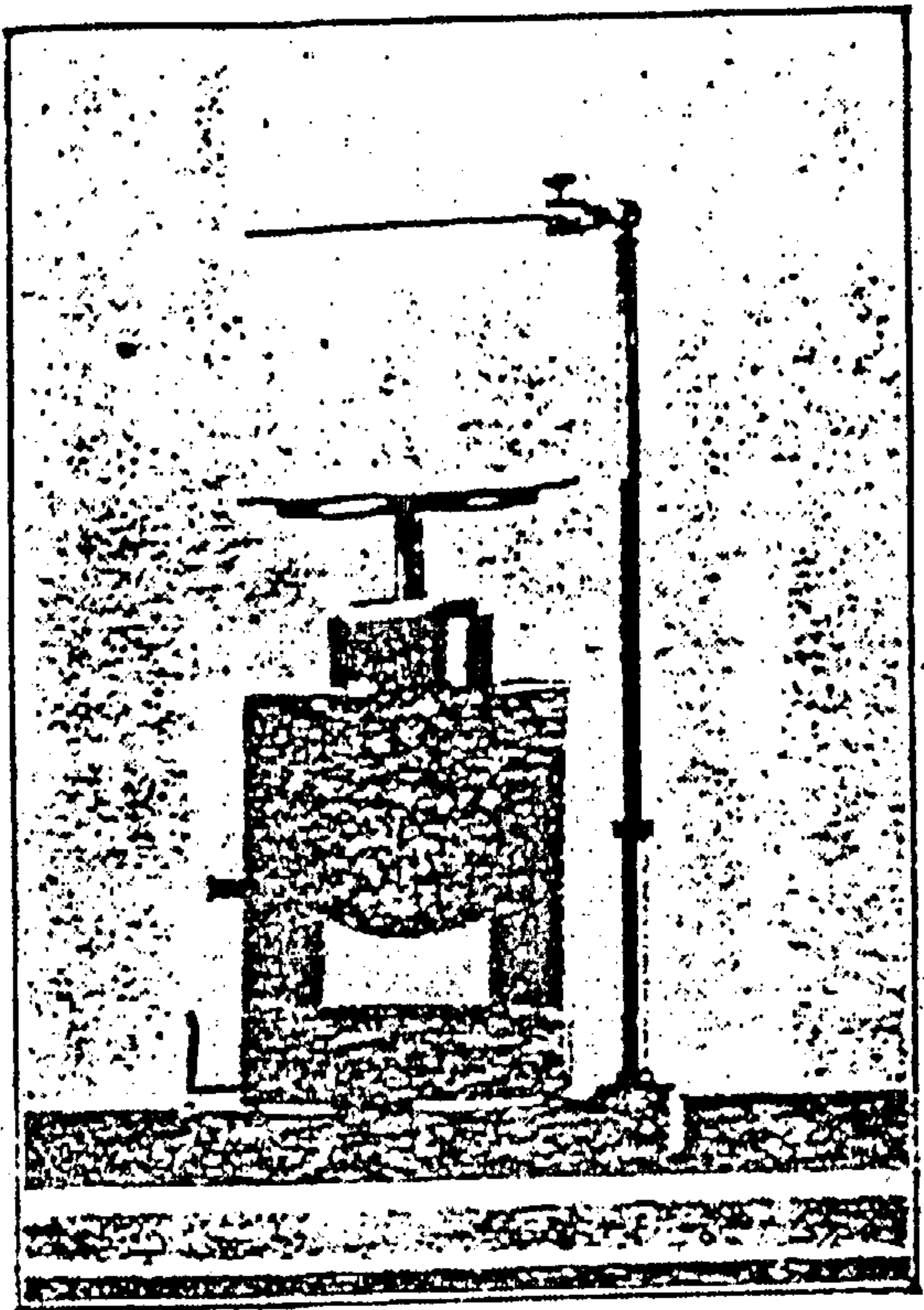


FIG. 37.—*Apparatus for reducing the rapidity of the loss of electricity produced by radio-active bodies.*—The radio-active substance is placed in a metal capsule placed on the plate of the electroscope, and the speed of the discharge is varied by means of a metallic blade placed at greater or lesser distance from the plate.

various contrivances, which need not be described here, electroscopes can be constructed so sensitive that 1° will represent one-tenth of a volt.

To read the fall of the gold leaves, the classic process of a microscope with a micrometer attached is not very convenient, especially in the case of rapid falls like those produced by light. It is much preferable to fix against one of the panes of glass forming the sides of the instrument a horn protractor, divided into degrees and backed with a sheet of rough white paper. To read the divisions, place a small lamp in the dark a few yards from the instrument. The gold-leaf throws the shadow of its extremity on the unglazed paper, and thus may be read to the quarter of a degree.

To reduce the sometimes troublesome sensitiveness of the electroscope during experiments with radio-active bodies, it is only necessary to place a strip of metal at varying distances from the plate (Fig. 37). It acts not only by its capacity but also by reducing the quantity of air on which the ions act. A radio-active substance which, for instance, produces 18 degrees of discharge per minute only gives 12 if the strip be at 5 cm. distant from the plate, and 8 if brought 2 cm. nearer.

*Condensing Differential Electroscope.*—For certain delicate experiments it becomes necessary to use an apparatus I have invented and called a condensing differential electroscope, which may be thus described: Having noticed from various experiments that the effluves proceeding from dissociated matter travelled round obstacles, I was led to invent an apparatus to make this impossible. By its use I discovered that all bodies contain, as do radio-active substances, an "emanation" which is constantly re-formed. In ordinary bodies it is only rapidly dissipated under the

influence of heat, and takes several days to re-form, as will be seen later in these researches.

A (Fig. 38) represents the ball of an electroscope mounted on a metallic rod, to the lower part of which

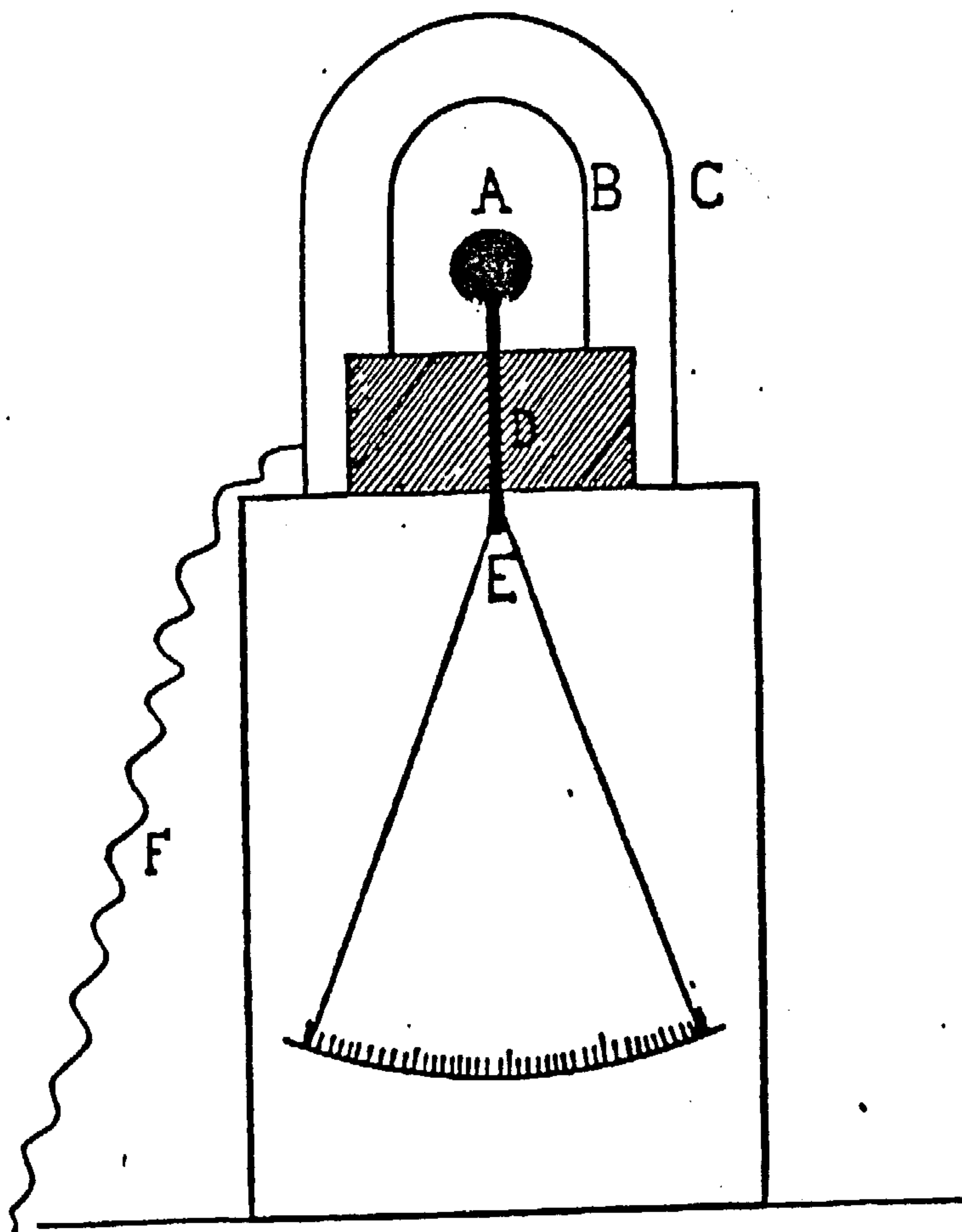


FIG. 38.—*Condensing differential electroscope of the author.*

are attached the gold leaves. This rod is supported by an insulating sulphur cylinder D. On this cylinder is placed an aluminium cylinder B, closed at the top. A second cylinder C, likewise of aluminium, covers the first. It forms a Faraday's cage, and is only put in

place after the electroscope has been charged. This cage is the only part of the system which must not be insulated, and this is prevented by connecting it with the earth by the chain F. Moreover, it is placed on the metallic part of the electroscope, a condition which, of itself, would prevent its electric insulation.

One must make these aluminium cylinders one's-self, which is very easy. After procuring the thin sheet aluminium of commerce, it is cut to the height and width required and wrapped round a wooden cylinder, and the two ends fastened together by a paper band coated with glue. The top of the cylinder is closed by a thin plate of tin, which is folded over and glued round it.

It will be seen that the cylinder C constitutes a Faraday's cage—that is to say, a screen completely protected against all external electrical influence. The leaves being charged and the large cylinder put in place, it is impossible to discharge the electroscope, even if a shower of sparks are made to fall on C.

The method of charging the instrument is as follows:—Taking away the outer cylinder C and leaving the small cylinder B round the ball, the instrument is inductively charged by bringing a glass rod rubbed with silk to the cylinder B, which is then touched with the finger. It will be readily understood that in these conditions the cylinder B is charged negatively, the ball A positively, and the gold leaves negatively. The outer cylinder C is then put in its place and connected with the earth by a chain, an excess of precaution which is by no means indispensable. The whole system is then exposed to the influence one wishes to act on it. If the cylinder C be penetrated, the gold leaves draw together more or less rapidly.

One can, if one pleases, make the electroscope receive a charge under these last conditions. Thus:—

The instrument being charged as before, open the

case of the electroscope and touch with a metal point the rod E bearing the gold leaves. They immediately fall. When the apparatus is immediately exposed to a radio-active influence—solar light, for instance—the leaves then separate several degrees.

The mechanism of this charge is easy to understand. Let us suppose that the instrument has been charged by means of an ebonite rod rubbed with catskin. Naturally, it is not the light which produces the electricity capable of charging the instrument. Its action is indirect. By touching the gold leaves, they were deprived of their positive charges, and therefore fell; but the negative charge of the ball, which is maintained by the positive electricity of the small cylinder, could not be annulled. When this small cylinder begins to discharge, under the influence of the effluves passing through the large cylinder, it will no longer be able to maintain the same quantity of negative electricity on the ball. Part of the electricity contained in the latter will then flow into the leaves, which, on being charged with electricity of the same sign, will diverge. The more the small cylinder discharges, the more the leaves will separate. The ball and the cylinder form, in a way, the two pans of a very sensitive balance. The separation of the gold leaves registers the slightest difference in the weights of the two pans. It is by reason of this analogy that I have given it the name of condensing differential electroscope.

Such are, in a general way, the instruments used in my researches.<sup>1</sup> I shall use many others, but they will be described in the chapters devoted to the various experiments.

<sup>1</sup> I have myself found that the electroscope invented by Professor Kolbe, of St. Petersburg, when furnished with the extra caps here described, will answer all practical purposes. A more accurate instrument is described in the paper of Sir William Ramsay and Dr. Spencer presently referred to.—F.L.

## CHAPTER II.

### METHODS OF OBSERVATION EMPLOYED TO STUDY THE DISSOCIATION OF BODIES BY LIGHT.

THE bodies under study are arranged in strips, at an inclination of forty-five degrees above the plate of a charged electroscope (Figs. 39 and 45), but without any direct connection with it. When these bodies are struck by solar light, they emit effluves which discharge the electroscope if this last is charged *positively*. But these effluves have hardly any action if the electroscope be negatively charged.

For demonstration purposes it is only necessary to use a simple strip of aluminium or zinc, first rubbed with emery paper, and fixed in any way above the *positively* charged plate of the electroscope.

For quantitative experiments I employed the apparatus represented in Fig. 39, but it is well to avoid as much as possible the use of the heliostat and to throw the light directly on to the metal to be experimented on. With a heliostat, the charge is sensibly reduced in consequence of the absorption of the ultra-violet by the surface of the mirror. The glass, indeed, hardly refracts more than 5% of the ultra-violet rays. As to metals, their refracting power, very great in the infra-red, diminishes considerably with the length of the waves. Polished silver, for instance, hardly refracts 10 to 15% of the incident ultra-violet radiations of the solar spectrum. At the beginning of the ultra-violet ( $0.400\mu$ ), on the contrary, it refracts nearly 80% of the rays.



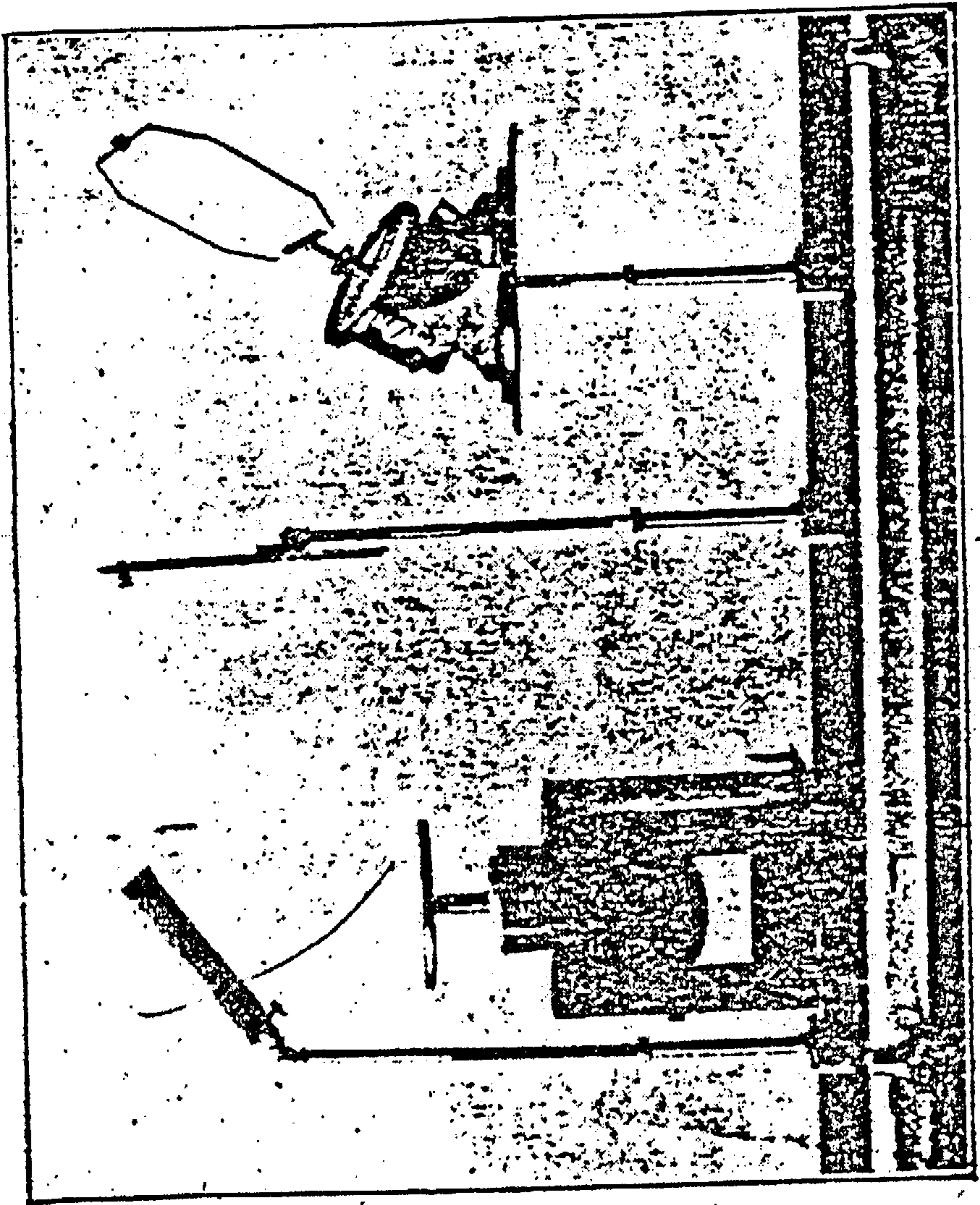


FIG. 39.—Apparatus used to demonstrate the dissociation of matter by the action of solar light.— On the left is a metal plate placed above a positively charged electroscope unconnected with it. In the centre of the figure is a support on which are placed the screens required to eliminate various parts of the spectrum. On the right is a heliostat for throwing the rays of the sun on to the metal plate. Its use must be avoided as much as possible, on account of the great absorption of ultra-violet rays by the surface of the mirror.

The electroscope may be charged by a dry battery or inductively by an ebonite rod rubbed with catskin. Care must be taken that the gold leaves are always brought to the same potential, and consequently separated by the same number of degrees from the vertical (20° in my experiments). The shadow of the leaves is thrown on to a plate of roughened glass divided into degrees, as seen in our figures. The instrument is lighted by a lamp placed four or five mètres off in a dark place at the end of the room where the experiments are made.

The sources of light employed were: 1st, the sun for the radiations of which the spectrum extends to  $0.295\mu$ ; 2nd, for the radiations extending further into the ultra-violet, I took, as source of light, the sparks of a condenser discharging between aluminium rods placed in a box closed by a plate of quartz covered with metal gauze, itself framed in a sheet of metal connected with the earth so as to be shut off from all electric influence. (Fig. 40.)

In order that the experiments may be compared, the bodies to be acted on by light are all cut into strips 10 cm. square, and placed at a distance of 15 centimètres from the electroscope. The ball of this latter is replaced by a large copper plate, which is indispensable for obtaining a rapid discharge. Copper is a metal but slightly sensitive to solar light but very sensitive to the electric light. It is, therefore, not necessary—though I did so—to shield this last from the action of light when operating in the sun; it is, on the contrary, indispensable to shield it from the luminous source when using the electric light. This is managed by the very simple arrangement shown in Fig. 40.

To separate the various regions of the spectrum and determine the action of each, we interpose between the light and the body it strikes several screens (quartz

trough containing a transparent solution of sulphate of quinine, glass 3<sup>mm</sup> thick, glass 0.1<sup>mm</sup> thick, mica 0.01<sup>mm</sup>

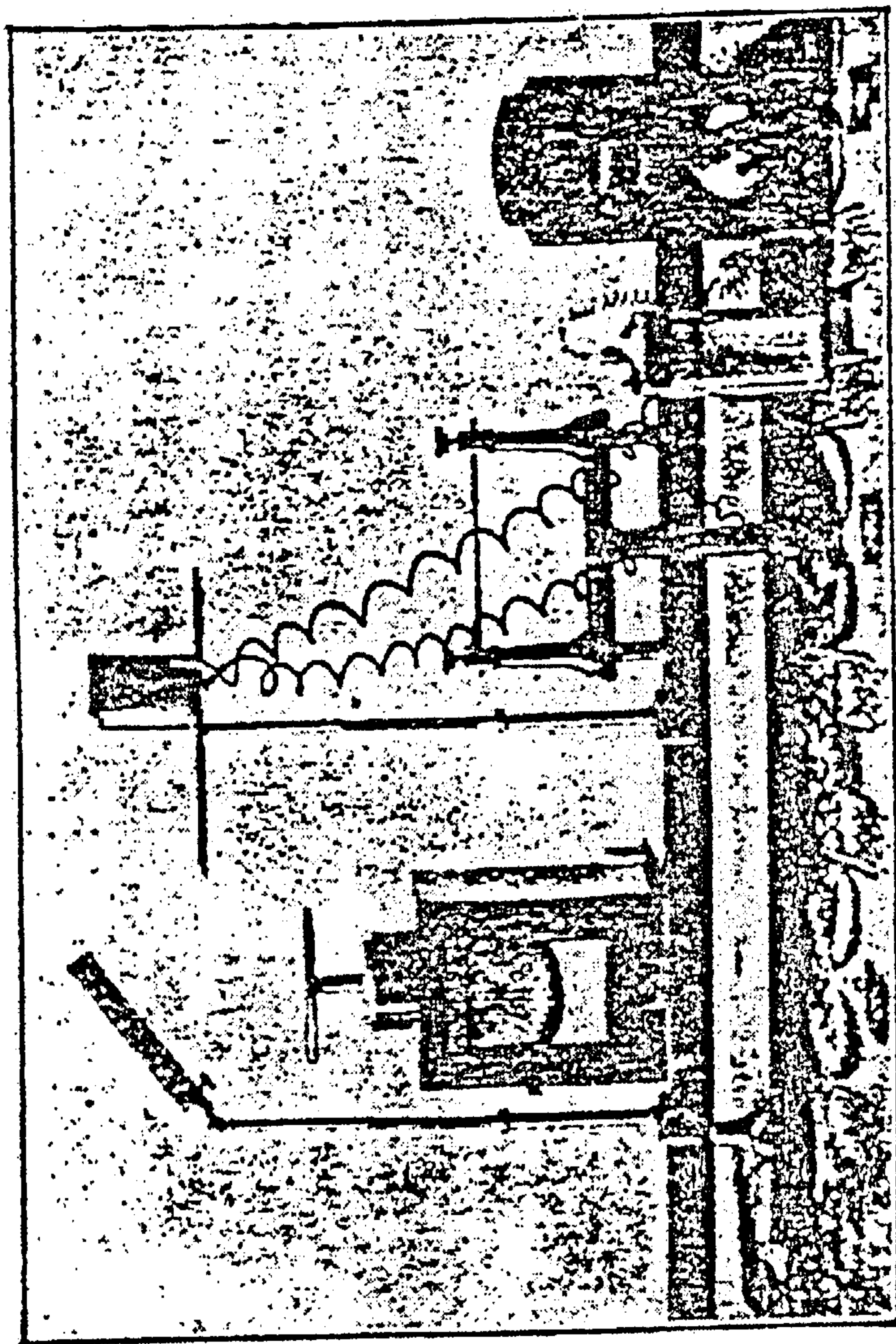


FIG. 40.—Apparatus used to show the dissociation of matter under the influence of the ultra-violet light produced by electric sparks.—The induction coil, the Leyden jars, and the metal gauze which protects the spark-box are not shown. On the plate can be seen the Branly coherer and bell for detecting the Hertzian waves which, as said in the text, sometimes interfere with the experiment.

thick, rock salt, quartz, etc.). The transparency of these screens to the various rays is first determined by placing them before a spectrograph and noting, by

means of the spectral rays photographed, the wavelength of the radiations which each transparent body allows to pass. The spectra here represented (Figs. 41 and 42) show the results of some of these photographs. Coloured glass, green and red excepted, cannot be utilized, for they really keep back very little, and only serve to reduce the intensity of the effect.

