RADIOACTIVE SUBSTANCES

MARIE CURIE

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MARIE CURIE (née Maria Sklodowska) was born on November 7, 1867, in Warsaw, Poland. Her mother, Bronsilawa Boguska, was an accomplished pianist, singer, and teacher, and her father, Wladyslaw Sklodowski, was a professor of mathematics and physics. A brilliant student, Marie gained a gold medal upon completing her secondary education in 1883. Refused admission to the University of Warsaw because she was a woman, she earned her living as a private tutor and governess. One of her sisters, Bronya, was already studying medicine in Paris, and she encouraged Marie to move there.

In November 1891 Marie enrolled at the Sorbonne, where she would earn her doctorate in physics in 1904. In 1894 she met Pierre Curie (1859–1906) at the School of Physics and Chemistry of the University of Paris while working in his laboratory on her research project. They wed in 1895.

The Curies began their research into the mysterious radiation from uranium that had been discovered by Antoine Henri Becquerel (1852–1908) and in 1898 announced the discovery of radium. In 1903 the Curies and Becquerel were awarded the Nobel Prize in physics for their work on radioactivity. In 1904 Marie published her thesis, *Radioactive Substances*.

After the death of Pierre on April 19, 1906, Curie succeeded her husband as professor of general physics at the Sorbonne, becoming the first woman faculty member in the 650 years of the school's existence. In 1908 she taught the first and at that time the only course on radioactivity ever offered at the Sorbonne. In 1911 she received the Nobel Prize in chemistry for her discovery of polonium and radium and for isolating pure radium. She was the first person ever to receive the award twice. During World War I she organized radiological units for hospitals. She was the director of the research department of the Radium Institute of the University of Paris (1918–1934).

Curie died on July 4, 1934, in Valence, France, a victim of exposure to the deadly rays from radium. Her last book, *Radioactivity* (1935), was edited by her daughter Irène, who shared the 1935 Nobel Prize in chemistry with her husband, Jean-Frédéric Joliet, for their discovery of new radioactive isotopes prepared artificially.

CONTENTS

INTRODUCTION

The object of the present work is the publication of researches which I have been carrying on for more than four years on radioactive bodies. I began these researches by a study of the phosphorescence of uranium, discovered by M. Becquerel. The results to which I was led by this work promised to afford so interesting a field that M. Curie put aside the work on which he was engaged, and joined me, our object being the extraction of new radioactive substances and the further study of their properties.

Since the commencement of our research we thought it well to hand over specimens of the substances, discovered and prepared by ourselves, to certain physicists, in the first place to M. Becquerel, to whom is due the discovery of the uranium rays. In this way we ourselves facilitated the research by others besides ourselves on the new radioactive bodies. At the termination of our first publications, M. Giesel, in Germany, also began to prepare these substances, and passed on specimens of them to several German scientists. Finally, these substances were placed on sale in France and Germany, and the subject growing in importance gave rise to a scientific movement, such that numerous memoirs have appeared, and are constantly appearing on radioactive bodies, principally abroad. The results of the various French and foreign researches are necessarily confused, as is the case with all new subjects in course of investigation, the aspect of the question becoming modified from day to day.

From the chemical point of view, however, one point is definitely established:—i.e., the existence of a new element, strongly radioactive, viz., radium. The preparation of the pure chloride of radium and the determination of the atomic weight of radium form the chief part of my own work. Whilst this work adds to the elements actually known with certainty a new element with very curious properties, a

new method of chemical research is at the same time established and justified. This method, based on the consideration of radioactivity as an atomic property of matter, is just that which enabled M. Curie and myself to discover the existence of radium.

If, from the chemical point of view, the question that we undertook primarily may be looked upon as solved, the study of the physical properties of the radioactive bodies is in full evolution. Certain important points have been established, but a large number of the conclusions are still of a provisional character. This is not surprising when we consider the complexity of the phenomena due to radioactivity, and the differences existing between the various radioactive substances. The researches of physicists on these substances constantly meet and overlap. Whilst endeavoring to keep strictly to the limits of this work and to publish my individual research only, I have been obliged at the same time to mention results of other researches, the knowledge of which is indispensable.

I desired, moreover, to make this work an inclusive survey of the actual position of the question.

I indicate at the end the particular questions with which I am specially concerned, and those which I investigated in conjunction with M. Curie.

