Enrico Fermi

Life, Personality and Accomplishments

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N Mukunda – his interests are classical and quantum mechanics, theoretical optics and mathematical physics.

A brief account of the life of Enrico Fermi, against the background of others of his generation, is given. His role in the revival of Italian Physics, and influence on many others, are described. Fermi's major contributions to quantum phys-

personality, are recounted.

Introduction

The opening years of the twentieth century saw the birth of several exceptionally gifted persons, all of whom, a generation later and in their twenties, played stellar roles in the creation, formalization, consolidation and interpretation of quantum mechanics: Wolfgang Pauli in 1900, Werner Heisenberg and Enrico Fermi in 1901, Paul Dirac and Eugene Wigner in 1902, and John von Neumann in 1903. Just a few years later, within the same decade, came John R. Oppenheimer and George Gamow in 1904, Hans Bethe and Ettore Majorana in 1906, Rudolf Peierls in 1907, and Lev Landau and Victor Weisskopf in 1908. One is tempted to ask – why and how did this near simultaneous appearance of such great talent in such profusion come about? After reflection, we are likely to agree with what Heisenberg said in a talk in 1973 celebrating the five hundredth birthday of Copernicus:

"To what extent are we bound by tradition in the selection of our problems? …Looking back upon history…, we see that we apparently have little freedom in the selection of our problems. We are bound up with the historical process, and our choice seems to be restricted to the decision whether or not we want to participate in a development that takes place in our time, with or without our contribution. … one may say that a fruitful period is characterized by the fact that the problems are given, that we need not invent them. This seems to be true in science as well as in art."

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And, one might add, within science, not in physics alone.

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– *Werner Heisenberg*

Early Years to PhD at Pisa

Enrico Fermi was born on 29 September 1901 in Rome, Italy, to parents of modest means. His grandfather Stefano came from a farming background, around Piacenza in northern Italy, and later became a county secretary. His father Alberto worked in the Italian State Railway system, and settled in Rome. Enrico's mother, Ida de Gattis, a school teacher, was fourteen years younger than Alberto. Enrico was the youngest of three children, with Maria born in 1899 and Giulio in 1900.

Being just a year apart, Giulio and Enrico were extremely close to one another, with shared interests and talents in building machines and gadgets. However, tragedy struck the family when Giulio died in 1915 after a freak incident in a hospital. During his school years, Enrico taught himself physics and mathematics from a book written by a Jesuit priest in 1840. He and Enrico Persico were great friends in this period. He was also guided in his reading by a friend of his father, and was soon recognized to be exceptionally gifted. In November 1918, after school, Enrico gained admission to the prestigious Scuola Normale Superiore in Pisa, an institution set up by Napoleon. The period 1918–1922 spent in Pisa, with his class fellow Franco Rasetti and enlivened by many pranks, were most happy and lively years for Enrico (hereafter Fermi) – the first world war had ended, and Trieste and Trento had been won back from Austria though at great human cost.

Fermi completed his PhD at Pisa in 1922, just around the time the fascist movement was taking control of Italy. He was clearly far ahead of his contemporaries and even his teachers. With support from fellowships, he then spent six months in Gottingen with Max Born, and somewhat later in Leiden with Paul Ehrenfest. However he felt somewhat of an outsider to the group around Born, wondering how he compared with others there and looking for appreciation and encouragement from Born.

The Rome Group – 'Senator Corbino's Boys'

Upon return to Italy, Fermi taught mathematics and physics as an Instructor at Rome during 1924, then at Florence till 1926. In the Florence period he completed a piece of work in quantum statistics which immediately established his reputation. At that point came the move to Rome. The initiative was taken by Professor Orso Mario Corbino, head of the physics department at Rome, and member of the Italian Senate. Fermi had met Corbino earlier, after finishing at Pisa. Corbino was from Sicily in southern Italy, and he had a vision and ambition to revive Italian physics which had declined compared to the days of Galileo and Volta. In comparison, Italian mathematics was doing very well, thanks to figures like Gregorio Ricci-Curbastro, Tullio Levi-Civita, Luigi Bianchi, Vito Volterra and others. By October 1926, Fermi was professor at Rome, then Rasetti came from Florence to join the group being built up by Corbino. Soon after, Edoardo Amaldi, Emilio Segrè and Ettore Majorana joined as Fermi's students, completed their Ph.D's, and became members of the Department. The years up to the late 1930's saw a great flowering of Italian physics around Fermi, the members of the group being referred to as 'Senator Corbino's boys' or the 'via Panisperna boys'. As the acknowledged leader, Fermi was 'the Pope'.

