

Appendix C

About the life and the scientific activity of Ettore Majorana¹

(Francesco Guerra and Nadia Robotti)

e-mail: francesco.guerra@roma1.infn.it

e-mail: robotti@fisica.unige.it

Here, for the sake of completeness, we give a brief summary about the life and the scientific activity of Ettore Majorana, by relying on archive sources kept at the Domus Galileana in Pisa, the University of Rome “La Sapienza”, and the Central Archive of the State in Rome.

Born in Catania (Sicily) on August 5th, 1906, in a family of high social level, he attended classical studies at the Institute “Massimiliano Massimo” in Rome, run by Jesuit Fathers, and earned his final diploma “licenza liceale” at the Royal Lyceum “Torquato Tasso” in 1923, one year in advance with respect to ordinary schedule.

On November 3rd, 1923, he enrolled in the two year preparatory course for Engineers, held at the Faculty of Sciences of the University of Rome, and earned the final diploma in the Fall of 1925. Then, he went to the three year School of Applications for Engineers, without earning the final doctoral degree. In fact, at the end of 1928, he obtained from the Faculty of Sciences the admission to the course in Physics. Here, he earned the doctoral degree “Laurea in Fisica”, with full marks and “summa cum laude”, on July 6th, 1929, by presenting a research Thesis, with the title “Sulla meccanica dei nuclei radioattivi” (“On mechanics of radioactive nuclei”), under Enrico Fermi supervision.

The career of Ettore Majorana as a university student was regular and brilliant in the years 1923-1927. He gave his examinations according to the schedule and always with high marks. In particular, we would like to remark that his record in the Archive of Rome show that he passed the examination in Hydraulics, on December 7th, 1927, with the respectable mark of 75/100. However, at the beginning of 1928 he became interested in Physics, and became involved in extensive research on the Thomas-Fermi statistical model for atoms and ions.

The Thesis of Majorana is one of the first works in Nuclear Physics developed in Rome, and surely the first on advanced topics. Here, Majorana extended the theory of G. Gamow and F.G. Houterman on the alpha decay of radioactive nuclei, which had been published at the end of 1928. The original theory was considering only alpha particles in the ground state, but

¹Appendix C and Appendix D from the paper: “A forgotten publication of Ettore Majorana on the extension of the Thomas-Fermi statistical model for atoms”, by Francesco Guerra and Nadia Robotti, Physics in Perspective, to appear.

Majorana performed also all calculations for particles in excited states with higher angular momentum.

However, already before earning the doctoral degree in Physics, during the year 1928, Majorana was involved in a very intense research activity, dealing in particular with the statistical model for atoms and ions (later called the “Thomas-Fermi” model), developed by Fermi at the end of 1927, only few months before.

On this subject, Majorana published two papers. The first was done in collaboration with his friend Giovanni Gentile Jr., and in fact it is the only paper done by Majorana in collaboration with other authors. It is an elaborate application of the Fermi model to the calculation of spectral levels for some atoms, and to the evaluation of spectral doubling due to the spinning electron. Moreover, they calculated the intensity ratios for spectral absorption lines. This paper is completely inside the general strategy as developed by Fermi.

Surely the second paper is more relevant, because it shows a complete independence of the young Majorana from the original Fermi formulation. The paper was presented by Majorana during the XXIIInd General Meeting of the Italian Physical Society, held in Rome from December 28th to 30th, 1928. Majorana communication is published on the proceedings of the meeting on *Nuovo Cimento*. It contains an improvement of the Fermi model, with extensions to positive ions, and applications to various spectroscopic problems. The improvement proposed by Majorana was adopted by Fermi only after many years, in 1934, in a conclusive paper written with Edoardo Amaldi.

However, after the communication, Majorana was not involved any more directly with the Fermi statistical model, even though his research continued intensively on problems of atomic and molecular physics.

In particular, he was involved with research topics on chemical bonds, partly in collaboration with G. Gentile Jr. The two authors however published separately their results. In particular, Majorana gave interesting results on the formation of the helium molecular ion, and the hydrogen molecule, in 1931.

In the same year 1931, he gave the theoretical interpretation for two new spectroscopic lines in helium, recently discovered by Krüger, and for some triplet lines in calcium of difficult understanding.

In the frame of atomic Physics, in the following year 1932, Majorana was involved in the study of the behavior of a beam of polarized atoms going through a rapidly changing magnetic field. He proposed an optimal arrangement for the magnetic field, in order to show the atomic space quantization for the spin direction, and the non-adiabatic transitions where the spin direction changes abruptly (Majorana flips). In the Majorana scheme, the

polarized beam is allowed to enter a zone very near to a point where the magnetic field becomes zero. Majorana proposal was immediately experimentally realized, with great success, by O.R. Frisch and E. Segrè, working in the Stern laboratory in Hamburg. In this paper, Majorana introduces a very interesting representation for quantum states on the polarization sphere, and calculates explicitly the probability amplitudes for spin flip in the general case.