I carried on the work in the laboratories of the School of Physics and Chemistry in Paris, with the permission of Schützenberger, late Director of the School, and M. Lauth, actual Director. I take this opportunity of expressing my gratitude for the kind hospitality received in this school.

HISTORICAL

The discovery of the phenomena of radioactivity is connected with researches followed, since the discovery of the Röntgen rays, upon the photographic effects of phosphorescent and fluorescent substances.

The first tubes for producing Röntgen rays were without the

metallic anticathode. The source of the Röntgen rays was the glass surface impinged upon by the cathode rays; this surface was at the same time actively fluorescent. The question then was whether the emission of Röntgen rays necessarily accompanied the production of fluorescence, whatever might be the cause of the latter. This idea was first enunciated by M. Henri Poincaré.

Shortly afterwards, M. Henry announced that he had obtained photographic impressions through black paper by means of phosphorescent zinc sulphide. M. Niewenglowski obtained the same phenomenon with calcium sulphide exposed to the light. Finally, M. Troost obtained strong photographic impressions with zinc sulphide artificially phosphorescent acting across black paper and thick cardboard.

The experiences just cited have not been reproduced, in spite of numerous attempts to this end. It cannot therefore be considered as proved that zinc sulphide and calcium sulphide are capable of emitting, under the action of light, invisible rays which traverse black paper and act on photographic plates.

M. Becquerel has made similar experiments on the salts of uranium, some of which are fluorescent.

He obtained photographic impressions through black paper with the double sulphate of uranium and potassium.

M. Becquerel at first believed that this salt, which is fluorescent, behaved like the sulphides of zinc and calcium in the experiments of MM. Henry, Niewenglowski, and Troost. But the conclusion of his experiments showed that the phenomenon observed was in no way related to the fluorescence. It is not necessary that the salt should be fluorescent; further, uranium and all its compounds, fluorescent or not, act in the same manner, and metallic uranium is the most active. M. Becquerel finally found that by placing uranium compounds in complete darkness, they continue acting on photographic plates through black paper for years. M. Becquerel allows that uranium and its compounds emit peculiar rays—uranium rays. He proved that these rays can penetrate thin metallic screens, and that they discharge electrified bodies. He also made experiments from which he

concluded that uranium rays undergo reflection, refraction, and polarization.

The work of other physicists (Elster and Geitel, Lord Kelvin, Schmidt, Rutherford, Beattie, and Smoluchowski) confirms and extends the results of the researches of M. Becquerel, with the exception of those relating to the reflection, refraction, and polarization of uranium rays, which in this respect behave like Röntgen rays, as has been recognized first by Mr. Rutherford and then by M. Becquerel himself.

CHAPTER I
RADIOACTIVITY OF URANIUM AND THORIUM. RADIOACTIVE MINERALS

Becquerel Rays.—The uranium rays discovered by M. Becquerel act upon photographic plates screened from the light; they can penetrate all solid, liquid, and gaseous substances, provided that the thickness is sufficiently reduced in passing through a gas, they cause it to become a feeble conductor of electricity.

These properties of the uranium compounds are not due to any known cause. The radiation seems to be spontaneous; it loses nothing in intensity, even on keeping the compounds in complete darkness for several years; hence there is no question of the phosphorescence being specially produced by light.

The spontaneity and persistence of the uranium radiation appear as a quite unique physical phenomenon. M. Becquerel kept a piece of uranium for several years in the dark, and he has affirmed that at the end of this time the action upon a photographic plate had not sensibly altered. MM. Elster and Geitel made a similar experiment, and also found the action to remain constant.

I measured the intensity of radiation of uranium by the effect of this radiation on the conductivity of air. The method of measurement will be explained later. I also obtained figures which prove the persistence of radiation within the limits of accuracy of the experiments.

For these measurements a metallic plate was used covered with a layer of powdered uranium; this plate was not otherwise kept in the dark; this precaution, according to the experimenters already quoted, being of no importance. The number of measurements taken with this

plate is very great, and they actually extend over a period of five years.

Some researches were conducted to discover whether other substances were capable of acting similarly to the uranium compounds. M. Schmidt was the first to publish that thorium and its compounds possess exactly the same property. A similar research, made contemporaneously, gave me the same result. I published this not knowing at the time of Schmidt's publication.