His finest achievements in the Rome period were his 1933 theory of beta decay; and soon after, the experimental work on slow neutron induced radioactivity.

A charming incident in this period is a conversation between Fermi and Majorana as reported by S Chandrasekhar:

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Majorana: There are scientists who 'happen' only once in every 500 years, like Archimedes or Newton. And there are scientists who happen only once or twice in a century, like Einstein or Bohr.

Fermi: But where do I come in, Majorana?

Majorana: Be reasonable, Enrico! I am not talking about you or me. I am talking about Einstein and Bohr.

The Rome group lasted till the mid to late 1930s. We will pick up Fermi's story later. As for the others – Rasetti left Rome for Universitè Laval in Quebec, Canada, in 1939; then moved to Johns Hopkins University in Baltimore, USA from 1947 to 1967. Emilio Segrè left Rome for Palermo in Italy in 1936, then to the University of Berkeley, USA, in 1938. Edoardo Amaldi left Rome in 1939, served in the Army 1939–1941, then stayed on in Italy and played an important role in the revival of Italian physics after the second world war. Majorana, in some sense a tortured genius, spent some time with Heisenberg in Leipzig in 1933; lived a secluded hermit's life 1933 to 1937; took up the Chair in Theoretical Physics at Napoli in 1937; and disappeared on a boat trip from Palermo to Napoli in March 1938.

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Some other well-known Italian physicists inspired by Fermi were Giulio Racah, Ugo Fano and Gian Carlo Wick.

Family Life – Personality – The Nobel Prize

At this point, let us return to the early 1920's, and describe important events in Fermi's family life. His wife Laura (*nee* Capon, born 1907) met him for the first time in 1924 as part of a hiking group with several other young people. She came from a non-observing Jewish family, her father was a naval officer, and she recalled later that Fermi showed a protective attitude towards her from the very beginning. Their second meeting was in late 1926 after he had joined the Rome physics department. They became engaged in early 1928, and married in July that year. For a while they lived a frugal life, on his monthly salary of US$ 90.00. Later, conditions improved – in 1929 Fermi was named to Mussolini's new Accademia d'Italia, bringing him a title and a higher salary. They had two children – a daughter Nella born in 1931, and son Giulio in 1936. Here are some descriptions of Fermi's nature and personality, taken from Laura's engaging biography of him titled *Atoms in the Family*: he felt that

' … a losing cause is worth no effort';

'… qualities that were to become assets in his scientific prose –

He was of simple tastes and, moreover, he thought that complaining was an idle form of expression directed to no purpose.
– Laura Fermi

the going straight to the point with no flourishes, the simplicity of style, the avoidance of any word not strictly essential';

'He was of simple tastes and, moreover, he thought that complaining was an idle form of expression directed to no purpose';

'he would never seek money, never ask or strive for more of it. "Money," he used to tell me, " has the tendency of coming of its own will to those who don't look for it. I don't care for money, but it will come to me".'

During the years of rising fascism, Fermi often felt it was better to emigrate to the USA; but Laura, feeling more strongly rooted in Rome, was reluctant to do so. Finally, in 1938 the persecution of Jews started, while politically Italy became sub-servient to Nazi Germany. All this culminated in their decision to leave for good. The timing was unusual. On November 10, 1938, the Nobel Prize in physics for 1938 was announced; it was given 'To Professor Enrico Fermi of Rome for his identification of new radioactive elements produced by neutron bombardment and his discovery, made in connection with this work, of nuclear reactions effected by slow neutrons.'

That year only two Nobel awards were given – to Pearl Buck for literature, to Fermi for physics. Fermi, Laura and their children went by train from Rome to Stockholm, attended the Nobel ceremonies, then went by ship via England to the USA, reaching New York on January 2, 1939. Fermi had been offered a professorship at Columbia University; he was to work there till April 1942.

