'A Subversive Element': Science, Politics and the Early Appropriation of Radioactivity in Spain

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In January 1904, two months after being awarded the Nobel Prize, Pierre Curie wrote to his collaborator Georges Gouy: "you have seen this sudden excitement about radium. We enjoyed the advantage of some popularity (...) perhaps this noise is not going to be useless, and it helps me to get a professorship and a laboratory".[1] Despite its ironical tone, this passage reveals something about the intricate relationship between research and its public representation. It is not unreasonable to think that public interest, aroused by radioactivity's potential medical and industrial applications and by its supposed opposition to traditional conceptions of matter could have played an important role in the extension of this science. However, the historiography of radioactivity has traditionally ignored the public dimension of this science, and yet there is not a global narrative about the history of its public image. Herein it is intended to examine this quite unexplored dimension of the early history of radioactivity, considering that the appropriation of radioactivity research in Spain was intimately related with hegemonic public and scientific discourses.[2] By exploring public image of radioactivity in the press and popular science books, and following research careers of main representatives of this science in Spain, it is suggested that these discourses no only determined the establishment of research lines, but also shaped the character of radioactivity research in Spain.

Radioactivity and its public: the emergence of a new science

Radioactivity was born in Paris, in a period –the *fin de siècle*– characterised by proliferation of new radiations like the Cathode rays, X-rays, N-rays, Moser rays, Lyman rays or Selenic rays.[3] These new entities received considerable attention not only in scientific journals, but also in the popular science magazines and the press. X-rays were the most fashionable, as they provided a window to the inside of the body. In contrast, radioactivity had a more nuanced reception. The experi-

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ments performed by Henri Becquerel in 1896 on the radiation of uranium appeared in academic journals and were replicated by scientists like William Thompson, C.T.R. Wilson, Gustave LeBon or Adolf Miethe, but they did not raise important public awareness. Differently from X-rays, which revealed invisible structures of human body, "uranic rays" were difficult to detect and did not exhibit any spectacular features. The phenomenon did not get notoriety until Pierre and Marie Curie used it to discover new elements such as polonium and radium, coined the term "radioactivity" and linked the production of radioactive elements with potential medical and industrial applications.[4]

Even if the first International Congress of Physics, held in Paris in 1900, devoted two of its five plenary lectures to radioactivity,[5] radioactivity did not become popular until late 1903, after the award of the Nobel prize to Becquerel and the Curies. The Curies, a young and unconventional couple, were transformed in the heroes of French science, and Pierre Curie's desire of obtaining a chair and a laboratory was accomplished the same year. Public notoriety helped to consolidate research lines and to promote the incipient radium industry.[6] In January 1904, the industrialist Armet de Lisle, who had provided the Curies with facilities for the production of radium, opened new industrial installations for producing this element and founded the journal *Le Radium*, exclusively devoted to this new element. Directed by engineer Henri Farjas, *Le Radium* initially aimed to be an "instrument of popularisation and research". Indeed, Farjas also established a collection of books, the "Librairie du Radium et de la Radioactivité". Although *Le Radium* soon became a strictly academic journal after six months, Farjas kept his editorial work for the promotion of the emerging radium industry, and combined it with participation in one of the first companies producing radium, "La Banque du Radium".[7]

The establishment of radioactivity as a science and an industry was intimately tied to an increase of its public visibility. Together with academic books published by Henri Becquerel or Marie Curie,[8] there were many popularisation books directed to broad audiences, such as, *Les applications médicales du radium*, written by Foveau de Courmelles, or the best-seller *Le radium et les nouvelles radiations*, by Alphonse Berget.[9] Berget's book was a quite comprehensive account of contemporary knowledge about radioactivity, which included an historical introduction about this area of research, a summary of current theories about the origin of radioactivity, and chapters about the properties of radium, the different kinds of radiation, emanation,[10] the applications of radium and its effects on living beings. This book can also be considered as pioneer contribution to the history of radioactivity and, according Gustave LeBon, had an important role in the retrospective construction of Becquerel as radioactivity's discoverer.[11]