Speaking of absorption, I would remark that absorbent bodies seem divisible into two classes—namely, specific absorbents and absorbents of intensity. By the first the spectrum is stopped dead in a particular region, whatever the exposure. The second sort, while being specific absorbents for certain regions, only act within a tolerably wide limit by reducing the intensity; the absorption in this case depends on the length of the exposure. Solutions of bi-chromate of potassium or of sulphate of quinine are specific absorbents; they only allow a particular region of the spectrum to pass, and this region is not prolonged whatever be the exposure. Uncoloured glass exercises, indeed, a specific absorption for certain regions, but throughout one relatively extended part it specially acts by reducing the intensity of the active rays—that is to say, by partially absorbing them. This is why the impression is not clearly stopped at a fixed point. Specific absorbents are limited in number, while absorbents of intensity are innumerable. All coloured glasses (red and dark green excepted) only reduce intensity. The evident proof of this is obtained by photographing the solar spectrum through coloured glass. By slightly lengthening the exposure through blue, yellow, violet, and other glasses, the totality of the visible solar spectrum is obtained. This point is interesting to physiologists, for it shows that the various experiments made on animals and plants with solar light filtered through coloured glasses prove absolutely nothing. The differences observed are due to causes

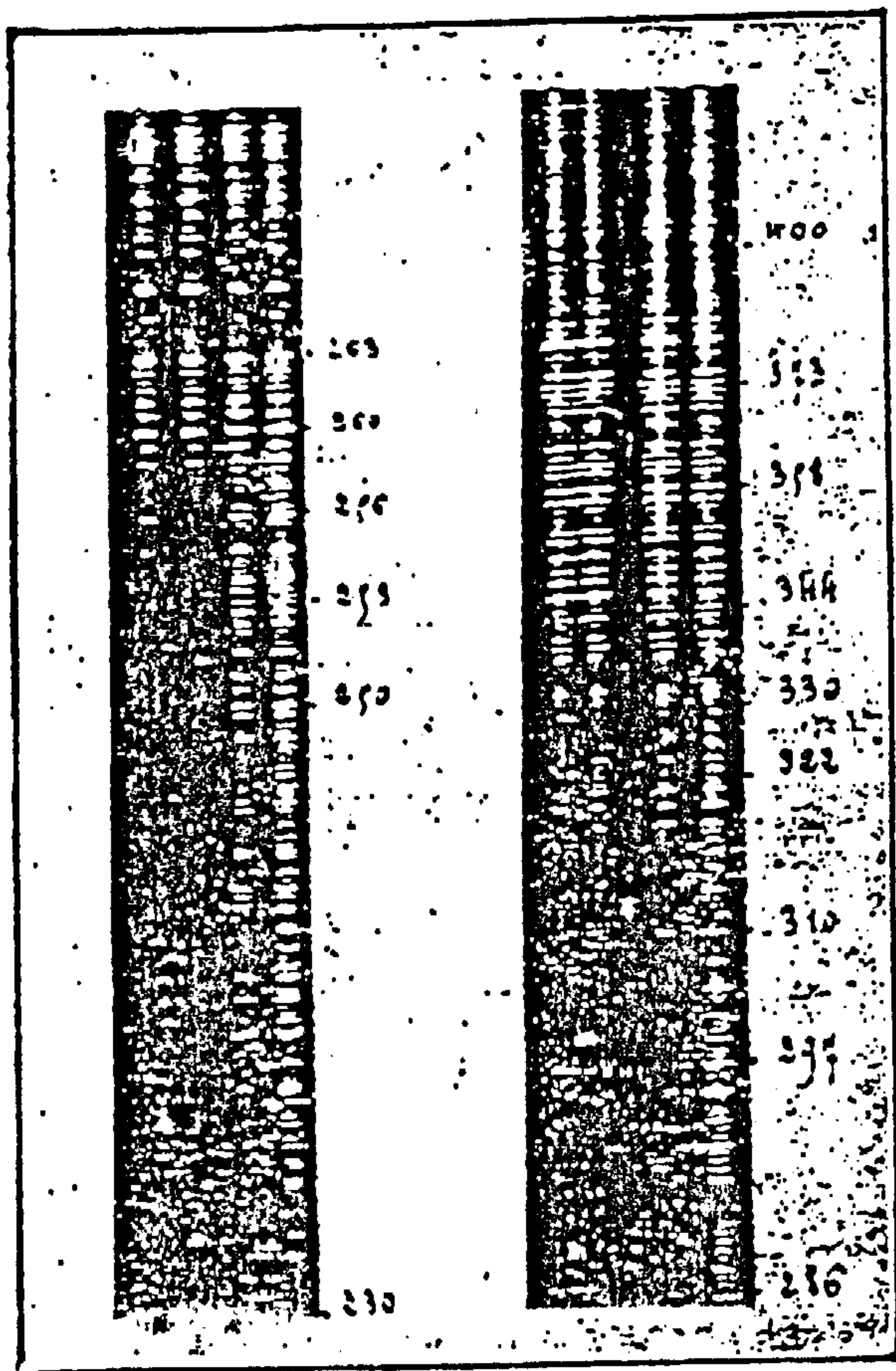


FIG. 41.

FIG. 42.

*Determination, by means of photography, of the transparency of bodies for the various regions of the spectrum.*—The first spectrum on the right of Fig. 42 represents the spectrum of the invisible ultra-violet of sparks from iron without the interposition of any body. The three other spectra on the left of Fig. 42 represent the absorption produced by uncoloured glass 0.8mm thick. The two spectra on the right of Fig. 41 represent the continuation of the ultra-violet spectrum of iron without any screens. The two spectra on the left of Fig. 41 represent the absorption produced by a strip of uncoloured glass 0.1mm thick. This strip, of the thickness of a sheet of paper, is entirely opaque for a fairly extended region of the spectrum. The figures represent the graduation of the spectra in wave length. The spectrum of Fig. 42 goes from  $\lambda=0.400\mu$  to  $\lambda=0.286\mu$ . The spectrum of Fig. 41 represents the continuation of the ultra-violet region. It is graduated from  $\lambda=0.263\mu$  to  $\lambda=0.230\mu$ . The solar spectrum extends, as we know, not nearly so far, as it does not exceed  $\lambda=0.295\mu$ .

quite different from those hitherto invoked to explain them.

The following is a table of transparency of the different screens or liquids employed by me to isolate the various regions of the spectrum. In the region of the extreme ultra-violet of the spectrum I availed myself of the kindness of my learned friend M. Deslandres for the graduation of the wave-lengths.

*Table of the Transparency of Various Screens.*

NATURE OF THE ABSORBENT BODY.	PORTION OF THE SPECTRUM THE ABSORBENT MEDIUM ALLOWS TO PASS.
<i>1 cm. of distilled water .</i>	All the visible spectrum and the greater part of the ultra-violet.
<i>Aqueous solution (10%) of sulphate of quinine acidulated with sulphuric acid . . . . .</i>	The visible spectrum up to about <i>h</i> . Keeps back all the ultra-violet.
<i>Esculine dissolved in alcohol . . . . .</i>	All the visible spectrum save a small part of the violet between <i>h</i> and H. Keeps back all the ultra-violet.
<i>Ammoniacal sulphate of copper . . . . .</i>	The visible spectrum from <i>b</i> and the ultra-violet up to N.
<i>Aqueous solution (10%) of bichromate of potassium . . . . .</i>	Absorbs all the ultra-violet and the visible spectrum up to between E and D—that is to say, a little beyond the limits of the green.
<i>Uranium glass half-centimetre thick . . . . .</i>	All the visible spectrum and the ultra-violet up to N.
<i>Dark green glass . . . . .</i>	Only the part of the visible spectrum comprised between F. and G.

*Transparency of Various Screens—continued.*

NATURE OF THE ABSORBENT BODY.	PORTION OF THE SPECTRUM THE ABSORBENT MEDIUM ALLOWS TO PASS.
<i>Ruby red glass . . . .</i>	All the infra-red from about $\lambda=2\mu$ and the red part of the visible spectrum. Stops all the rest of the spectrum.
<i>Common window-glass 3.3<sup>mm</sup> thick . . . .</i>	All the visible spectrum and the ultra-violet up to N and even up to O if the exposure and the weather be suitable.
<i>Uncoloured glass 0.8<sup>mm</sup> thick . . . . .</i>	The whole of the visible spectrum, and the ultra-violet up to about $\lambda=0.295\mu$
<i>Thin glass 0.1<sup>mm</sup> thick (microscopic plate) . .</i>	All the visible spectrum and the ultra-violet up to about $\lambda=0.252\mu$ . Completely opaque to the next region.

## CHAPTER III.

### EXPERIMENTS ON THE DISSOCIATION OF MATTER IN VARIOUS REGIONS OF THE SPECTRUM.

*Action of the Various Parts of the Spectrum on the Dissociation of Matter.*—By the method described above—*i.e.*, by various screens whose transparency has been determined by the spectrograph, it has been found possible to determine, by the rapidity of the electroscope's discharge, the proportion of effluves emitted by each body during dissociation, according to the regions of the spectrum to which it is subjected; or, in other words, the intensity of the dissociation. From this it is seen that bodies are very unequally dissociated by light, and that the action exercised by the various regions of the spectrum differs greatly. These are the results obtained:—

1st. *Bodies sensitive to the radiations comprised in the solar spectrum—that is, not exceeding  $0.295\mu$ .*—The majority of bodies are sensitive, but in extremely different proportions. The action may vary, in fact, from  $20^\circ$  of discharge of the electroscope in 5 seconds down to only  $1^\circ$  per minute. Some bodies are therefore about 500 times less sensitive than others.

The following is the order of sensitiveness of the bodies most sensitive to sunlight:—Amalgamated tin, amalgamated copper, aluminium recently cleaned, amalgamated silver, clean magnesium, clean zinc, amalgamated lead, mercury containing traces of tin.

The least sensitive bodies—that is to say, those



giving only from 1° to 2° of discharge in 2 minutes, are the following:—Gold, silver, platinum, copper, cobalt, pure mercury, tin, cardboard, wood, phosphorescent sulphides, and organic substances. With bodies of feeble dissociation, such as those just mentioned, there is generally no effect observable except when the solar rays contain the region of the spectrum from M to U, a region which often disappears, even when the weather is very bright, as I will explain shortly.

If, by means of the screens mentioned above and of their action on the electroscope, we ascertain the energy of the various regions of the solar spectrum on very sensitive bodies, such as amalgamated tin or aluminium, we shall find, representing by 100 the totality of the action produced, the following figures:—

Action of the region of the solar spectrum reaching to	. . . . .	$\lambda = 0.400\mu$	-	6%
Action of the region from	. . . . .	$\lambda = 0.400\mu$ to $\lambda = 0.360\mu$	-	9%
Action of the region from	. . . . .	$\lambda = 0.360\mu$ to $\lambda = 0.295\mu$	-	85%

It is possible, by various devices, to render certain bodies sensitive for regions where they otherwise are not so. Mercury and tin, separately, are bodies with little sensitiveness. It suffices, however, to add to the mercury  $\frac{1}{10}$  of its weight in tin, to render it very sensitive for the region of ultra-violet comprised between  $\lambda = 0.360\mu$  and  $\lambda = 0.296\mu$ . Mercury thus prepared is an excellent reagent for the study of the ultra-violet according to the hour, the day, and the season. If the added quantity of tin amounts to 10%, the mercury becomes sensitive for nearly the whole remainder of the spectrum.

2nd. *Bodies which become very sensitive only to radiations having wave lengths less than  $0.295\mu$ .*—Among these bodies I especially mention the following:—Cadmium, tin, silver, and lead.

3rd. *Bodies which are very sensitive only to radiations having wave lengths less than  $\lambda = 0.252\mu$ .*—These are the most numerous. Among them may be mentioned the following:—Gold, platinum, copper, iron, nickel, organic substances, and various chemical compounds (sulphates and phosphates of soda, chloride of sodium, chloride of ammonium, etc.). After the metals, the most active bodies are lamp-black (20 degrees of discharge per minute) and black paper. The least active are living organic bodies—especially leaves and plants.

The various chemical compounds dissociate like simple bodies, under the influence of light, but in rather different proportions. Phosphate of soda and sulphate of soda give 14° per minute, chloride of ammonium 8°, chloride of sodium 4°, etc. To verify the discharge, the bodies are made into a saturated solution. The solution is poured on a glass plate and made to evaporate. The glass plate is afterwards placed in the ordinary manner over the electroscope.

The variations of discharge which I have given are only of value for the particular regions of the spectrum which have been enumerated. In proportion as regions of higher refraction are employed, the sensitiveness of the various bodies differs less, and tends toward equality, without, however, reaching that point. In the solar ultra-violet, gold, for instance, is almost inactive—about 500 times less active than aluminium. In the extreme ultra-violet of the electric light (starting from  $0.252\mu$ ) it has, on the contrary, nearly the same rapidity of dissociation as this last metal. In this region of the ultra-violet, the difference of action between the least sensitive bodies (steel, platinum, and silver) and the most sensitive (amalgamated tin, for example) hardly varies more than from one to two.

Moderate conductors—lamp-black, chemical compounds, wood, etc.—have in this advanced region

of the spectrum a sensitiveness lower than that of metals. The discharge produced by the effluves of lamp-black, for instance, is much less than that of tin.

*Influence of Cleaning.*—The action of cleaning is of the highest importance for metals subjected to the radiations contained in the solar spectrum. They should be vigorously cleaned every ten minutes with very fine emery-cloth, under penalty of seeing the discharge become 200 times less rapid. In the ultra-violet, starting from  $0.252\mu$ , the influence of the cleaning is still manifest, but much less so than in solar light. It will do if the surface has not remained uncleaned for more than about 10 days. After 10 days the discharge is hardly more than half what it is after recent cleaning.

*Influence of the Nature of the Electrodes.*—When, in order to obtain radiations extending much farther into the ultra-violet than those of the solar spectrum, sparks from condensers (two Leyden jars placed in series on the secondary of an induction coil) are used, the intensity of the dissociation varies greatly with the nature of the metal of the electrodes.

Aluminium points give a light producing a dissociation which, all things being equal, is nearly three times greater than that from gold points. Electrodes of copper and of silver give about the same figures as gold electrodes.

The first explanation which occurs to the mind is, that certain metals possess a more extended spectrum than others. But this explanation is nullified by recent measurements made by Eder,<sup>1</sup> who has shown that the

<sup>1</sup> Eder and Valenta, *Normal Spectrum einiger Elemente* (Kaiserlichen Academie der Wissenschaften, Vienna, 1899).

spectra of most metals extend to about the same distance into the ultra-violet. It is thus, for instance, that the spectrum of the sparks from gold, electrodes of which are the least active, extends quite as far ( $\lambda = 0.185\mu$ ) as the spectrum from aluminium, electrodes of which are the most so.

Nor does it seem that the differences of effect observed under the influence of the light produced by the sparks from various metals are due to differences of intensity of light. I find the proof of this in the fact that photographic paper prepared with chloride of silver, when placed for 60 seconds before the quartz window which closes the spark-box, presents the same intensity of impression with all metals excepting steel electrodes, when it is more intense than with the sparks produced by aluminium, this being precisely the opposite to what occurs in the power of the dissociating action of their light. During these short exposures it is only radiations below  $0.310\mu$  which act on the paper, as is proved by the fact that the interposition of thin glass selected so as to stop the radiations of a wave length under  $\lambda = 0.310\mu$ , also stops the impression.

The preceding facts relative to the very great difference in electrodes according to the metals of which they are composed, would seem to prove that the spectrum of the various metals contains, in addition to light, a something with which we are not acquainted.

*Influence of the Varying Composition of the Solar Light on its Fitness to produce the Dissociation of Bodies. Disappearance at Certain Moments of the Ultra-violet.—* When working with solar light it is very soon noticed that numerous factors may vary enormously the production of the effluves resulting from the dissociation of matter, and consequently the intensity of the

discharge. I shall come back to this subject when treating of the so-called negative leak.

As soon as I had organized a series of regular observations, consisting of experiments with bodies having a constant action, I perceived that, when working for several days running at the same hour and in apparently identical weather, I suddenly observed considerable differences in the action of the electroscope.

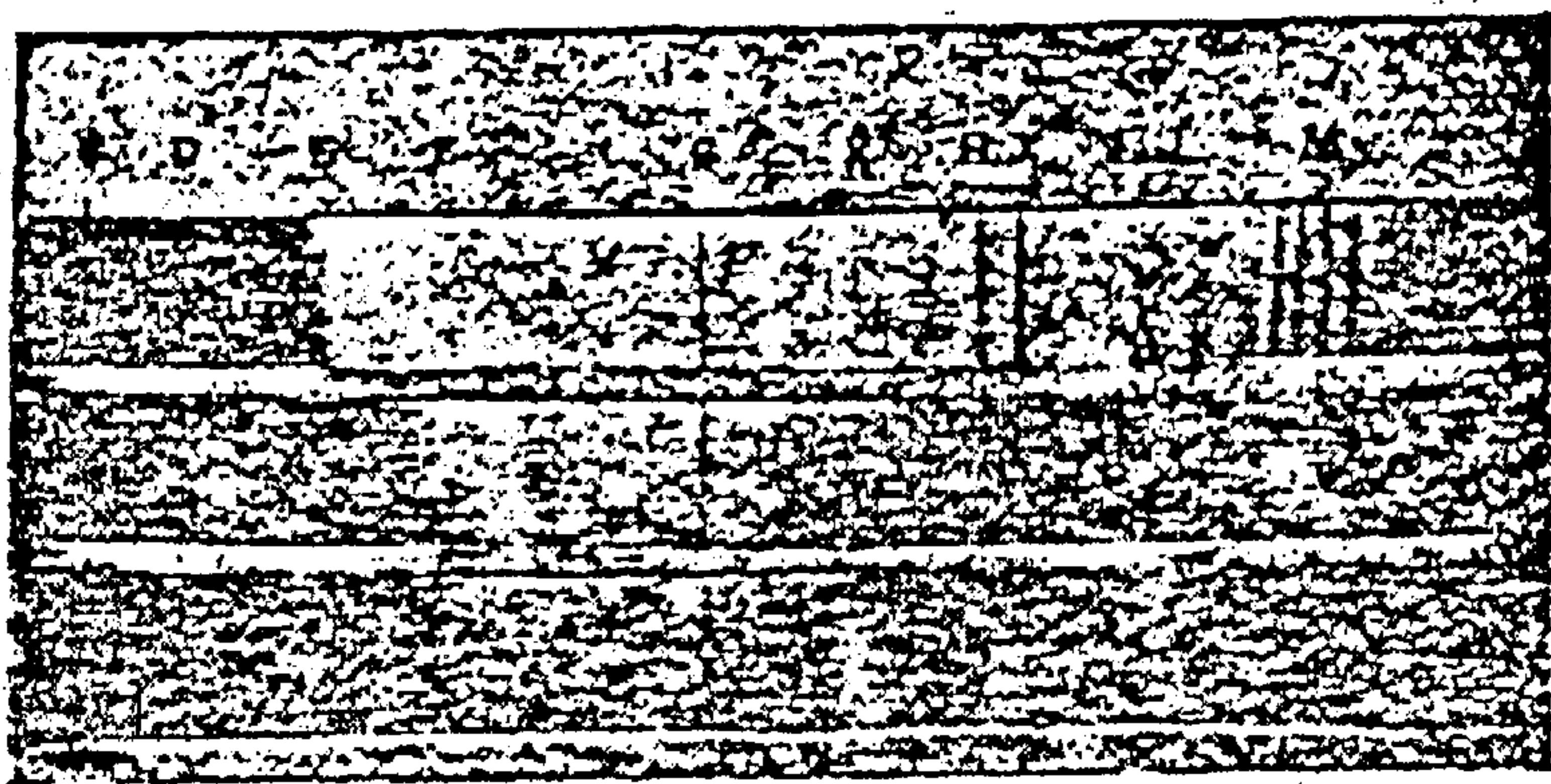


FIG. 43.—*Photographs showing the disappearance of the solar ultra-violet on certain days caused by unknown influences.*—The upper band represents an ordinary solar spectrum extending to the borders of the N ray. The band beneath it shows the disappearance of the solar ultra-violet starting from the L ray, notwithstanding the prolongation of the exposure. The lower band represents the total disappearance of the ultra-violet when the spectrum is photographed through a transparent solution of sulphate of quinine.

After having successively eliminated all intervening factors, I was left face to face with only one—the variation in the composition of the solar light. This was then only an hypothesis and had to be verified. As the variations were probably connected with the invisible parts of the spectrum, one single method of verification was at my disposal—the photography of this invisible region by the spectroscope. The only hirt

given in the text-books was that the ultra-violet disappears as the sun approaches the horizon, which, however, the action of the electroscope ought to have sufficiently indicated. But as I was noticing variations in the effects at the same hours every day and at a time when the sun was very high, this hint explained nothing.

Photographs of the spectrum repeated for several months showed me, in conformity with my previsions, that from one day to another, and often on the same day, without apparently any cause for the phenomenon, the greater part of the solar ultra-violet, starting from the L or M rays, sometimes disappeared abruptly (Fig. 43). This phenomenon always coincided with the slowness of the discharge of the electroscope. The apparent state of the sky had no connection with this disappearance of the ultra-violet, for it was sometimes manifest in very bright weather, while, on the contrary, I noticed the ultra-violet remained constant under a very cloudy sky. However, here are some of the results obtained:—

23rd August 1901, 3.50 p.m. Very fine weather; disappearance of the ultra-violet, beginning with the M ray.

30th August 1901, 11 a.m. Very fine weather; disappearance of the ultra-violet beginning with L.

31st August 1901, 3 p.m. Very hazy weather, sky entirely clouded; no disappearance of the ultra-violet.

26th October and 12th November 1901, 2 p.m. Fine weather; disappearance of the ultra-violet beginning with M.

It will be seen from the above that if the eye, instead of being sensible to the radiations going from the A to the H rays, were sensible only to the radiations going from H to U, we should find ourselves, now and then, though in full sunshine, plunged in darkness.

The ultra-violet possesses, according to my experiments, so special and so energetic an action that it must be supposed to have an active part in the phenomena of nature. It is to be desired that regular researches should be instituted in observatories on its presence and its disappearance in the light. In conjunction with this, studies might be made on the variations of the infra-red, for which I have shown there exists a re-agent—sulphide of zinc with green phosphorescence—as sensitive as gelatino-bromide is for visible light. The invisible spectrum has, it is well known, a much greater extent than that of the visible spectrum. It is probable that its really very easy study might raise meteorology from the wholly rudimentary state in which it still is at the present day.

*Identity of the Products of the Dissociation of Bodies by Light with those derived from Radio-active Substances.—*

I have always upheld the analogy of the effluves of dissociated matter as shown in the foregoing experiments with those emitted by spontaneously radio-active bodies. Lenard and Thomson have, since my researches, made this identity indisputable, by demonstrating their derivation by a magnetic field and by measuring the ratio  $\frac{e}{m}$  between the charge of the particles and their

mass. This ratio has been found to be identical with that observed with the cathode rays, and the particles of radio-active bodies. The condensation of water vapour by the particles of matter dissociated by the influence of light—which produces, as we know, cathode rays—has likewise been obtained by Lenard.

*Photographic Action of the Particles of Bodies dissociated by Light.—*The study of this photographic action caused me in the past a great loss of time; I abandoned it

because, in reality, by reason of its irregularity, it does not constitute a process of measurement, while the electroscope affords a precise one. I will only say that when a sensitized glass plate, enclosed in an envelope of black paper and covered by some object or other, is exposed—well protected from all light—to the effluves of a metal struck by the sun, there will be obtained, after fifteen minutes' exposure, the outline of the object placed on the black paper.

With metals exposed directly to the sun the impression on the photographic plate is sometimes intense, sometimes nil, and is too uncertain, in short, to provide a scientific means of investigation.

I have always observed, besides, that after a certain exposure to the sun, a metal generally loses the property of giving photographic images, even when a sensitized plate is exposed in the dark, directly on the surface of the insolated metal, instead of being placed beneath it. This phenomenon occurs, as I shall show later, through the metal exhausting rapidly, under the influence of slight heat, the provision of radio-active emanation it contains, which is only formed again very slowly.

*Diffusion of the Effluves proceeding from the Dissociation of Bodies by Light.*—One of the most curious properties I have noticed in these effluves is the rapidity of their diffusion, which enables them at once to pass round all obstacles. This diffusion is so considerable that, in the experiments given above, the plate of the electroscope may be placed behind the metallic mirror, entirely hidden by it, and consequently protected from all light, without the discharge being suppressed. With a mirror of aluminium it is only reduced to a seventh of what it was previously. If the electroscope be placed laterally beside the mirror so that its extreme edge is 1 cm.



within the vertical line of its edges, the discharge is hardly reduced by one-tenth. If the electroscope be removed to 10 cm. from the same edge of the mirror, the discharge is only reduced by three-quarters. The effluves, consequently, have entirely gone round the obstacle formed by the mirror. No doubt the propagation has partly been effected by the air, and also by the sides of the mirror itself, to which the dissociated particles seem to adhere and to slide along unless they are stopped by a non-metallic surface. This can be proved by the following experiment which succeeds very well in the sun:—

A strip of aluminium of which the face is intentionally well oxidized to render it inactive, and the other face cleaned with emery-paper is placed above the electroscope (Fig. 47), so that the cleaned face shall alone be struck by the light and shall project effluves on to the plate of the electroscope. The discharge of the instrument corresponds under these conditions to  $20^\circ$  in 15 seconds. The strip of metal is then turned round, so that it is the oxidized face which faces the electroscope, and the cleaned face is towards the sun. The effluves produced can then only act on the electroscope by passing round the strip. Now, the discharge is still  $5^\circ$  in 15 seconds. Without changing anything in the above arrangement, a band of black paper two centimetres in width is gummed on to the borders of the non-oxidized face towards the sun. This band prevents the passing round of the particles, and the discharge of the electroscope ceases.

Metals struck by light for the most part retain a small residual charge, which allows them to slightly discharge the electroscope in the dark for a few minutes. It therefore suffices to expose to the sun a cleaned piece of metal, and to place it in the dark above the electroscope, for a slight discharge to be produced for a few moments.