Columbia–Chicago–Los Alamos

In late 1938, the chemists Otto Hahn and Fritz Strassmann in Berlin discovered that when bombarded by a neutron, the uranium nucleus split in to fragments of substantial sizes – the fission process. The physicists Lise Meitner and Otto Frisch soon confirmed that a great deal of energy was also released. Fermi and his group in Rome had missed all this in their work. He now immediately hypothesized that many neutrons would also be released during fission; if they could be saved and slowed down, they could cause further fissions; and in principle a controlled self-sustaining chain reaction with enormous energy release could be created. He immediately started experiments at Columbia to realize this.

Meanwhile, over July and August 1939, Leo Szilard and Eugene Wigner met Einstein and persuaded him to sign a letter drafted by them addressed to President Franklin Roosevelt, informing him about the possibility of creating new extremely powerful bombs based on the nuclear fission chain reaction. The names of Fermi and Szilard, and their work, are repeatedly mentioned in the letter. It was received by Roosevelt on October 11, 1939, and an 'Advisory Committee on Uranium' was soon set up. Two years later, on December 6, 1941, the decision to make an all-out effort in atomic energy research was taken by the US Government, leading to the 'Manhattan Project'.

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As the work at Columbia grew in scale, it was shifted to the University of Chicago in 1942. Fermi moved there in April 1942, his family in June. On December 2, 1942, on the campus of the University of Chicago, the team led by Fermi achieved 'the first self sustaining chain reaction and thereby initiated the controlled release of nuclear energy'. In 1944 Fermi moved to Los Alamos to work on the atomic bomb project, under the leadership of Oppenheimer. After the success of the project and the end of the Second World War, he returned at the very end of 1945 to Chicago, where he lived and worked for the rest of his life.

Magnitude of Fermi's Work

Fermi had a very down-to-earth extremely physical approach to problems, and was able to see the essentials of any situation very quickly. The range of his work is amazing encompassing both theory and experiment. While we have referred to some of his important work already, it is worth describing some of them further.

In 1922, while still a student in Pisa, he contributed a beautiful and important idea in the framework of general relativity, which has come to be called 'Fermi transport'[1] or 'Fermi–Walker differentiation' after an extension made by A G Walker in 1932. This is distinct from covariant differentiation, and is a rule for carrying or evolving vectors and tensors along a given world-line in space time. It makes precise the idea of a 'non-rotating' or 'non-spinning' coordinate frame, and is an appealing and useful concept.

[1] See the article by Joseph Samuel in this issue.

Fermi's major contribution to quantum statistics has already been briefly mentioned. The Pauli Exclusion Principle, applied to electrons bound in an atom, had been enunciated in late 1925[2]. In February 1926, while in Florence, Fermi generalized this to the case of an ideal monatomic gas, and obtained a distribution function differing from both the classical Boltzmann distribution and the quantum Bose distribution of 1924. Later, in August 1926, Dirac showed how both Bose and Fermi distributions come from the basic principles of quantum mechanics, from two contrasting symmetry properties of wave functions for indistinguishable particles. It appears that when Fermi told Dirac he had obtained the result earlier, Dirac replied that he had seen Fermi's paper but then forgotten it! This statistical law is now named after both of them as the Fermi–Dirac statistics.

[2] The translation of Fermi's paper from German appears in the Classics Section.

Here is an interesting rejoinder to this story. The Fermi Golden Rule is a famous formula in quantum mechanics for the transition rate for a system to go from some given initial state to any chosen final state under the action of a perturbation. It was apparently first obtained by Dirac, but has ever since carried Fermi's name!

A very interesting application of his new statistics to the cloud of electrons bound in an atom followed in 1927. It was an approximate method which took in to account the exclusion principle and the Coulomb attraction to the nucleus, to calculate an effective potential in which the electrons move. As it was independently proposed also by L H Thomas, it is called the Thomas–Fermi model for the atom, applicable for heavy atoms.

In 1930 summer Fermi spent two months at the University of Michigan at Ann Arbor giving a series of lectures on the new quantum electrodynamics. This later appeared as 'Quantum Theory of Radiation' in Volume 4 of the *Reviews of Modern Physics* in 1932. It is probably the most beautiful account of this subject at the stage it had reached at that time. This was Fermi's writing at its best, so beautiful that one cannot resist quoting what many outstanding physicists said about it:

Fermi was unique in his way of doing physics. He had a very special way of attacking problems. He always managed to find the simplest and most direct approach, with the minimum of complication and sophistication.
– *Weisskopf*

Wigner: 'His article on the Quantum Theory of Radiation in the *Reviews of Modern Physics* (1932) is a model of many of his addresses and lectures: nobody not fully familiar with the intricacies of the theory could have written it, nobody could have better avoided those intricacies'.