Radium's celebrity soon spread out of France. In the United States, Saint Louis Universal Exhibition included an exhibition about radium and a series of conferences on the new element that spurred on public interest.[12] William Hammer, a former Edison's chief engineer, became the main populariser of radioactivity in America, holding a conference tour around the country in which he exhibited radium samples acquired in Paris. Inventor of radium-based paint, his book *Radium and Other Radioactive Substances* was one of the first popularisation books on radioactivity.[13] In the United Kingdom, radium was also prominent in the public sphere by late 1903. A keyword search of "radium" or "radioactivity" in *The Times* reveals the publication of an average of almost 80 articles per year between 1903 and 1906, that is, more than an article per week.[14] In the UK, we should also take into account popularisation efforts made by William Crookes, William Ramsay and Ernest Rutherford, who in 1904 published *Radio-activity*, the most influential book on radioactivity in the Anglo-Saxon world.[15] His collaborator, Frederick Soddy, published the same year *Radio-Activity: An Elementary Treatise, from the Standpoint of the Disintegration Theory* with minor success.[16] Together with these books, there were also more popular books on the subject, such as Selimo Bottone's *Radium, and All About It* or Hampson's *Radium Explained. A Popular Account of the Relations of Radium to the Natural World, to Scientific Thought, and to Human Life*.[17]

In the German speaking world, expert and lay accounts also coexisted. As early as 1902, the industrial chemist Friedrich Giesel published in Germany *Ueber radioaktive Substanzen und deren Strahlen*; in Switzerland, Paul Gruner published in 1906 *Die Radioaktiven Substanzen und die Theorie des Atomzerfalles*; in Austria Hans Mayer's, *Die Neuren Strahlungen. Kathoden-, Kanal, Roentgen-Strahlen und die radioaktive Selbstrahlung*, 1904. Similar movements took place in Denmark, were Kristine Meyer published in 1904 *Radium og Radioaktiver Stoffer samt nyere Opdagelser angaaende Straaler*.[18]

This literature, which shaped appropriations of radioactivity in different national contexts will not be discussed in detail. However, this short review points out the rapid propagation of radioactivity in the European public sphere, which was possibly related to the consolidation and institutionalisation of the discipline. The following sections will deal with these processes in more detail by focusing in the Spanish case, which reveals how a particular configuration of audiences shaped the development of radioactivity within this local context.

Muñoz del Castillo, Echegaray and the appropriation of radioactivity in Spain

In his study of the development of radioactivity in America, Lawrence Badash argued that chemists investigating radioactivity found more support in the community of physicists.[19] By studying the placement of radioactivity laboratories in academic structures, he showed that most of them were attached to physics departments, and that those in chemistry departments suffered from isolation. This is the case, for example, of Otto Hahn's laboratory. It was established in the Emil Fisher Institute at the University of Berlin, but his colleagues, organic chemists, considered his work with "no direct connection… [to] normal chemistry". The careers of Frederick Soddy, Kazimir Fajans, Georg Hevesy and Marie Curie suggest isolation from the profession of chemistry and a struggle for support. The hybrid character of radioactivity, which gathered theoretical and material resources from both physics and chemistry, was contested by traditional academic structures. Some chemists resisted to accept radioactivity claims in the first decade of the 20th century, in part because transmutation challenged the deep-rooted notion of the stability of elements. In some extent, the use of physical means of analysis to establish the existence of radioactive elements was a serious challenge to established chemical practice.[20]

In the case of Spain, this kind of tensions between radioactivity and chemistry were very rare. A reason for this is that the leader of radioactive research in Spain was José Muñoz del Castillo, a well established academic chemist, Professor of "chemical mechanics" in the University of Madrid. A second reason is that Madrid Laboratory's research line focused on the measuring of radioactivity in mineral waters, soils and fertilisers, which led to a particular appropriation of radioactivity which was at odds with the path followed in other countries. These practices relied and were strongly connected to conventional kind of analyses, such as general analysis of waters and minerals. Last, but not least, Munoz's theoretical approach to radioactivity was quite unconventional. He refused accepting Rutherford and Soddy's theory of atomic disintegration as explanation of radioactive phenomena. Instead, he regarded radioactivity as a sort of chemical reaction, similar to the capture of hydrogen by metals like platinum. I have previously argued elsewhere that Muñoz's success in shaping Spanish radioactive research was much related to the particular configuration of Spanish academia and patronage, to lack of a radio-elements industry in Spain and other contingent factors.[21] Here, I argue that the root of Munoz's view of radioactivity can be attached to the configuration of public scientific debate in Spain in the first decade of the twentieth century.