*Mechanism of the Discharge of Bodies electrified by the Particles of Dissociated Matter.*—The mechanism of the discharge of bodies electrified by the effluves of

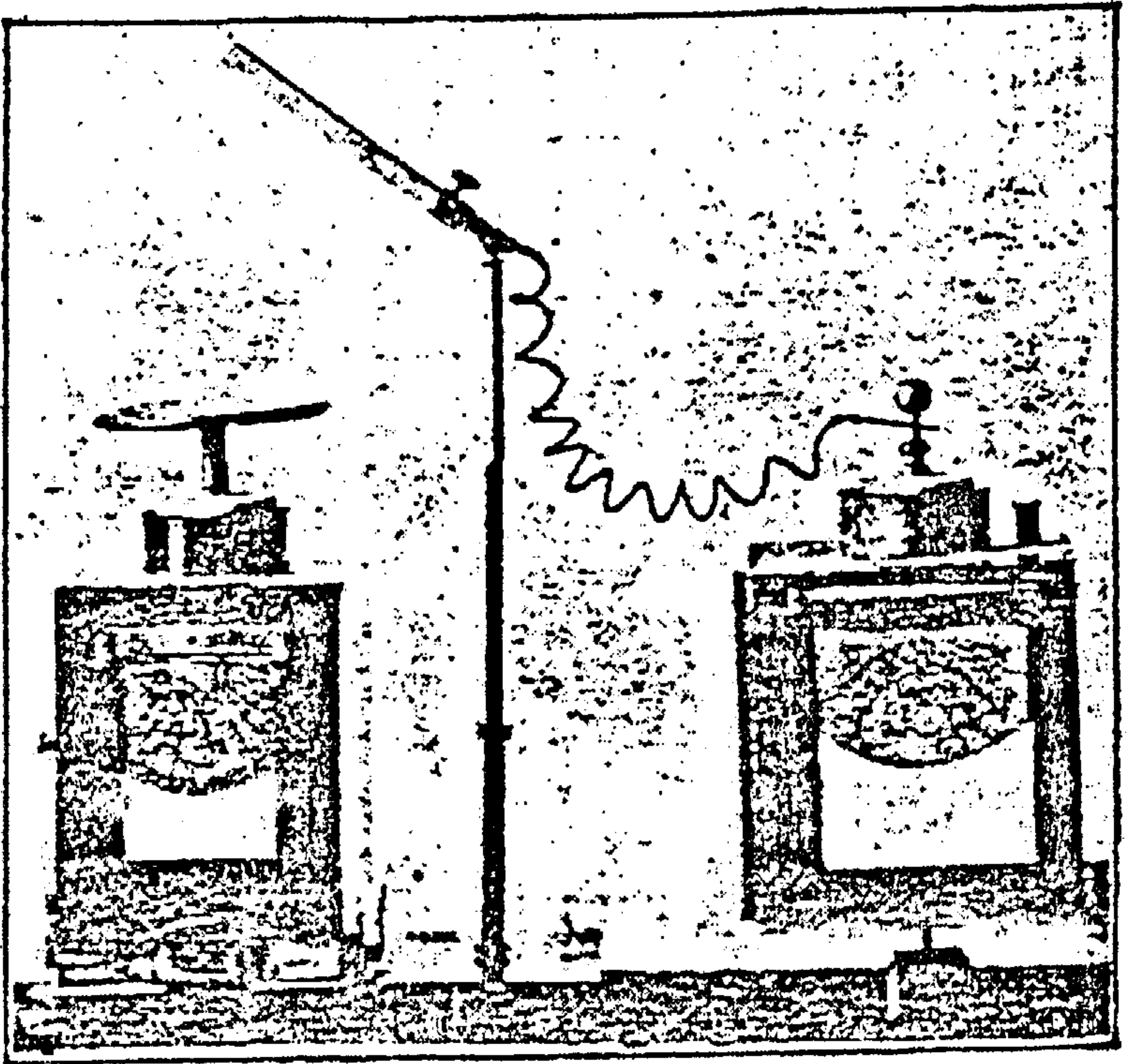


FIG. 44.—*Mechanism of the discharge of an electroscope by the effluves of the dissociated matter disengaged from the metals struck by solar light.*—The strip of metal placed on an insulating support is connected with an uncharged electroscope by a conducting wire, and placed above a charged electroscope. The apparatus being exposed to solar light, the effluves disengaged render the air a conductor. The result is that the charged electroscope discharges itself while the other becomes charged. This occurs as if the two electroscopes were connected by a wire.

dissociated matter by light, by the gases of flames, by the emanations of radio-active bodies, or, by the cathode rays, is always the same. All of them act by

rendering the air a conductor. Fig. 44 and the above explanation makes the mechanism of their action quite plain.

*Transparency of Matter to the Effluves of Dissociated Atoms.*—Do the particles of dissociated matter pass through material objects? We know that this is the case with the  $\beta$  rays of radium, but not with the  $\alpha$  rays which form 99% of the emission and are stopped by a thin sheet of paper. How do matters stand with the particles of bodies dissociated by light?

It appears easy, at first sight, to verify the phenomenon of transparency. As we possess a reagent sensitive to certain radiations, we interpose between it and these radiations, the body of which we wish to test the transparency. If the effect be produced through the object, we shall say the body has been transpierced. Nothing is more simple in appearance, and nothing more erroneous in reality.

It sometimes happens, in fact, that a body appears to have been transpierced when this has not been at all the case. It may have simply had its flank turned, which is exactly what happens in the case of very diffusible bodies, as was shown in the last paragraph, or as happens in the case of radiations with great wave-length—the Hertzian waves, for instance. It is this apparent transparency which formerly deceived physicists as to the supposed transparency of conducting and insulating bodies to electric waves. This transparency was admitted till the researches I carried out with Branly<sup>1</sup> proved that mountains and houses were passed by going round and not through them, and that if metals seemed to be transpierced, it was because the Hertzian waves passed through the cracks of the boxes which seemed

<sup>1</sup> Set forth in the *Comptes rendus de l'Académie des Sciences*, and in the *Revue Scientifique*, 1899.

to be hermetically closed—and, in fact, were so to light.

The apparent transparency may also be the consequence of the fact that when one face of a body is struck by a radiation there is produced, by a kind of induction, an identical radiation on that part of the other face which corresponds to the point struck. J. J. Thomson has maintained that this was precisely the case with the cathode rays, and Villard believes it to be the same with metals which are acted on by the radiations of radium. The photographic impression through a metal would be the simple consequence of a secondary emission on the posterior face of the strip opposite to the point struck.

We have a rough example of what happens in these various cases by taking, for instance, the propagation of sound. A person shut up within a completely closed metal chamber will hear very clearly all the musical instruments played outside that chamber. The vibrations of the air which produce the sound appear thus to pass through the metal. We know, however, that it is not so, and that the air which strikes the metal walls simply causes them to vibrate. The vibrations on one of the faces of the metal are propagated to the other face, which in turn causes the air in contact with it to vibrate. The vibrations seem thus to have passed through the metal, which, notwithstanding, is absolutely opaque to the air.

A like reasoning, however, may perhaps be applied to all forms of the transparency of bodies. We might even include the case of transparency to light, could this hypothesis be easily reconciled with the phenomenon of aberration.

However this may be, the complete solution of the problem of transparency is difficult, and the single fact that eminent physicists have been unable to agree on

the transparency of bodies for the cathode rays and for the emanations of radio-active bodies is sufficient to show the difficulties of the question. All we can say about an apparently transparent body is that things occur exactly as if it were transparent.

In the case of the effluves from matter dissociated by light, the problem is further complicated by the extreme diffusion of these effluves, which enables them, as we have seen, to go round objects. To simply interpose a strip of metal between the effluves and the electroscope would lead to very erroneous results. It would require to be of excessively large dimensions, which would not be very workable.

To prove the transparency—or, if it be preferred, the equivalent of transparency—it is necessary that the body one wishes to work with should be surrounded by an enclosure shut up on all sides. This I was able to obtain by means of my condensing differential electroscope, thanks to which it has been possible to study the transparency of bodies for the effluves emitted by light, by radio-active bodies, by the gas of flames, by chemical reactions, etc. Its use has permitted us to verify apparent transparency; but in further studying the phenomenon, I was led to recognize, as will be detailed later on, that all bodies contain an emanation similar to that belonging to spontaneously radio-active bodies, which appears to be the cause of the actions observed.

*Elimination of Causes of Error. Influence of the Hertzian Waves accompanying the Electric Sparks used to produce the Ultra-violet.*—All the experiments described above are extremely easy of repetition when made with the sun. There are only two precautions to be observed in this case. The first is to clean vigorously with emery-cloth every ten minutes the metal operated on, an

operation not required when using the ultra-violet rays obtained by means of electric sparks; the second consists in replacing the ordinary knob of the electroscope, with which the charge is insignificant, by a copper plate about 10<sup>cm</sup> in diameter. It is quite unnecessary to clean this latter.

The importance of a large receiving surface is paramount, and it is because many observers have neglected this essential point that they have been unable to repeat my former experiments.

When we have to do with very refrangible radiations, which do not exist in the solar spectrum at our altitudes, and can only be produced by means of electric sparks, the experiments become much more delicate; and if certain precautions are not taken, we are exposed to the causes of error I now point out. The most important consists in the action of electric influences capable of discharging the electroscope. Doubtless it suffices to hide the light of the sparks with black paper to be able to see if all discharges are suppressed, which is not the case when electrical influences supervene. But when one notices that these last are produced, it is not always an easy matter to suppress them.

The means generally employed to eliminate them consists in covering the quartz window of the spark-box with fine transparent wire gauze let into a frame made of a large strip of metal and connected with the earth, but this means is not always sufficient. Invariably examining after each experiment whether the action on the electroscope ceased when the light was covered up with black paper, I several times perceived rapid discharges due to electrical influences. As they did not act equally on both the positive and the negative electricity with which the electroscope was charged, but only on one of them, I conceived the idea of getting rid of them by connecting with the earth, without any change in the rest of the

arrangements, one or other of the coatings of the Leyden jars employed according to the direction of the discharge observed. This means always succeeded.

What is the origin of the electrical influences which are formed round the sparks of the electrodes, and of which physicists have often pointed out the existence and the effects without ever attempting to determine their nature? Not being able to find any hints on the subject, I was led to inquire of what they consisted. They are simply very small Hertzian waves. It was difficult to anticipate this, for they were not supposed to be produced by discharges between points.

Their existence is proved, either by the illumination at a distance of a Geissler tube (which necessitates working in the dark) or, better, by using a coherer in circuit with an easily working bell and a battery. This apparatus, which may remain fixed, as shown in several of the figures, immediately reveals to the ear, by the ringing of the bell, the formation of any Hertzian waves which may interfere with the experiment.<sup>1</sup>

By bearing in mind the researches I made together with Branly, on the enormous diffraction of the Hertzian waves which permits them to travel round all obstacles, and on the passage of these waves through the smallest crevices, it will be understood that it is very difficult, notwithstanding all possible precautions, to avoid their influence when they form. They must therefore be prevented from forming. Here are, from my obser-

<sup>1</sup> The Hertzian waves can not only discharge an electroscope, whether charged positively or negatively, but likewise recharge it again, sometimes positively, sometimes negatively, provided it be not placed beyond about a metre from the source of the waves. This can be verified by placing the electroscope at a distance of one metre from a Righi radiator and covering up the light of the sparks with a large sheet of black paper.

vations, some of the conditions in which they are generated:—

Hertzian waves manifest themselves when the spark-box is not carefully insulated from its support by a coating of paraffin. They also manifest themselves when the electrodes are too far apart, and especially when their points are blunted, which happens when they have been working for some time. The Hertzian waves which then form are very small and are hardly propelled farther than 50 to 60 cm., but they are sufficient to disturb the experiments. They disappear as soon as the extremities of the electrodes have been filed to very sharp points.

There exist other causes of the production of Hertzian waves in these experiments, but to enumerate them would carry us too far. With the arrangement I have described and figured in the plates, the operator will always be warned of their presence.

Among the causes of error which I must point out, there is one which has never, to my knowledge, been mentioned anywhere, and is of considerable importance. I refer to the superficial alteration in a strip of quartz exposed for less than a quarter of an hour to the sparks of the electrodes. It becomes covered with an almost invisible layer of particles of dust which suffice to render it opaque to the ultra-violet rays of a length inferior to  $0.250\mu$ . When quartz thus altered is used, it is as if use were made of a strip of thin glass, opaque, as we know, to the extreme ultra-violet; and all the effects observed are falsified. This cause of error, which occasioned me much loss of time, is very easy to avoid, since it is sufficient to wipe the quartz with fine linen cloth every ten or fifteen minutes.

All these causes of error may also have an influence on the so-called negative leak which we shall shortly study.



*Interpretation of the Preceding Experiments.*—We have already interpreted the experiments set forth in this chapter, and shall simply recall the fact that all the products of the dissociation of bodies by light are identical with those obtained from radio-active substances. There is the same deviation of the particles by a magnetic field, the same ratio  $\frac{e}{m}$  of the mass to the electric charge, etc.

But how are we to explain this dissociating action of a weak ray of light on a rigid metal? The explanation is not easy. I shall confine myself to reproducing that given by Professor de Heen in his memoir, *Les Phénomènes dits cathodiques et radio-actifs*:—

“When a luminous ray falls on the surface of a metallic mirror, the ions vibrate in unison with part or the whole of the radiations striking it. Therefore, during the action of this radiation, a superficial pellicule of infinitesimal thickness vibrates with the frequency of certain oscillations of the source itself. In the case of luminous and ultra-violet radiations, this surface actually corresponds to an excessive temperature imperceptible to the touch, because, its thickness being very slight, the quantity of heat confined in this pellicule is entirely negligible.

“Now, if this is so, the metallic surface, subjected to a luminous and, more especially, to an ultra-violet radiation, will be traversed in all directions by currents which we shall term high frequency currents.

“The ions will be subjected to such repellent actions that they *will jump*. Thenceforth the surrounding space will be subject to ionic projections, or radiations, similar to those noticed in vacuum tubes.

“Such is the interpretation of the fundamental fact discovered for the first time by Gustave Le Bon, which will be found at the basis of this new chapter in physics.

This physicist thenceforth supposed that this manifestation belonged to an order of natural phenomena *absolutely general*. It was this idea, much more than the admirable experiment of Röntgen, which decided me to take up the study of electric phenomena."

## CHAPTER IV.

### EXPERIMENTS ON THE POSSIBILITY OF RENDERING BODIES RADIO-ACTIVE WHICH ARE NOT SO. COMPARISON BETWEEN SPONTANEOUS AND PROVOKED RADIO-ACTIVITY.

THE idea that radio-activity is due to chemical reactions led me to search for the means of rendering artificially radio-active bodies which are not so. In this case we are quite certain that the presence of radium, uranium, or other similar substance counts for nothing in the radio-activity.

It will be seen later on that various chemical reactions, such as hydration, can produce this radio-activity. I shall now show that bodies presenting only traces of radio-activity under the influence of light, such as mercury, can, on the other hand, become extremely radio-active. It is sufficient to add to this metal a  $\frac{1}{1000}$ th of its weight in tin, a body which is no more radio-active under the influence of ordinary light than mercury. With this proportion of tin, mercury is sensitive only to the solar ultra-violet from  $\lambda = 0.360\mu$  to  $\lambda = 0.296\mu$ ; but if the proportion of tin be increased to 1%, the mercury is dissociated by most of the rays of the visible spectrum.

It was interesting to compare the radio-activity artificially given to a body with that of spontaneously radio-active bodies such as thorium and uranium. The experiment being very important, I will simplify it to such a degree that it can be easily repeated at a lecture.

The first thing is to determine the degree of dissociation of a body by light, and then to compare it with that of a spontaneously radio-active substance—a salt of uranium, for instance. We shall see that the dissociation provoked by light is much more important.

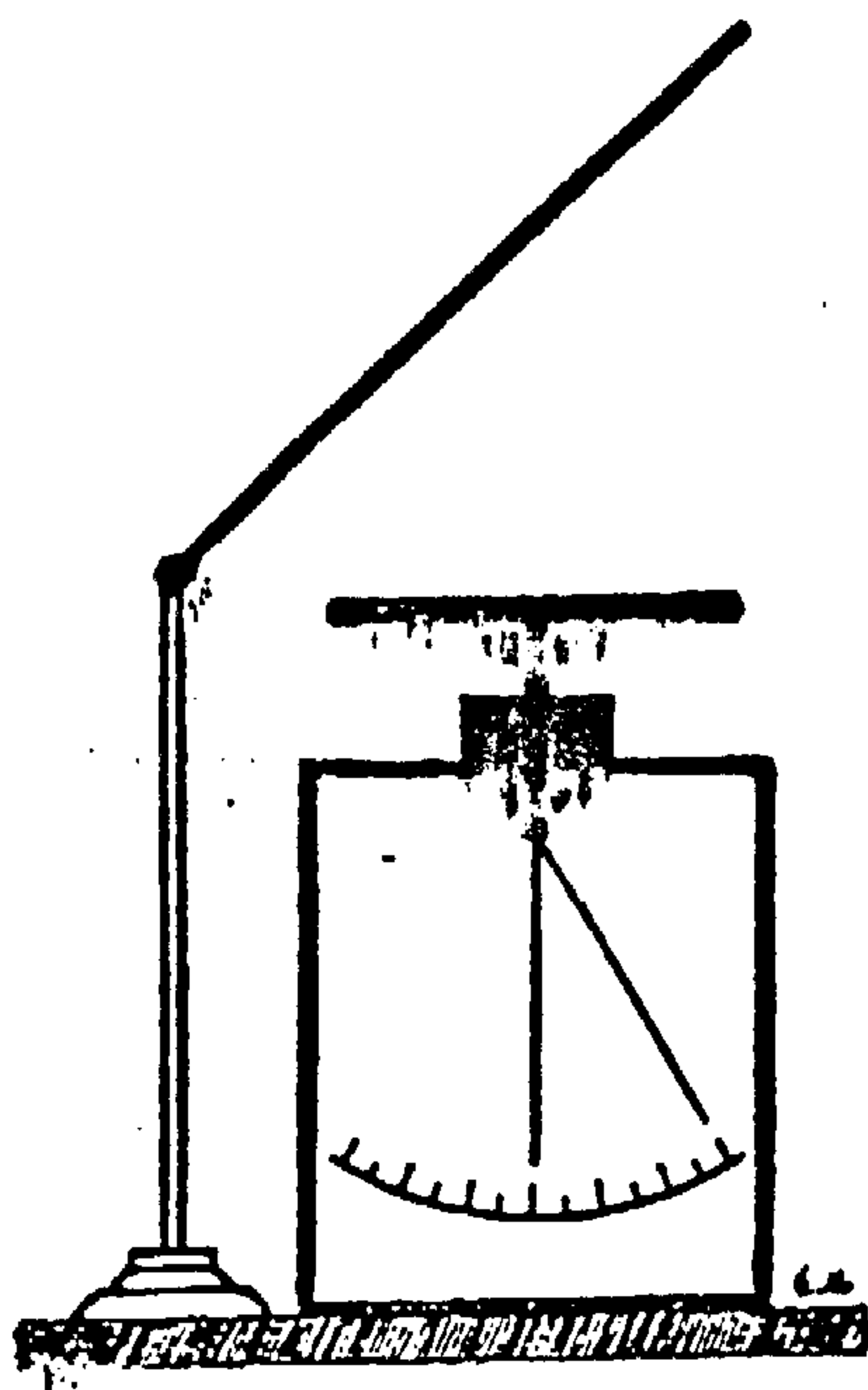


FIG. 45.—Comparison of the dissociation of spontaneously radio-active bodies and of metals under the influence of light.—A tin mirror prepared as described in the text and a screen of the same size coated with oxide of thorium or of uranium are used alternately. The dissociation of the atoms of the tin under the influence of light is forty times more rapid than that of the radio-active bodies just mentioned.

A strip of tin is taken, 10 cm. square and 2 cm. thick. Its borders are fastened by means of four narrow bands of gummed paper to a cardboard screen of the same size, and the whole is plunged for twenty-four hours into a bath of mercury, wiping off from time to time the layer of oxide formed on the surface. The strip thus prepared, which the cardboard prevents from breaking, will indefinitely retain its radio-activity under the influence of light so long as its surface is very slightly wiped with the finger from time to time.

This done, the experiment is arranged as indicated (Fig. 45). The electro-scope is inductively charged by an ebonite rod; its charge is, in consequence, positive.

By arranging the strip of tin so that the sun may strike its surface, it will be noticed that the gold leaves

strike its surface, it will be noticed that the gold leaves

draw together in a few seconds. With a diffused light, the discharge still takes place, but more slowly.

Having noted the number of degrees of discharge in a given time, the experiment is commenced anew with a screen covered with a salt of uranium, prepared in the following manner:—

Nitrate of uranium is pounded in some bronzing varnish, and spread on a cardboard screen of exactly the same size as the strip used in the preceding experiment (10 cm.  $\times$  10 cm.). If this screen be arranged, and the electroscope charged as previously indicated (Fig. 45), a discharge of about 6° in 60 seconds will be noted. By operating in the sun with a mirror of amalgamated tin placed at exactly the same distance from the electroscope, it was shown that this latter discharged itself at the rate of 40° in 10 seconds. It is therefore seen *that artificial radio-activity given to a metal by light may be forty times greater than the spontaneous radio-activity possessed by salts of uranium.* With oxide of thorium, approximate figures are obtained. If we suppose, with Rutherford, that 1 gramme of uranium emits 70,000 particles per second, it follows that metals, which under the dissociating influence of light have an activity four times as great, would emit, surfaces being equal, nearly 3,000,000 particles per second.

## CHAPTER V.

### EXPERIMENTS ON THE SO-CALLED NEGATIVE LEAK CAUSED BY LIGHT IN ELECTRIFIED BODIES.

SINCE Hertz' experiments, it has been known that a conducting body electrified negatively loses its charge if it be subjected to the action of the ultra-violet rays obtained from electric sparks, and it is recognized in more recent works—

1st. That this leak can only take place under the influence of the ultra-violet light; 2nd. That it is the same for all metals; 3rd. That the discharge only takes place when the charge of the metal is negative<sup>1</sup> and not positive.

Elster, Geitel, and Branly, it is true, mentioned some time ago two or three metals which discharged in ordinary sunlight, and the last-named cited several bodies which show the positive leak; but these phenomena were considered as exceptional and as in no wise possessing a general character.

As the subject did not appear to me exhausted, I deemed it well to take it up anew. Although there is a certain difference between the phenomena of the discharge of a body already electrified and that of the production of effluves emanating from an unelectrified body and capable of acting on an electrified one as shown in the preceding chapter, yet the two phenomena

<sup>1</sup> "The ultra-violet rays only act when they meet with a surface positively electrified."—Bouty, 2nd Supplement to the *Physique* of Jamin, 1899, p. 188.

have the same cause—namely, the dissociation of matter by light. No experimenter had suspected this cause before my researches.

The experiments I am going to set forth prove—1st, that the so-called negative leak is also, though generally in a lesser degree, positive; 2nd, that the discharge takes place under the influence of the various regions of the spectrum, although the maximum occurs in the ultra-violet; 3rd, that the discharge is extremely different in the various bodies, the metals especially. These are, as will be seen, three propositions exactly contrary to those generally received and recapitulated above. Now for the justification of them.

*Method of Observation.*—For studying the negative leak in solar light the method of observation is quite simple, since we have only to place the body, the discharge of which is to be observed, on the plate of the electroscope, and it charges itself at the same time as the latter. This charge is given by influence either by a glass or an ebonite rod, according to the sign of the charge desired. Care must be taken that the gold leaves are the same distance apart in all cases.

When it is desired to study the discharge produced by the ultra-violet rays beyond the solar spectrum, recourse must be had to the special arrangement shown in Fig. 46.

The bodies to be studied are fixed in a clamp replacing the ball of the electroscope. They become charged with electricity at the same time as the latter. The light is supplied by aluminium electrodes connected with the coatings of a condenser kept charged by an induction coil giving sparks of about 20 cm. The electrodes are placed in a box with a quartz window covered over with wire gauze framed in a sheet of metal and earthed.

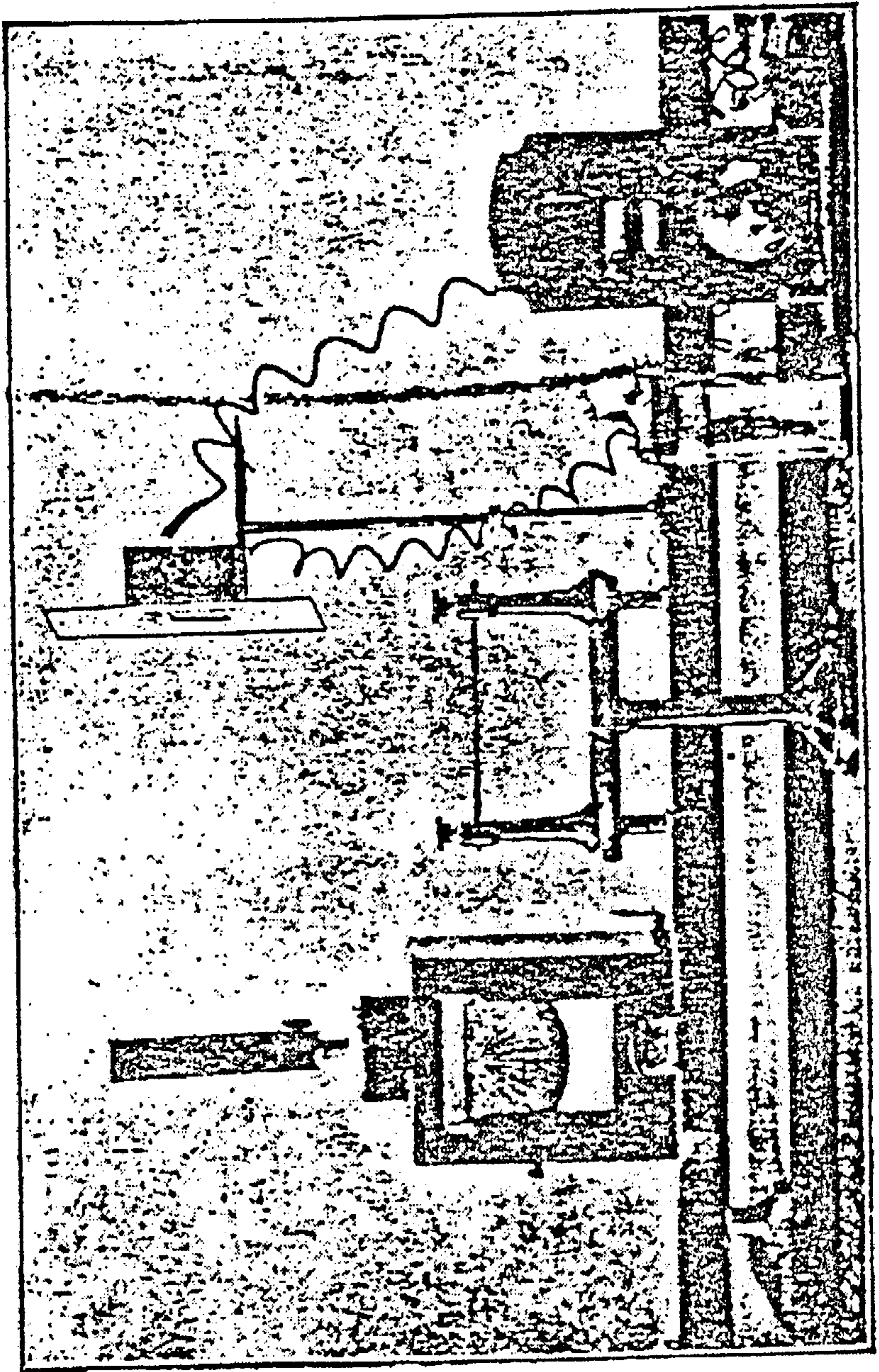


FIG. 46.—Apparatus employed for the study of the leak under ultraviolet light of electrified bodies.—The coil used for the production of the spark is not shown in the Fig. On the right is seen the bell and coherer which reveal the production of Hertzian waves capable of disturbing the experiments.