Bethe: '… It is an unsurpassed example of simplicity in a difficult subject. It appeared after a group of extremely complicated papers on the subject, and preceded another group of papers that were equally complicated. Without Fermi's luminous simplicity I think that many of us would have been unable to explore field theory in depth. I am certainly one of them.'

Weisskopf: 'Fermi was unique in his way of doing physics. He had a very special way of attacking problems. He always managed to find the simplest and most direct approach, with the minimum of complication and sophistication. In the early 1930's, when I tried in vain to understand the new quantum electrodynamics I was lucky enough to find in '*Reviews of Modern Physics*' Fermi's article called 'Quantization of radiation in the Coulomb gauge'. I studied it, and from then on I understood field theory. I know I am not the only one who reached this result and who has this opinion'.

Finally we come to Fermi's monumental 1933 theory of beta decay[3]. After the two classical theories of gravitation and electromagnetism, this is the next fully quantitative and detailed theory of a fundamental interaction in nature, completely in the quantum domain. It is astounding that so soon after quantum field theory in

[3] See the article by G Rajasekaran in this issue.

> The same simplicity and realism, which was manifest in Fermi's scientific work, manifested itself also in his human relations.
> – *Wigner*

the form of quantum electrodynamics was founded, and the Pauli neutrino hypothesis had been presented as a way to preserve energy and angular momentum conservation in beta decay, Fermi constructed this next quantum field theoretic description of a fundamental interaction in nature. Ideas of particle creation and annihilation and (vector) current current interaction, which would dominate elementary particle physics for decades to come, were all present in Fermi's theory. Truly the starting point of a great saga in physics of the twentieth century.

Two more gems of his pedagogical skills deserve mention. The first is a book on 'Thermodynamics' based on his 1936 Columbia lectures, published in 1937 and available as a Dover paperback. The second is the course in Nuclear Physics given by him at Chicago in 1949, written up by three of those who attended – Jay Orear, A H Rosenfeld and R A Schluter. It is amazing to see the range and depth of the topics covered, both theoretical and experimental, in such an authoritative manner.

Fermi died at the tragically young age of fifty three, on November 29, 1954. In Wigner's words again:

'The same simplicity and realism, which was manifest in Fermi's scientific work, manifested itself also in his human relations. Although he never engaged in subtle analyses of personalities, he knew what he could expect of his friends and colleagues and he seldom went wrong in his estimates. On a heroic scale was his

acceptance of death. … He was so completely composed that it appeared superhuman.'

Of very few can it be said that '20th century physics would have been only a shadow of what it became', in their absence. Enrico Fermi was certainly one of them.

Suggested Reading

[1] **Laura Fermi, *Atoms in the Family – My Life with Enrico Fermi*, University of Chicago Press, 1961.**

[2] **Carlo Bernardini and Luisa Bonolis, (Eds), *Enrico Fermi – His Work and Legacy*, Springer, 2004.**

[3] **E Fermi, Quantum Theory of Radiation, *Reviews of Modern Physics*, Vol.4, pp.87–132, 1932.**

[4] **E Fermi, *Thermodynamics*, Dover Publications, 1956.**

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"As soon as Fermi read Pauli's article on the exclusion principle, he realized that he possessed all the elements for a theory of an ideal gas that could satisfy Nernst's principle at absolute zero and give the correct Sackur–Tetrode formulae for the absolute value of the entropy in the low density and high temperature limit."

– Franco Rasetti

"Fermi did not take a direct interest in those applications of his theory, on which generations of physicists will work, but turned instead to what was in that moment the new frontier of theoretical physics: quantum electrodynamics, with all its problems linked to the emission and absorption of photons, and he wrote a series of magistral works, widely admired for their extreme clarity."

– G Parisi

"The language of fields allowed the description of phenomena in which particles are created or destroyed, but Fermi's work on beta radioactivity is the first in which this possibility was used outside the photon theory."

– N Cabibbo