In this study of the early appropriation of radioactivity in Spain, it is considered that Madrid's Royal Academy of Science had an important role, as forum for communicating research results, and its President a representative of hegemonic scientific thinking in Spain. Established in 1847, the Royal Academy gathered the most distinguished members of the scientific community and served as links with foreign scientific communities, as a place to communicate scientific results and as an *agora* to debate the country's scientific policy.[22] Being the president of Madrid's Academy, the leading Spanish organic intellectual was José Echegaray (1832-1916).[23] Trained as engineer and member of the Academy since 1864, Echegaray had played an important role in the institutionalisation of mathematical physics in Spain. Combining a scientific prestige (being one of the main actors in the introduction of thermodynamics and modern mathematics in Spain)[24] with a successful career as a playwright (which served to get the Nobel Prize in literature in 1904) and with a notorious political involvement (being minister in several governments)[25], Echegaray exerted an important influence in the Spanish academic system. In this sense, he not only acted as the President of Madrid's Academy, but also was the first President of the Spanish Society of Physics and Chemistry (established in 1903), of the Spanish Association for the Progress of Science (established in 1908) and of Spanish Mathematical Society (established in 1908). From these positions of power, he tried not only to consolidate the institutional position of Spanish physics and chemistry, but also to spread his own scientific worldviews.

His perspective, which we can call "Echegarian paradigm", was an adaptation of Laplacian views of science, which was based on three elements: the use of a very abstract kind of mathematical physics as the fundamental explanatory device, the idea that all physical and chemical phenomena could be explained as manifestation of a unified Newtonian force, and the idea that this force could explain from cosmic evolution to the nature of chemical elements. As will be seen, this paradigm shaped Spanish appropriation of new physical and chemical theories like radioactivity, by means of its influence on José Muñoz del Castillo's perspective. Indeed, that these influences were shaped not only by means of conventional academic influence, but taking into account the result of debates in the public sphere, where political ideas crucially intervened.

In order to assess how the hegemony of Echegaray's image of radioactivity was exerted, it is helpful to examine the depiction of radioactivity in the press and in popularisation books written in Spain. Consider, to begin with, Echegaray's own production. He was a very prolific author, who published more than fifty books (without counting his literary production) and hundreds of articles in magazines and newspapers. [26] In his "popularisation" of the discovery of the radioactivity,

Echegaray played with the reaction of surprise and even scandal regarding the new French discoveries, and established a vivid political analogy:

"The 'radium' appears to the science as a revolutionary metal, like an anarchist that comes to disturb the order established and to destroy all or most of the laws of the classical Science."[27]

Faced with this revolution, which seemed to demolish established physical theories, Echegaray asked for prudence, explaining these radiation features by means of most universally accepted theories. This is the purpose of his article "The energies of radium", appeared in *El Imparcial* in 1903. According to Echegaray, the new phenomenon should not alarm anyone, as it

"complies with the existing law (…) which come into the world of science while respecting its order, as new factories and new industries come to the society without seeking annihilation, but only to increase employment and wealth."[28]

After saying this, Echegaray sorted out two problematic questions raised by the new phenomena: the "endless production of energy" and the origin of radioactivity. In dealing with the them, Echegaray proposed two different explanations to save the "established order": the hypothesis proposed by Marie and Pierre Curie, which set out radium's capacity to produce light and heat from an invisible energy permeating the space, and the planetary atomic hypothesis, which considered atoms as stable systems and radium as a setting-up system, which emitted particles because of its instability. By means of these hypotheses, Echegaray safeguarded the principle of energy conservation, which was the basis of his thermodynamics and concluded that "phenomena caused by radium do not break any important law of physics". In later popular articles on radioactivity, Echegaray got back to the dichotomy between order and chaos, and to the analogies with the anarchist movement, pointing out his opposition to modern physics. For instance, in an article published in the *Revista de Obras Pública* in 1910, Echegaray still considered that new interpretations of radioactive phenomena reflected the transition from a "individualist" science to a "socialist" science, and that in physical sciences, "the atom is could be destroyed, as the individual is in social sciences".[29]

Echegaray was not alone in considering as subversive the interpretation of radioactivity as atomic disintegration. A similar opinion can be found in the section "Scientific Notes" that Josep Comas y Solá published in conservative newspaper *La Vanguardia* since 1896.[30] A retrospective article written by Comas in 1907 about the "crisis of matter", showed his discontent with recent paradigm changes, which he described in the following terms:

