

Fleeting genius

Ettore Majorana was hailed a genius by none other than Fermi himself and made contributions to neutrino physics that are only now being fully recognized. On the centenary of Majorana's birth, **Salvatore Esposito** traces a remarkable life that ended with a mysterious disappearance



On Saturday 26 March 1938 the director of the Institute of Physics at the University of Naples in Italy, Antonio Carrelli, received a mysterious telegram. It has been sent the previous day from the Sicilian capital Palermo, some 300 km across the Tyrrhenian Sea, and read: "Don't worry. A letter will follow. Majorana." That same Saturday, Ettore Majorana – who had just been appointed as full professor of theoretical physics at the university at the age of 32 – had not turned up to give his three-weekly lecture on theoretical physics. By Sunday the promised letter had reached Carrelli. In it Majorana wrote that he had abandoned his suicidal intentions and would return to Naples, but it revealed no hint of where the illustrious physicist might be. The picture was quickly becoming clear: Majorana, who was widely regarded as a genius and whose work continues to impact on physics today, had disappeared.

Troubled by the news, Carrelli called his friend Enrico Fermi in Rome, who immediately realized the seriousness of the situation. Fermi, who would be awarded the Nobel Prize for Physics later that year, was working in his laboratory with the young physicist Giuseppe Cocconi at the time. In order to give him an idea of the seriousness of the loss to the community of physicists caused by Majorana's disappearance, Fermi told Cocconi: "You see, in the world there are various categories of scientists: there are people of a secondary or tertiary standing, who do their best but do not go very far. There are also those of high standing, who come to discoveries of great importance, fundamental for the development of science. But then there are geniuses like Galileo and Newton. Well, Ettore was one of them. Majorana had what no-one else in the world had."

An audacious start

Ettore Majorana was born on 5 August 1906 in Catania, Sicily, to Fabio Majorana and Dorina Corso. The fourth of five sons, he had a rich scientific, technological and political heritage: three of his uncles were chan-

cellors of the University of Catania and members of the Italian parliament, while another was a renowned experimental physicist who was once president of the Italian Physical Society. Indeed, Ettore's father was an engineer who founded the first telephone company in Sicily and who went on to become chief inspector of the Ministry of Communications.

Fabio Majorana was also responsible for the education of his son in the first years of his life, until the family moved to Rome in 1921. Ettore left school in 1923 at the age of 17 and joined the faculty of engineering at the University of Rome, where he excelled and counted Giovanni Gentile Jr and future Nobel laureate Emilio Segrè among his friends. In the spring of 1927 Orso Mario Corbino, the director of the Institute of Physics at Rome and an influential politician, launched a famous appeal to the students of the engineering faculty to entice the most brilliant young minds into studying physics. Segrè and his friend Edoardo Amaldi rose to the challenge, joining Fermi and Franco Rasetti's group and telling them of Ettore's exceptional gifts.

After some encouragement from Segrè and Amaldi, Majorana eventually decided to meet Fermi in the autumn of that year. The pair immediately started talking about the statistical model of atoms that Fermi was working on, later to be known as the Thomas–Fermi model, which describes the energy of an atom in terms of the density of its surrounding electrons. The model involves a complicated non-linear differential equation. The analytical solution of the equation was then unknown, but Fermi had managed to obtain a numerical table of approximate values for it. Majorana carefully followed what Fermi said and, after asking a few questions, left the institute. The following morning he returned to Fermi's office and asked for a closer look at the numerical table so that he could compare it with an analogous table he had drawn up the previous evening. Once he had established agreement between the two tables, Majorana noted that Fermi's table was

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Enrico Fermi

correct and left the institute with no further comment.

What seems nothing more than an amusing anecdote, as recalled by Rasetti, Segrè and Amaldi, has since been carefully tested on scientific grounds. From previously unpublished study notes written by Majorana between 1927 and 1932, we now know that Majorana had arrived at a “series solution” of the Thomas–Fermi equation using a peculiar method that applies to an entire class of mathematical problems. It is testament to Majorana’s genius that although some of his results anticipated by several years those of renowned mathematicians and physicists, several others (including his solution of the Thomas–Fermi equation) have not been obtained by anyone else since.

