The contribution of Maria Sklodowska-Curie and Pierre Curie to Nuclear and Medical Physics. A hundred and ten years after the discovery of radium

Aristidis Diamantis[1]
Emmanouil Magiorkinis[1]
Athanasios Papadimitriou[2]
Georgios Androutsos[3]

1. *Department of Cytopathology and*
2. *Department of Nuclear Medicine, Naval Hospital of Athens, Greece*
3. *Department of History of Medine, Faculty of Medicine, Athens University, Greece*

***

Keywords: Marie Curie – Pierre Curie – Radiology – Radium – Polonium

Correspondence address:
E. Magiorkinis BSc, MD
Department of Cytopathology,
Naval Hospital of Athens
Dinokratous 70, P.C. 11521,
Athens, Greece
Tel: +30 2107261154,
Fax: +30 2107261397
E-mail: mayiork@med.uoa.gr

Received:
23 January 2008
Accepted revised
17 March 2008

Abstract

This review aims to commemorate the life, and the accomplishments of Pierre and Marie Curie in Physics and in Medicine. Although they are primarily known for their discoveries of the elements of radium and polonium, which took place two years after the discovery of radioactivity by Henry Becquerel, Pierre's discovery of the piezo-electric phenomenon, his research on crystal symmetry, magnetism and paramagnetic substances, are equally important. With the discovery of the two radioactive elements, Pierre and Marie Curie established the new field of Nuclear Physics. It is not an overstatement to say that their discovery contributed much to our modern way of life. Marie received the Nobel Prize twice and later she became the first woman to become member of the French Academy of Sciences. Today, both Pierre and Marie Curie rest in Panthéon, in Paris.

Hell J Nucl Med 2008; 11(1): 33- 38

Introduction

Among the books published, dealing with the life and work of Marie Curie, one can note an autobiography and the books that her daughters Eve-Denise and Irene wrote about her [1-3]. One of her students, Cezary Pawlowski, also published a memoir about Marie Curie [4]. On the other hand, the life and work of Pierre Curie is also memorable, although his life has not been a subject for publishing books for him. Despite the premature death of Pierre Curie, his contribution to Marie Curie's scientific achievements was crucial; it is not an overstatement to say that if Marie had not met Pierre in 1894, she probably would not have made any of her great discoveries.

Marie and Pierre's early lives

Marie Curie, or Marya or Manya Salomée Sklodowska, was born in 1867 in Warsaw, Poland at 16 Freta Street. She was the fifth and the youngest child in her family. Both of her parents were teachers; Bronislawa her mother, was a musician and her father, Vladislav, taught mathematics and physics [5, 6]. Her mother contracted tuberculosis and died when Marie was at the age of eleven. However, being brought up in a well-educated family, Marie acquired important traits for her future career; from her mother inherited kindness and an increased sense of duty, whereas from her father, introspection, preciseness and a fervent will for self-education [7]. As a result, Marie completed "with excellence" her exams at the age of 16, winning a gold medal [6-9].

Marie was denied work in Poland for political reasons because her father had studied mathematics at St Petesburg's University, when Poland was occupied by the Russian Empire [9]. In order to send her sister to study in Paris and gather money for her own studies, Marie worked as a governess for eight years. Finally, she went to Paris where, after two years, she received on 1893, her first diploma in Physics. She also won an Aleksandrowicz family scholarship and in 1894, received her second diploma in Mathematics [5], ranking second on the licentiate list [7]. Her first scientific paper was on the magnetic properties of iron alloys, while she was working in Professor Gabriel Lippmann's laboratory.

Pierre, the youngest son of Eugene and Sophie-Claire Curie, was born in 1859, in Cuvier, Paris [10]. His mother was a manufacturer's daughter, whereas his father, Eugene, was a physician, also involved in natural science and research. Pierre like Marie, grew up in a well-educated family. From his father he inherited idealism and generosity, a great interest in science and nature, the exceptional skill to observe and the ability to interpret precisely various circumstances and facts [8]. He never attended any school; instead his education was undertaken by his parents and by Professor A. Bazille. He completed the *'Bacalaureat es Sciences'* at the age of 16 sucessfully and enrolled in the University of Sorbonne. He obtained the *'Licence es Sciences Physiques'* in 1877 and one year later was involved in scientific research in parallel with teaching duties as a Laboratory Assistant in charge of physic tutorials. Soon, Pierre's research produced remarkable results. In 1880 he published a paper with P. Desains, where he described a new method for infrared wave determination by the use of thermophile and a metallic grid [11]. However, his most important research findings which would later be used by Marie, were in collaboration with his brother Jacques. The same year, they discovered the piezo-electric phenomenon [12] and later, they showed the inverse phenomenon: the production of electric fields during crystal deformation.