"Atomic structure, light, heat, magnetism, electricity, gravity, and life and soul themselves were transparent to us. We had turned the whole universe into a bil-

liard table [...], we climbed to the top of science leaning on our mathematical cue."[31]

According to Comas, Maxwell contributions in the previous century had laid the foundation of this paradigm shift, but X-rays and radioactivity had given the *coup de grâce* to the old worldview and had opened a period of theoretical confusion:

"Behind this avalanche of new phenomena, which seem to conspire with the aim of demolish all we believed to know, we found the real chaos of a new aimless hypothesis appear, a chaos that does not show consideration for most common sense principles, neither for doctrines we considered as invulnerable."[32]

These attitudes seem to act in response to a menacing environment for traditional scientific worldviews. What was at the origin of this menace? The atomic disintegration theory could be innovative and scientifically challenging in some aspects, but relating them to revolutionary upheaval seem exaggerated. To make sense of these reactions we need to take into account other alternative contemporary readings of radioactivity, particularly the appropriations of these findings in the socialist milieu.

Revolutionary readings of radioactivity in the socialist press

Treatment of science news was widespread in socialist press, as science was traditionally considered by this ideology as a liberating tool and as antidote against material and intellectual oppression by capitalist system, the state and the church. Journals and leaflets of worker's movement informed of latest scientific developments, reflected about their social implications and served as an alternative to hegemonic worldviews. References to radioactivity abound in this literature, and also in works of prominent members of the socialist movement like Paul Lafarge, Karl Marx's son in law, who commented on radioactivity discovery in the following terms:

"recent discovery of radioactivity breaks down the fundamental laws of mathematical physics, destroys the atomic basis of chemical structure. We cannot found a better example to illustrate the sterility of spoken discourse and of the fertility of experience."[33]

In Spain, a good example of these appropriations can be found in *La Revista Blanca. Sociología, ciencia y arte*.[34] Established in 1898, it can be considered as one of the most important socialist magazines because of its quality and widespread circulation. With a bi-weakly periodicity, it originally counted with sixteen pages without illustrations. Since 1902 onwards, its size increased to thirty-two

pages with illustrations and its readership peaked at 8000, which is a very important circulation for the period. *La Revista Blanca* defined itself as "positivist and anticlerical", and was much inspired by its French counterpart *La Revue Blanche*, which regularly lent illustrations and articles. Divided in three sections ("Sociology", "Science and Art" and a "General section"), scientific content was in charge of engineer Fernando Tárrida de Mármol, who elaborated periodical chronicles of current scientific and technological news.[35]

Tárrida de Mármol covered a great diversity of subjects, in the style of short notes, one or two pages long. He showed special interest for extraordinary scientific news and cosmological speculation, generally bringing into account thermodynamic scatology.[36] His section dealt several times with radioactivity, stressing that this phenomena shacked the traditional idea of the stability of atoms, and emphasizing its revolutionary character. According to Tárrida,

"atomic theory, which is still so young and successful, is also going to disappear, as it is energetically challenged by inflexible facts that doesn't honour beliefs, traditions or theories."[37]

Indeed, radioactivity could be the key for a new interpretation of nature:

"What a new field of study! It seems that we are in front of a very peculiar kind of matter. Are we leading towards recognising the unity of matter? This radioactive propriety, is only particular of a number of bodies? Is the living cell a result of these phenomena? [...] Does inert matter has a sort of life, sending to the space all kinds of emanations, some in form of light, other modifying the medium and operating on the living beings, causing sensations? Then, all psychical phenomena would be real, a purely dynamical phenomenon... How many ideas can suggest a few centigrams of matter"[38]

In his chronicles, Tárrida considered radioactivity as a crucial step towards the establishment of a truly materialistic theory of nature. This position, along the lines of Buchner's materialism, appears explicitly in a later article, where he points out that radioactivity could explain phenomena like "mental suggestion" and "telepathy" from a physical, not spiritual basis:

"The day will arrive when we will see the fall of all these systems that attribute supernatural causes to the most important phenomena in nature, mostly those concerning human nature."[39]

Tárrida de Mármol was also interested in applications of the new science. His column included references to the application of radium in the production of light, radiography and the treatment of cancer.[40] However, the high price of radium

could limit the widespread use of this element in medicine, and gave him ground for social critique:

"It is evident that a so scarce pharmaceutical like radium is not going to be used by poor people who, after a life of hard work, could not afford a single atom of radium. This pharmaceutical would only cure millionaires or even richer people. The poor, in relation to these remedies, are only to be used like dogs and guinea pigs, that is, as a matter for experiments."[41]

Subversive readings of radioactivity in the socialist press are the counterpoint of Echegaray's politically and scientifically conservative position. Accordingly, it is reasonable to think that reaction to new physical interpretations of radioactivity could be somewhat related to containment of its subversive readings by the Spanish scientific establishment. A way to evaluate this claim is by reading the first popularisation books on radioactivity published in Spain, in which we can appreciate a thorough limitation of radical interpretations of the new phenomena.