As if satisfied that Fermi had passed his “examination”, Majorana decided to leave engineering and join what became known as the “via Panisperna boys” – Fermi’s influential group that was named after the street in Rome where the physics department was located. Majorana made substantial theoretical contributions to the group’s research, and in 1928 – while still an undergraduate – published his first paper, in which he calculated the splitting of certain spectroscopic terms in gadolinium, uranium and caesium due to the spin of the electrons. At the end of that same year, Fermi invited Majorana to give a talk at the Italian Physical Society on some applications of the Thomas–Fermi model. Then on 6 July 1929, Majorana graduated with a masters degree in physics, his dissertation was titled “The quantum theory of radioactive nuclei”.

Reluctant scientist

By the end of 1931 the 25-year-old physicist had published two articles on the chemical bonding of molecules and two more papers on spectroscopy, one of which anticipated results later obtained by a collaborator of Samuel Goudsmith on the “Auger effect” in helium. The following year Majorana published an important paper on the non-adiabatic spin-flip of

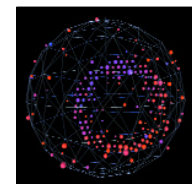
atoms in a magnetic field, which then waited five years before being extended by future Nobel laureate Isidor Isaac Rabi. But Majorana’s most important results were still to come.

In 1932 Majorana published an article titled “Relativistic theory of particles with arbitrary intrinsic momentum”, which became a major contribution to group theory that has led to key results in theoretical physics and anticipated analogous work by Nobel laureates Eugene Wigner in 1938 and Paul Dirac in 1945. Due to Majorana’s peculiar character, which made him averse to publicizing his work, it is unfortunately a recurring feature of his professional life that even his published papers were not adequately known by the broader physics community.

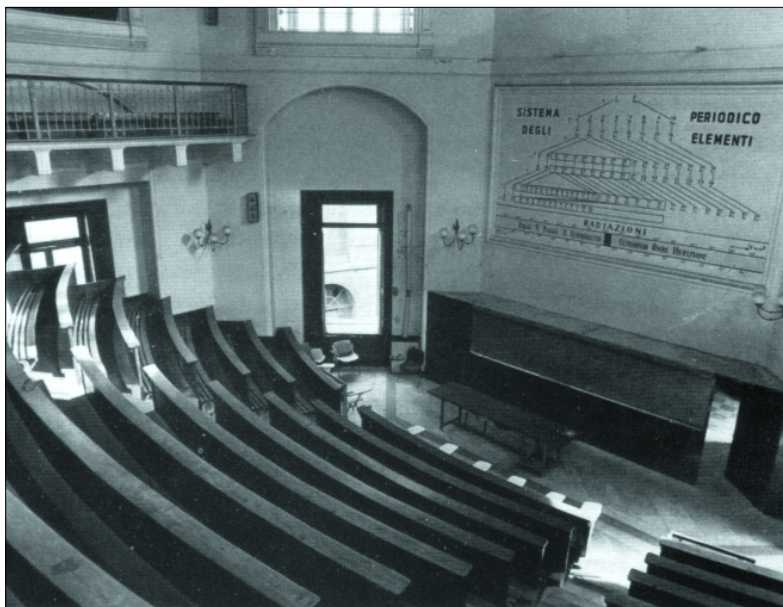
In March 1932 James Chadwick announced the discovery of the neutron, after which Majorana revealed to his friends and colleagues in Rome that he had built a theory of light nuclei based on the quantum concept of exchange forces. Although encouraged by Fermi to go public with his results, Majorana’s hypercritical judgement prevented him from doing so. True to style, his work was not recognized until a few months later when it was independently elaborated by Werner Heisenberg. But Heisenberg’s theory contained defects that Ettore immediately realized.