Figure 1. Pierre and Marie Curie (adopted by https://eee.uci.edu/clients/bjbecker/SpinningWeb/lecture19.html).

Figure 2. Pierre and Marie Curie in their laboratory (adopted by http://www.atomicarchive.com/Bios/CuriePhoto.shtml).

In 1883, Pierre was admitted as a Chief Laboratory Assistant in 'Ecole de Physique et Chimie Industrielles de la Ville de Paris' and in 1895, he became a Professor. In this Institution, Pierre's research focused on crystals' symmetry, establishing the properties of symmetry and asymmetry and studying related phenomena such as light transmission, heat and electricity. In his classic paper entitled *'Symétrie dans les phénomènes physiques'*, he presented his theories based on the results of numerous experiments [13]. However, his most important work, on magnetism, began only in 1891. With his paper in 1895 entitled *'Lois expérimentales du magnétisme- Propriétés magnétiques des corps ă diverses températures'*, Pierre established the famous Curie's law: "the magnetic susceptibility of paramagnetic substances is proportional to the inverse of the absolute temperature" [14]. This was the subject of his Doctoral Thesis presented in the Paris Faculty of Science, on the same year.

Marie met Pierre in 1894, when Marie was looking for a place that she could conduct her experiments. Pierre during this time, was chief of the physics laboratory at the *'Ecole Municipale de Physique et de Chimie Industrielles'* in rue l' Homond. They were introduced by a Marie's friend and fellow student, Professor Kovalski. Pierre and Marie were married on the 26th of July, 1895 [8] (Fig.1) and soon afterwards, they joined research activities, since Marie obtained a laboratory space in the above School of rue l'Homond [5].

Towards the discovery of radium, Marie follows the steps of her supervisor, Henry Becquerel

In the autumn of 1897, Marie was looking for a topic for her doctorate thesis (Fig. 2). She decided to focus on research of materials having similar properties to those of uranium. The discovery of radioactivity by her supervisor Herny Becquerel [15] came after the discovery of the X-rays by Wilhelm Conrad Röntgen, in 1895 [16] and after the paper by Henri Poincaré, in which he made an important speculation between the association of fluorescence and X-rays [17]. H. Becquerel at the same year, after the discovery of radioactivity, showed that this new, yet unknown property was present in all uranium compounds including those that did not emit fluorescence [15]. It is worth mentioning that in parallel with H. Becquerel, Sylvanus Thomson, president of the Röntgen Society of London, was also experimenting on uranium salts and showed that uranium nitrate could blacken the film of photographic plates [5].

Marie's efforts focused on finding an accurate and reliable method to measure the emission of uranium salts. A new instrument, associating an ionization chamber with a quadrant Curie electrometer and a Curie piezo-electric quartz based on the piezoelectric phenomenon described by Pierre Curie, was constructed by Pierre and his brother Paul-Jacques for that purpose [8]. Marie performed a series of experiments on many samples including pure elements and compounds such as metals, oxides and salts without finding any radioactivity but confirmed H. Becquerel's measurements of uranium salts. After laborious experiments, in 1898 Marie, in parallel with Carl Schmidt [18], discovered that thorium ore showed similar emission to that of uranium salts. However, since C. Schmidt managed to publish his results two months earlier than Marie, the presentation of Marie's results on thorium compounds by the director of her laboratory, Dr F.A. Lippmann on April 1898 [19] at the *'Académie des Sciences'* was not quite impressive.

