Radium and Radioactivity

By Mme. Sklodowska Curie, Discoverer of Radium

from *Century Magazine* (January 1904), pp. 461-466

The discovery of the phenomena of radioactivity adds a new group to the great number of invisible radiations now known, and once more we are forced to recognize how limited is our direct perception of the world which surrounds us, and how numerous and varied may be the phenomena which we pass without a suspicion of their existence until the day when a fortunate hazard reveals them.

The radiations longest known to us are those capable of acting directly upon our senses; such are the rays of sound and light. But it has also long been recognized that, besides light itself, warm bodies emit rays in every respect analogous to luminous rays, though they do not possess the power of directly impressing our retina. Among such radiations, some, the infra-red, announce themselves to us by producing a measurable rise of temperature in the bodies which receive them, while others, the ultra-violet, act with specially great intensity upon photographic plates. We have here a first example of rays only indirectly accessible to us.

Yet further surprises in this domain of invisible radiations were reserved for us. The researches of two great physicists, Maxwell and Hertz, showed that electric and magnetic effects are propagated in the same manner as light, and that there exist "electromagnetic radiations," similar to luminous radiations, which are to the infra-red rays what these latter are to light. These are the electromagnetic radiations which are used for the transmission of messages in wireless telegraphy. They are present in the space around us whenever an electric phenomenon is produced, especially a lightning discharge. Their presence may be established by the use of special apparatus, and here again the testimony of our senses appears only in an indirect manner. If we consider these radiations in their entirety - the ultra-violet, the luminous, the infra-red, and the electromagnetic - we find that the radiations we see constitute but an insignificant fraction of those that exist in space. But it is human nature to believe that the phenomena we know are the only ones that exist, and whenever some chance discovery extends the limits of our knowledge we are filled with amazement. We cannot become accustomed to the idea that we live in a world that is revealed to us only in a restricted portion of its manifestations.

Among recent scientific achievements which have attracted most attention must be placed the discovery of cathode rays, and in even greater measure that of Roentgen rays. These rays are produced in vacuum-tubes when an electric discharge is passed through the rarefied gas. The prevalent opinion among physicists is that cathode rays are formed by extremely small material particles, charged with negative electricity, and thrown off with great velocity from the cathode, or negative electrode, of the tube. When the cathode rays meet the glass wall of the tube they render it vividly fluorescent. These rays can be deflected from their straight path by the action of a magnet. Whenever they encounter a solid obstacle, the emission of Roentgen rays is the result. These latter can traverse the glass and propagate themselves through the outside air. They differ from cathode rays in that they carry no electric charge and are not deflected from their course by the action of a magnet. Everyone knows the effect of Roentgen rays upon photographic plates and upon fluorescent screens, the radiographs obtainable from them, and their application in surgery.

The discovery of Becquerel rays dates from a few years after that of Roentgen rays. At first they were much less noticed. The world, attracted by the sensational discovery of Roentgen rays, was less inclined to astonishment. On all sides a search was instituted by similar processes for new rays, and announcements of phenomena were made that have not always been confirmed. It has been only gradually that the positive existence of a new radiation has been established. The merit of this discovery belongs to M. Becquerel, who succeeded in demonstrating that uranium and its compounds spontaneously emit rays that are able to traverse opaque bodies and to affect photographic plates.

It was at the close of the year 1897 that I began to study the compounds of uranium, the properties of which had greatly attracted my interest. Here was a substance emitting spontaneously and continuously radiations similar to Roentgen rays, whereas ordinarily Roentgen rays can be produced only in a vacuum-tube with the expenditure of energy. By what process can uranium furnish the same rays without expenditure of energy and without undergoing apparent modification? Is uranium the only body whose compounds emit similar rays? Such were the questions I asked myself, and it was while seeking to answer them that I entered into the researches which have led to the discovery of radium.