The distance at which the electrified body is placed from the source of light plays, at least for very refrangible rays, a most important part, and it is useful to mount the electroscope, as I did, on a graduated bar which allows its distance from the source of light to be regulated.

When one wishes to separate the various rays of the spectrum, one works, as I said before, by means of various screens interposed between the source of light and the electroscope, and the transparency of the screens is determined by the spectrograph.

When the experiments are made in the sun, the plates of metal must be very frequently cleaned with emery-cloth (every ten minutes at least), but as we advance into the ultra-violet this cleaning becomes of less importance. It is no longer every ten minutes, but only once every two or three days that it needs repetition. With so long an interval when operating in the sun, the discharge would not be entirely suppressed, but would become more than a hundred times less. For the light from electric sparks, the omission of the cleaning only reduces the discharge by a half or two-thirds.

I have, however, succeeded in forming alloys requiring, for experiments in the sun, no cleaning and preserving their properties for about a fortnight, with the simple precaution of passing a finger on their surface, from time to time, in order to clear away the dust or the slight layer of oxide which may have formed. The best are strips of amalgamated tin prepared as directed in a former paragraph.

*Negative Leak in the Light of the Sun.*—The following table shows the rate of discharge in light of a strip of metal 10 cms. square placed on the plate of the electroscope. This rapidity is calculated from the time

necessary to produce a discharge of 10 degrees, the maximum of rapidity being represented by 1000.

*Rapidity of the negative leak in the solar light.*

Amalgamated tin	-	-	1000
Amalgamated zinc	-	-	980
Aluminium recently cleaned	-	-	800
Amalgamated silver	-	-	770
Magnesium recently cleaned	-	-	600
Zinc recently cleaned	-	-	240
Amalgamated lead	-	-	240
Cadmium	-	-	14
Cobalt	-	-	12
Gold, steel, copper, nickel, mercury, lead, silver, phos- phorescent sulphides, car- bon, marble, wood, sand, etc.	-	-	2 (maximum).

All these bodies discharge themselves when charged positively, but in the light of the sun the leak is throughout very weak (1 degree at most in 1 or 2 minutes). It increases greatly when the light of the sun is replaced by the light from electric sparks, but its maximum is no way produced, as is the case with the negative leak, by the radiations of the end of the spectrum. The fact is proved by this very simple experiment. A thin strip of glass one-tenth of a millimetre thick which considerably retards the negative leak in many cases when placed before the source of light, has only a very feeble diminishing action on the positive leak. *The radiations which produce the negative leak are, therefore, not the same as those producing the positive leak.*

*Leak with Bodies charged with either Sign in the Electric Ultra-violet Light.*—Substances in strips are

arranged as before, or, what comes to the same thing, are fixed vertically on the electroscope by a clamp as in Figure 46. The source of light (electric sparks) is placed at 20 cm. from the body on which it is to act. The tables below give, for this distance, the intensity of the discharge of the bodies charged either negatively or positively under the light from electric sparks. The greatest negative leak corresponds to  $6^\circ$  per second ( $360^\circ$  per minute); the slowest to  $\frac{1}{2}^\circ$  per second ( $30^\circ$  per minute). For the positive discharge it is much weaker, since it varies between  $7^\circ$  and  $16^\circ$  per minute. Taking 1000 as the maximum rapidity of leak, the following figures are obtained:—

1st. *Negative leak in the ultra-violet light of electric sparks.*

Aluminium	-	-	-	-	1000
Amalgamated tin,	-	-	-	-	680
Zinc	-	-	-	-	610
Red copper	-	-	-	-	390
Cadmium	-	-	-	-	340
Cobalt	-	-	-	-	270
Tin	-	-	-	-	270
Nickel	-	-	-	-	240
Lead	-	-	-	-	210
Silver	-	-	-	-	200
Steel (polished)	-	-	-	-	80

2nd. *Positive leak under the same light.*—The discharge of the electroscope varies from  $16^\circ$  per minute in the case of nickel, zinc, and silver to  $7^\circ$  in that of steel. There is, therefore, no question of an insignificant discharge, but of a really very important one.

The above figures represent the leak produced by the totality of the luminous radiations given by the sparks proceeding from aluminium electrodes.

From the foregoing we may conclude that *all electrified bodies exposed to the ultra-violet light are subject to a negative or positive leak without any other difference than that of intensity.*

*Far from being identical in all bodies, as was asserted up to the present, this leak varies considerably according to the bodies employed.*

*Sensitiveness of various Bodies to the Different Regions of the Ultra-violet. Elimination of Causes of Error.*—The rapidity of the discharge of divers bodies varies greatly with the several regions of the spectrum, as may be gathered from the hints in a preceding paragraph. Some, such as aluminium, zinc, etc., are sensitive to the regions of the visible solar spectrum; others, such as nickel, steel, platinum, etc., are only sensitive to the extreme region of the ultra-violet of the electric spectrum: which is why a simple plate of glass, one-tenth of a centimètre thick, placed before the quartz window of the spark-box stops all discharges for the nickel series, but stops only a part of the discharge produced by the other.

The figures given above show that there is a predominance of the negative leak over the positive for good conducting bodies—that is to say, metals. It is otherwise with bad conductors—such as wood, cardboard, paper, etc. For these latter the positive discharge, as pointed out by Branly, may become equal to the negative discharge, and even exceed it. But we must here take account of two sources of error which appear to have escaped former observers.

The first, already mentioned, is the state of the quartz. If not cleaned every 10 minutes it absorbs the extreme region of the ultra-violet, and as this absorption does not prevent the positive leak produced by less refrangible regions, the negative discharge will

be diminished, and, consequently, may appear the same as or less than the positive leak. Such would be the case with a metal much oxidized or covered by a greasy body which is sensitive only to the extreme regions of the ultra-violet.

The second cause of error is the considerable influence of distance. The most extreme regions of the spectrum are most active on the negative discharge, while they have a rather weak action on the positive. Being absorbed by the air in an increasing degree as its density increases, it follows that their effect on the negative discharge becomes slower as the distance from the source of light is increased. Thus, at 25 cm. from the spark, the positive discharge of wood will be double the negative discharge; at 8 cm. it is the other way—the negative leak will then be four times greater than the positive. The paramount importance of distance in these experiments is therefore obvious. To this should be added that at a short distance the dissociation of the gases of the air begins to manifest itself;—a matter I will go into later.

Having made these reservations, I give here the positive and negative discharges observed in some of the bodies in which experiments were made at a distance of 25 cm.

I give the figures of the discharges in degrees of the electroscope per minute, without bringing them to 1000, as in the preceding experiments:—

	Negative discharge in 1 minute.	Positive discharge in 1 minute.
Various woods (deal, teak, plane)	6°	10°
Yellow cardboard	10°	16°
Lamp-black	61°	7°

It will be seen that for several of the bodies on which the experiments were made, the positive discharge was

markedly superior to the negative discharge. The rays which produce the negative discharge on these various bodies have a wave-length under  $0.252\mu$ , and it suffices to suppress them from the spectrum for the negative charge to be likewise suppressed.

The sensitiveness of black bodies, especially lamp-black spread on a strip of cardboard, is considerable. I have obtained  $61^\circ$  of negative discharge per minute, at a distance of 25 cm., from the spark; but at 10 cm., it rises to figures which would represent  $300^\circ$  for the same length of time (figures approaching the sensibility of the most sensitive metals). With the same variations in distance, the positive leak only increases from  $7^\circ$  to  $12^\circ$ .

*Influence of the Nature of the Electrodes.*—The nature of the electrodes employed to produce the electric sparks has a considerable influence, as already stated, and this influence is not the same for the positive as for the negative discharge. The following table gives the leak per minute, calculated from the number of seconds necessary to produce  $10^\circ$  of discharge, with electrodes of various metals acting by the light they produce on a strip of electrified zinc connected with the electroscope:—

	Negative discharge per minute.	Positive discharge per minute.
Aluminium electrodes	$246^\circ$	$18^\circ$
Steel            ,,	$140^\circ$	$10^\circ$
Gold             ,,	$112^\circ$	$4^\circ$
Copper          ,,	$110^\circ$	$3^\circ$
Silver           ,,	$108^\circ$	$6^\circ$

According to the electrodes used, the negative discharge may, it will be seen, vary from single to double, and the positive discharge from single to triple. I have already shown that this phenomenon is not due

to the length of the spectrum of the metals, since that of gold goes as far as that of aluminium.

By comparing the various tables published in this work, it will be seen that the leak produced by solar light is far different from that resulting from the action of electric light. This is due solely to the fact that the spectrum of the light from electric sparks is much further extended into the ultra-violet than that of the solar light.

It is easy to give to the electric spectrum properties identical with those of the solar spectrum, by arresting in the former case the rays which do not exist in the latter. All that is required for this, is to replace the quartz in front of the sparks by a glass plate  $0.8^{\text{m}}$  thick. This stops all radiations which do not occur in the solar spectrum—that is to say, those exceeding  $0.295\mu$ . It is then noticed that metals which, like copper, produce a very rapid discharge in the electric light and hardly any in the sun, become insensible to the electric light; while metals like aluminium, which produce a discharge in the sun, continue to produce it in the electric light.

*Divers Influences able to vary the Leak of Electricity under the Action of Light.*—Several causes, in addition to those mentioned already, also cause the leak of electricity to vary under the action of light, notably of that of the sun. As in order to study these variations a body with a constant sensitiveness was required, I made use of plates of amalgamated tin as before mentioned. This substance is extremely active, but only attains its maximum of intensity after an exposure of some minutes to the light, a fact precisely contrary to what is observed in various metals, especially aluminium and zinc.

The best of all bodies with a constant sensitiveness, if its manipulation were not so inconvenient, is mercury containing a small proportion of tin. With a thickness of

its weight in tin, it is, as I have said, only sensitive to the advanced regions of the solar ultra-violet—that is, beyond about the ray M. By increasing the proportion of tin to  $\frac{1}{10}$ th, it becomes sensitive for a far more extended region of the spectrum.

Continuous researches for eighteen months with plates of amalgamated tin proved to me that the sensitiveness of metals to light—that is to say, the time taken by them to lose the electric charge they have received—varied not only with the hour of the day, but also with the season. The figures I first gave several years ago, having been taken in winter and in very cold weather, were too low.

The discharge is always less rapid in winter than in summer, but during the same day it may vary in the proportion of 1 to 4. It diminishes rapidly as the hours progress. For instance, on the 9th August 1901 the discharge, which at 4.30 p.m. was  $50^\circ$  per minute, fell to  $16^\circ$  at 5.50 p.m. On the 24th August 1901, the discharge, which was  $80^\circ$  per minute at 3.25 p.m., fell to  $40^\circ$  at 4.30 o'clock. For several days I followed, hour by hour, the variations of the leak, and drew up tables of them. There would be no interest in publishing them, for the differences do not depend on the hours, but mainly on the variations of the solar ultra-violet, which often disappears in part (from M, and even from L) under the influence, as I have already stated, of causes totally unknown.

Clouds do not sensibly reduce the discharge, which remains about the same as in the shade. Nor does their presence noticeably reduce the solar ultra-violet, which I have been able to photograph through fairly thick clouds.

*Dissociation of the Atoms of Gases in the Extreme Region of the Ultra-violet.*—We have just seen that all bodies,



simple or compound, conductors or insulators, subjected to the action of light undergo dissociation. But among none of the bodies examined up to now do gases appear. Are we to suppose that they escape the common law?

This exception seemed improbable. Yet up to Lenard's last researches the dissociation of gases by the action of light had not been observed. No doubt it was supposed that the discharge of electrified bodies, when struck by light, might be due to the action of the luminous rays in the air, but this hypothesis fell to the ground in face of these two facts—first, that the discharge varies according to the metals, which would not be the fact if it were the air and not the metal which was acting; and second, that the discharge takes place still more rapidly in a vacuum than in the air.

The reason of this apparent indifference of gases, air especially, to the light which strikes them is very simple. Some metals are dissociable only in a very advanced region of the ultra-violet. If gases should happen to be dissociable only in still more advanced regions, the observation of their dissociation must be difficult, seeing that the air with slight density is as opaque as lead for the radiations of the extreme ultra-violet.

Now, as Lenard has shown,<sup>1</sup> it is solely in this extreme region of the ultra-violet that what was then called the ionization of gases, which is no other than their dissociation, is possible. He saw that it sufficed to bring the bodies under experiment to within a few centimètres from the source of light—that is, from the electric spark—for the discharge to be the same for all.

<sup>1</sup> "Über Wirkungen des ultra-violetten Lichtes auf gasförmige Körper" (*Annalen der Physik*, Bd. 1., 1900).

bodies,<sup>1</sup> which shows that it is then the air which becomes the conductor and acts. It is light, and no other cause, which intervenes, for the interposition of thin glass stops all effect.

By a special arrangement, which there would be no advantage in describing here, Lenard has measured the wave-length of the radiations which produce the ionization of the air. They begin towards  $0.180\mu$ —that is to say, just at the limits of the electric spectrum as formerly known ( $0.185\mu$ ), and extend as far as  $0.140\mu$ .<sup>2</sup> The discovery of these short radiations is, as is

<sup>1</sup> In a former memoir Lenard asserted that the nature of the charge was indifferent, and even gives this fact as new: "Das aber positive Ladungen in Licht fast ebenso schnell von der Platte verschwinden, stimmt nicht mit Bekannten überein" ("Über Wirkungen des ultravioletten Lichtes, in *Annalen der Physik*, 1900, p. 499).

In a subsequent memoir (same publication, vol. 3, p. 298) Lenard indicates, contrary to his first assertion, that the positive is superior to the negative charge. In his first experiments there must have arisen causes of error, such as the production of Hertzian waves, which the eminent physicist subsequently eliminated.

<sup>2</sup> The production of these very refrangible rays seems due partly to the tension of the current which produces the sparks. Lenard, whose memoir is very summary, gives no details on this point, and confines himself to saying that he added to the Leyden jars a very large coil fitted with a Wehnelt interrupter. The influence of this coil is very evident from the fact that it increased the effect fivefold by modifying the primary, but he gives no further details save those indicated in this three following lines:—

"Hierin konnte zunächst Vorteil erzielt werden durch Anbringung einer zweckmässigeren Primärwicklung im Inductorium, es verfünffachte dies bisher in Luft erreichte Entfernung" (p. 491).

The tension of the sparks cannot be the sole factor to be noticed. I have considerably increased it by the well-known Tesla apparatus, but without obtaining any greater advantage than a slight increase in the positive and a slight decrease in the negative discharge. The contradictory results in the nature of the discharge noted by Lenard in his two memoirs and those repeatedly noted by myself seem to indicate that the action of causes yet unknown is at times superposed on that of known actions.

known, due to Schuman. By creating a vacuum in a spectrograph, he proved that the ultra-violet spectrum, which, from the incorrect measurements of Cornu and Mascart, were believed to be limited to  $0.185\mu$ , in reality extended much farther. He has succeeded in photographing rays reaching as far as  $0.100\mu$ . It is probably the absorption exercised by the gelatine of the sensitive plates, and no doubt also by the material of the prism, which prevents further progress.

As we advance into the ultra-violet spectrum, all bodies, the air especially, become more and more opaque to the radiations. It would therefore be very surprising if the X rays, which pass through all bodies, were constituted by the extreme ultra-violet, as some physicists have maintained.

Most bodies, including air of a thickness of 2 cm. and water of a thickness of 1 mm., are, in fact, absolutely opaque for these radiations of very short wave-length. There are hardly any transparent to them except quartz, fluor spar, gypsum, and rock salt, and even these only on condition of their surface not being roughened. Pure hydrogen is equally transparent.

The extremely refrangible radiations of light therefore dissociate, not only all solid bodies, but also the particles of the air they pass through, while radiations less refrangible possess no action on gases, and only dissociate the surface of the solid bodies they strike. These are two very different effects which may be superposed on each other, but which will not be confused if it be borne in mind that when it is the air that is decomposed, the nature of the metal struck and the state of its surface are points of no importance; while the leak varies considerably with the metal when it is the latter that becomes dissociated. Besides, the influence of the extreme ultra-violet can be almost entirely avoided by removing the source of light to a little

distance, since a layer of air of 2 cm. suffices to stop this region of the spectrum. If, therefore, the sparks from the electrodes are at several centimètres from the quartz window of the spark-box, no effect due to the decomposition of the air can be produced.

In comparing some of the experiments set forth so far, it will be noticed that those bodies which absorb most light are precisely those which are the most dissociable. For example, air which absorbs the radiations below  $0.185\mu$ , is decomposed by these radiations. Lamp-black, which completely absorbs light, is energetically dissociated by it, and disengages effluves in abundance. This explanation does not appear at first sight at all to tally with the fact that metals which have recently received a mirror polish are likewise the seat of an extremely abundant disengagement of effluves. The objection vanishes, however, when it is considered that polished metals which reflect visible light very well reflect very badly the invisible light of the ultra-violet extremity of the spectrum, and absorb the greater part of it. Now, it is precisely these absorbable and invisible radiations which produce most effect.

To give a clear idea of the properties of the various parts of the ultra-violet spectrum, I will put them in tabular form. It shows that the aptness of light to dissociate bodies increases with every step into the ultra-violet.

*The Property of Dissociating Matter possessed by the various Parts of the Ultra-violet Spectrum.*

From $0.400\mu$ to $0.344\mu$	These radiations pass through ordinary glass. They can only dissociate a small number of metals, and even then only if they have been recently cleaned.
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*The Property of Dissociating Matter possessed by the various Parts of the Ultra-violet Spectrum—continued.*

From $0.344\mu$ to $0.295\mu$	The ultra-violet of this region only passes through glass not thicker than $0.8\text{mm}$ . After $0.295\mu$ , it is completely absorbed by the atmosphere, and consequently plays no part in the solar spectrum. This region, though much more active than the preceding one, has still only a rather weak dissociating activity on most bodies.
From $0.295\mu$ to $0.252\mu$	The ultra-violet of this region is not met with in the solar but only in the electric spectrum. It can only pass through glass plates not exceeding $0.1\text{mm}$ , in thickness. Its dissociating action is much more intense and more general than that of the preceding region of the spectrum, but much less than that of the following region. It dissociates all solid bodies, but has no action on gases.
From $0.252\mu$ to $0.100\mu$	This region of the ultra-violet is so little penetrating that air, as soon as the radiations of $0.185\mu$ are reached, is as opaque to it at a thickness of two centimètres as metal. A glass plate one-tenth of a millimètre thick stops this extreme ultra-violet absolutely. The dissociating power of this region is much greater than that of the other parts of the spectrum. Starting from $0.185\mu$ , it dissociates not only all solid bodies, metals, wood, etc., but also the gases of the air on which the preceding region of the spectrum had no action.

To sum up, the more we advance into the ultra-violet—that is to say, the shorter the wave-lengths of the radiations become, the less penetration these

radiations have; but their dissociating action on matter shows itself more and more energetically. At the extremity of the spectrum all bodies are dissociated, including gases, on which the other parts of the spectrum have no action. *The dissociating action of the various luminous radiations is therefore in inverse ratio to their penetration.*<sup>1</sup>

The law thus formulated was quite unforeseen previous to my researches. All earlier observations seemed to show that the rays at the ultra-violet end of the spectrum possessed so slight an energy as to be almost inappreciable by the most delicate thermometers. It is, however, these radiations which most quickly dissociate the most rigid bodies, such as steel, for example.

<sup>1</sup> These experiments on the electrical charges induced by ultra-violet light have been lately repeated in precise and careful fashion by Sir Wm. Ramsay and Dr. Spencer. The results are given in the *Philosophical Magazine* for October 1906, to which the reader is referred.  
—F. L.

## CHAPTER VI.

### EXPERIMENTS ON THE DISSOCIATION OF MATTER IN THE PHENOMENA OF COMBUSTION.

*General Action of the Gases of Flames on Electrified Bodies.*—If feeble chemical reactions, such as a simple hydration, can, as we shall see later, provoke the dissociation of matter, it is conceivable that the phenomena of combustion which constitute intense chemical reactions must realize the maximum of dissociation. This is, in fact, what is observed in the gases of flames, and has led to the supposition that incandescent bodies give forth into the air emissions of the same family as the cathode rays.

For at least a century it has been known that flames discharged electrified bodies, but no pains whatever were taken to search for the causes of this phenomenon, although it was one of primary importance.

The first precise researches on this subject are due to Branly. It is he who pointed out that the active parts of flames are the gases emitted by them. He also studied the influence of temperature on the nature of the discharge. Using as a source of radiation a platinum wire made more or less red hot by an electric current, he noted that at a dark red the negative discharge was much higher than the positive discharge, while at a bright red heat the two discharges were equalized, which would seem to prove that at different temperatures ions are formed charged with different electricities. Figures 47 and 48 show modes of very easily proving

the emission, during combustion, of particles with the power of rendering air a conductor of electricity. With a flame placed at 10 cm. from the electroscope (Fig. 47) a very rapid discharge ( $60^\circ$  in 30") is obtained. With

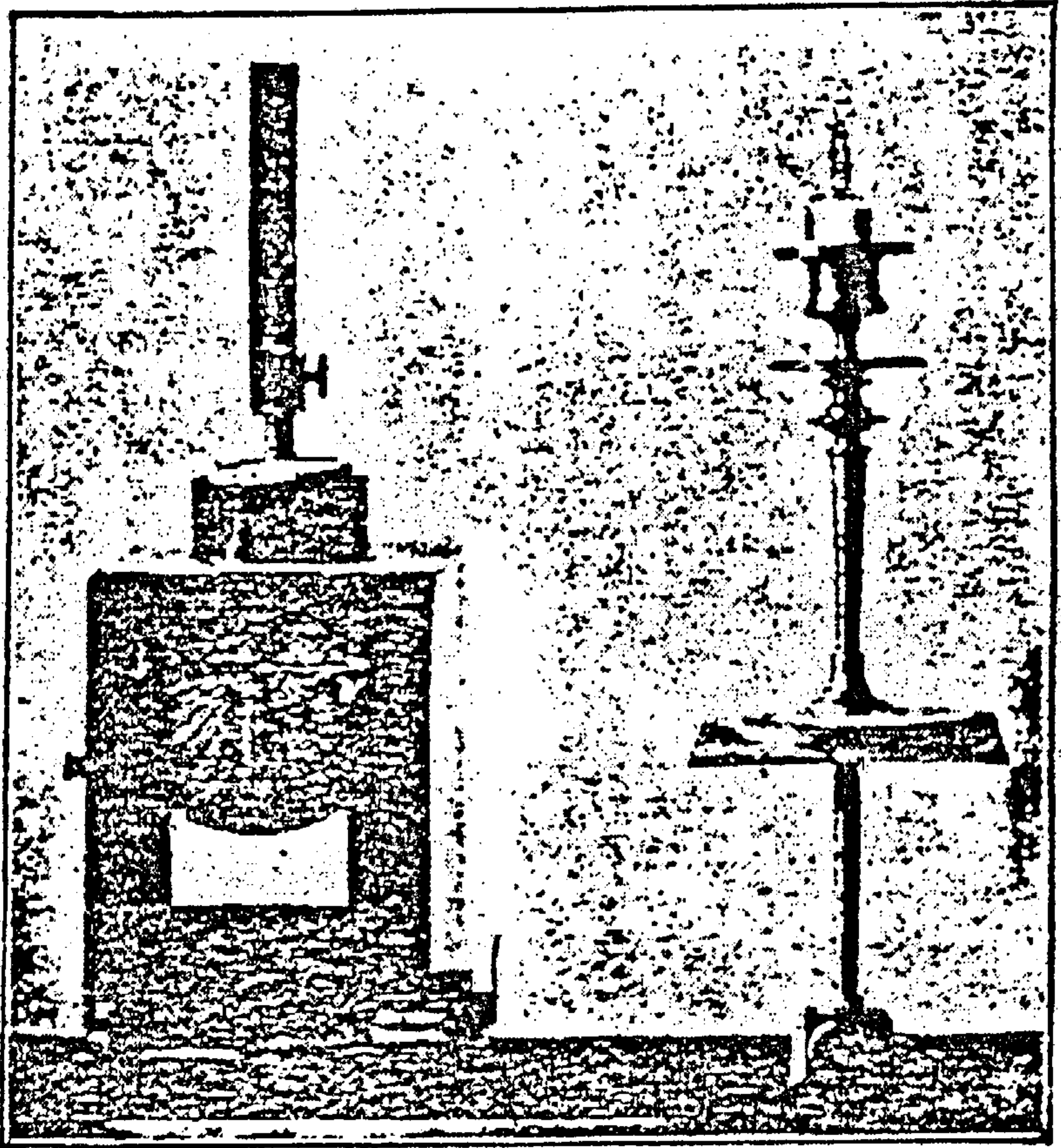


FIG. 47.—Apparatus for showing the leak of electricity under the influence of flames according to the distance and the nature of the body on which the action is produced. The charged strip on the electroscope draws to itself the ions of contrary sign which discharge it.

an ordinary candle in a closed lantern with an elbowed chimney placed at 13 cm. from the electroscope (Fig. 48) the discharge gives  $18^\circ$  in the same space of time.



At 20 cm. it falls to  $4^\circ$ . The extreme diffusion of the ions in the air explains these differences.

After passing through a long cooled tubular worm, according to the arrangement represented in another chapter (Fig. 52), the gas from the flames still produce, though feebly, a discharge of the electroscope.