In order to assist Marie in her research activities, Pierre decided to join her in the laboratory along with the help of Gustave Bémont, chief chemist [10]. Marie and Pierre focused on other minerals and especially on uranium ores, autunite and chalcolite and also on pitchblende that emitted radiation. To their surprise, they found that the intensity of the activity of pitchblende, a residue ore resulting from the uranium extraction, was four times higher than that of metallic uranium, whereas the activity of the mineral chalcolite (hydrous uranium cooper sulphate) was twice higher. To verify their results, Marie compared the radioactivity of natural and chemically prepared chalcolite, and found that natural chalcolite was about six times more radioactive than the chemical one [8]. In July 1898, Marie and Pierre Curie sent to the *'Académie des Sciences'* a new communication presented on behalf of them by H. Becquerel [20], on the discovery of a new substance which was associated with bismuth. This new substance was called 'polonium'. "We believe the substance we have extracted from pitchblende contains a metal not yet observed, related to bismuth by its analytical properties. If the existence of this new metal is confirmed, we propose to call it *polonium*, from the name of the original country of one of us".

The work of Marie and Pierre Curie along with the findings by E. Rutherford and later, A. Einstein, inaugurated the atomic era [6].

Further research on pitchblende, led the Curies to the discovery of a second radioactive element chemically akin to barium. In December 1898, Henry Becquerel on behalf of the Curies, again presented their paper to the French Academy of Sciences reporting that Pierre and Marie Curie discovered the second radioactive element, which was called radium [21]. As it was reported in this paper: "The various reasons we have just enumerated lead us to believe that the new radioactive substance contains a new element to which we propose to give the name radium. The new radioactive substance certainly contains a very strong proportion of barium; in spite of that its radioactivity is considerable. The radioactivity of radium must therefore be enormous" [2, 22].

The Curies had been told that their paper would not be accepted unless spectrometry confirmed the existence of the new element Eugene Demarçay [23], a French chemist and a famous spectrum specialist of his times, ended his presentation with the following conclusion: "The presence of the radiation 3814. 8 confirms the existence in small quantity, of a new element in the specimen of barium chloride, by Mr and Mme Curie".

In 1900 Marie was appointed lecturer of physics at the Ecole Normale Superieure for girls in Serves. In order to define polonium's and radium's physical properties and atomic weight, they had to process 500 tons of pitchblende from Bohemia and later from Colorado [6]. At first, radium was extracted and after three years in 1902, they managed to obtain 0.1 g of radium chloride. The high radium content of this compound was such that it emitted a spontaneous and beautifully colored light "source of emotion and rapture" according to the Curies [8]. André Demarçay, being a top specialist in spectrum analysis in France during this time undertook the task to define the atomic weight of radium. He finally managed to define spectroscopically the atomic weight of radium as, 225 (Fig. 3), which is extremely close to 226, the presently accepted value [24]. In her autobiography, Marie characteristically says [2]: "Finally the moment came, when the separated substance began to show signs of a pure chemical element. This element, radium, had a characteristic spectrum for its radiation. I could also determine its atomic weight".

Marie strongly believed that since radium is a chemical element, it should be the property of all men. Thus, all details and processes for the production of radium were published but were not patented [25]. Marie Curie noted the importance of their discovery for mankind. She wrote: "It is easy to understand how important for me is the conviction that our discovery is a blessing for human-kind not only by its scientific importance but also because it permits to reduce human suffering and treat a terrible disease. This is indeed a great reward for the years of our enomous effort" [2].

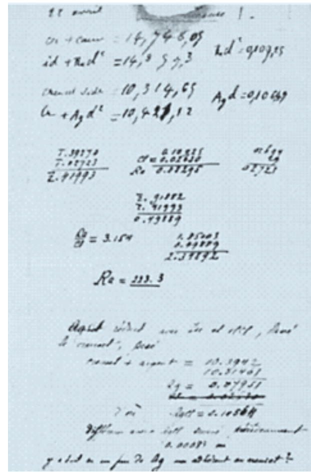

Figure 3. Determination of the atomic weight of Radium (adopted by Mould, 1998) [5].

The Curies' contribution in the analysis of radioactive emissions and in radiobiology

The Curies' work on radioactive elements also helped to elucidate the three main components of radioactive emissions, i.e. the alpha, beta and gamma rays. Marie was the first to call this emission as 'radioactivity' derived from the Latin word *radius* or ray [26]. She was also able to show that this phenomenon was an intrinsic property of uranium and thorium atoms [27] and was the first to propose the atomic transformation as a possible explanation [26-28]. The Curies also noticed the emergence of radioactivity from non-radioactive substances, from objects with close vicinity to the radioactive source and also noticed the expontential decay of radioactivity [29-34]. This phenomenon was due to the emanation of thoron gas by thorium and of radon gas by radium [35] as identified by F.E. Dorn in 1901 [36] and by E. Rutherford and F. Soddy in 1902 [37, 38]. The Curies observed that the radiation of radium could be deviated by electric and magnetic fields [39, 40], and consisted mainly of two components, as Ernest Rutherford had observed for uranium one year before [41].