A good example of this is *El Radio y las nuevas radiaciones*, the Spanish translation of Berget's *Le Radium et les nouvelles radiations* by Eduardo Navarro Beltran del Río, civil engineer and Professor of Electrical Engineering at Bilbao Industrial Engineering School.[42] In the original edition, Berget compared the discovery of radioactivity with the discovery of America, and emphasised revolutionary aspects of radioactivity such as the endless emission of energy. This kind of readings were attenuated in the Spanish version, which included an appendix written by Navarro praising the laws of conservation of matter and energy. Navarro justified his interference by claiming that "we feel the philosophical necessity of these laws and, when considering that these hypotheses could disappear, the ghost of chaos would raise from the very deep of our body, which is matter and energy". Indeed, Navarro adopted Echegaray's hypothesis to explain the origin of radioactivity, considering that radium was a condensation of helium and that emanation was a condensation of ozone, in the context of an evolutionist theory of elements.

Another example of cautious appropriation of radioactivity is another book published in 1904 by Ramón Pomés y Soler, *El Radium y la Radiografía*.[43] Pomés considered radium as a "matter of huge importance" and pointed out that his treatment of the issue would be restricted to explain the facts "experimented and described by Röntgen, Becquerel, the Curies, Rutherford, Geitel and other eminent scholars", without adding anything himself. However, when he reached the controversial point of radioactivity origin, he omitted mention to Rutherford's and Curie's hypothesis, and simply took into account traditional chemical views of the atom.

Conclusion

The images portrayed in the press and in the popularisation literature in Spain, together with the lack of alternative interpretations outside the radical press, suggests that the Spanish scientific community showed a cautious attitude in relation to the different interpretations about the origin of radioactivity. This attitude prevailed in the first decade after the discovery of radioactive phenomena, and can be related to a widespread conservative approach among Spanish scientists, who could have endangered their efforts to institutionalise science if they had embraced radical readings of radioactivity. This conservative attitude to the new physics in the Spanish academia was the context in which this new discipline was appropriated, and shaped the approach of its main representative in Spain, chemist José Muñoz del Castillo. His closeness to the Echegarian paradigm, together with other contingent personal and institutional factors, can explain the divergent path of Spanish radioactivity in relation to the practice of this science in other countries, both in the theoretical and in the practical aspects.

Notes

[1] Pierre Curie to G. Gouy letter, January 22, 1904. Reproduced in Soraya Boudia, *Marie Curie et son laboratoire. sciences et industrie de la radioactivité en France* (Paris, Editions des archives contemporaines, 2001), 81-83.

[2] In this article the term "appropriation" is used instead of "reception" in dealing with the processes of translation and communication of science, as suggested by Kostas Gavroglu, *The Sciences in the European Periphery During the Enlightment* (Dordrecht: Kluwer Academic Publishers, 1999).

[3] On the *fin de siècle* physics, see John L. Heilbron, "Fin de Siècle Physics", in Science, Technology and Society in the time of Alfred Nobel, ed. Carl Gustaf Benhard et al. (Oxford, Pergamon Press, 1982), 51-73. The discovery of "new radiations" circa 1900, has been analysed in Helge Kragh, "The New Rays and the Failed Anti-Materialistic Revolution", in *The Emergence of Modern Physics*, ed. Dieter Hoffmann et al. (Pavia, Università degli Studi di Pavia, 1995), 61-78.

[4] Nuanced reception of uranic rays is coherent with recent historical research, which plays down Becquerel's role in the discovery of radioactivity. According to Boudia, *Marie Curie et son laboratoire*, 37-39, Becquerel's main role fundamentally reflected his important position as prominent member of the French scientific establishment. Boudia claims that the discovery of radioactivity was not a punctual and isolated event, but we should alternatively consider the gradual emergence of a new area of study, with participation of different actors and closure of different controversies in several spaces. On the construction of Becquerel's image as discoverer of radioactivity, see Paul Fournier & Josette Fournier, "Hasard ou mémoire dans la découverte de la radioactivité?", *Revue d'histoire des sciences* 52 (1999): 51-79.