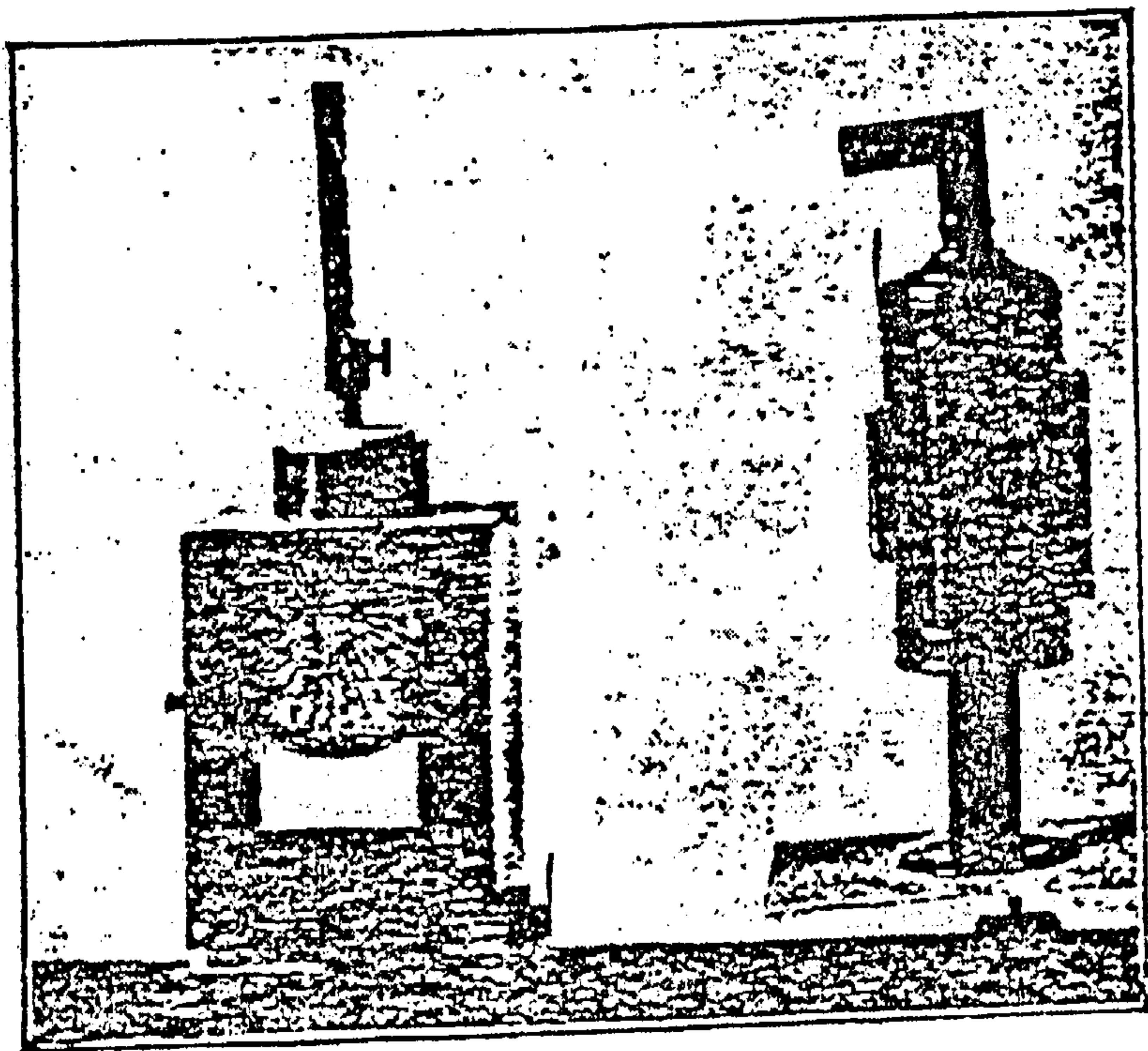


FIG. 48.—Apparatus showing visibly the electric leak under the action of the particles of dissociated matter contained in the gases of the flames.

I have already recalled to mind that the recent experiments of J. J. Thomson have shown that an incandescent body is a powerful and unlimited source of electrons—that is, of particles identical with those of radio-active bodies. He has proved it by the fact that the relation between their electric charge and their mass is the same.

The phenomena of combustion therefore constitute one of the most energetic causes of the dissociation of matter. They produce such an enormous quantity of effluves from dissociated matter that it is possible to hope that some means of utilizing them may be discovered. Meanwhile, these effluves diffuse themselves in the atmosphere, where they play some part not yet known to us.

*Properties of the Particles of Dissociated Matter contained in Flames.*—I have noticed in my experiments three curious facts which have not been pointed out before. The first is the property possessed by the elements of dissociated gas of traversing, in appearance at least, metallic receptacles; the second is the increasing rapidity of the discharge according to the thickness of the metal connected with the electroscope; the third is the loss rapidly undergone by several metals of the property of being influenced by the gases of flames.

The electroscope is charged as directed in a former paragraph, and the lamp for the purpose of producing dissociated gases is arranged as shown in Fig. 49. There will be then noticed a rather rapid discharge at the beginning of the experiment, which soon becomes slower and then stops. The metal does not regain its sensitiveness by being cleaned, but only after a prolonged repose of at least twenty-four hours. The figures below give an idea of the variations thus observed. The source of light was placed at such a distance as to obtain a rather slow discharge, so that the differences could be noted:—

Discharge during the first three minutes	9°
"    "    next three minutes	4°
"    "    following three minutes	2°

We shall see on interpreting this last phenomenon, that it is due to an emission of radio-active emanation analogous to that of radium, but very quickly exhausted and very slowly renewed.

But a part of the discharge seems certainly produced by the transparency of the metal forming the Faraday's

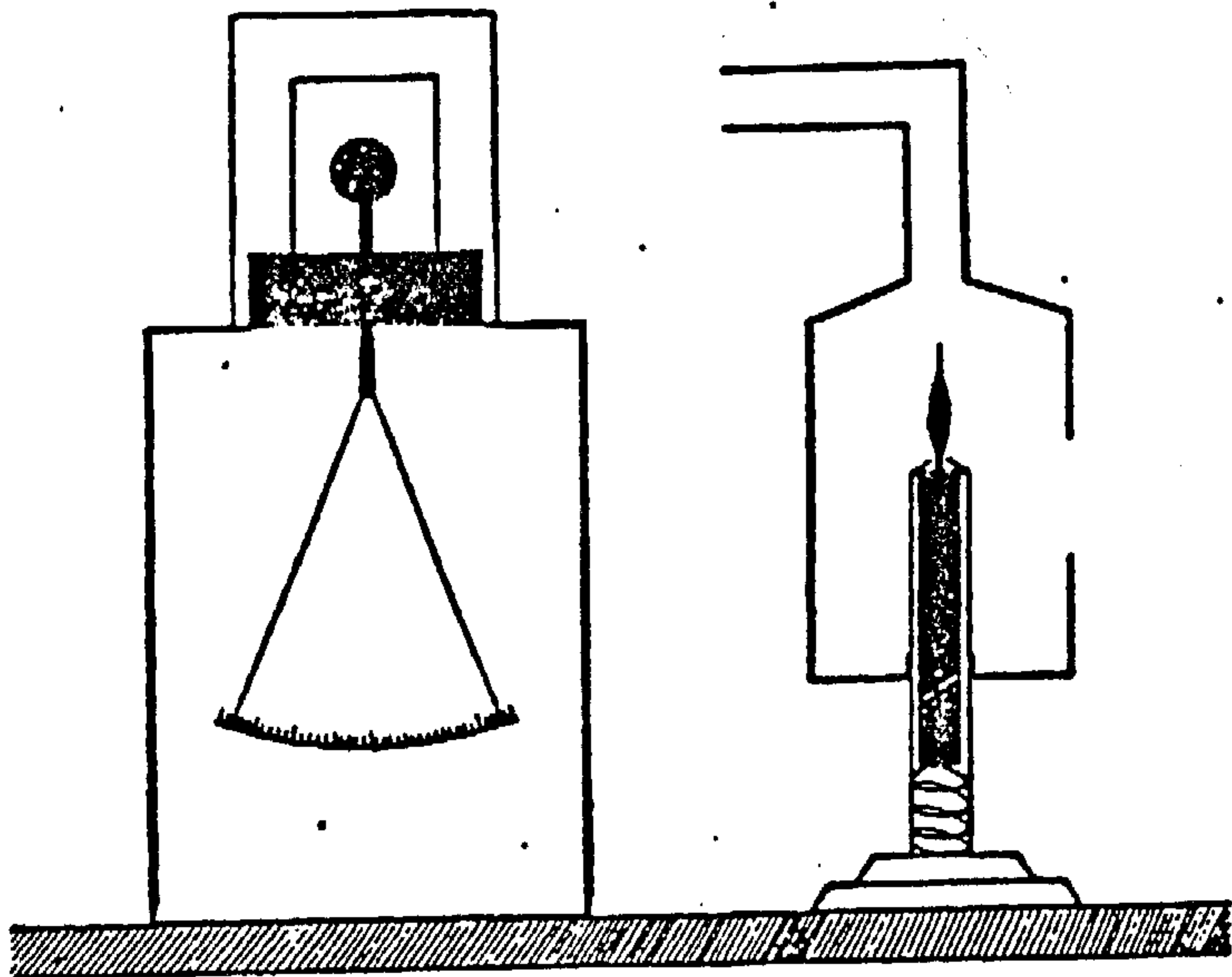


FIG. 49.—*Apparatus showing the action of dissociated matter contained in the gases of flames on an electrified body contained in a metal cage.*—The effect produced is as if the metal cage were rapidly transpierced by the dissociated matter. When it is desired to entirely eliminate the action of heat, the gases are made to pass through a worm  $\frac{1}{2}$  metres long immersed in a reservoir of water (Fig. 52). They then only reach the electroscope after complete cooling, and still produce a slight discharge.

cage, since it manifests itself, though in a slight degree, with gases completely cooled so as to eliminate the action of heat.

When working as indicated in Fig. 49, it suffices to place the extremity of the elbowed chimney of the lamp

at 2 or 3 centimètres from the cylinder forming the Faraday's cage to obtain a discharge of from 7° to 10° per minute. This continues for about ten minutes, and then stops entirely. It is useless to clean the cylinder; it must be allowed to rest for several days. The alteration is spread over the whole circumference of the cylinder and not solely on the part exposed to the gases of the flames. It is due, I repeat, to the emission of a radio-active matter similar to the emanation of radio-active bodies.<sup>1</sup> When working with gases cooled by their passage through a worm, as shown in Fig. 52, the discharge does not exceed 2° per minute, and appears in that case to be due to the transparency of the metal.

<sup>1</sup> It would be satisfactory to have this experiment checked by an independent observer. McLennan and Burton (*Phil. Mag.*, Sept. 1903) have shown that if a cylinder of any metal is enclosed within a second one of the same material insulated from it and surrounded by air, it gradually acquires a negative charge. So C. T. R. Wilson (*Proc. Roy. Soc.*, vol. 69, pp. 55 *et seq.*) asserts that there is a continuous production of ions in air contained in a closed vessel, even when it is not exposed to any known ionizing agent.—F.L.

## CHAPTER VII.

### EXPERIMENTS ON THE DISSOCIATION OF MATTER BY CHEMICAL REACTION.

I HAVE discovered a large number of chemical reactions producing the dissociation of matter. This is revealed by the characteristics which prove this dissociation—that is, the power of rendering the air a conductor of electricity, and in some cases of producing phosphorescence.

To establish the fact of this dissociation, instead of working by the method shown in Fig. 36, it is simpler in the case of merely qualitative experiments to place the body under study on the plate of the electroscope, which is then charged (Fig. 50).

Here are a few examples of reactions accompanied by the dissociation of matter:—

*Dissociation of Matter by the Hydration of certain Salts.*  
—Among the various reactions I formerly pointed out as accompanied by radio-activity is the hydration of sulphate of quinine. This body, as has long been known, becomes phosphorescent by the action of heat; but what was not known, is that when it has lost its phosphorescence after sufficient heating, it suddenly becomes brightly luminous and at the same time radio-active on cooling. After searching for the cause of these two phenomena I found that they were due to a very slight hydration. The radio-activity only manifests itself at the beginning of the hydration and

lasts but a few minutes. The phosphorescence, on the other hand, persists for a quarter of an hour.

This property of sulphate of quinine—viz., that of becoming phosphorescent by cooling—is quite contrary to what is observed in the many other phosphorescent bodies which never phosphoresce as they cool.

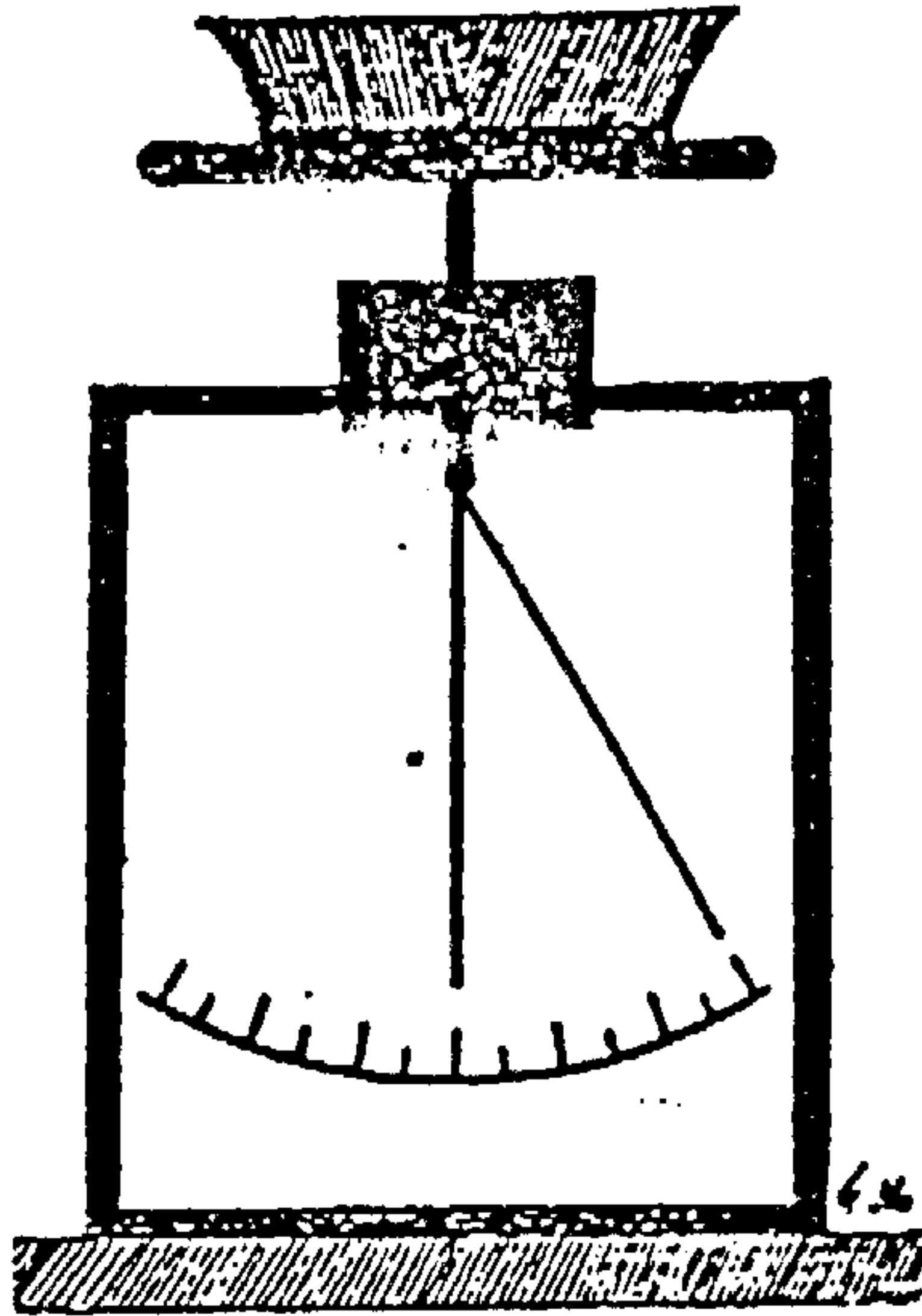


FIG. 50.—*Study of the Dissociation of Matter by Chemical Reactions.*—The bodies capable of producing the dissociation of matter by their reactions are introduced into the receiver placed on the plate of the electroscope; this latter is then charged and its discharge watched. This arrangement is much more simple than the classic method indicated in Fig. 36, and gives as good results when quantitative ones are not required.

In order to realize the experiments of phosphorescence by refrigeration and radio-activity in sulphate of quinine, it should be heated to  $125^{\circ}\text{C}$ . on a metal plate till all phosphorescence has completely disappeared. When removed from the plate on which it was heated, the sulphate of quinine again becomes phosphorescent as it cools, and, placed at once on the plate of the electroscope, gives for three or four minutes an abundant disengagement of effluves, which cause the leaves of the instrument to collapse ( $12^{\circ}$  during the first minute,  $4^{\circ}$  in the second). The amount employed in my experiments was about 2 grammes of sulphate of

quinine. The cessation of the phosphorescence occurs long before the disappearance of the discharge. The two phenomena are therefore independent of each other.

From the measurements kindly made for me by M. Duboin, Professor of Chemistry at the Faculté des Sciences of Grenoble, the absorption of 1 milligramme of water vapour is sufficient to render phosphorescent and radio-active 1 gramme of dried sulphate of quinine.

The foregoing experiment can be repeated indefinitely. When the sulphate of quinine is hydrated it simply has to be heated anew. It becomes phosphorescent by heat, is extinguished, and shines afresh and becomes radio-active in the course of cooling by hydration. Since hydration and dehydration are the causes of the phosphorescence of sulphate of quinine, we can, by causing it to be hydrated or dehydrated by means other than heat, obtain the same phosphorescence. Introduce into a wide-mouthed bottle some sulphate of quinine with a little anhydrous phosphoric acid, and cork the bottle. The phosphoric acid will at once deprive the sulphate of quinine of its moisture. One has only to open the bottle and blow into the interior to see the sulphate of quinine become quickly phosphorescent. On closing the bottle again the salt of quinine dehydrates itself anew, and the same operation can be repeated numbers of times.

Sulphate of cinchona gives the same results as sulphate of quinine, but the phenomena, especially that of phosphorescence, are less intense.

*Dissociation of Matter during the Formation of various Gases.*—Among the great number of reactions producing dissociation of matter I will also cite the following:—

*Formation of oxygen by the decomposition of oxygenated water by means of dioxide of manganese.*—The products are placed in the metal capsule on the plate, which is then charged (Fig. 50). The reaction lasts a little over a minute. The leak of the electroscope is about 9°.

*Formation of hydrogen by the decomposition of water by means of the sodium amalgam.*—Operation as before. Loss, 9° per minute. The discharge is exactly the same whether the electroscope be charged positively or negatively. The decomposition of water by sulphuric acid and zinc gives the same results.

*Formation of acetylene by the action of water on carbide of calcium.*—The same operation. Loss, 11° per minute.

*Formation of ozone.*—Air charged with ozone by means of a large coil and an ozonizer is directed by a bellows on to the plate of the electroscope. The loss is very slight, hardly 1° per minute, if the instrument be charged negatively, and 4° if charged positively.

It would be tedious to multiply these examples. The dissociation of matter is observed in many reactions, and especially in hydrations. Oxidations, even the most energetic (oxidation of sodium in moist air, for instance), have generally little or no action.

To close this branch of the subject I will merely cite the dissociation of matter during the oxidation of phosphorus.

*Dissociation of Matter during the Oxidation of Phosphorus.*—Phosphorus is one of the bodies with the most intense radio-activity. To prove this, phosphorus may be rubbed with a damp leather, then placed on the electroscope and a discharge of 80° per minute (calculated on the loss in 20 seconds) will be observed, whatever be the sign of the charge. The amount used is 1 centigramme of phosphorus. When the leather becomes dry the discharge stops almost entirely. Red phosphorus and sesquisulphide of phosphorus have no action.

The phosphorescence of phosphorus is due to causes as yet not clearly defined, which do not seem to be confined solely to oxidation and hydration. By very



carefully drying the phosphorus by means of the apparatus (Fig. 51), the phosphorescence is extremely slight, while it becomes very vivid under the influence of a trace of water vapour.

The numerous memoirs published during the last

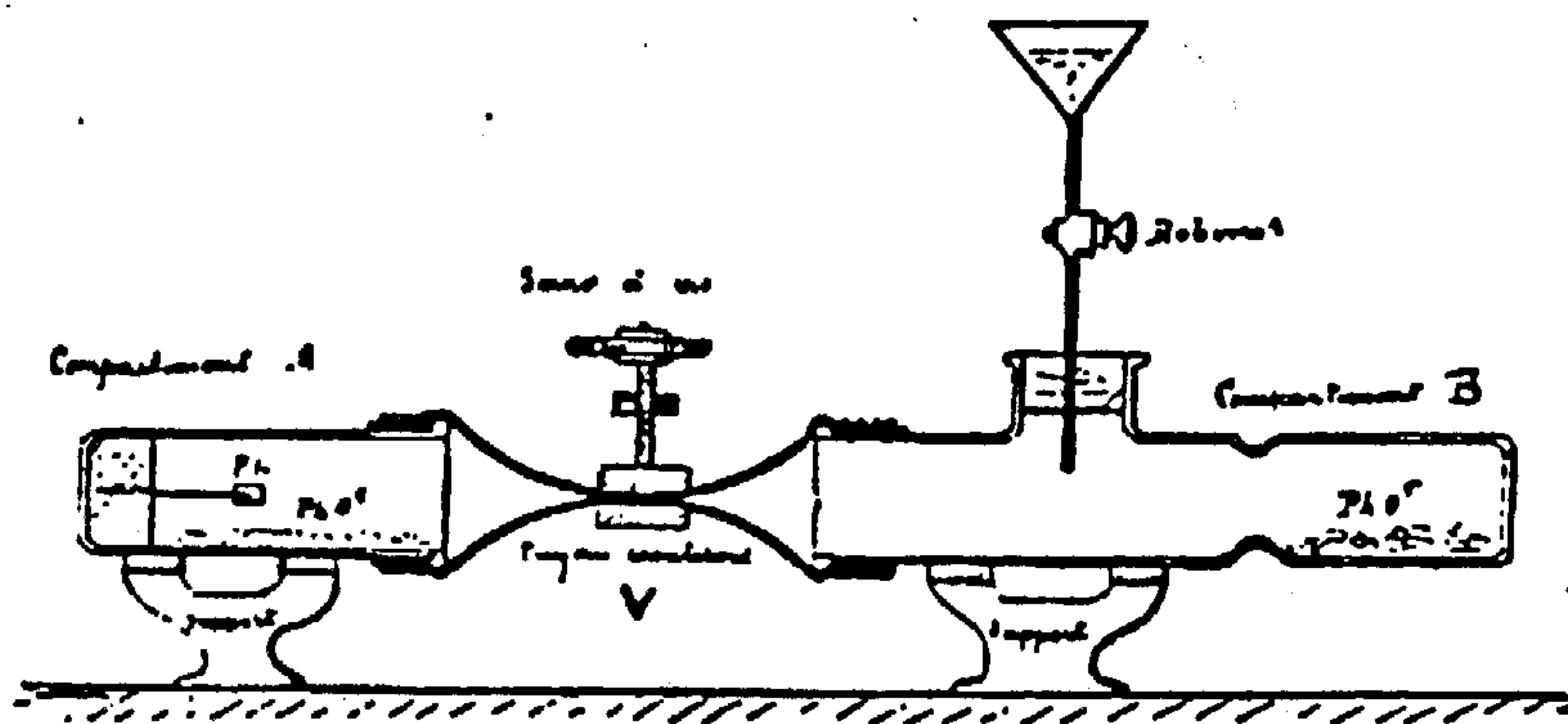


FIG. 51.—Apparatus of Gustave Le Bon and Martin, used for determining the part played by water vapour in the phosphorescence of phosphorus.—The two compartments A and B being supplied with anhydrous phosphoric acid, phosphorus is introduced into A, then A and B are separated by tightening the screw V. The phosphorus absorbs the oxygen of A, shines and then becomes extinguished. The screw V is then loosened and the dry air from B penetrates into A. One observes only a very slight phosphorescence, confined to the surface of the piece of phosphorus. If then, by means of the funnel represented in the figure, a drop of water is allowed to fall into B, the small quantity of vapour it emits is enough to render the phosphorus much more brilliant and there will form round it a luminous cloud. Water vapour therefore plays a manifest part in phosphorescence.

century on this question have not yet elucidated the causes of the phosphorescence of phosphorus. Several authors assert that the phosphorescence will be maintained in a current of pure hydrogen carefully freed from all trace of oxygen, but I have never observed anything

of the kind in my experiments. The presence of air has always appeared indispensable.

The experiments I carried out with the co-operation of M. Martin, engineer to the great phosphorus works at Lyons, have given the following results:—

1st. In the barometrical vacuum phosphorus is never phosphorescent.

2nd. In an atmosphere of carbonic acid gas, dry or saturated with water vapour, phosphorus does not shine. If into the globe of carbonic acid gas containing phosphorus a simple bubble of air be introduced, this bubble becomes instantaneously phosphorescent.

3rd. Phosphorescence in moist air is not accompanied by the production of phosphuretted hydrogen.

4th. During phosphorescence there is a production of ozone revealed by the blue coloration of iodine paper. To remove all doubts as to its presence, we deprived the air of the ozone it might normally contain, by passing it through two bottles, one containing mercury, the other protochloride of zinc. Thus deprived of its natural ozone, as is evident by the absence of any coloration of the iodine paper, the air comes to phosphorus which has been dried at 200° C. in a current of carbonic acid gas. The iodine paper becomes quite blue as soon as the air has passed through the globe containing the phosphorus. This latter has therefore the property of transforming the oxygen of the air into ozone.

In a recent study effected at Professor J. J. Thomson's laboratory, which was published in the *Philosophical Magazine* of April 1905, under the title of "Radio-activity and Chemical Change," Mr. Norman Campbell contests my conclusions on radio-activity from chemical reactions. He does not deny the discharge observed on the electroscope, but he attributes it to the action of the heat produced by various reactions.

He admits, however, being unable to explain how heat can produce the leak of electricity observed.<sup>1</sup>

I have never dreamed of disputing the influence of heat, of which I have explained the effects by showing that it acted by expelling the provision of radio-activity which the bodies contain; but it is very evident that its intervention cannot be claimed in chemical reactions which are unaccompanied by any rise in temperature, such as the hydration of sulphate of quinine during cooling, the oxidation of phosphorus, etc. On the other hand, there are reactions accompanied by a rise in temperature, such as the oxidation of sodium, which produce no radio-activity. The influence of heat and that of chemical reactions constitute two factors whose action is very distinct though at times they may be superposed.