E. Rutherford was a physicist from New Zealand who worked at the Cavedish laboratory under J.J. Thomson. E. Rutherford called the two parts of the uranium rays as alpha (α) and beta (β) rays [41]. It should be noted that E. Rutherford's research was synchronous and equally important to that of the Curies. E. Rutherford began his research career as Pierre Curie did, working on magnetism. His first paper focused on magnetic viscosity [42] and on magnetization of iron [43]. E. Rutherford published numerous reports on radioactivity, among which the most important are those on radioactive emissions, the properties of alpha, beta and gamma rays and the changes in the atoms of radioactive elements [44-54]. Curies could not identify the gamma rays, because of the low sensitivity of their detection method. These rays were later identified by Paul Ulrich Villard [55]. Nevertheless, Marie Curie in her paper entitled '*Sur la pénétration des rayons de Becquerel non deviables par le champ magnétique*' [56] suggested that the limited range of the 'non-deviated' polonium particles observed in the air, was directly determined by the loss of these particles' energy.

Besides their research in radioactivity, initial experiments in radiobiology should also be attributed to the Curies [5]. The first report on the biological effects of radiation was from F. Walkhoff and F.O. Giesel in 1900, who observed the effects of radiation on the skin as compared to the X-rays effect [57, 58]. Pierre Curie reproduced F.O. Giesel's experiments by putting an amount of radioactive substance for 10 hours on his arm and published this report together with H. Becquerel in 1901 [59]. These effects varied from erythema to pigmentation, ulceration, healing and telangiectasia [59]. These findings led H. Danlos and P. Block at Saint Louis Hospital, to use radium sources for the treatment of lupus erythymatosus and other skin lesions in 1901 [60]. A number of studies reporting clinical experiments were soon reported [61-65].

The discovery of radium changed the lives of P. and M. Curie. Marie's research after the tragic death of Pierre

By her experiments, Marie defended her doctoral thesis in June 1903 entitled '*Recherches sur les substances Radioactives*' [66] in June 1903 and became *Docteur des Sciences* (Fig. 4). As a result of their work, Pierre and Marie Curie jointly with Henry Becquerel were awarded the Nobel Prize of Physics, in December 1903 for "their joint researches on the radiation phenomena" [6]. Marie was the first woman to receive a Nobel Prize.

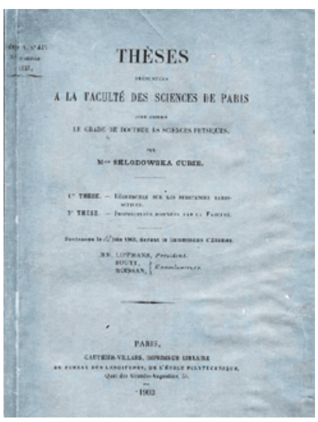

Figure 4. The first page of Marie Curie's doctoral thesis (adopted by http://pimm.wordpress.com/2007/06/04/editing-my-doctoral-thesis-on-stem-cells-in-a-blog-why-not/).

Later, in 1905, they traveled to Sweden in order to give the customary Nobel lecture. Pierre Curie was the one to give the lecture. Pierre ended his lecture with a warning about the use of their discovery: "It is also conceivable that in the hands of criminals, radium may become very dangerous and here one may well ask oneself if mankind benefits from knowing Nature, if we are mature enough to take advantage of the benefits, or if this knowledge isn't harmful to us. The examples of Nobel's discoveries are typical: these powerful explosives have allowed men to perform admirable works. They also constitute a terrible means of destruction in the hands of the great criminals who are drawing the people towards war. I am one of those who believe, as did Nobel, that mankind will derive more good than ill from these new discoveries" [67].

