

IV

THE SCIENTIFIC WORK OF MADAME CURIE

THE discovery of the element radium by Madame Curie in 1898 and the investigation of its properties profoundly modified nineteenth century conceptions about matter and electricity. Up to about 1890 the classical Newtonian theory was unchallenged and some scientists thought that no new fundamental discoveries were to be expected. Then came Roentgen's discovery of X-rays, J. J. Thomson's discovery of electrons, Curie's discovery of radium and polonium, Planck's quantum theory of radiation, Rutherford's nuclear theory of the atom, Bohr's theory of spectra, and Einstein's theory of relativity, and the whole classical Newtonian conception collapsed.

During the nineteenth century the atoms of the chemical elements were thought of as hard particles, those of any particular element all exactly alike and indivisible. The radioactive atoms were found to disintegrate spontaneously, a radium atom splitting up into a helium atom and a radon atom. Thus the conception of the elementary atoms as indivisible, indestructible particles was proved untenable. The atoms are not hard, indivisible particles, but are complicated structures built up out of smaller particles. These discoveries opened up a new field for investigation, namely, that of the structure of atoms, which has ever since occupied the foremost place in physical science.

Marie Sklodowska was born in Warsaw in 1867, and she married Pierre Curie, who was a professor of physics in

Scientific Work of Madame Curie 149

the Sorbonne, Paris. In 1896, in Paris, Becquerel found that uranium emits penetrating rays similar to X-rays, and Madame Curie immediately became interested in this new phenomenon and began experimental work on it. She found that certain minerals containing uranium were several times more strongly active than pure uranium. This suggested to her that these minerals must contain substances besides uranium more active than pure uranium. Madame Curie and her husband then obtained a large quantity of the residues left after the commercial extraction of uranium from uranium minerals and proceeded to search for new radioactive bodies in them. They found two new elements, radium and polonium, which are several million times more strongly radioactive than uranium. From about one ton of the residues they finally got about one ten millionth of a ton of pure radium chloride.

Radium is a white metal like silver, but it tarnishes readily in air. Its chemical properties are very similar to those of the well known element barium. It has a characteristic spectrum, an atomic weight of 226, and all the ordinary properties of a metallic element. It is usually prepared and sold in the form of radium bromide, which is a white crystalline salt easily soluble in water. Radium is very costly because the process of extracting the minute amounts present in uranium minerals is long and complicated, and the demand for medical purposes is greater than the supply. The market price at present is about fifty dollars per milligram of radium element, or at the rate of twenty million dollars for one pound. Some hospitals have half a million dollars' worth of radium in use for the treatment of cancer.

Radium is remarkable because it disintegrates or decomposes spontaneously into a series of new bodies which emit peculiar radiations. A quantity of radium therefore slowly

diminishes in amount, so that it is calculated that about half of it will disappear in sixteen hundred years.

The radiations emitted by radium and its decomposition products are of three distinct sorts, namely, alpha rays, or helium atoms charged with positive electricity which are shot out with velocities of about twenty thousand miles per second, beta rays, which are negative electrons with velocities up to one hundred and eighty thousand miles a second, and gamma rays, which are very penetrating rays similar to X-rays.

The investigation of the products of decomposition of radium and the other radioactive elements and of the radiations which they emit has been going on now for over thirty years, but is yet far from complete, and new discoveries continue to appear in this fertile field of research. In this long series of investigations Madame Curie and her associates played a leading part.

The discoveries of radioactivity by Becquerel and of radium by Madame Curie were of such striking scientific interest that the investigation of the new phenomena was immediately taken up by physicists and chemists all over the world. Many new discoveries about radioactivity were made independently at almost the same times by different scientists, so that it is sometimes difficult to be sure who first announced a particular result.

The rays emitted by radium can be detected in several different ways. For example, they affect a photographic plate like light and they cause air to become a conductor of electricity. If a small quantity of radium is put near to a charged electroscope the air is made to conduct and the electricity on the electroscope rapidly escapes. With polonium instead of radium there is no effect unless the polonium is within about two inches of the electroscope.

Scientific Work of Madame Curie 151

Polonium emits only alpha rays, which are stopped by about two inches of air. This experiment with polonium was first done by Madame Curie soon after she discovered it. Alpha rays can be easily studied with C. T. R. Wilson's cloud expansion apparatus. This consists of a cylinder with a glass top, inside which a piston can be moved up and down so as to compress and then rarefy the air in the cylinder. If there is a little water in the cylinder so that the air is saturated with water vapor, then when it is caused to expand quickly by suddenly moving the piston down, the air is cooled and the water vapor tends to condense into a cloud or fog of small droplets. These droplets form on minute dust particles in the air and if there are no dust particles the droplets do not appear. When an alpha ray goes through the air it collides with the air molecules and knocks electrons out of them so that it leaves a track of electrons and positively charged molecules. These charged particles act like dust particles and cause the water vapor to condense so that we get a visible track of water droplets. In this way we can make the paths of the alpha rays visible as thin, nearly straight tracks which can be photographed. An alpha ray is just a helium atom, so that we are able to see and photograph tracks made by single atoms. The beta rays also make tracks in the expansion apparatus, but much thinner ones than the alpha rays. The gamma rays themselves do not make tracks, but they knock electrons out of atoms and these electrons make tracks like beta rays.