<sup>1</sup> The mistake made by Mr. Campbell was shown in the *Athenæum* of 24th March 1906.—F. L.

## CHAPTER VIII.

### EXPERIMENTS ON THE CAUSE OF THE DISSOCIATION OF SPONTANEOUSLY RADIO-ACTIVE BODIES.

THE experiments which follow were made at the outset of the discovery of the radio-active bodies in order to prove that their dissociation, contrary to the opinion then current, depended upon certain chemical reactions of a nature unknown indeed, but resembling those which produce phosphorescence.

The phenomena of radio-activity—that is, the emission of effluves—obtained with uranium, thorium, and radium, are very noticeably modified by heat and moisture. Prolonged heat at first excites radio-activity, which increases very much for a time but can then no longer be brought back to its primitive state excepting after long repose. As to hydration, it suppresses phosphorescence and diminishes radio-activity.

The diminution of the action on the electroscope by hydration varies greatly with the substances employed. I give the figures obtained with divers radio-active substances, first dried at 200° C., then pounded and mixed with their own weight in water—

	DISCHARGE.
2 grammes of dried nitrate of uranium ...	26° in 10 minutes.
Same quantity of hydrated nitrate of uranium	7° ,, 10 ,,
2 grammes of dried red oxide of uranium ...	37° ,, 10 ,,
Same quantity hydrated red oxide of uranium	5° ,, 10 ,,
2 grammes of dried oxide of thorium ...	45° ,, 10 ,,
Same quantity of hydrated oxide of thorium	17° ,, 10 ,,
2 grammes of dried bromide of radium of poor activity ... ..	30° ,, 5 seconds.
Same quantity of hydrated bromide of radium	10° ,, 5 ,,

I should add that if the water acts chemically, it at the same time acts partly by the absorption of a part of the emitted particles—that is to say, like a screen.

Wetted, or simply exposed to moisture, radio-active bodies lose all phosphorescence, which is not at all the case with ordinary phosphorescent bodies, and they only regain it when brought to a white heat.

Temperature also plays a considerable part in the phosphorescence of radio-active bodies. It suffices to heat salts of radium, to cause them to momentarily lose their phosphorescence. The necessary temperature varies according to the samples, which are evidently of a very variable composition. Some among them require a temperature of  $500^{\circ}$  C., and the phosphorescence reappears so soon as the body cools. For other samples, a temperature of  $225^{\circ}$  C. is sufficient, and the body does not regain its phosphorescence when becoming cool, but only after some hours, and sometimes even only after a few days.

The preceding considerations deduced from the actions of heat and moisture apart, the following experiment would seem to indicate the existence of those new chemical combinations which I have examined elsewhere, combinations in which one of the elements is in an infinitesimal proportion compared with the other.

After having determined the radio-activity of 30 grammes of chloride of thorium—which spread out on a metal receptacle 10 cm. square, and placed on the electroscope, give  $9^{\circ}$  of discharge per minute—we dissolve them in water, adding 1 gramme of chloride of barium, a body which possesses no radio-activity, and we precipitate the chloride in the state of sulphate by the addition of a small quantity of sulphuric acid. The product, weighing about 7 décigrammes, is collected in a filter. These 7 décigrammes placed on the plate

of the electroscope give  $16^\circ$  of discharge, when the utmost that should be obtained is  $9^\circ$ , since the activity extracted from the chloride of thorium cannot be greater than that which was found therein at first, if it is not a case of chemical reaction. The chloride of thorium remaining has only lost the half of its activity.

I must point out, however, that no measurements of the radio-activity of bodies by the electroscope have any very precise quantitative value. I only draw conclusions from them with reserve, since I have noticed the extreme influence of the greater or less degree of division of the matter treated. I said above that the 7 décigrammes of precipitated matter had given  $16^\circ$  of discharge, but the filter used, which no longer contained anything, unless it were the very fine matter adhering to its rims, gave  $40^\circ$  of discharge per minute on the electroscope. Yet it only contained at the most a few millegrammes of matter, though spread over a large surface.

Still more simply can be shown the influence of the division of matter on its radio-activity by the following experiment:—1 gramme of pure chloride of thorium is spread in powder on the plate of the electroscope and gives a discharge of  $1^\circ$  per minute. We dissolve this powder in 2 cm. cube of distilled water, and in this solution dip a piece of filtering paper 10 cm. square; we dry it and place it on the plate of the electroscope. The discharge rises to 70 per minute—that is, 7 times more than with the same product in fine and dry powder. When the same sheet of paper is folded over so as to reduce its surface, the discharge falls to 3 degrees.

The same phenomena are observed with uranium. Place on the electroscope a small block of metallic uranium weighing some 30 grammes. It gives  $12^\circ$  of discharge in 10 minutes. Take a third of the same block—that is, 10 grammes—reduce it to powder, and

spread it over a metal receptacle 10 cm. square placed on the plate of the electroscope. The discharge rises to about  $28^\circ$  in ten minutes. So, by the fact alone of increasing the surface of the radio-active body, a quantity of the same substance three times less, gives a discharge twice as great. The discharge which radio-active bodies produce is therefore reduced in large proportions by diminishing the surface.

This reduction is not, however, proportional to the surface. As soon as the layer of a radio-active body attains a certain thickness, fresh additions, which only increase this thickness, have no effect. It appears as if these bodies were capable of absorbing the radiations they themselves emit.

50 or 25 grammes of thorium, spread thinly on a receptacle of the same dimensions ( $12 \times 17$  cm.) as before, so as to cover it entirely, give exactly the same discharge ( $12^\circ$  per minute).

These same quantities (50 grammes or 25 grammes) placed in a smaller receptacle, will only give a discharge of  $7^\circ$  per minute.

## CHAPTER IX.

### EXPERIMENTS ON THE IONIZATION OF GASES.

It was in gases that the dissociation of simple bodies was first observed, and that at a time when one hardly thought of speaking about the dissociation of atoms. The phenomenon was then called by the name of ionization. This term, in reality, should be considered as absolutely synonymous with that of dissociation of matter, as I have already stated.

The products of the dissociation of the atoms of gases are of the same nature as those attained by the dissociation of other bodies, such as metals. The relation of their electric charge to their mass is always the same. Their properties only vary, as explained elsewhere, according to whether the ionization takes place under ordinary pressure or in a very rarefied gas as in that of a Crookes' tube.

Ionizing a gas, or, in other words, dissociating it, consists in withdrawing from its atoms those elements known by the name of ions, some bearing a positive, others a negative charge.

These ions of contrary signs are always equivalent in number, so that, as J. J. Thomson has remarked, the mass of an ionized gas, taken as a whole, betrays no electric charge. This statement is, besides, in conformity with all our knowledge of electricity. It is impossible to produce an electric charge of one sign without creating at the same time an exactly equal charge of the other sign. When, for instance, an



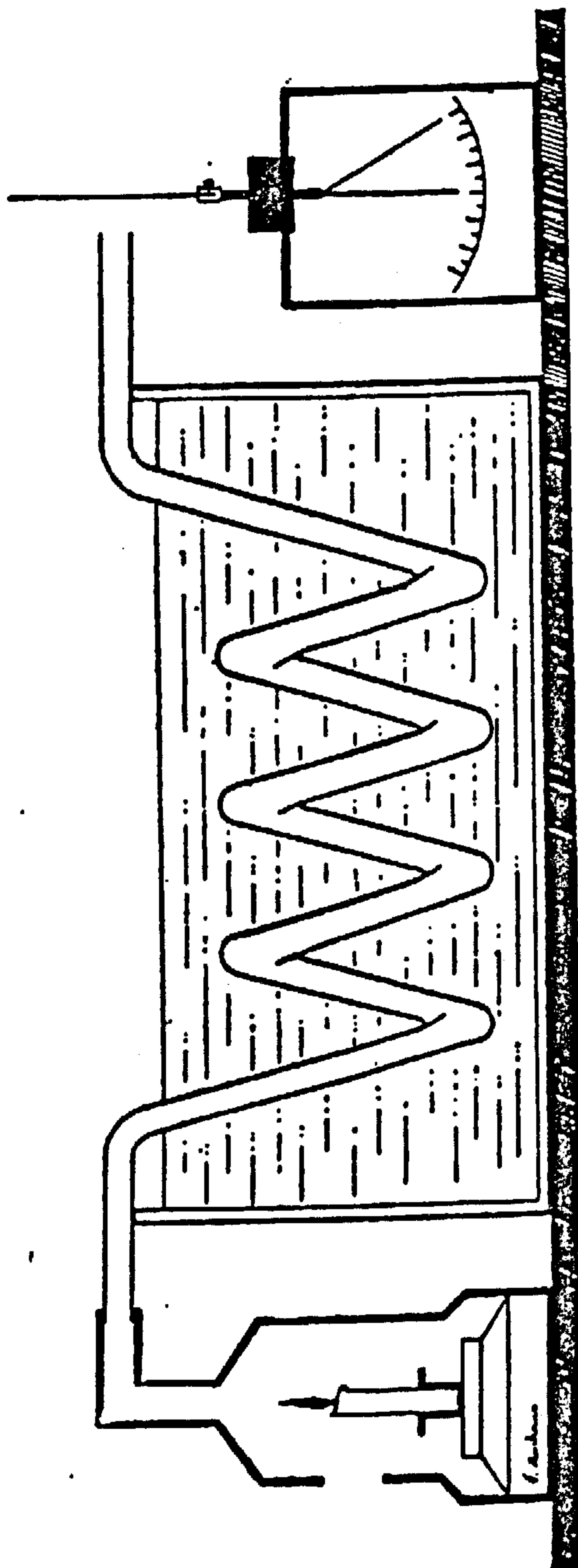


FIG. 52.—*Experiment on the properties of gases dissociated by flames.*—The ions produced in this form of the dissociation of matter neutralize each other with extreme slowness, since they can pass through a long metal worm and discharge the electroscope at the other end.

electric fluid is decomposed by friction, each of the two bodies employed contains a quantity of electricity strictly equal to that of the other, but of contrary sign.

An ionized gas, therefore, taken as a whole reveals no sign of electricity, but if it be directed between two parallel electric plates, one charged with positive the other with negative electricity, the ions of contrary signs are attracted by one or other of the two plates, and the neutralization of a part of the charge of the plates can be verified by means of an electrometer.

What becomes of the positive and negative ions formed in a gaseous mass? An ionized gas preserves its conductivity for some time, but it does not keep it for ever, and at last it becomes impossible to detect in it any electric charge. The conclusion is that the positive and negative ions have recombined to form neutral electricity.<sup>1</sup>

The rapidity of recombination of the ions appears to be proportional to the number of ions present, and that is why, in gases ionized by very active bodies, such as radium, it is very rapid. The recombination of ions is rendered much more rapid by the presence of solid particles, as may be verified by blowing tobacco smoke between two metallic plates charged with electricity, with an ionized gas passing between them.

It is generally supposed at the present day that all ions, whatever their origin, are alike, and this opinion is especially founded on the sameness of their electric charge. My experiments have led me to suppose, on the contrary, that the various ions ought to exhibit notable differences among themselves. I have observed, in fact, that the rapidity of their recombination, or rather, of their disappearance—not to prejudge any-

<sup>1</sup> See on this subject the researches of Mr. Kleeman, *Phil. Mag.*, April and October 1906.—F. L.

thing—varies greatly with their origin. Here are, for instance, three cases in which, from my researches, ions behave very differently:—

1st. *Ions produced by combustion.*—These can pass through a cooled metallic tube, 2 mètres long, as is shown by the action they exercise on an electroscope placed at the extremity of this tube (Fig. 52), but a very thin layer of water stops them.

2nd. *Ions produced by certain chemical reactions.*—Of these reactions I shall only mention the formation of hydrogen by the action of sodium amalgam or water. The ions obtained almost entirely disappear after passing through a few centimètres of the tube (Fig. 53).

3rd. *Ions produced by the oxidation of phosphorus.*—By bubbling through a bottle containing water, air which has passed through a globe containing finely divided fragments of phosphorus, it is verified by the action of the air on the electroscope that all the ions have

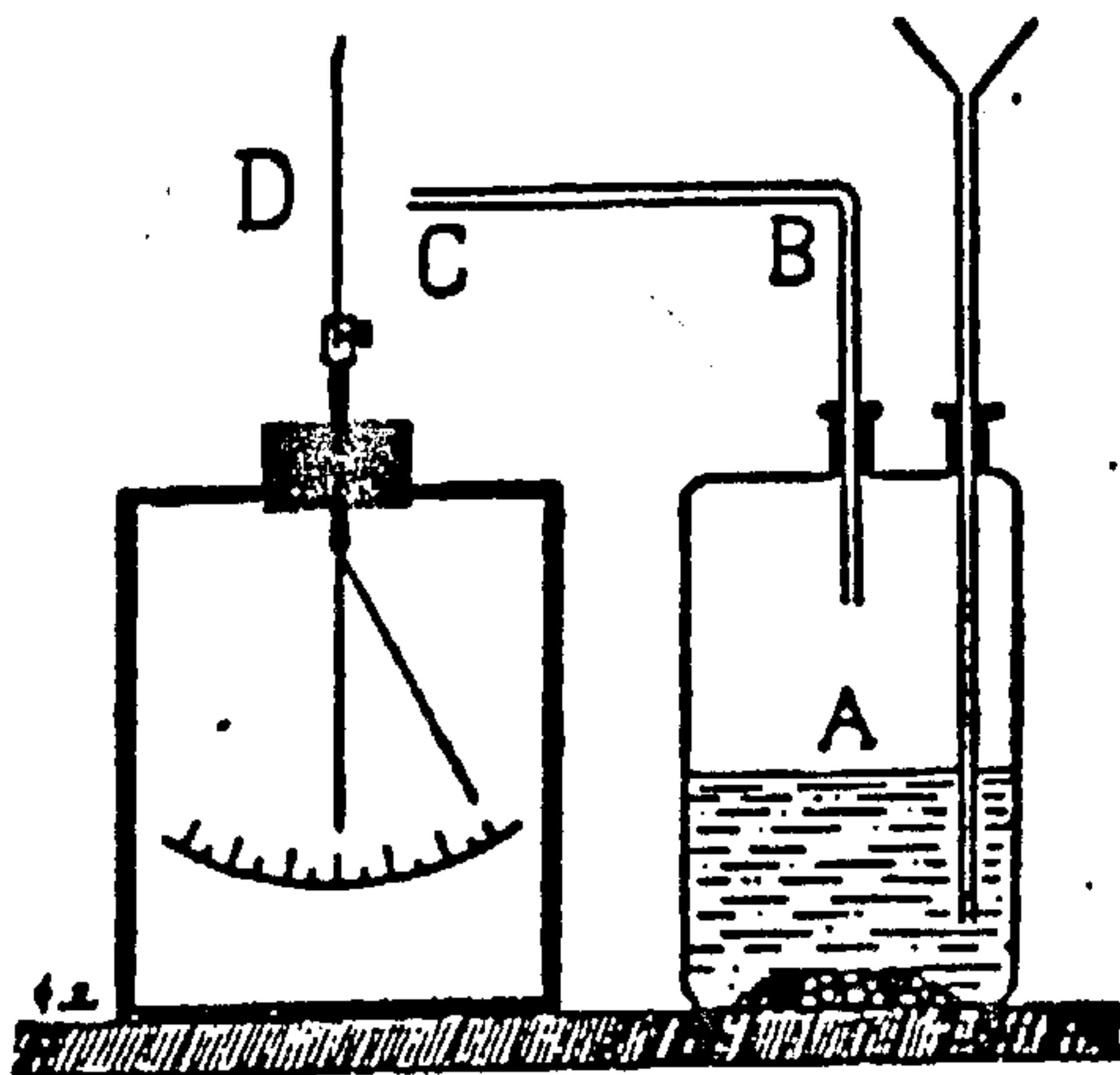


FIG. 53.—*Recombination of the ions obtained in the dissociation of matter by chemical reactions.*—A, bottle containing water and sodium amalgam. CB, tube conducting the ionized gas on to the charged electroscope D. The ions generated in this form of the dissociation of matter neutralizing each other very quickly, it is sufficient to give a certain length to the tube CB for the discharge of the electroscope to become, contrary to what is observed in the experiment in Fig. 52, almost nil. For this reason it is preferable to make use of the arrangement represented in Fig. 50, for studying the dissociation of matter by chemical reactions.

not been retained by the water, as was noticed in the case of those obtained in the previous operations.

It will be seen by these three examples that ions may show real differences among themselves notwithstanding their indisputable analogies.

The quantity of gaseous molecules capable of being ionized in a given mass of gas is relatively very small, however energetic may be the process of ionization employed. Were it otherwise, it would be easy to extract from atoms a colossal amount of energy. Rutherford calculates the number of molecules dissociated, or rather, having undergone a commencement of dissociation, at 1 in 100,000,000. This figure is arrived at in various ways, notably by verifying the number of drops of water which result from the condensation of water vapour produced by the presence of ions. Though this figure may appear insignificant, the number of ions is still considerable by reason of the number of particles contained in a gas, which is estimated at 36,000 billions per millimètre cube. The cubic millimètre of a gas might therefore contain 360 million particles having undergone a commencement of dissociation, although only one molecule in a hundred millions might be partly dissociated.

## CHAPTER X.

### EXPERIMENTS ON THE SPONTANEOUS DISSOCIATION OF MATTER AND ON THE EXISTENCE IN ALL BODIES OF AN EMANATION ANALOGOUS TO THAT OF THE RADIO-ACTIVE SUBSTANCES.

THE concatenation of my experiments led me to discover the existence in all bodies of an emanation similar to that of the radio-active substances, which shows that all bodies dissociate spontaneously. This is how I was led to this demonstration.

With the object of studying the transparency of metals to particles of dissociated matter, whether by light or combustion, I made use of the condensing electroscope previously described—of an electroscope enclosed in a Faraday's cage, and I noticed an important discharge under the influence of a heat slight enough to raise the temperature of its walls by only some 30°.

The first explanation obviously was that the metal cylinder was transparent to radiations.

I now give the experiments that showed me that the principal cause of the phenomenon was not due to any transparency, but to an emanation from the metal identical with that observed in radio-active bodies, such as thorium, uranium, etc., which, some time after my researches (published in the *Revue Scientifique*, 22nd November 1902, p. 650), J. J. Thomson discovered in all bodies.<sup>1</sup>

Let us again take in hand the apparatus (Fig. 49), which will enable us to verify the following facts:—

If the discharge takes place from the exposure of the

<sup>1</sup> As mentioned in an earlier note, Professor J. J. Thomson does not admit this. He claims, on the contrary, that the emanation proved by

instrument to the sun, it is only noticeable if the temperature of the sun is high enough to heat the metal.

With the ultra-violet light of electric sparks, so much more active than solar light, but which does not heat metal, the discharge is almost nil.

In arranging the apparatus as shown in Fig. 49 for studying the action of heat, it will be found that after repeating the experiment five or six times, the metal, which at first gave a discharge of some  $10^7$  a minute, soon gives a very small one, then none at all, and only regains its properties at the end of a few days.<sup>1</sup>

If, when a cylinder is very active under the influence of the heat of the gases of the flame, the lantern be withdrawn, the discharge continues for two or three minutes, as if the interior of the cylinder contained something able to neutralize a certain quantity of the electricity with which the electroscope is charged.

The action produced by heat can be easily separated from that due to the transparency of the metal to particles of dissociated matter. The action of ionized gases and that of heat are two independent effects which are superposed, but which it is possible to separate. A slight increase in temperature produces a fairly strong discharge. Gases cooled by their passage through a long worm produce on the contrary but a slight discharge. The metal, in this last case, acts as if it were transparent. The walls of the Faraday's cage employed in this last experiment were only 0.2 mm thick.

him to exist in Cambridge tap-water and some other bodies may be due to the admixture of some radio-active substance. The alternative explanation of Elster and Geitel that all nature is exposed to the bombardment of a radiation from some unknown source, to which only rock-salt is impenetrable, should be borne in mind. (See their communication in *Physikalische Zeitschrift*, 10th October 1905.)—F. L.

<sup>1</sup> This is confirmed by Sir William Ramsay's experiments referred to above (p. 376). The explanation he gives of the phenomenon differs from that in the text.—F. L.

It is possible even without the action of heat to verify in ordinary bodies the existence of a constant emanation from dissociated matter, though this emanation is extremely small in quantity.

To cause it to be apparent, it is necessary to compel it to accumulate in a restricted space. It is sufficient for this to fold a sheet of metal so as to transform it into a small cylinder similar to the one which encloses the ball of the condensing electroscope. The lower opening is then closed and it is left for eight days in darkness, and then—still keeping it in darkness so as to avoid any possible influence from light—it is placed on the insulating disc of the electroscope to examine its radio-activity. It will then be found, after having charged the whole system exactly as I have directed, that a discharge of 1 to 2° per minute is obtained. As the metal rapidly loses that which it has accumulated, the discharge soon ceases. Many bodies other than metals, a box-wood cylinder especially, produce the same effect.

The metal, after ceasing to act on the electroscope, has not on that account exhausted its provision of radio-activity. It has simply parted with the quantity it can emit at the particular temperature at which the operation was effected. But, as with phosphorescent bodies or radio-active matter, it only has to be slightly heated to cause it to again yield a more considerable emission of active effluves. To produce this, simply proceed exactly as indicated in Fig. 49, but to avoid certain objections, replace the lantern containing a candle by a small mass of metal heated to 400°C.—that is, at less than red heat, and placed at 3 cm. from the Faraday's cage. Though the walls of the latter only become heated by radiation to about 35°C., it is sufficient to give a discharge of 5 or 6 degrees per minute. This discharge lasts 2 or 3 minutes, and stops when the

metal has exhausted all its provision of radio-activity. It can afterwards regain this only by repose.

It will be seen in all the preceding experiments that things occur just as if the metal contained a limited provision of something—acting exactly in the same way as the emanation of radio-active bodies—which it can emit rapidly under the influence of heat, but can then only recuperate by repose.

This theory of the disengagement, under the influence of heat, of effluves of particles of dissociated matter, the elements of which are closely reformed by repose, has the advantage of assimilating all bodies to the substances called radio-active like thorium and radium, which seemed to constitute strange exceptions to ordinary rules. The only difference is that the emanations of the latter reconstitute themselves as fast as the loss occurs. In ordinary metals, on the contrary, the loss is only very slowly repaired, whence arises the necessity of allowing the metal a certain length of rest.

These experiments in any case prove clearly the phenomenon of the spontaneous dissociation of matter. I repeat that J. J. Thomson arrived later at the same conclusion by a different method.<sup>1</sup>

Radio-activity is then an absolutely general phenomenon whose study will certainly lead to important practical results.<sup>2</sup> It is already considered that the hitherto inexplicable action of certain mineral waters may be due to their radio-activity. This radio-activity would seem to show that the interior of the globe is the seat of disintegrations of matter which are perhaps not unconnected with earthquakes in view of the immense energy which matter may liberate by its dissociation.

<sup>1</sup> See notes on pp. 115, 148, and 399.

<sup>2</sup> M. le Prof. Garrigou, in his inaugural lecture, has described in too flattering terms the importance of my researches from the medical point of view.



## CHAPTER XI.

### EXPERIMENTS ON THE ABSENCE OF RADIO-ACTIVITY IN VERY FINELY DIVIDED BODIES.

THE division of matter, however far it may be carried, does not produce any effects like those of its dissociation. This seemed evident *a priori*, but it was useful to verify it by experiment.

The finest state of division in which matter is known to us seems to be that in which bodies emit odours. The olfactory sense is in that case much more sensitive than the balance of the chemist, since small quantities of odoriferous matter can perfume for a long time several cubic metres of air without any sensible loss of weight.

However divided these particles may be, they have none of the properties of matter in a state of dissociation, and, consequently, do not render the air a conductor of electricity. I have experimented on the most odoriferous bodies I could find—iodoform, vanilla, and artificial musk especially. All one has to do is simply to introduce them into a metal receptacle placed on the plate of the electroscope. The latter is then charged, first positively, and then negatively. It is found that in both cases the discharge is nil.

The particles which these bodies give off represent then a state of simple division, and in no wise a dissociation of matter. Ordinary matter, however divided it may be supposed to be, cannot be confused with matter whose atoms are dissociated. Vaporization or pulverization, which does not affect the atom, cannot produce the same effects as its dissociation.

## CHAPTER XII.

### EXPERIMENTS ON THE VARIABILITY OF CHEMICAL SPECIES.

THE simple bodies chosen for experiment are mercury, magnesium, and aluminium, elements which in a normal state can form no combinations among themselves. By subjecting them to certain conditions of shock or pressure, we shall compel them to form admixtures in which one of the elements shall be infinitesimally small compared with the other. This is all that is required for these metals to acquire entirely new chemical properties.

Here is a table of the principal properties of these bodies in their ordinary state, and of these same bodies transformed:—

CLASSIC PROPERTIES OF METALS IN THEIR NATURAL STATE	NEW PROPERTIES OF THE SAME METALS TRANSFORMED.
<i>Mercury.</i> —Does not decompose water when cold, and does not oxidize in air.	<i>Mercury containing traces of Magnesium.</i> —Decomposes water when cold, and is instantly transformed, when exposed to the air, into a voluminous dark powder.
<i>Magnesium.</i> —Does not decompose water when cold, and does not oxidize in air.	<i>Transformed Magnesium.</i> —Decomposes water when cold, but does not oxidize when dry.

CLASSIC PROPERTIES OF METALS IN THEIR NATURAL STATE.	NEW PROPERTIES OF THE SAME METALS TRANSFORMED.
<p><i>Aluminium.</i>—Does not decompose water when cold, and does not oxidize. Cannot be affected by sulphuric, nitric, or acetic acids.</p>	<p><i>Transformed Aluminium.</i>—Oxidizes instantaneously, if dry, and becomes covered with thick white tufts of alumina. Rapidly decomposes water until the metal completely disappears and transforms itself into alumina. Is violently affected by sulphuric, nitric, and acetic acids. Possesses an electromotive force double that of ordinary aluminium.</p>

We will now examine in detail the transformations we have just briefly indicated. I give first the *modus operandi* of these transformations:—

*Transformation of the Properties of Mercury.*—If a fragment of magnesium be placed in a bath of mercury the contact of the two metals may be maintained for any lapse of time without their combining. If roughly shaken in a bottle the magnesium is still unattacked. In their ordinary state, then, these metals refuse to combine, but we shall see that we have only to modify their usual physical conditions very slightly to enable them to join in very unequal proportions.