The constant work with radioactive materials had a huge impact on Marie's and Pierre's health. Both began to suffer from chronic skin lesions, especially on their hands and general symptoms such as pain and fatigue. Marie had lost weight and most of the times she often forgot to sleep. G. Sagnac, a friend of the Curies, in a letter dated April, 1903 and addressed to Pierre, wrote [6]: "I have been struck, when I have seen Mme Curie at the Society of Physics, by the alteration in her appearance… you hardly eat at all, either of you. More than once have I seen Mme Curie nibble on slices of sausage and swallow a cup of tea with you. Do you think that a robust constitution would not suffer from such insufficient nourishment? … Her indifference or stubbornness will be no excuse for you. I foresee the following objection: "She is not hungry. She is old enough to know what she has to do!". Well, frankly, no: she is behaving at present like a child…"

At the summer of the same year, M. Curie became ill, mainly because of a miscarriage and of her constant exposure to radiation. P. Curie was appointed to a newly created Chair of Physics at the Paris University in October 1904 and in parallel, M. Curie was appointed as his Chief of Laboratories. Marie accidentally was able to give birth to her second healthy daughter, Eva on 6 December, 1904. On July 3, 1905 Pierre was elected to the *"Académie des Sciences"*.

Until 1906, M. Curie mainly worked on the production of radium and on radium emissions [8], whereas P. Curie worked on different subjects besides radioactivity. In 1906, Marie published a paper in *Physics Zeitschrift*: "On the decay constant of polonium" [68].

On 19 April 1906, Pierre died in a tragic street accident when he was overrun by a horse drawn wagon. His death was a turning point in both Marie's personal life and career, since she had to bring up her two daughters. However, she did not give up and continued fervently their common work.

In 1909, Marie managed to found the "Institute of Radium" in Paris which was designed to study the radioactivity and the biological effects of ionizing radiation. For that purpose, the Institute was divided into two laboratories, the "Curie Pavillion" directed by Marie Curie and the "Pasteur Pavillion" directed by Claudius Regaud, a professor of histology and pathology. The construction of the Institute was completed just before the outbreak of the First World War in 1914. Other similar Institutes were later founded in Europe such as the "Radium Hemmet" in Stockholm (1910), the "Marie Curie Hospital" in London, the "Memorial Center" in New York (1913) and the "Warsaw Institute of Radium" in which M. Curie was the honorary director. M. Curie's career continued to evolve, and in 1908 she became a titular professor [7].

Around 1910, a radium industry developed in Europe, since the medical use of radium for the treatment of cancer was very popular and much more important than other therapeutic activites [8]. The wide use of radium raised the question about the accurate determination of the activity of radioactive sources. During the International Congress of Radiology and Electricity in Brussels, the need for an international radium standard was discussed [69]. The commission members for France were: M. Curie and A. Debierne, for England: E. Rutherford and F. Soddy, for Germany: H.F. Geitel and O. Hahn, for the US B.B. Boltwood and for Canada Eve Curie. M. Curie undertook the task to prepare a solid state standard made of a thin walled glass tube, with a radium content of about 20 mg and it was agreed that all other radium samples would be measured against it. In March 1912, the Comission declared this as the International Radium Standard after comparison with similar standards prepared in Vienna [8]. The activity unit was defined as "the quantity of emanation in equilibrium with one gram of radium" and named "Curie" to honor Pierre Curie. During the preparation of this standard. M. Curie published her two-volume classic treatise on radioactivity entitled '*Traité de radioactivité*' [70]. The years between 1909-1911 were particularly prolific in the life of M. Curie. In 1910, M. Curie and A. Debierne managed to acquire a small amount of metallic radium and to determine its melting point (700 °C) [71], whereas they published numerous papers on the radioactive properties of polonium, radium and radon and proved that polonium is also a distinct chemical element [5, 72, 73]. In 1910 Marie Courie was encouraged to apply for election to the French Academy of Sciences but her application was turned down, early in 1911 [74].

M. Curie received her second Nobel Prize on Chemistry in 1911 and she became the first scientist and the only woman to be awarded twice the Nobel Prize. In 1913, M. Curie became the honorary director of the newly established '*Kernbaum Radiological Laboratory*' in Warsaw [7].

Marie Curie's role during the First World War and the post-war period until her death

During the First World War, M. Curie played an active role in organizing the radiological services in military hospitals and in the battlefield [8]. As the technical director of "*L'Oeuvre Radiologique du Patronage National des Blessés*" (The radiological work under the patronage of the National Fund for the wounded) she established an auxiliary radiological department for the Army Medical Corps. However, one of her achievements was the design and equipment of mobile radiological units called '*les petites Curies*'. She also trained 150 volunteer operators to the use of radiological equipment and established more than two hundred radiology rooms [6].