In the same year 1932, Majorana began to be involved with problems connected with elementary particle theory. Also in this new fields, he immediately obtains astonishing new results. In fact, he succeeds in the construction of relativistic wave equations, linear in the energy, and relativistically invariant, for particles having a generic value for the spin. The paper, that he published in 1932 on *Nuovo Cimento*, contains the first description of a large class of infinite dimensional unitary representations for the relativistic Lorentz group. During a conversation held in Lipsia in 1933, B.L. van der Waerden noticed that these results are a great mathematical discovery. In fact, E.P. Wigner, Nobel laureate in Physics in 1963, in his fundamental paper of 1939 on *Annals of Mathematics*, fully recognizes the pioneering role played by Majorana in the discovery of these representations.

In January 1933, Majorana received a grant from the Italian National Council of Research, in order to continue his research abroad, in Leipzig in the Heisenberg group. The amount of the grant was 12.000 Italian Lire, over a six month period. The application was supported by Fermi, who in a letter to the ruling board of the Council, dated January 2nd 1933, wrote that Majorana was involved since many years in “various questions regarding the theory of the atom, and in particular the applications of group theory in these researches”, with brilliant results. The grant would allow Majorana to “continue his researches” with great profit. However, the explicit research program was communicated by Majorana to the Council, in a letter of January 9th, in different terms. In fact, Majorana wrote that his intention was “to be involved, under the guide of prof. W. Heisenberg, in theoretical researches concerning mainly the structure of nuclei, and the relativistic formulation of the new quantum theory”. The discrepancy about the research topics, between Fermi support letter and Majorana explicit program, shows that Majorana had reached a complete independence, and was ready to develop his scientific personality beyond Fermi advice and guide. All documents, concerning Majorana fellowship, can be found at the Central Archive of the State in Rome (C.N.R. B155 F).

This choice of Majorana was extremely important. He reached Leipzig in the middle of January 1933, and immediately he established intense relations with Werner Heisenberg. In few weeks, he obtained fundamental

results, through the modification of the nuclear theory, developed by Heisenberg starting from June of the past year, after the discovery of the neutron. Majorana made two crucial modifications to the exchange forces, introduced by Heisenberg for the interaction between neutrons and protons in the nucleus. Majorana work received immediate recognition. In particular, Heisenberg dedicated most of his report, at the October 1933 Solvay Conference in Bruxelles, to an explanation of the Majorana results. Still now, after so many years, we speak about the Heisenberg-Majorana model for the nucleus, and about the Majorana exchange forces, as opposed to the Heisenberg exchange forces.

As it is possible to see from the complete list in Appendix D, Majorana produced a considerable number of ten publications, in the years 1931-1933. Among these, there are two Letters to “La Ricerca Scientifica”, the bi-monthly Journal of the National Council of Research, where Majorana gives announcements about his forthcoming papers, together with short dense conceptual summaries. We remark here explicitly these facts, because they show how Majorana was sensitive to the need of letting his results to be known, as an essential part of his scientific professional activity. Surely, he did not need any external push in order to be convinced to publish his results, as it has been too many times written, without any substantial reason.

The stay is so described by Majorana: (letter to C.N.R. 14-9-1933) “My stay abroad has taken place in two periods of around three months each. The first goes from the middle of January to the middle of April, and I have split it in equal parts between the Institute in Leipzig, directed by Heisenberg, and the Institute in Copenhagen, directed by Bohr. The second period, from the beginning of May to the beginning of August, has been spent entirely in Leipzig”. In fact, he was back for a couple of weeks in Rome for Easter, in the second half of April. He returned definitively in Rome in the first days of August.

The intense and tense scientific activity of Majorana, his ability to confront himself with advanced topics, on a large spectrum of interests, by giving always innovative contributions of high conceptual level, his willingness to show to the world the results that he was obtaining, all these aspects of a great researcher went abruptly to the end after his coming back to Italy.

From this point on, we find a very long silence, interrupted only by the publication of a single and last paper on *Nuovo Cimento* in 1937. This paper, may the most important produced by Majorana, deals with the formulation of the symmetrical theory for electrons and positrons, in a frame of second quantization. There no need any more for the artificial hypothesis of a completely filled sea of electrons in states of negative energy. It was a great intuition of Majorana to understand that a completely consistent

interpretation of the relativistic wave equations can be reached only in the frame of quantum field theory, at the level of second quantization. Moreover, Majorana choice of a real representation for Dirac matrices, allows him to realize the possibility of spin $1/2$ particles that are their own anti-particles. This is the famous hypothesis of the “Majorana neutrino”, which is still an important contemporary research topics, even at the experimental level.