To compel the mercury to dissolve a small quantity of magnesium, the intervention of a slight pressure alone is needed. This pressure constitutes one of those causes peculiar to the effect required, one of those appropriate reagents, of which I have several times pointed out the importance in this work.

This pressure may be light but it must be continuous. To obtain it we have only to fill a tube with mercury and to close it with a cork having a strip of magnesium, carefully cleaned with emery-paper, passed through it (Fig. 54). By thus stopping the tube with the cork, the magnesium remains dipped in the mercury

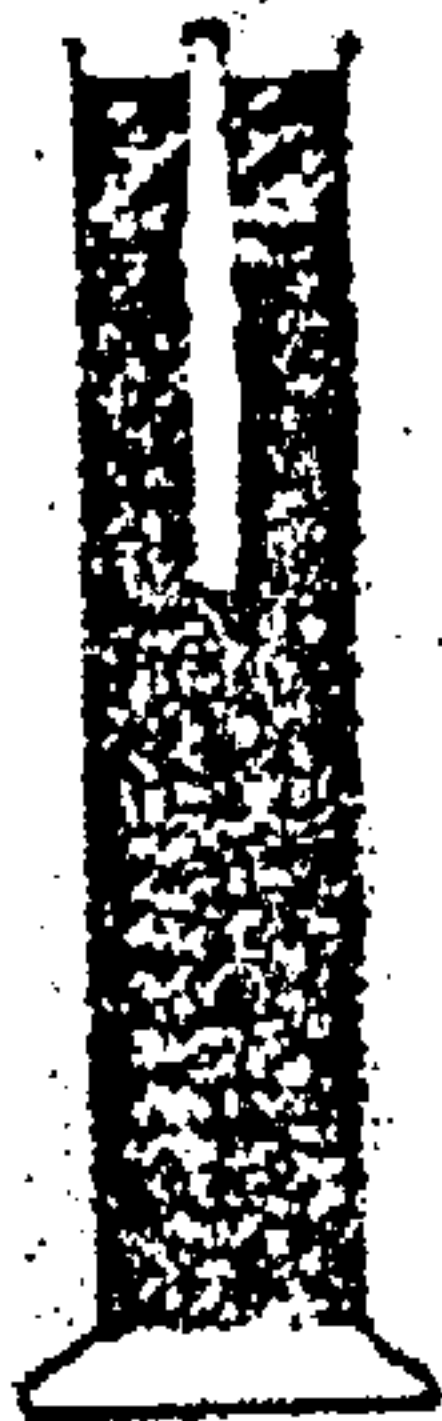


FIG. 54.—*Arrangement by which the transformation of the properties of mercury is obtained by combination, under the influence of slight pressure, with traces of magnesium.*

without being able to float on its surface. Subjected to this feeble pressure it is slightly attacked in a length of time varying from a few minutes to a few hours, according to the quality of the metal and the perfection of the cleaning. The properties of the mercury then become profoundly modified. It acquires the property, as curious as it was unexpected, of appearing to oxidize rapidly in dry air, and it vigorously decomposes water so soon as it is immersed in it (Fig. 55).

To verify the apparent dry oxidation of the mercury it only has to be poured into a recently cleaned glass. Its surface is then instantaneously covered with a black powder which forms again every time it is wiped away. If not removed, the coating of oxide soon reaches the thickness of a centimètre. This permanent oxidation continues for an hour.

The oxidation of the mercury is, however, only apparent. It is not in reality the mercury which oxidizes, but the traces of magnesium contained in it.

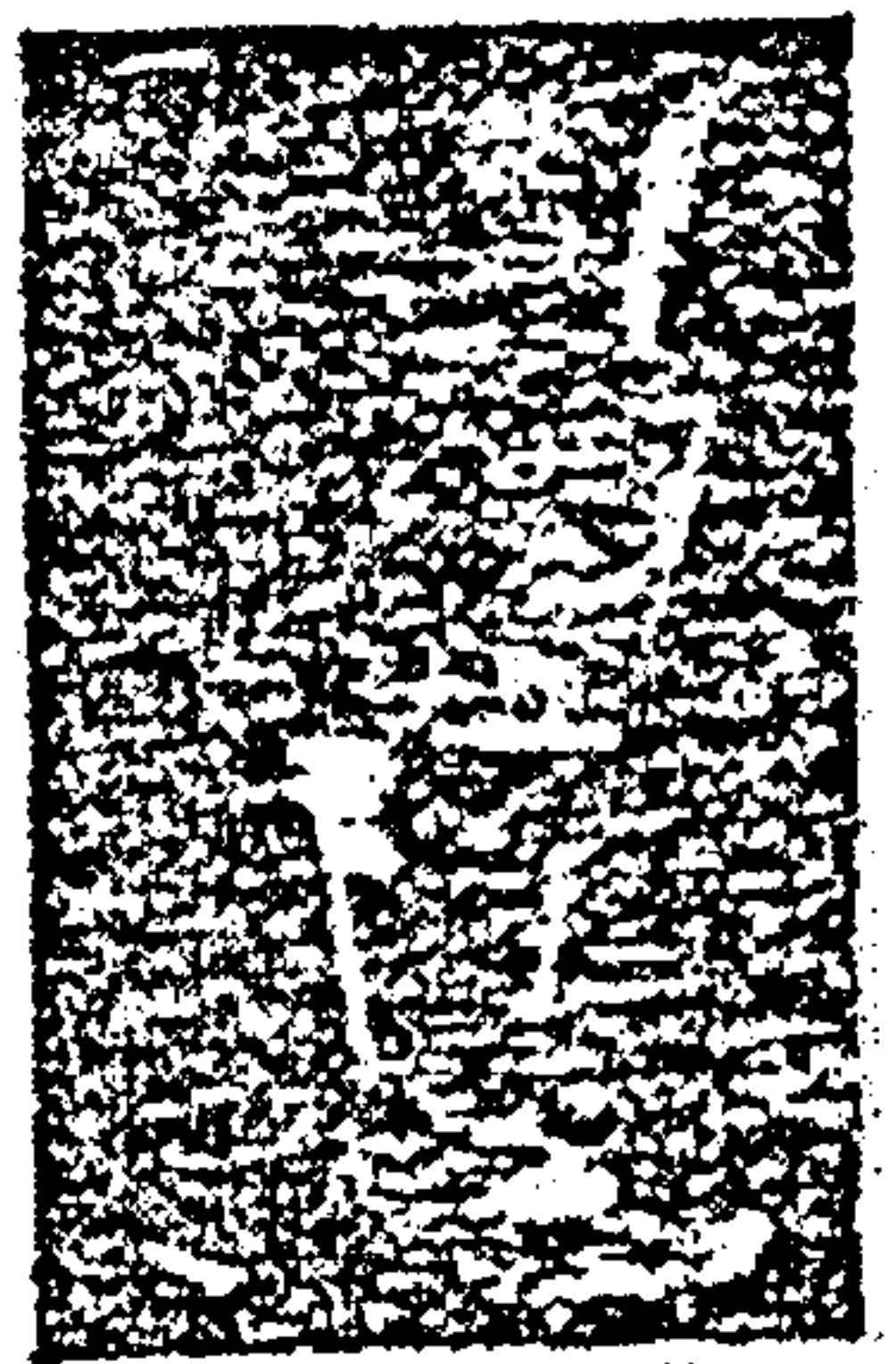


FIG. 55.—*Decomposition of water by mercury containing a trace of magnesium. (Instantaneous photograph.)*

By oxidizing, the magnesium transforms the mercury into an impalpable black powder of considerable volume.

To verify the decomposition of water by the mercury, it is poured into a glassful of this liquid as soon as the magnesium is taken out of it. The decomposition of the water is immediate. It becomes slower at the end of fifteen minutes, but lasts over an hour.

The modified mercury rapidly loses its properties when exposed to the air, but it may be kept indefinitely and retains its new properties by covering it with a thin layer of oil of vaseline.

*Transformation of the Properties of Magnesium*—If, in the last experiment, instead of a thin fragment of magnesium being placed in the mercury under pressure, a strip of a certain thickness—one millimètre, for instance—be introduced, it will be found, by taking out this strip at the expiration of two or three hours and plunging it into water, that the liquid is rapidly decomposed (Fig. 56). The hydrogen of the water is disengaged, and the oxygen combines with the metal to form magnesia.

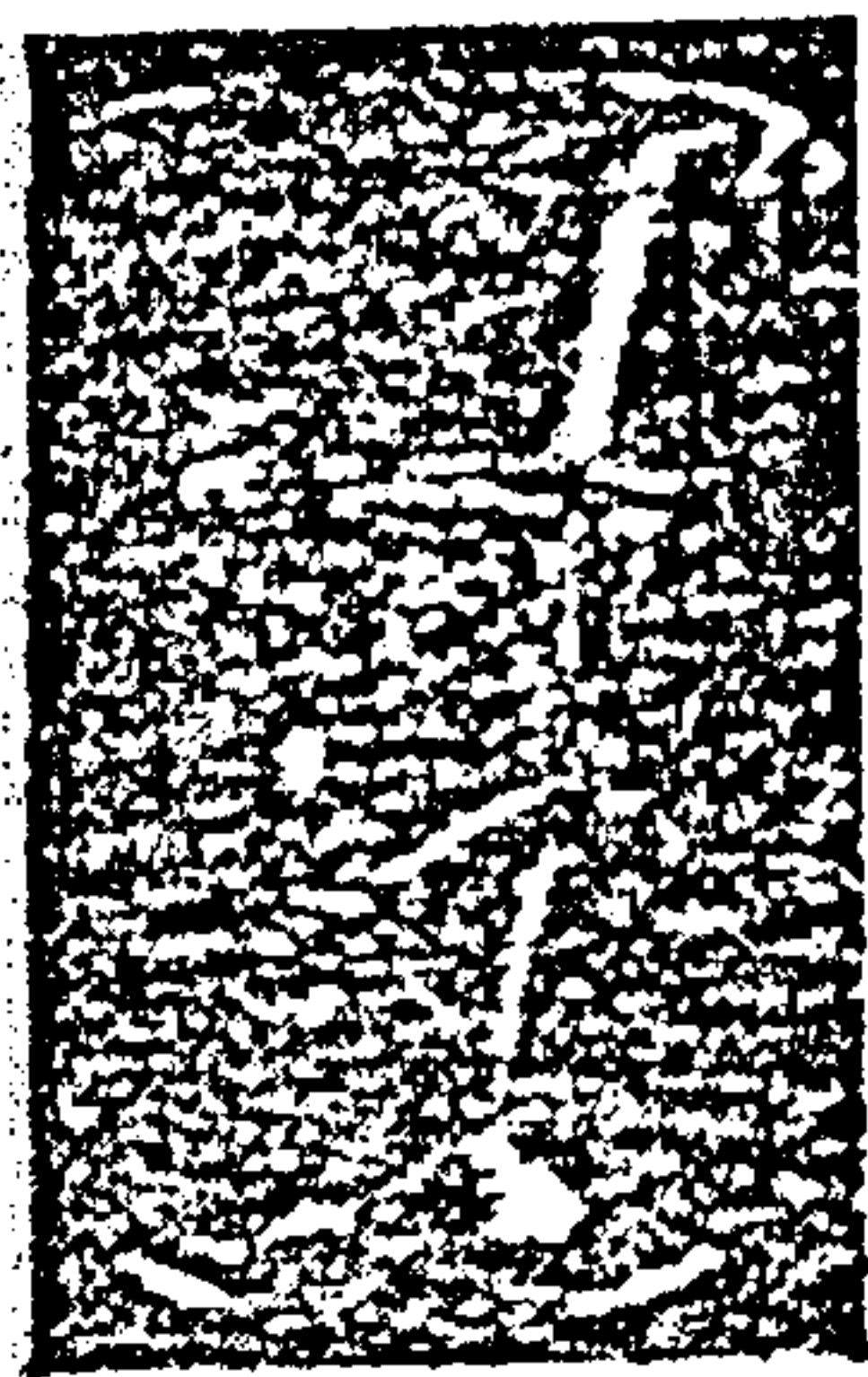


FIG. 56. — *Decomposition of water by magnesium containing traces of mercury. (Instantaneous photograph.)*

The operation lasts about an hour, and as in the case of mercury, at last stops. If, after having immersed the magnesium in water, it is withdrawn, its temperature rises considerably and it oxidizes in the air.

This oxidation of magnesium in the air is—contrary to what was observed with mercury, and contrary to what will be observed in aluminium—very slight and only shows itself when the metal is wet. Withdrawn from the mercury and dried at once with a dry cloth,

it does not oxidize, but retains indefinitely, if kept in a very dry place, the property of decomposing water.

In the preceding experiments I have worked without the intervention of any reagent, simply by putting in presence of each other two metals which will not combine in the ordinary way, but which I have compelled to interpenetrate by the action of slight pressure. The operation requires several hours. It will only require a few seconds if I call in a reagent which by the sole fact that it attacks magnesium will diminish its resistance to the action of mercury.

I now introduce into a large bottle a few centimètres cube of mercury, a strip of magnesium, and water containing 1% of hydrochloric acid, and roughly shake the bottle for 10 seconds. I now withdraw the magnesium, wash it to quickly remove all traces of hydrochloric acid, dry it and throw it into a precipitating glass full of water. It will at once decompose this liquid. Taken from the bottle and poured into a glass full of water the mercury will likewise decompose that.

*Transformation of the Properties of Aluminium.*—The experiments with aluminium are much more striking than those effected with magnesium.

To generate immediately on the polished surface of an aluminium mirror a vegetation in thick tufts as white as snow, constitutes one of the most curious experiments in chemistry, and one of those which has most struck the learned persons to whom I have shown it. Its realization is very simple.

It is possible, as with magnesium, to compel the mercury to act under pressure, but the action of impact is much more rapid.

It is sufficient to introduce into a bottle containing a few centimètres cube of mercury some strips of aluminium polished with rouge or simply cleaned with

emery, and then to roughly shake the bottle for two minutes.<sup>1</sup> If one of the strips then be taken out, carefully wiped, and vertically placed on a support, it will be seen to be almost instantaneously covered with white tufts of alumina, which in a few minutes grow to a height of 1 centimètre from the surface (Figs. 57 to 60). At the commencement of the experiment the temperature of the strip rises to 102° C.

The above oxidation does not manifest itself if the aluminium be introduced into air or oxygen completely dry. The presence of a small quantity of water vapour is therefore indispensable for the production of the phenomenon. The alumina formed is, besides, always hydrated.

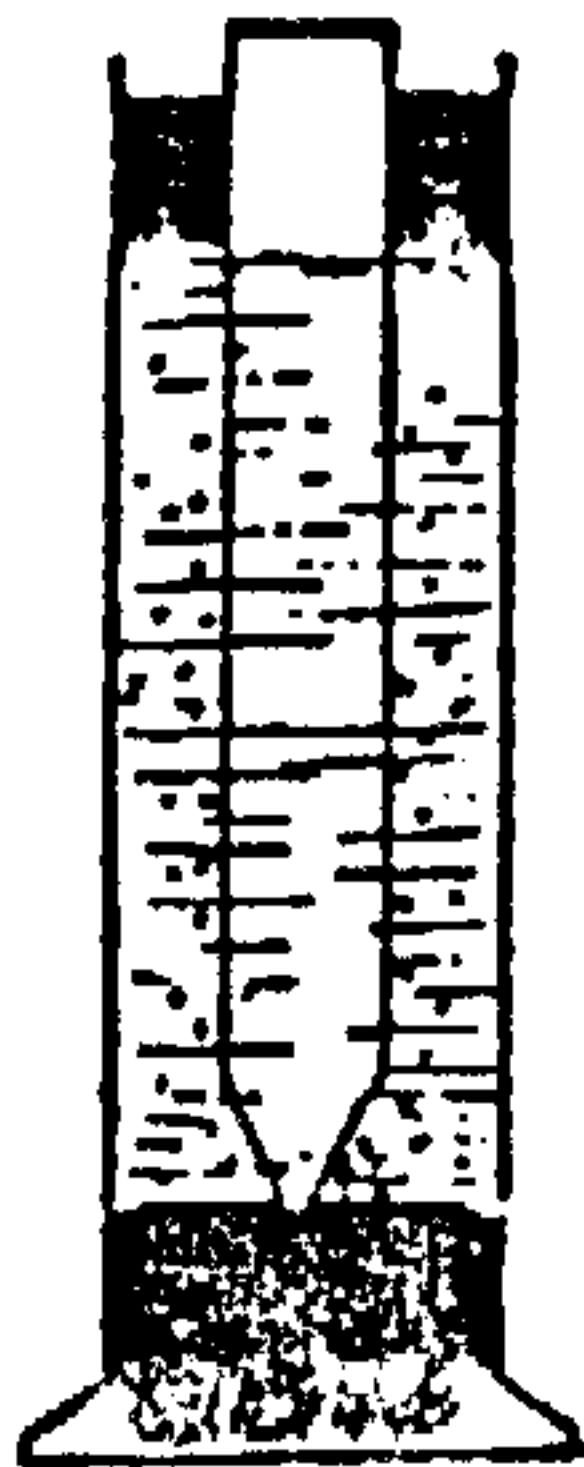


FIGS. 57 to 60.—Formation of tufts of alumina on strips of aluminium covered with invisible traces of mercury. (Instantaneous photograph.)

The alumina formed is, besides, always hydrated.

<sup>1</sup> All the figures given by me in this book must be very exactly followed by any one wishing to repeat my experiments. The repeated shocks produced by the shaking tend to generate combinations which do not occur otherwise. It was by shaking a bottle containing ethylene and sulphuric acid some 3000 times that M. Berthelot, as is well known, obtained the synthesis of alcohol.

If, instead of placing the aluminium on a support, it is thrown into a vessel full of water immediately after taking it out of the mercury, it energetically decomposes the liquid and transforms itself into alumina. This operation only ceases when the aluminium is entirely destroyed, a complete destruction which never occurs with magnesium. A strip of aluminium 1 millimètre in thickness, 1 centimètre in width, and 10 centimètres in length is entirely destroyed by oxidation in less than forty-eight hours.



**FIG. 61.**— Arrangement of the experiment which allows us to give to a strip of aluminium, after its extremity has touched mercury, the property of decomposing water, and of transforming itself entirely into alumina, even when the mercury is withdrawn after the decomposition of the water has commenced.

As with the transformed mercury, it is easy to preserve indefinitely in the modified aluminium all its properties by simply immersing it in a bottle of oil of vaseline.

An idea of the minute quantity of mercury necessary to transform in so great a degree the properties of aluminium may be gathered by putting into a precipitating glass filled with distilled water, but containing a small quantity of mercury, a strip of aluminium cleaned with emery and fixed in a cork, so that it can only touch the mercury with its lower extremity (Fig. 61). After a few hours the water begins to decompose, and this decomposition, even after the mercury has been taken away, continues till the strip has been eaten away for a length of 5 to 6 centimètres above the point in contact with the mercury.

In this experiment the action of the mercury has thus extended far beyond the part in contact with it. It may therefore be supposed that the mercury has travelled along the strip of aluminium by an electro-capillary phenomenon. The



following experiment is free from this objection, and shows even more clearly the slight quantity of mercury necessary to transform the properties of aluminium.

Into a dry and very clean bottle is put a small quantity of pure distilled mercury; the bottle is shaken for one minute, then the mercury is poured out so that there remains no visible trace of it on its sides, which, moreover, will have kept all their transparency if the metal used was perfectly pure. The bottle has, nevertheless, retained traces of metal sufficient to transform the properties of aluminium. It is only necessary to wash it with water acidulated by one-fifth part of hydrochloric acid, to place in it a strip of aluminium, and to shake the bottle for thirty seconds to cause the strip to exhibit the properties of oxidation mentioned, although it is impossible to discover on its surface any trace whatever of amalgamation.<sup>1</sup>

The proportion of mercury necessary to produce the transformation of aluminium can be represented in figures. If, to a bottle containing water acidulated by one-fifth of hydrochloric acid is added a trace of bichloride of mercury so weak that the liquid only contains  $\frac{1}{1000}$ th of its weight, and a strip of aluminium be inserted, and the bottle shaken for two minutes, the aluminium will have acquired all the properties I have indicated, although, as in the preceding experiment,

<sup>1</sup> As the conditions in which aluminium can combine with mercury without the intervention of any reagent may be met with in any laboratory, I at first supposed that some of the facts I noted must have long been known. After fruitlessly consulting the most accredited chemical treatises without finding anything but facts relating to the amalgamation of aluminium in the presence of bases, I made inquiries of the most eminent chemists, and notably of M. Ditte, Professor of Chemistry at the Sorbonne, and author of the most complete and recent work on the properties of aluminium. One and all answered that none of the facts I pointed out, neither as regards aluminium nor mercury nor magnesium, had before been published.

there is no trace of amalgamation visible to the naked eye.

The electro-motive force of the modified aluminium is more than double that of ordinary aluminium. With a couple formed of platinum, pure water, and ordinary aluminium the electro-motive force I found was 0.75 volts. By replacing in the same couple the ordinary aluminium by the modified aluminium, the electro-motive force rose to 1.65 volts.

The hydrogen which is disengaged during the decomposition of water by the modified aluminium renders the air a conductor of electricity, as may be verified by connecting an electroscope with a metal receptacle containing water and fragments of transformed aluminium. The discharge of the electroscope is about the same whether its charge be positive or negative.

In addition to these new properties of oxidizing when cold and of decomposing water exhibited by the aluminium, it has also acquired the property of being affected by sulphuric, acetic, and nitric acids, which in general have no action upon it.

- To observe this new property the following precautions should be taken:—For acetic acid, it is only necessary to use it pure and crystallizable; for nitric acid, the metal drawn from the bottle of mercury must be plunged into the nitric acid of commerce. After a few seconds the metal is very violently attacked, its temperature raised considerably, accompanied by the disengagement of heavy russet-coloured vapour. The reaction is rendered less dangerous by adding to the nitric acid half its weight of water.

If nitric acid pure at 40° were employed instead of the nitric acid of commerce, the aluminium would not be affected.

The difference of action by pure and impure nitric acid is not an isolated example. It has long been

known that there is a difference in the action exercised on lead by pure and ordinary water. Pure water attacks it, while ordinary water does not. It is sufficient to pour distilled water on recently prepared lead filings for the liquid to become tinted in a few minutes by the formation of oxide of lead. With ordinary instead of distilled water the liquid remains perfectly limpid. Ordinary water modifies the surface of the metal, and deposits on it insoluble carbonates and sulphates.

Sulphuric acid does not affect ordinary aluminium, as the chemistry books teach us; but it energetically attacks modified aluminium. Pure sulphuric acid is almost devoid of action. Sulphuric acid in twice its volume of water must be used. Once the action has commenced, enough water can be added to reduce the sulphuric acid to one-hundredth part. The reaction continues with almost the same vivacity. Sulphuric acid diluted to the one-hundredth degree, which has an action almost nil on aluminium not already attacked, has, on the contrary, a very great action as soon as the reaction has started. Consequently, it has the power of continuing but not of exciting it.

The fact that sulphuric acid pure or diluted does not attack ordinary aluminium is taught in chemistry books, but it is not quite exact. Pure sulphuric acid, it is true, has no action, but with half its measure of water added it instantaneously attacks aluminium, though less energetically than in the case of modified aluminium. The verification of so simple a fact not being open to any misconception, it must be supposed that the divergence between what is written in the books and what is shown by observation is due to the chemists, who first studied the action of sulphuric acid on aluminium, making use of a metal containing foreign bodies which modern manufacture has succeeded in

eliminating. Foreign bodies in aluminium greatly modify its properties. I have come across samples of impure aluminium with which I was unable to effect any of the preceding experiments.

In his notable memoir on the properties of aluminium, M. Ditte had already shown that this metal could be affected by acids, but only by adopting certain devices. For weak sulphuric acid to act, a little chloride of platinum has to be added; for nitric acid, a vacuum has to be made above the metal plunged into the acid. The attack, moreover, is very slow, and in no wise violent, as is the case with modified aluminium. M. Ditte has concluded, from his numerous experiments, that aluminium is a metal easily liable to attack under many conditions, several of which are still undetermined. The fact appears indisputable. The Navy has been compelled to abandon the use of aluminium, and unless means be found to associate it with a metal able to modify its properties, it will be impossible to employ it, as has been proposed, for metallic constructions.

## CHAPTER XIII.

### EXPERIMENTS ON THE PASSAGE OF THE ELEMENTS PRODUCED BY THE DISSOCIATION OF MATTER THROUGH MATERIAL OBSTACLES.

I HAVE already given, in the body of this work, photographs showing how varied are the equilibria which may be imposed on particles of dissociated matter by utilizing their attractions and repulsions, and it would be useless to return to the subject. I have likewise reproduced photographs showing that by increasing the speed of projection of these particles by a rise in the electric tension of the apparatus generating them, they may be made visibly to pass through material objects. This operation having great importance, I recur to it so as to fully describe the *technique* which I did not previously go into.