After the end of the war, M. Curie published her wartime experience in a book entitled '*Le radiology et la guerre*' [75] and resumed her research activities. Her first paper after the war was entitled '*On the energy distribution of the alpha particles from polonium'* [5]. The same year, she was persuaded to visit the US and on May 12, 1921 the New York Times published a front-page article to describe the monumental event [76]. The ultimate purpose of her trip was to receive one gram of radium from the US President Harding, which was the result of funds raised by Marie Mattingly Meloney, editor of the *Delineator Journal*. In 1922, Marie Curie was elected in the Academy of Medicine of Paris 'in recognition of the part she took in the discovery of radium, and of a new treatment in medicine, Curietherapy' [1].

In 1925, M. Curie traveled to Poland in order to found the Polish Radium Institute, which was named after her [77]. Another gram of radium was also purchased later with the help of Ms Meloney for the Marie Sklodowska-Curie Institute of Radium, and for that reason, she re-visited the United States in October 1929.

Marie Curie continued her work until 1934, when her health deteriorated. She was admitted to a sanatorium in Sancellmoz near Sallanches (France) after a rather wrong recommendation by her doctors [7]. A few months before her death, her daughter Irene and her son-in-law Frederic Joliot, discovered artificial radioactivity. She died on 4 July, 1934 of leukaemia, an illness which was caused by her long term irradiation. She was buried next to her husband Pierre in the cemetery of Sceaux, the town where Marie and Pierre were married thirty nine years ago.

As final remarks: In 1995, Pierre and Marie Curie were reburied in the Panthéon in Paris at a ceremony attended by the Presidents of France and Poland, the mayor of Paris, Eve Curie-Labrousse, Pierre and Marie Curie's grandchildren. Marie was again the first woman to be buried in Panthéon, a place which notably, is in close proximity to rue l' Homond and to the first Radium Institute building in Paris. Their work and their contribution to modern science is considered invaluable; among all, the birth of Nuclear Physics and, later the new field of Medical Physics and Nuclear Medicine are the fruits of Curies hard work and unflagging zeal.

Bibliography

1. Curie E. *Madame Curie.* London: Heinemann, 1938; p. 411.
2. Sklodowska-Curie M. *Autobiografia* (Polish translation by J and H Sklodowska). Warsaw: Panstowe Wydawnicto Naukowe, 1959; p. 79.
3. Joliot-Curie I. Marie Curie, ma mère. *Europe,* 1954; 32: 89-121.
4. Pawlowski CA. Maria Sklodowska-Curie's scientific achievements and research trends at the Radium Institute in Paris (English translation by Chomicki OA). *Polish J. Med Phys Eng.* 1997; 3: 201-251.
5. Mould RF. The discovery of radium in 1898 by Maria Sklodowska-Curie (1867-1934) and Pierre Curie (1859-1906) with commentary on their life and times. *Br J Radiol* 1998; 71: 1229-1254.
6. Coppes-Zantinga AR, Coppes MJ. Madame Marie Curie (1867-1934): A giant Connecting two centuries. *Am J Roentgenol* 1998; 171: 1453-1457.
7. Gasińska A. Life and Work of Marie Sklodowska-Curie and her family. *Acta Oncol* 1999; 38: 823-828.
8. Chavaudra J. Pierre and Marie Curie-Sklodowska. *Med Phys* 1995; 22: 1877-1887.
9. Giroud F. *Une femme honorable.* Paris: Fayard, 1981; p. 382.
10. Mould RF. Marie and Pierre Curie and radium: History, mystery and discovery. *Med Phys* 1999; 26: 1766-1772.
11. Desains P, Curie P. Recherches sur la détermination des longueurs d'onde des rayons calorifiques à basse température. Séance du 28 June. *C R Acad Sci Paris* 1880; 26: 1506-1501.
12. Curie P. La pyroélectricité. *C R Acad Sci Paris* 1880; 91: 294-297.