The rays are found to be emitted when a radioactive atom disintegrates or decomposes into two new atoms. Thus radium atoms disintegrate into radon atoms and helium atoms, and the helium atoms are the alpha rays. Radon is a gas and its atoms disintegrate into helium atoms and new atoms called radium A atoms. Radium A then gives a

series of new bodies and finally lead remains. Besides this radium series of radioactive elements, several other similar series are now known. All these different bodies have different properties and disintegrate at different rates. The subject of radioactivity is now a large and important branch of physics which is very active at present.

Let us now consider in more detail Madame Curie's more important contributions to the subject. Her greatest discovery was that of radium in 1898. She separated the radium from Pitchblende¹ and finally obtained pure radium chloride. No other strongly radioactive element has been prepared pure in appreciable quantities. The separation of pure radium from Pitchblende was an extraordinarily difficult operation, or rather long series of operations. It was possible only because of the radiations emitted by the radium which enabled minute amounts to be detected and measured. Thus the chemical fractions of the material could be classified according to their radioactivity and the activity gradually concentrated.

About the year 1900 Madame Curie determined the atomic weight of radium by an exact analysis of pure radium chloride, finding it equal to 225. The latest value of this important constant is 226, so that Madame Curie's first determination was within one half of one per cent of the true value.

Madame Curie showed that radioactivity is an atomic property. She found that the activity of compounds of radioactive elements depends only on the amount of the active element present and is not affected by the nature of the other elements with which the active element is combined. Also she showed that the activity is not affected by changes

¹The uranium mineral from which the residues used by the Curies were derived.

Scientific Work of Madame Curie 153

of temperature or other physical conditions. These results were important in that they pointed towards the correct theory of radioactivity, namely, that it is due to atomic disintegrations and not to any sort of ordinary chemical change.

Besides radium Madame Curie also discovered another radioactive element in Pitchblende which she named polonium in honor of her native land, Poland. This element was found along with bismuth in the chemical fractions and could not be separated completely from it. Madame Curie found that the radioactivity of the impure polonium gradually diminished so that after four months it had only one half its initial value. This was a fundamentally important result because it showed that a radioactive body gradually disappears. The atoms disintegrate or decompose into new bodies which may or may not be radioactive. It has since been shown that all radioactive elements disappear in this way, some very slowly and some more rapidly. For example, radium slowly disappears so that it will be half gone in sixteen hundred years, and radon, one of the disintegration products of radium, disintegrates so that half of it is gone in four days. This means that out of say 1024 radon atoms only 512 are left after four days, 256 after eight days, 128 after twelve days, 64 after sixteen days, and so on. Any particular radon atom may last for a hundred days or more, but on the average half of the atoms disintegrate every four days. The disintegration is not affected by physical or chemical conditions; it is a property of the radioactive atoms. The atoms are all exactly alike, but they do not last equally long. The 32 atoms left out of 1024 after twenty days behave just like the original 1024, that is, half of them disappear every four days. We may say that the expectation of life of a radioactive atom is independent of its age. A radon atom always has a one in two chance of

four more days of life however old it may be. What particular atoms disintegrate during any interval appears to be purely a matter of chance, whatever that may mean. Suppose a small quantity of a radioactive element is emitting say one hundred alpha rays per second, then the average interval between the rays is one hundredth of a second, but the intervals are not all equal. A few will be as great as one tenth of a second, or as small as one thousandth of a second. Madame Curie measured the intervals between the emissions of single alpha rays by a small amount of polonium during several months and showed that they are just what would be expected if the emissions are determined just by chance.

During the nineteenth century it was supposed that all material particles obeyed exact laws of nature so that nothing happened by chance. This idea has proved untenable, and we now suppose that the laws of nature do not determine exactly what will happen, but that they merely fix the relative chances of various possible events. The disintegration of radioactive atoms with the emission of alpha rays is an example of this sort of thing. The laws of nature do not require an atom to disintegrate at any particular time; they merely fix the chance that it will disintegrate in a given interval. An atom of radon has a one in two chance of disintegrating in any interval of four days, but it may last for years.

Radioactive disintegration provided one of the first examples of the statistical character of natural laws, so that its discovery and investigation by Madame Curie helped to start a profound change of a very general character in our ideas as to the nature of the physical world.

In 1903 Madame Curie, working with a colleague, Laborde, discovered that radium generates heat continuously,

Scientific Work of Madame Curie 155

so that it is always hotter than surrounding bodies. They found that radium produces enough heat to raise the temperature of an equal weight of water to the boiling point in about one hour. This heat energy is mainly the kinetic energy of the alpha rays which are stopped by the radium itself and by the walls of the vessel containing it. Since radium disappears so slowly that half of it remains after sixteen hundred years, it must contain an enormous store of energy much greater than that set free by any chemical reaction. During the sixteen hundred years one gram, or one-twenty-eighth of an ounce of radium generates enough heat to boil ten tons of water.