About the institutional relations of Ettore Majorana with the University, and in particular with the University of Rome, it must be stressed that he represents a true anomaly, as compared with the other brilliant and further promising young people, who had relations with the Institute of Physics at the University, and with Enrico Fermi in particular. In fact, he never got any appointment, neither as assistant or assistant professor. The only official recognition was the six month 1933 fellowship of the National Council of Research, for research abroad.

Surely he was very interested in an academic career. In fact, he applied for, and obtained, the “Libera Docenza” (“private professorship”) in Theoretical Physics at the end of 1932, at the age of only 26 years (Minister decree of January 22nd, 1933). As found in the Archives of the University of Rome, for many years he submitted to the Faculty detailed and always different programs for advanced courses (“Mathematical Methods of Quantum Mechanics” for the a.y. 1933-34, “Mathematical Methods for Atomic Physics”, for the a.y. 1935-36, “Quantum Electrodynamics”, for the a.y. 1936-37). However, he never succeeded in giving the “free” course.

Nevertheless at the end Ettore Majorana became full professor in Theoretical Physics. His promotion to the chair in 1937, and his official removal in 1938, are a nice piece in the history of the Italian University. It is possible to find all related documents in the efficient Central Archive of the State in Rome.

On June 1937, the Royal University of Palermo in Sicily issued an official competition for a full professorship in Theoretical Physics. Ettore Majorana diligently submitted his application.

The selecting Committee, directly appointed by the Minister of National Education and chaired by Enrico Fermi, in the first meeting, on October 25th 1937, reached unanimously a very important conclusion. It was recognized that the competitor Ettore Majorana enjoyed a national and international scientific position of such high resonance, that the Committee was hesitating to apply for his case the normal procedure of University competitions. Therefore, it was suggested to the Minister to consider the opportunity to appoint directly Majorana as full professor of Theoretical Physics in some University of the Kingdom, independently from the competition issued by the University of Palermo. A detailed report about Majorana scientific activity

was included.

The Minister, who surely could exploit very efficient advisors, immediately issued a decree, dated November 2nd, with the direct appointment of Ettore Majorana as full professor of Theoretical Physics at the University of Naples, with the yearly salary of around 26.000 Italian Lire. The motivation was given by the “alta fama di singolare perizia cui è pervenuto nel campo degli studi di Fisica teorica” (“high fame of singular expertise reached in the field of theoretical Physics”). The “Corte dei Conti” (Court of State account control) approved the decree on December 4th. The whole procedure is surely a remarkable example of bureaucratic efficiency.

Then, the Committee met, without taking into account Majorana any more. The winning triplet was selected immediately among the surviving five competitors, in the following order: Gian Carlo Wick, Giulio Racah, Giovanni Gentile Jr.

G.C. Wick, as the first in the triplet, was regularly appointed in Palermo, then moved to Padova in 1938, and finally in 1940 took the chair left by Enrico Fermi in Rome. G. Racah was appointed in Pisa, but lost the chair in 1938, as a consequence of the infamous racial laws, and after some years reached the University of Jerusalem. G. Gentile Jr., son of the influential Senator and former Minister Giovanni Gentile Sr., was appointed in Milan. He passed away prematurely in 1942, due to a trivial infection.

Majorana moved to Naples in January 1938, and gave regularly his first course in Theoretical Physics, until the end of March, when he disappeared, under still mysterious circumstances. We have collected the testimony of his student Gilda Senatore, about the course and the lecture notes left by Majorana, in a paper to appear in the next issue of *Physis* (Felice Cennamo, Francesco Guerra, Nadia Robotti and Gilda Senatore, “Ettore Majorana a Napoli: la testimonianza dell’allieva Gilda Senatore” (“Ettore Majorana in Naples: the testimony of the student Gilda Senatore”), *Physis*, in press).

Nine months after Majorana disappearance, on December 6th 1938, the Minister issued a decree where Ettore Majorana was considered as having resigned from his public office, starting from March 25th 1938, because he “abandoned the duty of his office for more than ten days, without any justified reason”. It is amusing to find that the controlling Court did not approve immediately the decree, which clearly was seriously damaging legitimate interests in the hypothetical case that the absence was “justified”. The Minister had to send additional information to give foundation to his decision. This information was provided through letters of the Rector in Naples, and incredibly through excerpts from the daily press! It was only in September 1939 that the Official Bulletin of the Ministry of National Education, with a short two line notice, announced publicly that “Prof. Ettore Majorana,

full professor of Theoretical Physics, is declared resigned from office, starting from March 25th, 1938". Ministerial bureaucracy was by far more efficient to raise Majorana to the professorship, than to remove him.