13. Curie P. Symétrie dans les phénomènes physiques. *J Phys* 1894; 3: 393-416.
14. Curie P. Lois expérimentales du magnétisme. Propriétés magnétiques des corps a diverses temperatures. *Ann Chim Phys* 1895; 5: 289-405.
15. Becquerel H. Sur les radiations invisibles émises par les corps phosphorescence. *Comptes Rendus des Séances de l'Academie des Sciences, Paris* 1896; 122: 501-503.
16. Röntgen WC. Uber eine neue Art von Strahlen (vorläufige mittheilung). *Sber Phys-Med Ges Würzb* 1895; 132-141.
17. Poincaré H. Les rayons cathodique et les rayons Röntgen. *Rev Gen des Sci* 1896; 7: 52-59.
18. Schmidt GC. Uber die von thorium und den thorverbindlungen ausgehende stralung. *Verh Phys Ges Berlin* 1898; 17: 14 -16.
19. Sklodowska-Curie M. Rayons émis par les composés de l'uranium et du thorium. *C R Acad Sci Paris* 1898; 126: 1101-1103.
20. Curie P, Sklodowska-Curie M. Sur une substance nouvelle radioactive contenue dans la pechblende. *C R Acad Sci Paris* 1898; 127: 175-178.
21. Curie P, Curie M, Bémont. Sur une nouvelle substance fortement radioactive contenue dans la pechblende. *C R Acad Sci Paris* 1898; 127: 1215-1217.
22. Maria-Sklodowska-Curie. Memorial Issue of the Polish Oncological Journal Nowotwory, E. Towpik and R. F. Mould eds. Nowotwory, Warsaw. 1998; p 112.
23. Demarçay E. Sur le spectre d'une substance radioactive. *C R Acad Sci Paris* 1898; 127: 175-178.
24. Curie P. Sur le poids atomique du radium. *C R Acad Sci Paris* 1902; 135: 161-163.
25. Quinn S. *Marie Curie. A life.* New York, NY: Simon & Schuster, 1995; p. 509.
26. Curie M. Les rayons de Becquerel et le polonium. *Rev Gen Sci* 1899; 10: 41-50.
27. Curie P, Sklodowska-Curie M . Sur les corps radioactifs. *C R Acad Sci* 1902; 134: 85-87.
28. Curie M. Les nouvelles substances radioactive. *Rev Sci (Revue Rose) Ser.* 1900; 14: 65-71.
29. Curie P, Curie M. Sur la radioactivité induite provoquées par les rayons de Becquerel. *C R Acad Sci Paris* 1899; 129: 714-716.
30. Curie P, Debierne A. Sur la radioactivité provoquée par des sels de radium. *C R Acad Sci Paris* 1901; 132: 548-553.
31. Curie P, Debierne A. Sur la radioactivité provoquée par des sels de radium. *C R Acad Sci Paris* 1901; 132: 768-770.
32. Curie P, Debierne A. Sur la radioactivité provoquée par des sels de radium. *C R Acad Sci Paris* 1901; 133: 276-279.
33. Curie P, Debierne A. Sur la radioactivité provoquée par les sels activés par le radium. *C R Acad Sci Paris* 1901; 133: 931-934.
34. Curie P, Danne J. Sur la disparition de la radioactivité induite par le radium sur les corps solides. *C R Acad Sci Paris* 1903; 136: 364-366.
35. Curie P, Danne J. Sur l' emanation du radium et son coefficient de diffusion dans l'air. *C R Acad Sci Paris* 1903; 136: 1314-1316.
36. Dorn FE. Abh. Naturforsch. Ges. Halle 23, 1 (1901) according to Patterson. *J R Nature London* 1957; 179: 912.
37. Rutherford E, Soddy F. The cause and nature of radioactivity. *Philos Mag* 1902; 4: 370-396.
38. Rutherford E, Soddy F. The cause and nature of radioactivity. *Philos Mag* 1902; 4: 569-585.
39. Curie P. Action du champ magnétique sur les rayons de Becquerell. Rayon déviés et non déviés. *C R Acad Sci Paris* 1900; 130: 73-76.
40. Curie P, Curie M. Sur la charge électrique des rayons déviables du radium. *C R Acad Sci Paris* 1900; 130: 647-650.
41. Rutherford E. Uranium radiation and the electrical conduction produced by it. *Phil Mag* 1898; ser 5 xlvii: 109-163.
42. Rutherford E. Magnetic viscosity. *Trans NZ Inst* 1895; xxviii: 182-204.
43. Rutherford E. Magnetization of iron by high frequency discharges. *Trans NZ Inst* 1894; xxvii: 481-513.