Working with her husband, Madame Curie discovered that radium causes any substance kept near it to become temporarily radioactive. This effect, called induced radioactivity, is due to the gas radon which radium emits. The radon gas disintegrates into a series of solid radioactive elements of short life which are deposited on bodies with which the radon comes in contact.

Madame Curie and her husband, Pierre Curie, were awarded a Nobel Prize for the discovery of radium and polonium, and a new Chair was founded at the Faculty of Sciences of Paris for Pierre Curie. Most unhappily Pierre Curie was killed by an automobile in 1906 and Madame Curie succeeded him in the new professorship. She continued her researches on radium and made many more important discoveries.

An international congress of physics was held in 1910 with Madame Curie presiding. This Congress adopted a new scientific unit which was called a "Curie" in honor of Madame Curie, and denotes the amount of radon in equilibrium with one gram of radium. A millicurie and a microcurie are respectively one thousandth and one mil-

lionth of a curie. Madame Curie was requested to prepare an international standard of pure radium chloride, which is kept along with the standard meter at St. Cloud, near Paris. This radium standard is used to determine the amount of radium metal in any preparation of radium. The intensity of the penetrating gamma rays from the standard is compared with the intensity of the same rays from the preparation by methods developed by Madame Curie. The Bureau of Standards in Washington has a radium standard which has been compared with Madame Curie's international standard. When radium is sold in the United States, the specimen is sent to the Bureau of Standards and compared with the Bureau's radium standard. In this way the purchaser can be sure of the exact amount of radium that he gets.

Soon after the discovery of radium, it was found that the radiations from it have powerful physiological effects. They produce serious burns on the skin, destroying the tissues. The treatment of cancer by radium radiations was later developed and proved to be valuable in many cases. For such treatments radium itself need not be used. The gas radon emitted by radium may be sealed up in a small glass tube and used instead of the radium. Thus the valuable radium may be kept in a safe place and only the radon from it used in treating cancer. The radon tubes can be sent by mail to patients anywhere. The activity of the radon tubes drops to one half every four days, so that it becomes very small after a few weeks, but it lasts long enough for the cancer treatments. The radium generates fresh radon all the time, so that new tubes can be prepared to replace the old ones which have lost their activity.

During the war Madame Curie had charge of the Red Cross X-ray service. She equipped many X-ray cars and

Scientific Work of Madame Curie 157

drove several of them to the front. She also got over two hundred X-ray outfits for war hospitals, helped greatly with the actual X-ray examinations of wounded soldiers, and established a training school of Radiology for nurses. In 1916 she developed, in Paris, a center for the distribution of radon tubes for medical purposes, using her whole stock of radium for this. In all this war work she was assisted by her elder daughter, Mlle. Irene Curie, now Madame Curie-Jolliot, who is also a prominent physicist.

Two laboratories were established in Paris soon after the discovery of radium, for research on radioactivity. These laboratories are known as the Radium Institute, and Madame Curie gave to this Institute all the radium which she and her husband extracted from Pitchblende. Later she gave to the Radium Institute the gram of radium presented to her by the women of the United States. Associated with the Radium Institute is the Curie Foundation, built and endowed by Henri de Rothchild, who gave to it half a gram of radium. These laboratories are devoted to research work on radioactivity, including medical applications, and they supply radon tubes for cancer treatments in French hospitals.

Madame Curie's scientific work was universally recognized as of outstanding merit. She received innumerable honors and awards from universities and scientific societies throughout the world. She was awarded a second Nobel Prize, and so had the distinction of being the only scientist ever to win more than one. During the war she gave up research and worked for France in every way possible. She died on July 4, 1934, of anaemia due to radioactive radiations. Shortly before Madame Curie died her daughter announced the discovery of artificial radioactivity, a discovery comparable in importance with that of radium. Ma-

dame Curie and her daughter are the only women who have ever made scientific discoveries of first rate importance. Just as Faraday's discovery of electromagnetic induction led to all the modern applications of electricity which have profoundly changed human civilization, so Madame Curie's discovery of radium has started a series of scientific events which will ultimately result in changes equally great.

Madame Curie was a great experimenter, and she developed a chemical technique for the study of radioactive elements. The workers in her laboratories are equipped to investigate problems in radioactivity rapidly and efficiently by her methods. Thus her example and her point of view inspire the workers in her field. The science of radioactivity advances rapidly and new discoveries of extraordinary interest appear almost daily, largely because of the foundation so well laid by the discoverer of radium.

Radioactive elements spontaneously transform themselves into new elements, and the study of radioactivity has led to the artificial transmutation of one element into another. Just as chemists are able to make new compounds of old elements, so physicists may now make new elements. So just as we expect the chemists to produce all sorts of new compounds with valuable properties, so we may now expect the physicists to produce new elements with new properties.

There has never been a more exciting time for physicists and chemists than the present. If only scientific research is not destroyed along with civilization, but is allowed to go on under favorable conditions, no limits can be imagined to the results to be expected, and no branch of science seems to have greater promise for the future than radioactivity.

H. A. WILSON.