According to Heisenberg, the underlying nuclear forces should be interpreted in terms of nucleons exchanging spinless electrons, thus implicitly assuming that a neutron is formed by a proton and an electron. In Majorana’s view, however, the neutron was pictured as a “neutral proton”, as it effectively is, and the erroneous experimental consequences of the Heisenberg model were quickly recognized by Heisenberg himself and others.

This fact caused a sensation in the Rome group, and Fermi urged Majorana, successfully, to visit Heisenberg – who would be awarded the 1932 Nobel Prize for Physics at the end of 1933 – in Leipzig for a six-month



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Neutrino reaction in the MiniBooNE detector at Fermilabxxxxxxxxxxxx



Lasting the course

The large lecture room at the Institute of Physics in Naples, where Majorana gave the opening lecture for his course on theoretical physics.

period in 1933. Here, Majorana's ability and results largely impressed Heisenberg who later, on several occasions while discussing the "Heisenberg–Majorana" exchange forces, only marginally mentioned his own contribution, whereas annoyingly that of Majorana was pointed out as if Heisenberg knew he was indebted to his young colleague.

Once Majorana had returned from abroad, where he met several other important personalities including Bloch, Bohr and Weisskopf, he did not publish any papers for several years. But his research activity during this period, which focused mainly on field theory and quantum electrodynamics, is well testified by a number of unpublished scientific notes that are currently being studied. In 1937, however, probably after being invited by Fermi to compete for a full professorship, Majorana published what was to become his most famous paper: "Symmetric theory of electrons and positrons", in which he introduced the so-called Majorana neutrino hypothesis.

This hypothesis was revolutionary because it argued that the antimatter partner of a given matter particle could be the particle itself. This was in direct contradiction to what Dirac had successfully assumed in order to solve the problem of negative energy states in quantum field theory (i.e. the existence of the positron). With unprecedented farsightedness Majorana suggested that the neutrino, which had just been postulated by Pauli and Fermi to explain puzzling features of radioactive beta decay, could be such a particle. This would make the neutrino unique among the elementary particles and, moreover, enable it to have mass. Today many experiments are still devoted to detect these peculiar properties, which include the phenomenon of neutrino oscillation (see pages XX–YY) and possible neutrinoless double beta decay (see *Physics World* July 2004 pp8–9).

Return to Naples

As far as we know, the last chapter of Majorana's life had Naples as its centre, where Ettore arrived in January 1938. Upon request of the board in charge of the competition for a new full professorship in theoretical

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physics in Italy, the Minister of Education appointed Majorana "independently of the competition rules, as full professor of theoretical physics in a university of the Italian kingdom because of his high and well-deserved reputation". The chairman of the board was Fermi and its secretary Carrelli.

At Naples, Majorana lectured on theoretical physics, presenting quantum mechanics in a very modern way by skilfully sandwiching its mathematical formalism with real applications. The text of the complete set of Majorana's lectures is now available thanks to the recent discovery of the "Moreno paper" – a faithful copy of the original handwritten notes. Majorana's course was suddenly and unexpectedly interrupted by his mysterious disappearance three months after his appointment at Naples.

On Friday 25 March 1938 Majorana went to the Institute of Physics and handed over the lecture notes and some other papers to one of his students. After that, Ettore returned to his hotel and, after writing farewell letters to his family and to Carrelli, embarked on a ship to Palermo. He reached his destination the following morning, where he lodged for a short time in the Grand Hotel Sole. It was here that he wrote the telegram and the letter to Carrelli pointing out a change of mind about his disappearance. On Saturday evening Majorana embarked on a ship from Palermo to Naples. From here onwards, no other reliable information about him is available.

There have been several conjectures about the fate of Majorana, including suicide, a retreat in a monastery and a flight to a foreign country. The search for a reason for such a dramatic decision ranges from the personal and familiar, such as Ettore's peculiar relationship with his extremely possessive mother (especially after the death of his father), to nice literary tales, such as that related by Leonardo Sciascia in one of his famous novels on Majorana's possible foresight of the tragedy of the atomic bomb. However, to quote Ettore himself on his approach to doing physics: "We cannot give to such hypothesis greater likelihood than to some other theoretical presumptions without a too much subjective appraisal."