First of all, I studied the radiation of the compounds of uranium. Instead of making these bodies act upon photographic plates, I preferred to determine the intensity of their radiation by measuring the conductivity of the air exposed to the action of the rays. To make this measurement, one can determine the speed with which the rays discharge an electroscope, and thus obtain data for a comparison. I found in this way that the radiation of uranium is very constant, varying neither with the temperature nor with the illumination. I likewise observed that all the compounds of uranium are active, and that they are more active the greater the proportion of this metal which they contain. Thus I reached the conviction that the emission of rays by the compounds of uranium is a property of the metal itself—that it is an atomic property of the element uranium independent of its chemical or physical state. I then began to investigate the different known chemical elements, to determine whether there exist others, besides uranium, that are endowed with atomic radioactivity—that is to say, all the compounds of which emit Becquerel rays. It was easy for me to procure samples of all the ordinary substances—the common metals and metalloids, oxides and salts. But as I desired to make a very thorough investigation, I had recourse to different chemists, who put at my disposal specimens—in some cases the only ones in existence—containing very rare elements. I thus was enabled to pass in review all the chemical elements and to examine them in the state of one or more of their compounds. I found but one element undoubtedly possessing atomic radioactivity in measurable degree. This element is thorium. All the compounds of thorium are radioactive, and with about the same intensity as the similar compounds of uranium. As to the other substances, they showed no appreciable radioactivity under the conditions of the test.

I likewise examined certain minerals. I found, as I expected, that the minerals of uranium and thorium are radioactive; but to my great astonishment I discovered that some are much more active than the oxides of uranium and of thorium which they contain. Thus a specimen of pitch-blende (oxide of uranium ore) was found to be four times more active than oxide of uranium itself. This observation astonished me greatly. What explanation could there be for it? How could an ore, containing many substances which I had proved inactive, be more active than the active substances of which it was formed? The answer came to me immediately: The ore must contain a substance more radioactive than uranium and thorium, and this substance must necessarily be a chemical element as yet unknown; moreover, it can exist in the pitch-blende only in small quantities, else it would not have escaped the many analyses of this ore; but, on the other hand, it must possess intense radioactivity, since, although present in small amount, it produces such remarkable effects. I tried to verify my hypothesis by treating pitch-blende by the ordinary processes of chemical analysis, thinking it probable that the new substance would be concentrated in passing through certain stages of the process. I performed several experiments of this nature, and found that the ore could in fact be separated into portions some of which were much more radioactive than others.

To try to isolate the supposed new element was a great temptation. I did not know whether this undertaking would be difficult. Of the new element I knew nothing except that it was radioactive. What were its chemical properties? In what quantity did it appear in pitch-blende? I began the analysis of pitch-blende by separating it into its constituent elements, which are very numerous. This task I undertook in conjunction with M. Curie. We expected that perhaps a few weeks would suffice to solve the problem. We did not suspect that we had begun a work which was to occupy years and which was brought to a successful issue only after considerable expenditure.

We readily proved that pitch-blende contains very radioactive substances, and that there were at least three. That which accompanies the bismuth extracted from pitch-blende we named Polonium; that which accompanies barium from the same source we named Radium; finally, M. Debierne gave the name of Actinium to a substance which is found in the rare earths obtained from the same ore.

Radium was to us from the beginning of our work a source of much satisfaction. Demarçay, who examined the spectrum of our radioactive barium, found in it new rays and confirmed us in our belief that we had indeed discovered a new element.

The question now was to separate the polonium from the bismuth, the radium from the barium. This is the task that has occupied us for years, and as yet we have succeeded only in the case of radium. The research has been a most difficult one. We found that by crystallizing out the chloride of radioactive barium from a solution we obtained crystals that were more radioactive, and consequently richer in radium, than the chloride that remained dissolved. It was only necessary to make repeated crystallizations to obtain finally a pure chloride of radium.

But although we treated as much as fifty kilograms of primary substance, and crystallized the chloride of radiferous barium thus obtained until the activity was concentrated in a few minute crystals, these crystals still contained chiefly chloride of barium; as yet radium was present only in traces, and we saw that we could not finish our experiments with the means at hand in our laboratory. At the same time the desire to succeed grew stronger; for it became evident that radium must possess most intense radioactivity, and that the isolation of this body was therefore an object of the highest interest.

Fortunately for us, the curious properties of these radium-bearing compounds had already attracted general attention and we were assisted in our search.

A chemical factory in Paris consented to undertake the extraction of radium on a large scale. We also received certain pecuniary assistance, which allowed us to treat a large quantity of ore. The most important of these grants was one of twenty thousand francs, for which we are indebted to the Institute of France.