44. Rutherford E. Emanations from radio-active substances. *Nature* 1901; 64: 157-158.
45. Rutherford E, Soddy F. The radioactivity of thorium compounds I. *Trans Chem Soc* 1902; 81: 321-350.
46. Rutherford E. Penetrating rays from radio-active substances. *Nature* 1902; 66: 318-319.
47. Rutherford E, Soddy F. The radioactivity of thorium compounds II. *Trans of Chem Soc* 1902; 81: 837-860.
48. Rutherford E, Grier A. Deviable rays of radioactive substances. *Phil Mag* 1902; ser 6, iv: 315-330.
49. Rutherford E. The radiation and emanation of radium part I. *Technics* 1904: 11-16.
50. Rutherford E. The radiation and emanation of radium part II. *Technics* 1904: 171-175.
51. Rutherford E. Change carried by the alpha rays from radium. *Nature* 1905; 71: 413-414.
52. Rutherford E. Some properties of the alpha rays from radium. *Trans Roy Soc of Canada* 1905; 11: 13-16.
53. Rutherford E. Charge carried by alpha and beta rays of radium. *Phil Mag* 1905; ser 6, x: 193-208.
54. Rutherford E. Slow transformation products of radium. *Phil Mag* 1905; ser 6, x: 290-306.
55. Villard P. Sur la transparence de l'aluminium pour le rayonnement du radium. *Comptes rendus* 1900; 130: 1154–1157.
56. Sklodowska-Curie M. Sur la pénétration des rayons de Becquerel non déviables par le champ magnétique. *C R Acad Sci* 1900; 130: 76-79.
57. Giesel FO. Ueber radioactive Stoffe. *Ber Dtsche Chem Ges*1900; 33: 3569-3571.
58. Walkoff F. Unsichtbare, photographisch wirksame Strahlen. Photographische *Rundsch Z Freunde Photographie* October 1900; 14: 189-191.
59. Becquerel H, Curie P. L'action physiologique des rayons du radium. *C R Acad Sci Paris* 1901; 132: 1289-1291.
60. Danlos H, Bloch P. Note sur le traitement du lupus érythèmateux par des applications de radium. *Ann Dermatol Syphil* 190; 2: 986-988.
61. Bohn G. L'influence du radium sur les animaux en voie de croissance. *C R Acad Sci Paris* 1903; 136: 1012-1013.
62. Perthes G. Versuche über den einfluss der röntgenstrahlen und radiumstrahlen auf die zellteliung. *Deutsch Med Wochenscrh.* 1904; 30: 632-634.
63. Bergonié J, Tribondeau L. Premières expériences sur le rat blanc. *C R Soc Biol* 1904; 57: 400, 592 & 595.
64. Dominci H, Barcat J. Modifications histologiques déterminées par le rayonnement du radium. *Arc d'Elec Méd* 1907; 15: 835-836.
65. Bouchard C, Baltharzard V, Curie P. Action physique de l'émanation du radium. *C R Acad Sci Paris* 1904; 138: 1385-1389.
66. Curie M. *Recherches sur les substances radioactive.* Paris: Gauthier-Villars, 1903; p. 142.
67. Curie P. *Conference de P. Curie, Les Prix de Nobel 1903.* Stockholm: Imprimerie Royale, 1906; p. 8.
68. Pawlowski CA. Maria Sklodowska-Curie's scientific achievements and research trends at the Radium Institute in Paris (English translation by Chomicki O.A.). *Polish J Med Phys Eng.* 1997; 3: 201-251.
69. Rutherford E. Radium standards and nomeclature. *Nature* 1910; 84: 430-431.
70. Curie M. *Traité de radiactivité.* Paris: Gauthier-Villars, 1910; 2: 548.
71. Curie M, Debierne A. Sur le radium métallique. *C R Acad Sci* 1910; 151: 523-525.
72. Curie MP, Debierne A. Sur le polonium. *C R Acad Sci* 1910; 150: 386-389.
73. Curie MP, Debierne A. Sur le polonium. *Le Radium* 1910; 7: 38-40.
74. Saenger EL, Adamek GD. Marie Curie and nuclear medicine: closure of a circle. *Med Phys* 1999; 26: 1761-1765.
75. Curie M. *La radiologie et la guerre.* Paris: Libraire Félix Alcan, 1921; p. 143.
76. Lewicki AM. Marie Sklodowska Curie in America, 1921. *Radiology*, 2002; 223: 299-303.
77. Mazeron JJ, Gerbaulet A. The centenary of discovery of radium. *Radiother Oncol* 1998; 49: 205-216.