We shall say that uranium, thorium, and their compounds emit *Becquerel rays*. I have called *radioactive* those substances which generate emissions of this nature. This name has since been adopted generally.

In their photographic and electric effects, the Becquerel rays approximate to the Röntgen rays. They also, like the latter, possess the faculty of penetrating all matter. But their capacity for penetration is very different; the rays of uranium and of thorium are arrested by some millimeters of solid matter, and cannot traverse in air a distance greater than a few centimeters; this at least is the case for the greater part of the radiation.

The researches of different physicists, and primarily of Mr. Rutherford, have shown that the Becquerel rays undergo neither regular reflection, nor refraction, nor polarization.

The feeble penetrating power of uranium and thorium rays would point to their similarity to the secondary rays produced by the Röntgen rays, and which have been investigated by M. Sagnac, rather than to the Röntgen rays themselves.

For the rest, the Becquerel rays might be classified as cathode rays propagated in the air. It is now known that these different analogies are all legitimate.

MEASUREMENT OF THE INTENSITY OF RADIATION

The method employed consists in measuring the conductivity acquired by air under the action of radioactive bodies; this method possesses the advantage of being rapid and of furnishing figures which are comparable. The apparatus employed by me for the purpose consists essentially of a plate condenser, A B (Fig. I). The active body, finely powered, is spread over the plate B, making the air between the plates a conductor. In order to measure the conductivity, the plate B is raised to a high potential by connecting it with one pole of a battery of small accumulators, P, of which the other pole is connected to earth. The plate A being maintained at the potential of the earth by the connection C D, an electric current is set up between the two plates. The potential of plate A is recorded by an electrometer, E. If the earth connection be broken at C, the plate A becomes charged, and this charge causes a deflection of the electrometer. The velocity of the deflection is proportional to the intensity of the current, and serves to measure the latter.

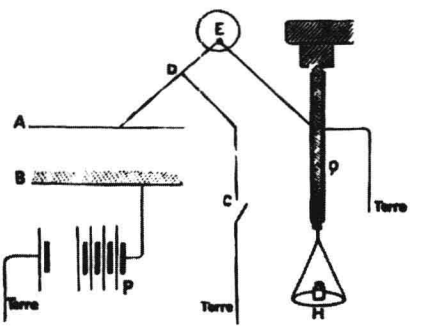

FIG. 1.

But a preferable method of measurement is that of compensating the charge on plate A, so as to cause no deflection of the electrometer. The charges in question are extremely weak; they may be compensated by means of a quartz electric balance, Q, one sheath of which is connected to plate A and the other to earth. The quartz lamina is subjected to a known tension, produced by placing weights in a plate, π; the tension is produced progressively, and has the effect of generating progressively a known quantity of electricity during the time observed. The operation can be so regulated that, at each instant, there

is compensation between the quantity of electricity that traverses the condenser and that of the opposite kind furnished by the quartz. In this way, the quantity of electricity passing through the condenser for a given time, i.e., the *intensity of the current*, can be measured *in absolute units*. The measurement is independent of the sensitiveness of the electrometer.

In carrying out a certain number of measurements of this kind, it is seen that radioactivity is a phenomenon capable of being measured with a certain accuracy. It varies little with temperature; it is scarcely affected by variations in the temperature of the surroundings; it is not influenced by incandescence of the active substance. The intensity of the current which traverses the condenser increases with the surface of the plates. For a given condenser and a given substance the current increases with the difference of potential between the plates, with the pressure of the gas which fills the condenser, and with the distance of the plates (provided this distance be not too great in comparison with the diameter). In every case, for great differences of potential the current attains a limiting value. which is practically constant. This is the *current of saturation*, or *limiting current*. Similarly, for a certain sufficiently great distance between the plates the current hardly varies any longer with the distance. It is the current obtained under these conditions that was taken as the measure of radioactivity in my researches, the condenser being placed in air at atmospheric pressure.

I append curves which represent the intensity of the current as a function of the field established between the plates for two different plate distances. Plate B was covered with a thin layer of powdered metallic uranium; plate A, connected with the electrometer, was provided with a guard-ring.

Fig. 2 shows that the intensity of the current becomes constant for high potential differences between the plates. Fig. 3 represents the same curves on another scale, and comprehends only relative results for small differences of potential. At the origin, the curve is rectilinear; the ratio of the intensity of the current to the difference of potential is constant for weak forces, and represents the initial con-