We were thus enabled to treat successively about seven tons of a primary substance which was the residue of pitch-blende after the extraction of uranium. Today we know that a ton of this residue contains from two to three decigrams (from four to seven ten-thousandths of a pound) of radium. During this treatment, and as soon as I had in my possession a decigram of chloride of radium recognized as pure by the spectroscope, I determined the atomic weight of this new element, finding it to be 225, while that of barium is 137.

The properties of radium are extremely curious. This body emits with great intensity all of the different rays that are produced in a vacuum-tube. The radiation, measured by means of an electroscope, is at least a million times more powerful than that from an equal quantity of uranium. A charged electroscope placed at a distance of several meters can be discharged by a few centigrams of a radium salt. One can also discharge an electroscope through a screen of glass or lead five or six centimeters thick. Photographic plates placed in the vicinity of radium are also instantly affected if no screen intercepts the rays; with screens, the action is slower, but it still takes place through very thick ones if the exposure is sufficiently long. Radium can therefore be used in the production of radiographs.

The compounds of radium are spontaneously luminous. The chloride and bromide, freshly prepared and free from water, emit a light which resembles that of a glow-worm. This light diminishes rapidly in moist air; if the salt is in a sealed tube, it diminishes slowly by reason of the transformation of the white salt, which becomes colored, but the light never completely disappears. By redissolving the salt and drying it anew, its original luminosity is restored.

A glass vessel containing radium spontaneously charges itself with electricity. If the glass has a weak spot,—for example, if it is scratched by a file,—an electric spark is produced at that point, the vessel crumbles like a Leiden jar when overcharged, and the electric shock of the rupture is felt by the fingers holding the glass.

Radium possesses the remarkable property of liberating heat spontaneously and continuously. A solid salt of radium develops a quantity of heat such that for each gram of radium contained in the salt there is an emission of one hundred calories per hour. Expressed differently, radium can melt in an hour its weight in ice. When we reflect that radium acts in this manner continuously, we are amazed at the amount of heat produced, for it can be explained by no known chemical reaction.The radium remains apparently unchanged. If, then, we assume that it undergoes a transformation, we must therefore conclude that the change is extremely slow; in an hour it is impossible to detect a change by any known methods.

As a result of its emission of heat, radium always possesses a higher temperature than its surroundings. This fact may be established by means of a thermometer, if care is taken to prevent the radium from losing heat.

Radium has the power of communicating its radioactivity to surrounding bodies. This is a property possessed by solutions of radium salts even more than by the solid salts. When a solution of a radium salt is placed in a closed vessel, the radioactivity in part leaves the solution and distributes itself through the vessel, the walls of which become radioactive and luminous.

The radiation is therefore in part exteriorized. We may assume, with Mr. Rutherford, that radium emits a radioactive gas and that this spreads through the surrounding air and over the surface of neighboring objects. This gas has received the name emanation. It differs from ordinary gas in the fact that it gradually disappears. [The modern name for this element is radon.]

Certain bodies—bismuth, for instance—may also be rendered active by keeping them in solution with the salts of radium. These bodies then become atomically active, and keep this radioactivity even after chemical transformations. Little by little, however, they lose it, while the activity of radium persists.

The nature of radium radiations is very complex. They may be divided into three distinct groups, according to their properties. One group is composed of radiations absolutely analogous to cathode rays, composed of material particles called electrons, much smaller than atoms, negatively charged, and projected from the radium with great velocity—a velocity which for some of these rays is very little inferior to that of light.

The second group is composed of radiations which are believed to be formed by material particles the mass of which is comparable to that of atoms, charged with positive electricity, and set in motion by radium with a great velocity, but one that is inferior to that of the electrons. Being larger than electrons and possessing at the same time a smaller velocity, these particles have more difficulty in traversing obstacles and form rays that are less penetrating.

Finally, the radiations of the third group are analogous to Roentgen rays and do not behave like projectiles.

The radiations of the first group are easily deflected by a magnet; those of the second group, less easily and in the opposite direction; those of the third group are not deflected. From its power of emitting these three kinds of rays, radium may be likened to a complete little Crookes tube acting spontaneously.