We believe that the highest human respect should be reserved to the decisions taken by Ettore at the end of March 1938, whatever they were, and we abstain from any intrusion in this delicate matter.

Appendix D

List of the scientific publications of Ettore Majorana

The list of scientific publications included in all available biographies of Majorana is nothing but the list of the papers that Majorana himself presented in the application to Palermo professorship in 1937. Usually, this list is supplemented with an additional paper, on the meaning of the statistical laws, which was published, after Majorana disappearance, by his friend Giovanni Gentile Jr., who found the manuscript in Majorana house in Rome.

However, we decided to perform a careful scan of all Journals of the time, in order to have a more complete information. Therefore, we present here a complete list of all publications available in the printed literature of the time. The list includes the communication at the 1928 meeting of the Italian Physical Society, and two additional short announcements about his work on the oriented atoms in a variable magnetic field, and on the theory of nuclei. We believe that these additional items are important for the complete reconstruction of the scientific activity of Ettore Majorana. The reason why he did not present them for the competition is self-evident.

For a better understanding of the temporal sequence of the research arguments, we have included in this list of published contributions also the Thesis, submitted for the 1929 doctoral degree in Physics.

1. G. Gentile and E. Majorana, *Sullo sdoppiamento dei termini Roentgen e ottici a causa dell'elettrone rotante e sulle intensità delle righe del cesio (On the doubling of Röntgen and optical terms due to the rotating electron, and on the intensities of caesium lines)*, Rendiconti dell'Accademia dei Lincei **8**, 229-233 (1928), (presented by Orso Mario Corbino in the Academy meeting of July 24th, 1928).
2. E. Majorana, *Ricerca di un'espressione generale delle correzioni di Rydberg, valevole per atomi neutri o ionizzati positivamente (Search for a general expression of Rydberg corrections, valid for neutral atoms or positive ions)*, Nuovo Cimento **6**, XIV-XVI (1929), (communication

to the XXIIInd general meeting of the Italian Physical Society, Rome, December 28-30, 1938).

3. E. Majorana, *Sulla meccanica dei nuclei radioattivi (On mechanics of radioactive nuclei)*, Thesis submitted for the doctoral degree in Physics, Roma, July 7th, 1929, (mentioned by Majorana himself some years after as *Sulla meccanica quantistica dei nuclei radioattivi (On quantum mechanics of radio-active nuclei)*).
4. E. Majorana, *Sulla formazione dello ione molecolare di elio (On the formation of the molecular helium ion)*, (announced in Rendiconti dell'Accademia dei Lincei **12**, 583 (1930), presented by Orso Mario Corbino in the Academy meeting of December 7th, 1931), Nuovo Cimento, **8**, 22-28 (1931).
5. E. Majorana, *Reazione pseudopolare fra atomi di idrogeno (Pseudopolar reaction between hydrogen atoms)*, Rendiconti dell'Accademia dei Lincei, **13**, 58-61 (1931), (presented by Orso Mario Corbino in the Academy meeting of January 4th, 1931).
6. E. Majorana, *I presunti termini anomali dell'elio (The presumed anomalous terms of helium)*, Nuovo Cimento, **8**, 78-83 (1931).
7. E. Majorana, *Teoria dei tripletti P' incompleti (Theory of incomplete P' triplets)*, Nuovo Cimento, **8**, 107-113 (1931).
8. E. Majorana, *Atomi orientati in campo magnetico variabile (Oriented atoms in a variable magnetic field)*, La Ricerca Scientifica **5**, 329 (1932).
9. E. Majorana, *Atomi orientati in campo magnetico variabile (Oriented atoms in a variable magnetic field)*, Nuovo Cimento, **9**, 43-50 (1932).
10. E. Majorana, *Teoria relativistica di particelle con momento intrinseco arbitrario (Relativistic theory of particles with arbitrary intrinsic momentum)*, Nuovo Cimento, **9**, 335-344 (1932).
11. E. Majorana, *Nuove ricerche sulla teoria dei nuclei (New researches on the theory of nuclei)*, La Ricerca Scientifica, **4**, 522 (1933).
12. E. Majorana, *Über die Kerntheorie (On the theory of nuclei)*, Zeit. für Physik, **82**, 137-145 (1933).
13. E. Majorana, *Sulla teoria dei nuclei (On the theory of nuclei)*, La Ricerca Scientifica, **4**, 559-565 (1933).

14. E. Majorana, *Teoria simmetrica dell'elettrone e del positrone (Symmetrical theory of the electron and the positron)*, Nuovo Cimento, **5**, 171-184 (1937).
15. E. Majorana, *Il valore delle leggi statistiche nella fisica e nelle scienze sociali (The value of the statistical laws in Physics and Social Sciences)*, Scientia, **36**, 58-66 (1942), (published with an introduction by G. Gentile Jr.).