[5] The congress was held in August, 6-12, 1900 as part of Paris Universal Exhibition on radioactivity were read by Becquerel and the Curies.

[6] Xavier Roqué, "Marie Curie and the Radium Industry: a Preliminary Sketch", *History and Technology* 13 (1997): 267-281; Boudia, *Marie Curie et son laboratoire.*

[7] It is interesting to trace similarities between the careers of Farjas and Jacques Danne, his successor in the journal direction. As well as Farjas, Danne was involved in radium production since

1904. In 1911, he established his own radium producing company, and also a laboratory for certifying radioactive products: the Laboratoire d'Essais des Substances Radioactives.

[8] Despite Marie Curie's dissertation was conceived as an academic work, it was soon translated and edited into English and German: Marie Curie, *Radio-Active Substances. Thesis presented to the Faculté des Sciences de Paris* (London: Chemical News Office, 1904); Marie Curie, *Untersuchungen ueber die Radioactiven Substanzen* (Braunschweig, Vieweg, 1904). Another example of early interest on radioactivity in the Anglo-Saxon world is the edition of Becquerel's works: Henri Becquerel, *On the Radio-Activity of Matter* (Washington, USGPO, 1903).

[9] Foveau de Courmelles, *Les applications médicales du radium* (Paris, 1904). Alphonse Berget, *Le radium et les nouvelles radiations: que faut-il en penser? Que faut-il en attendre?* (Paris, G. Charpentier, 1904).

[10] Emanation was the first name given to radon, a radioactive by-product of radium disintegration.

[11] Gustave LeBon, *La evolución de la materia* (Madrid, Librería Gutemberg de José Ruíz, 1911), p. 379.

[12] Lawrence Badash, *Radioactivity in America. Growth and Decay of a Science* (Baltimore, The John Hopkins University Press,1979).

[13] William J. Hammer, *Radium and Other Radio-Active Substances: Polonium, Actinium and Thorium, with a Consideration of Phosphorescent and Fluorescent Substances, the Properties and Application of Selenium and the Treatment of Disease by the Ultra-Violet Rays* (New York, Van Nostrand, 1903).

[14] Keyword search has been performed using *The Times Digital Archive*.

[15] Ernest Rutherford, *Radio-Activity* (Cambridge, Cambridge University Press, 1905). In 1905, Rutherford published an enlarged edition of this book, which was translated into German in 1907: Ernest Rutherford, *Die Radioaktivitaet. Unter Mitwirkung des Verfassers ergaentzte autorisierte deutsche Ausgabe* (Berlin, Springer, 1907).

[16] Frederick Soddy, *Radio-Activity: An Elementary Treatise, from the Standpoint of the Disintegration Theory* (London, The Electrician, 1904). Nonetheless, this book was translated into German the same year: Frederick Soddy, *Die Radioaktivitaet vom Standpunkt der Desaggregationstheorie elementar dargestellt. Unter Mitwirkung von Dr. L.F. Guttman. Uebersetzt von Prof. G. Siebert* (Leipzig, Barth,1904a). Soddy also published a short piece on radium with a more popular tone: *The Interpretation of Radium. Being the Substance of Six Free Popular Experimental Lectures Delivered at the University of Glasgow* (Soddy, 1909).

[17] Selimo Bottone, *Radium, and All About It* (London, New York, Whittaker & Co., 1904). W. Hampson, *Radium Explained. A Popular Account of the Relations of Radium to the Natural World, to Scientific Thought, and to Human Life*, (London, Jack,1905).

[18] Friedrich O. Giesel, *Ueber radioaktive Substanzen und deren Strahlen* (Stuttgart, 1902). Paul Gruner, Die *Radioaktiven Substanzen und die Theorie des Atomzerfalles* (Bern, A. Francke, 1906). Hans Mayer, *Die Neuren Strahlungen. Kathoden-, Kanal, Roentgen-Strahlen und die radioaktive Selbstrahlun*. (Maehr.-Ostrau, R. Papauschek, 1904). Kristine Meyer, *Radium og Radioaktiver Stoffer samt nyere Opdagelser angaaende Straaler*. (Kobenhavn, Gyldendalske Boghandel,1904).