Radium is a body which gives out energy continuously and spontaneously. This liberation of energy is manifested in the different effects of its radiation and emanation, and especially in the development of heat. Now, according to the most fundamental principles of modern science, the universe contains a certain definite provision of energy, which can appear under various forms, but cannot be increased.

Without renouncing this conception, we cannot believe that radium creates the energy which it emits; but it can either absorb energy continuously from without, or possess in itself a reserve of energy sufficient to act during a period of years without visible modification. The first theory we may develop by supposing that space is traversed by radiations that are as yet unknown to us, and that radium is able to absorb these radiations and transform their energy into the energy of radioactivity. Thus in a vacuum-tube the electric energy is utilized to produce cathode rays, and the energy of the latter is partly transformed, by the bodies which absorb them into the energy of Roentgen rays. It is true that we have no proof of the existence of radiations which produce radioactivity; but, as indicated at the beginning of this article, there is nothing improbable in supposing that such radiations exist about us without our suspecting it.

If we assume that radium contains a supply of energy which it gives out little by little, we are led to believe that this body does not remain unchanged, as it appears to, but that it undergoes an extremely slow change. Several reasons speak in favor of this view. First, the emission of heat, which makes it seem probable that a chemical reaction is taking place in the radium. But this can be no ordinary chemical reaction, affecting the combination of atoms in the molecule. No chemical reaction can explain the emission of heat due to radium. Furthermore, radioactivity is a property of the atom of radium; if, then, it is due to a transformation this transformation must take place in the atom itself. Consequently, from this point of view, the atom of radium would be in a process of evolution, and we should be forced to abandon the theory of the invariability of atoms, which is at the foundation of modern chemistry.

Moreover, we have seen that radium acts as though it shot out into space a shower of projectiles, some of which have the dimensions of atoms, while others can only be very small fractions of atoms. If this image corresponds to a reality, it follows necessarily that the atom of radium breaks up into subatoms of different sizes, unless these projectiles come from the atoms of the surrounding gas, disintegrated by the action of radium; but this view would likewise lead us to believe that the stability of atoms is not absolute.

Radium emits continuously a radioactive emanation which, from many points of view, possesses the properties of a gas. Mr. Rutherford considers the emanation as one of the results of the disintegration of the atom of radium, and believes it to be an unstable gas which is itself slowly decomposed.

Professor Ramsay has announced that radium emits helium gas continuously. If this very important fact is confirmed, it will show that a transformation is occurring either in the atom of radium or in the neighboring atoms, and a proof will exist that the transmutation of the elements is possible. [In fact radium does emit helium, as alpha particles.]

When a body that has remained in solution with radium becomes radioactive, the chemical properties of this body are modified, and here again it seems as though we have to deal with a modification of the atom. It would be very interesting to see whether, by thus giving radioactivity to bodies, we can succeed in causing an appreciable change in their atoms. We should thus have a means of producing certain transformations of elements at will. [These observations were misleading. True artificial radioactivity was not produced until the work of Irène and Frédéric Joliot-Curie in 1934.]

It is seen that the study of the properties of radium is of great interest. This is true also of the other strongly radioactive substances, polonium and actinium, which are less known because their preparation is still more difficult. All are found in the ores of uranium and thorium, and this fact is certainly not the result of chance, but must have some connection with the manner of formation of these elements. Polonium, when it has just been extracted from pitch-blende, is as active as radium, but its radioactivity slowly disappears; actinium has a persistent activity. These two bodies differ from radium in many ways; their study should therefore be fertile in new results. Actinium lends itself readily to the study of the emanation and of the radioactivity produced in inactive bodies, since it gives out emanation in great quantity. It would also be interesting, from the chemical point of view, to prove that polonium and actinium contain new elements. Finally, one might seek out still other strongly radioactive substances and study them.

But all these investigations are exceedingly difficult because of the obstacles encountered in the preparation of strongly radioactive substances. At the present time we possess only about a gram of pure salts of radium. Research in all branches of experimental science—physics, chemistry, physiology, medicine—is impeded, and a whole evolution in science is retarded, by the lack of this precious and unique material, which can now be obtained only at great expense. We must now look to individual initiative to come to the aid of science, as it has so often done in the past, and to facilitate and expedite by generous gifts the success of researches the influence of which may be far-reaching.