The apparatus used, represented in Fig. 62, is very simple, but the adjustment of the great solenoid serving to considerably raise the electric tension is rather delicate. The position in which one of the wires starting from the small solenoid will give the maximum result—that is, a long sheaf of effluves round the ball terminal of the solenoid—has to be ascertained by repeated experiments. The coil used must give at least 30 centimètres of spark for the effects observed to be very clear. When the apparatus is properly regulated, there will be seen to issue from the terminal a sheaf of effluves having the exact appearance of the

dotted rays reproduced in the sketch. These effluves possess the surprising property of traversing without

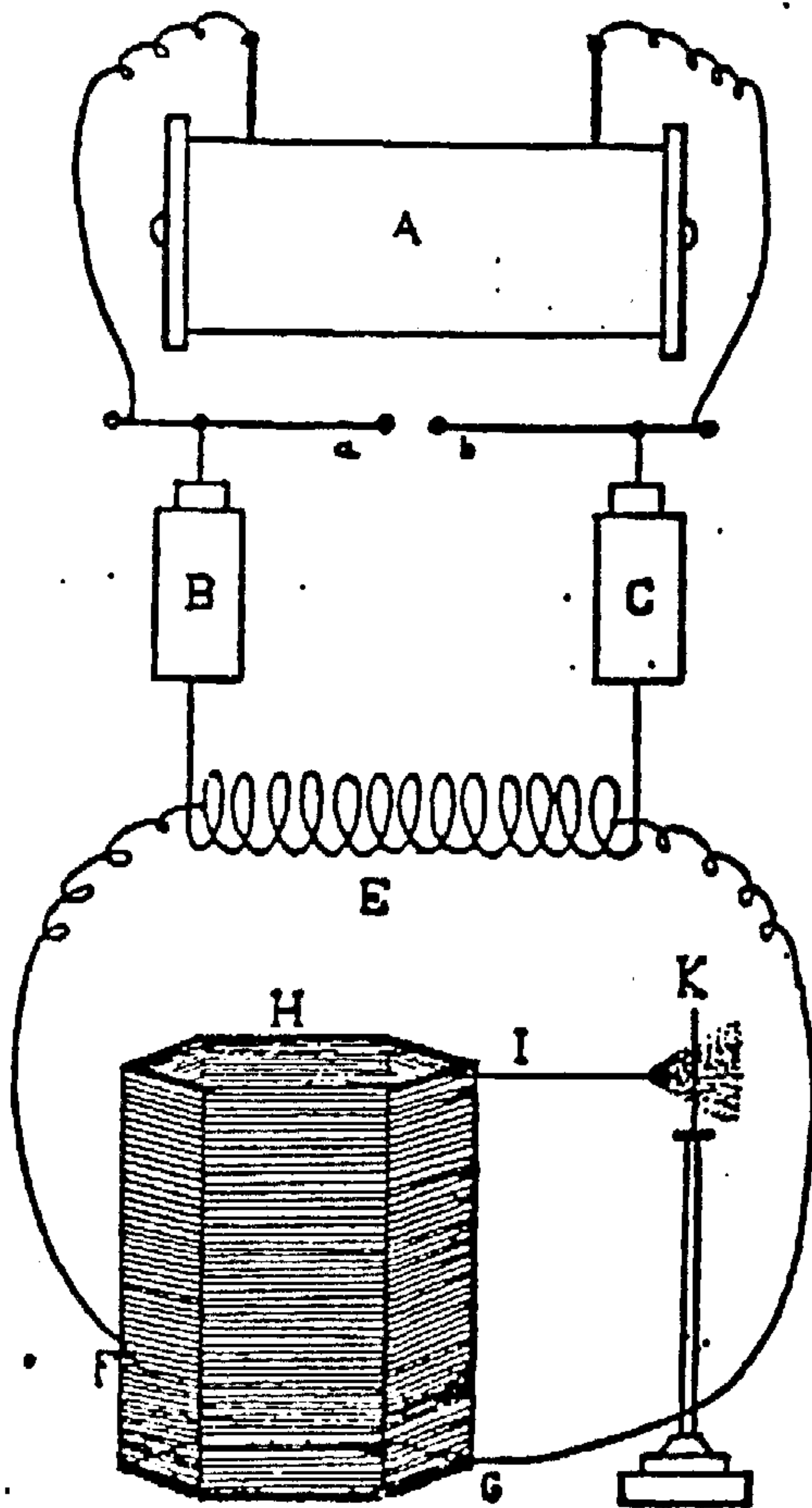


FIG. 62.—*Diagram of the arrangement for giving to the effluves produced by particles of dissociated matter sufficient tension to enable them to pass through thin plates of non-conducting bodies, such as glass and ebonite.*

A, induction coil. It must be able to give sparks of 30 centimètres minimum length.

B, C, Leyden jars connected with the poles of the coil. Their internal coatings are connected to two rods, *a b*, terminating with balls which are set about a centimètre apart, and between which the discharge takes place.

E, small solenoid, connected with the two external coatings of the Leyden jars.

H, large solenoid formed of coiled copper wire. It is connected with the solenoid E by two wires, GF. The position of the wire G is invariable. That of the wire F should be deter-

mined by experiment until the maximum of effluves in tufts at K is obtained.

I, metallic rod fixed to the first spire of the solenoid. At its extremity are formed the tufts capable of passing through opaque bodies.

K, strip of glass or ebonite through which the tufts of effluves pass. Its thickness must not exceed  $\frac{1}{2}$  millimètre maximum.

deviation thin strips of various bodies: ebonite, glass' etc., placed in their way. This effect can seldom be

produced if the thickness of these strips exceeds half a millimètre.<sup>1</sup>

The experience is very striking. The course of these rays can be followed with the naked eye, which would not be the case if it were a question of a secondary emission or of a phenomenon of condensation.

I know of no other experiment by which the visible passage of particles through a material obstacle can be verified. I need not recall the fact that an electric spark can very well pierce through a solid body, as can be verified by placing a strip of glass or of cardboard between the two poles of a static machine or of an induction coil. But then the object is pierced, while in my experiment the effluves pass through it without piercing it.

Mr. F. Legge has repeated this experiment with a Tesla transformer, surrounded by solid vaseline. Owing to the elevation of tension thus obtained, he has succeeded in compelling the effluves to pass through ebonite discs half-centimètre thick, while with the apparatus at my disposal they will not pass through strips thicker than half-millimètre.<sup>2</sup>

If the effluves, obtained as has been explained, are made to pass through a Crookes' tube without either metallic cathode or anode—that is to say, through a simple glass receiver in which a high vacuum has been

<sup>1</sup> It should be noted that the substance to be traversed must be an insulator of electricity. I have myself used with success discs of glass, ebonite, sulphur, and shellac respectively, of  $\frac{1}{2}$ -cm. in thickness, and a disc of paraffin wax of 1 cm.; nor do I doubt that these thicknesses might be exceeded if the tension were sufficiently raised.—F. L.

<sup>2</sup> The apparatus employed by me consists of a transformer of the pattern designed by Elster and Geitel, and made by Ernecké of Berlin. The oscillatory discharge is given by two Leyden jars 40 cm. high, connected in parallel, discharging through a spark gap sheltered from the light of 1 cm., and fed by a very powerful induction coil with a spark-length of 35 cm.—F. L.

created, a production of X-rays will be obtained in sufficient abundance to show clearly the skeleton of the hand on a screen of platino-cyanide of barium. This very unforeseen experiment has always surprised the physicists to whom I have shown it.<sup>1</sup>

<sup>1</sup> By suspending above the apparatus an inverted glass funnel containing an inner funnel of thin copper foil from which a wire is run so as to make contact with the charging rod of an electroscope, it can be shown that these "effluves" are positively charged. That the discharge from the secondary coil of such a transformer as is mentioned in Note 2, p. 417, is positive, has been shown by the researches of Dr. von Wesendonk.—F. L.



## CHAPTER XIV.

### DOCUMENTS RELATING TO THE HISTORY OF THE DISCOVERY OF THE UNIVERSAL DISSOCIATION OF MATTER.

IN a recent work M. Becquerel has given an historical sketch of the discovery of radio-activity, and has caused the passages relating to me to be reproduced in small volumes for popular use. He asserts therein that my experiments for the most part affect a complication "which conceals the real cause of the phenomena observed." He concludes by saying, "It is sufficient to read the publications of M. Gustave Le Bon in *Comptes rendus* [*de l'Académie des Sciences*] to be convinced that, at the time they were written, the author had no idea of the phenomena of radio-activity."

Evidently no one is going to verify the assertions of M. Becquerel in the *Comptes rendus* of this period (1896-97), but should any one do so, what would he learn?

He would learn that for three years, M. Becquerel took infinite pains, with multiple and varied experiments, to prove that the radiations emitted by uranium could be polarized, reflected, and refracted, and, consequently, were only, according to the definition of J. J. Thomson, "one of the forms of light"—an opinion which M. Becquerel himself acknowledged later to be entirely erroneous. The idea M. Becquerel himself entertained at that time was therefore as inexact as possible.

In papers published by me at this very period, I upheld an opinion diametrically opposite to his. I laboured, in fact, to prove, contrary to his assertions, that the radiations of uranium could not be reflected, refracted, nor polarized. They, therefore, had no relationship to light, and constituted in my ideas a new form of energy very much akin to the X rays. I added that the uranium rays were identical with the effluves emitted by all bodies, under the influence of light. Time has proved the correctness of these various assertions, which I was then alone in maintaining.

The historical sketch of M. Becquerel thus constitutes a complete inversion of the most evident facts, and, were I inclined to make use of the expressions he uses with regard to me and the first experiments on the phenomena afterwards termed "radio-activity," I have the right to say that it was he, at that time in question, who "had no conception of the phenomena of radio-activity." But since the text of the *Comptes rendus* of the Académie des Sciences are referred to, I will quote them.

All the experiments of M. Becquerel tending to prove that the rays emitted by uranium refract, reflect, and polarize, are described therein most circumstantially and in detail. He proves the refraction of the uranium rays by means of a mirror, and their polarization by the classic process of tourmaline plates with crossed axes. These various experiments he checks one by the other, and on three different occasions repeats his assertions, each time bringing forward new demonstrations (*Comptes rendus*, 1896, pp. 561, 693, 763). His last controlling experiment was, according to him, absolutely categorical, and he drew from it the following conclusions:—

"This experiment therefore shows, for the invisible rays emitted by salts of uranium, alike the double

refraction, the polarization of the two rays and their unequal absorption through the tourmaline."

We know—for M. Becquerel has since acknowledged it—how incorrect these experiments were, and, consequently, what a false idea he then entertained of radio-activity.

"What there is piquant in this," writes Professor de Heen on the subject of the polarization and the reflection of the uranium rays, "is, that it took three years for M. Becquerel to convince himself that Dr. Gustave Le Bon was right, and even then an American physicist had to come to the rescue.<sup>1</sup>

M. Becquerel, moreover, gave explanations on this matter before the Physical Congress in 1900 in a manner that would lead to the belief that he had spontaneously discovered his mistake.

"The experiment on the polarization of the uranium rays," he stated, "did not in the end yield the same results either with tourmaline plates or with other methods. The same negative conclusions have been arrived at by M. Rutherford and M. Gustave Le Bon."<sup>2</sup>

I have indicated the passages in the *Comptes rendus* relating to the first experiments of M. Becquerel; I will now recall those concerning my own. At that period (1896-97) I was still confusing two very different things: 1st, infra-red radiations which, contrary to the teachings of science, passed through, as I proved, most non-conducting bodies—wood, stone, black paper, ebonite, etc.; 2nd, radiations emitted by metals under the influence of light and which I affirmed to be identical with the cathode and uranium rays, as thenceforth admitted by all physicists.

<sup>1</sup> Professor Rutherford, who appears to be intended, is, as has been said, not an American, but a Canadian.—F. L.

<sup>2</sup> *Congrès de Physique*, t. iii. p. 34.

Here are a few extracts from my published papers—

“From the beginning of the year 1897 (*Comptes rendus*, 5th August 1897, p. 755) I showed that all bodies struck by light give birth to radiations of the family of the cathode rays.”

A few weeks later I showed the analogy of these radiations emitted by bodies under the action of light with uranium rays, and concluded my paper with the words, “*The properties of uranium must therefore only be one particular case of a very general law.*” (*Comptes rendus*, 1897, p. 895.)

My first researches were developed for eight years in numerous memoirs, in which I detailed every time new experiments. And my first experiments having appeared to be somewhat forgotten by authors who daily rediscovered facts already pointed out by me, I drew attention to my anterior publications in a note in the *Comptes rendus de l'Académie des Sciences*, 1902, p. 32, from which I extract the following:—

“At the very beginning of my researches on the mode of energy to which I gave the name of Black Light, I stated that the effluves emitted by bodies struck by light are of the same nature as the uranium rays, which are commonly considered as identical with the cathode rays, and as being constituted by the elements of dissociated atoms, and the carriers of electric changes.

“Enlarging the circle of these researches, I demonstrated later that similar effluves were manifested in a large number of chemical reactions, and I was able to conclude that this production of effluves under very varying influences constituted one of the most widespread of the phenomena of nature.

“Since that epoch, several authors, Lenard especially, have also arrived at this conclusion that metals struck

by light generate cathode rays which are subject to deviation by a magnet.

“All effluves disengaged under the action of light in the conditions just set forth exhibit the closest analogies with the emissions now described under the name of radio-activity of matter. The production of these last therefore does appear to be, as I was a long time alone in maintaining, *a particular case of a very general law*. This general law is, that under divers influences, the atoms of matter may be subject to a strong dissociation, and give birth to effluves with properties very different from those of the bodies from which they emanate.”  
(*Comptes rendus*, 1902, p. 32.)

The loss of memory on the part of certain physicists had already struck one of the most eminent of them. M. de Heen, Professor of Physics at the University of Liège, somewhat scandalized by this fact, wrote a memoir: *Quel est l'auteur de la découverte des phénomènes dits radio-actifs?* (published by the Institut de Physique of Liège in 1901) in which, from published documents alone, he re-established the truth.

I had at that time never seen the learned professor, and only knew his paper through its being sent to me. Had he consulted me before publishing it, I should have informed him that the only point I cared for was the demonstration of the universality of the radio-activity of matter, seeing that the real author of the discovery of radio-activity was Niepce de Saint-Victor, who revealed, fifty years ago, the properties which salts of uranium possessed, of emitting for months together radiations in the dark, as I will again show later on. Those who afterwards brought the question entirely up to date were Curie, with his great discovery of Radium, and Rutherford with his study of the radiation of radio-active bodies.

The works for popular use due to the disciples of M. Becquerel exhibit the above facts in a totally different light. In M. Berget's work *Le Radium* may be read, page 37, "Thereafter the labours of M. Becquerel were so many victories: one after the other he discovered in 1896 and 1897 that the rays emitted by uranium were subject neither to reflection by mirrors nor refraction by prisms." This is the exact contrary to what M. Becquerel was then persistently seeking to demonstrate. The quotations given above prove this clearly.

More than one philosophical lesson can be learned from the above. I am not speaking, let it be understood, of the method of writing history of which the above is a specimen; it has never been written otherwise. I simply wish to point out the intensity of the illusions which the suggestion derived from preconceived ideas may create in the mind of a clever physicist with many assistants. If Niepce de Saint-Victor had not formerly written that the radiations emitted in the dark by salts of uranium were light stored up—that is to say, a kind of phosphorescence—M. Becquerel would assuredly never have dreamed of considering that they must necessarily be refracted, reflected, and polarized. Such errors as these easily explain some of the enormities written in complete good faith on the subject of the N rays.

In the same book, where I am so harshly dealt with, M. Becquerel finally decided, for the first time, to mention the name of Niepce de Saint-Victor, having hitherto confined himself to reproducing his experiments on the salts of uranium and following his predecessor even in his errors, since he shared his belief in a kind of stored-up light.

Not very equitable towards the living, M. Becquerel is still less so towards the dead, and his suppressions

are at times very unilluminating. Niepce is disposed of in a few lines. "Niepce," he says, "was unable to observe the radiation of uranium because he employed plates insufficiently sensitive."

It is sufficient to read the *Comptes rendus* of that period to see how little foundation there is for this assertion. As early as 1867, Niepce observed that salts of uranium enclosed in a tin case caused impressions on plates in the dark. "The same activity," he says, "is noticed *after* several months as on the first day."<sup>1</sup>

If it were true—and such is not at all the case—that Niepce de Saint-Victor had actually divined the existence of the only body in nature which possessed the property of emitting radiations in obscurity, such a divination would have been a little more than a stroke of genius.

But Niepce had no such claims. He was a conscientious and patient observer, ignored during his lifetime, forgotten when dead. The fact that only two physicists have dared to recall to M. Becquerel the experiments of Niepce shows how small a degree of scientific independence exists in France.

It is impossible to think without bitterness of the opposition offered to Niepce by the official scholars of his time. If, instead of endeavouring to ridicule his memorable experiments, an attempt had been made to repeat them, there certainly would have been found some one to think of determining how long the salts of uranium could continue, in the darkness, to impress plates, exactly as it occurred to M. Becquerel. And if Niepce had persisted, as did later M. Becquerel, in the mistake of believing in stored-up light, akin to phosphorescence, some one would again have been found to show him—as was shown to M. Becquerel—that these

<sup>1</sup> Quoted by M. Guillaume from the *Comptes rendus de l'Académie des Sciences*, 1867, in *Radiations Nouvelles*, 2nd edition, p. 133.

radiations, not being polarizable, could not be light. Radio-active phenomena would then have been as quickly discovered as they were when the demonstration of the non-polarization of the uranium rays proved that it was a question of something entirely novel. In view of the discoveries brought to light by the simple fact that uranium preserves indefinitely its powers of impressing a photographic plate in darkness, it may be said that the opposition and indifference to Niepce de Saint-Victor's experiments have immensely retarded the progress of science for more than fifty years.

To end definitely a polemic which might continue for ever, I do not fear contradiction when I state that to judge the work of one who makes researches, the subject of them should be examined as to its state before and its condition after his researches.

Now, when I published my experiments in 1897, what were the current ideas on the question?

1stly. It was thought that uranium emitted a kind of invisible light. Well, I proved that it emitted something entirely new, which was analogous to the radiations of the family of the X rays, and consequently had no relationship whatever to light—a fact which has since been completely verified.

2ndly. It was absolutely unknown that metals struck by light acquired properties identical with those of the uranium and the cathode rays. I demonstrated this, contrary to all accepted ideas. The fact, which has long been known, that certain electrified metals lost their electric charge under the influence of light, proceeded, according to Lenard, from the fact that under this influence their surface became pulverized into dust, which, disseminated in the air, carried off the electric charges of the electrified particles of the metal.

Lenard, however, was the first to acknowledge his



error. On the publication of my experiments, he renewed his own, and found that metals under the influence of light emitted cathode rays which could be deviated by a magnet,<sup>1</sup> and the experiments were subsequently confirmed by J. J. Thomson.

3rdly. At the time referred to it was believed, and M. Becquerel believed, that radio-activity was a quite exceptional phenomenon belonging to an infinitely limited number of bodies. In a series of experiments I showed that it was one of the most widespread phenomena in nature, produced, not only under the influence of light, but under that of heat, and of a large number of chemical reactions. This opinion has gradually gained ground, and is now almost universally admitted.

In the above enumeration I do not bring into prominence the demonstration that all these phenomena are manifestations of a new force—namely, intra-atomic energy, which surpasses all others by its colossal magnitude. The existence of this force is still in some measure contested, and I only desired to recall here those facts which are above all dispute.

4thly. The doctrine of the dissociation of matter was only formulated a long time after my researches. The physicists of the University of Cambridge have become its warm partizans, since one of them declared in the course of a recent polemic that it was "the most important theory of physics"; but they have taken a long time to range themselves on its side. In 1900, J. J. Thomson, a very eminent scholar, but one who easily forgets the work of his predecessors, still believed that radio-active emissions were a form of light. This

<sup>1</sup> Lenard's memoir, *Erzeugung Kathodenstrahlen durch ultra violette Licht*, was presented to the Academy of Sciences of Vienna on the 18th October 1899. My experiments were published in the *Comptes rendus de l'Académie des Sciences* of Paris, on the 5th April 1897.

is what he wrote at that date: "Becquerel found that the radiations of uranium can be reflected, polarized, and refracted, so that it is evidently one of the forms of light." (*Discharge of Electricity through Gases*, p. 57. 1898.)

This is what I wrote at the same date at the end of a long memoir filled with experiments: "As a general conclusion, we may say that under the influence of very varied causes—light, chemical reactions, electrification, etc.—bodies can dissociate. Matter thus dissociated manifests itself under the form of infinitely small particles of immense speed, and capable of rendering the air a conductor of electricity, and of traversing opaque bodies. These particles represent a form of matter quite different from those which chemistry has made known to us—a new state where the atom is probably dissociated.

"And surely there can be no question here of properties only belonging to certain special bodies, such as uranium, thorium, etc., for these bodies only represent, as I said long since, particular cases of a very general law." (*Revue Scientifique*, p. 458. April 1900.)

5thly. I will finally add that I was the first to formulate in a special memoir the doctrine that all the phenomena of the dissociation of matter are the manifestations of a new force—*Intra-atomic Energy*—which surpasses all others by its colossal magnitude, and whence are derived, according to my researches, the greater part of the forces of nature, especially electricity and the heat of the sun.

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## ERRATA.

- Page 9, line 15, for "instable" *read* unstable.
- " 13 " 30, for "Nature and Energy" *read* Matter and Energy.
- " 17 " 5 and 6, for "measured by its weight, remained" *read* measured by its weight—remained.
- " 18 " 20, for "something very simple, governed" *read* something very simple and governed.
- " 29 " 31, for "In one of the annual reviews" *read* In one of the reviews.
- " 37 " 9, for "phenomena" *read* phenomenon.
- " 37 " 22, for "to" *read* of.
- " 38 " 9, for "of succeeding in dissociating" *read* of dissociating.
- " 38 " 10, for "we could dissociate" *read* we could manage to dissociate.
- " 38 " 20, for "phenomena" *read* —phenomena.
- " 38 " 25, for "define" *read* verify.
- " 42 " 23, for "an" *read* per.
- " 45 " 15, for "have reached" *read* have sometimes reached.
- " 45 " 16, for "sometimes very much higher" *read* very much higher.
- " 48 " 6, for "kilogrammes" *read* kilomètres.
- " 54 " 31 and 32, "condensation, in immense quantities, within" *read* condensation in immense quantities within.
- " 57 " 31, "the history of sciences" *read* the history of the sciences.
- " 62 " 2, for "must always bear in mind to understand" *read* must always bear in mind in order to understand.
- " 70 " 2 and 5, for "instable" *read* unstable.
- " 81 " 9, for "Physics, in fact, still maintains a wide separation" *read* Physics in fact still maintains that a wide separation.
- " 82 " 12, for "matter and energy, reproduced" *read* matter and energy reproduced.
- " 87 " 19, for "prominent parts" *read* crest.
- " 87 " 20, for "hollow parts" *read* trough.
- " 90 " 20, for "that is to say, their mass, is" *read* that is to say their mass—is.
- " 93 " 5, for "and thus" *read* and thus to .

- Page 94, line 20, for "instable" *read* unstable.
- " 95 " 8, for "vibrations and vortices" *read* vibrations, and vortices.
- " 95 " 15, for "the thermometer, the attractions" *read* the thermometer the attractions.
- " 99 " 10, for "fixed and cast in layers" *read* fused and cast in thin layers.
- " 116 " 27, for "aggregate of electrons and neutral particles form" *read* aggregate of electrons and neutral particles forms.
- " 123 " 24-26, for "bodies are found, has proved, as has just been said, the cathode rays and the emission from radio-active their identity" *read* the cathode rays and the emission from radio-active bodies are formed, has proved, as has just been said, their identity.
- " 127 " 24, for "For the extreme violet" *read* For the extreme ultra-violet.
- " 127 " 25, for ".160 $\mu$  to .100 $\mu$ " *read* 0.160 $\mu$  to 0.100 $\mu$ .
- " 155 " 3, for "phenomena" *read* phenomenon.
- " 161 " 9, for "recover" *read* find.
- " 175 " 18, for "temperatures," *read* temperatures.
- " 175 " 22, for "leads" *read* lead.
- " 176 " 13, for "radiations" *read* the radiations.
- " 177 " 17, for "at times powerfully modify" *read* powerfully modify.
- " 178 " 26, for "became" *read* becomes.
- " 186 " 31, for "instable" *read* unstable.
- " 195 " 17, for "from its condition as an electrified body" *read* from their condition as electrified bodies.
- " 205 " 24, for "magnetic" *read* negative.
- " 211 " 18, for "under  $\lambda = .230\mu$ " *read* under  $\lambda = 0.230\mu$ .
- " 213 " 11, for ".230 $\mu$ " *read* 0.230 $\mu$ .
- " 213 " 18 and 19, for "they hardly propel themselves farther" *read* they are hardly propagated farther.
- " 234 " 24, for "state of rapid motion" *read* state of rapid motion within the atom.
- " 251 " 9, for "delicate sign in life" *read* delicate sign of life.
- " 264 " 4, for "quantity of heat, expressed in calories" *read* quantity of heat expressed in calories.
- " 266 " 3, for "to acquire, a knowledge" *read* to acquire a knowledge.
- " 269 " 5, for "Recent researches in colloidal metals, which we" *read* The recent researches in colloidal metals which we.

- Page 295, line 17, for "would paralyze all efforts" *read* would then paralyze all our efforts.
- " 306 " 21, for "we barely see" *read* we see.
- " 311 " 21, for "assume to affect" *read* assume to effect.
- " 312 " 11, for "continued to exist, since their formation" *read* continued since their formation.
- " 315 " 24, for "nor" *read* or.
- " 318 " 22, for "truths approximately true" *read* truths which are approximately true.
- " 321 " 15, for "very simple experiments, and consequently easy" *read* only experiments very simple and consequently easy.
- " 325 " 1 of Figure description, for "reducing" *read* evidencing.
- " 325 " 4 " " for "capsule placed on the" *read* capsule on the.
- " 345 " 23, for "derivation" *read* deviation.
- " 348 " 4, for "dissociated matter by light" *read* matter dissociated by light.
- " 354 " 10, for "propelled" *read* propagated.
- " 360 " 2 of Note, for "positively" *read* negatively.
- " 364 " 24, for "radiations of the end of the spectrum" *read* radiations at the end of the spectrum.
- " 376 " 1 of Note, for "charges" *read* changes.
- " 386 " 7, for "carbide" *read* carbide.
- " 394 " 27, for "an" *read* the.
- " 400 " 28, for "only 0.2 thick" *read* only 0.2 mm. thick.
- " 402 " 11, for "closely" *read* slowly.
- " 417 " 4 and 5 of Note 2, for "spark gap sheltered from the light of 1 cm." *read* spark gap of 1 cm. sheltered from the light.