[19] Lawrence Badash, *Radioactivity in America.*

[20] Xavier Roqué, "From Radiochemistry to Nuclear Chemistry and Cosmochemistry", in *Bridging Boundaries. Chemical Sciences in the Twentieth Century*, ed. Carsten Reinhardt (Weinheim, Wiley-VCH, 2000), 49-65.

[21] Néstor Herran, *Aguas, semillas y radiaciones. El laboratorio de radiactividad de la Universidad de Madrid, 1904-1929* (Madrid, CSIC, 2008). A summary of this book in English has been published as Néstor Herran, "Waters, Seeds and Radiation: Radioactivity Research in Early

Twentieth Century Spain", in ed. Josep Simon et al., *Beyond Borders: Fresh Perspectives in History of Science* (Cambridge, Cambridge Scholars Publishing, 2008), 325-344.
[22] In order to perform these functions, Academies counted with journals. Reception ceremonies for new members also played an important role as political events.
[23] Echegaray was president of Madrid's Academy in the period 1894-1896, and again between 1901-1916.
[24] On Echegaray's role in the introduction of thermodynamics in Spain, see Stefan Pohl, *La "circulación" de la energía: Una historia cultural de la termodinámica en la España de la segunda mitad del siglo XIX* (Universitat Autònoma de Barcelona, Unpublished PhD dissertation, 2007). For a short review of Echegaray's science, see José Manuel Sánchez Ron, ed., *José Echegaray* (Madrid, Fundación Banco Exterior, 1990).
[25] Echegaray political views are typical of the period of Spanish monarchic restoration: initially republican and liberal, he then evolved towards conservatism.
[26] Part of Echegaray's popularisation literature was reprinted in books such as José Echegaray, *Ciencia Popular. Colección de articulos publicados en los periódicos* El Imparcial *y* El Liberal (Madrid, Hijos de J. A. García, 1905) and José Echegaray, *Vulgarización científica* (Madrid, Imprenta de Rafael Gutiérrez Jiménez, 1910).
[27] José Echegaray, *Vulgarización científica*, 79-90.
[28] José Echegaray, *Vulgarización científica*, 79-90.
[29] José Echegaray, "La evolución actual de las ciencias", *Revista de Obras Públicas* 58(1910): 467-479.
[30] On Comas y Solà, see Xavier Barca, "Josep Comas i Solà, Barcelona, 1868, Barcelona, 1937. L'Astronomia de posició", in ed. J. M. Camarasa & Antoni Roca Rosell, *Ciència i Tècnica als Països Catalans. Una aproximació biogràfica.* (Barcelona, Fundació Catalana per a la Recerca, 1995), 793-825. A selection of his Scientific Notes were published as a book: *José Comas y Solá, Astronomía y ciencia general. Colección de trabajos científicos de popularización referentes a la astronomia, a la sismologia, a la historia de las ciencias en el siglo XIX, etc.* (Barcelona, F. Granada, 1907).
[31] José Comas y Solà, "La crisis de la materia", *La Vanguardia*, March, 28th, 1907, 7-8. Comas y Solá note followed a previous article titled "Science in crisis", where he tried to warn about "our most classical and well established principles in physical and mathematical sciences are in imminent danger of reaching the point of collapse".
[32] José Comas y Solà, "La crisis de la materia", *La Vanguardia*, March 28th, 1907, 8.
[33] Paul Lafargue, *Karl Marx' Historischer Materialismus*, 1903.
[34] On *La Revista Blanca*, see María Cruz Seoane & María Dolores Sáiz, *Historia del periodismo español. Vol. 3. El siglo XX.* (Madrid, Alianza Universidad, 1997).
[35] Tárrida de Mármol (1861-1915) was son of a wealthy family of Cuban-born Catalan industrialists. He studied engineering in Barcelona, Toulouse and Madrid. In Barcelona, he worked as a teacher and director of the Polytechnic Academy of Barcelona until his incarceration after Montjuich trials in 1896 and his escape to France this same year.
[36] On the ideological and religious readings of thermodynamics, see Helge Kragh, Matter and Spirit in the Universe. Scientific and Religious Preludes to Modern Cosmology (London, Imperial College Press, 2004).
[37] Tárrida de Mármol, "Crónica Científica", September 1st, 1901.
[38] Tárrida de Mármol, "Crónica Científica", September 1st, 1901.
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