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Enrico Fermi

The Obedient Genius

Translated by Ugo Bruzzo

GIUSEPPE BRUZZANITI

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Giuseppe Bruzzaniti

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The Obedient Genius

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Giuseppe Bruzzaniti
Genova, Italy

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To my parents

Preface to the English Edition

I am honored that Birkhäuser is publishing my scientific biography of Enrico Fermi in English, eight years after the original Italian edition was released. The opinions I expressed eight years ago have no changed; should I write Fermi's biography now, I would write it exactly the same way.

I would like to thank Birkhäuser, in particular Chris Tominich, and Einaudi, the publisher of the Italian edition. A special thank you also goes to Allen Mann, who made this project possible.

It is difficult to find the right words for thanking Ugo Bruzzo, who not only performed this translation but also carried out an accurate scientific revision. (I, however, still bear responsibility fo any potential inaccuracies that remain).

I would also like to once again thank those who made the original project possible in various way in particular Claudio Bartocci, whose support was invaluable.

And finally, thank you, Orietta.

Giuseppe Bruzzani
Genova, Ita

Preface

Enrico Fermi was born in Rome in 1901; his scientific production started in 1921 and ended in 1954 with his death. At the beginning of his activity, only two fundamental forces of nature were known, gravitation and electromagnetism, and only two elementary particles, the hydrogen nuclei (protons) and electrons. In the mid 1950s, the fundamental forces, with the addition of the strong and weak nuclear interactions, were four, and over thirty elementary particles were known. In little less than thirty years, the conception of matter underwent such a radical and unprecedented change to make perhaps that period, for the amount and rapidity of the acquisition of new notions, a unique one in the history of the Western scientific thought.

Fermi’s research deeply marked those thirty years, not only for the number and importance of his results but mostly for their historical role. It may happen indeed that enormously important scientific achievements are the result of long and tenacious researches and are the culmination of a carefully planned project. There are also discoveries that are perhaps less extraordinary, but lead to unexpected reorganizations of the acquired knowledge, dismantle the standard methodological principles and the commonly accepted notions, and point to new, unforeseen directions for the scientific enterprise. In his scientific itinerary, which we are going to revisit together, Fermi succeeded in both objectives.

The documents about Fermi’s research depict a composite array of diverse scientific interests, crossing many areas of physics, both experimental and theoretical. However, Fermi’s scientific biography is not just an ordered collection of documents. The specific result, the scientific paper, is not an inert object, well defined and limited by the objectives declared in the introduction and the results described in the conclusion. We must enter the document, clarify its structure, and section it t highlight its diverse causal connections with other documents, which not only delineate a more articulate research itinerary, but also anchor it to its scientific context.

However, this work of establishing the causal connections underlying a scientist’s research itinerary raises subtle interpretative questions. The links indeed are not always explicit, and to unveil them one needs to examine other sources, such as personal reminiscences, letters, popular and review papers, and also completely external elements, such as the political and cultural events that took plac in the relevant historical period. Sometimes one does not find direct connections to other documents, but rather links with elements that belong to what we could call the “global maps,” that is, those networks of connections among the various elements of a certain discipline which the scientific community regards as well established.

The global maps, like the scientific itineraries, are deeply conditioned by some general regulating principles. Let us considerer, for instance, the postulate that the duration of a time interval does not depend on the reference frame where it is measured, which was at the basis of mechanics till the birth of the theory of relativity, or the idea that the elementary particles, such as the electrons, cannot be created or destroyed, which underlay all research on the nuclear structure until the early 1930s.

So, by means of “research itineraries” and “global maps,” we shall analyze how Fermi was able t establish a number of concepts that turned out to be fundamental for the elementary particle physics. The structure of this text will reflect this twofold path. The first chapter has a biographical nature, while the second and fourth are devoted to the description of the global maps of nuclear physics before and after 1933, a date which is a kind of divide; Fermi’s 1933 theory on β -decay decreed indeed the end of what we call the “nuclear protophysics” and opened the way to the construction of what still nowadays is called “nuclear physics.” The third and fifth chapters are devoted to Fermi’s research itineraries during those two periods.

I would like to end this brief introduction with a caveat. The book contains several notes and references to the appendixes, which have a didactic nature; they aim to help the reader to understand the ~~content of the theories that we are describing. This book indeed is also addressed to those~~ who, while not being specialists, are interested in Fermi's figure and want to understand his work in some detail.

Finally, I want to conclude by thanking three persons; without their unconditional personal and scientific help, this book would have not been written. I want to thank them in the simplest way, just with their names, in alphabetical order: thank you Claudio, thank you Ori, thank you Ugo.

Note on the sources

Fermi's works have been published in two volumes: E. Fermi, *Note e memorie (Collected papers)* Accademia Nazionale dei Lincei — The University of Chicago Press, Rome and Chicago 1962. The two volumes are here referred to as *CPF I* and *CPF II*.

The papers cited as "E. Fermi [number]" refer to the list of Fermi's works at pages 319–331.

Giuseppe Bruzzani

Genova, Ita

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1. The last Galilean

Giuseppe Bruzzaniti[1]

(1) Genova, Italy

Galileo’s investigation of nature, based on a deep interplay between “sensible experiences” and “certain proofs,” has been a foundational passage in the history of modern science. The empirical an the rational aspects of the scientific investigation correspond to two different figures of researchers: the experimentalist and the theorist. Enrico Fermi belonged to the last generation of scientists in which the two attitudes could coexist. Nowadays, the higher mathematics needed in theoretical research and the more and more sophisticated instrumentation used in experiments require an extrem specialization and cannot be mastered by the same person.

In this chapter we go through the main events of Fermi’s life, trying to reconstruct his human profile and profound intellect, abstract and concrete at the same time.

1.1 Elementorum physicae mathematicae

Alberto Fermi, a railway clerk, and Ida de Gattis, a primary school teacher, were 44 and 30 years old, respectively, when, 3 years after their marriage, Enrico Fermi was born. He was the third and las of their offspring; Maria was born in 1899, and Giulio in 1900. There was a deep tie between Enrico, reserved boy of few words, and Giulio, extroverted and loving. They shared from their childhood inclinations and readings that already foretold the future prevailing interests in the scientist’s life. Enrico and Giulio built an electric pile, some toys, and some small electrical engines; at age 10 — as told by Emilio Segrè, his friend and collaborator — Enrico tried to understand the meaning of the sentence “the equation $x^2 + y^2 = r^2$ represents a circle.”[1]

Also young Enrico’s readings reveal his interests and what he later chose to study. “Elementorum physicae mathematicae” is the title of a treatise on mathematical physics, written in Latin in 1840 by the Jesuit Andrea Caraffa. Fermi bought it when he was about 14 years old from a second-hand bookstall in Campo de’ Fiori in Rome, a place he liked to haunt, and studied it carefully, as testified by the many annotations in the margins of the book.

In 1915, Enrico Fermi’s life was deeply affected by the loss of his brother Giulio, who died after the anesthesia for a trivial operation to remove a throat abscess. Enrico’s mother, as reported by his wife Laura,[2] never recovered from the loss; her character changed, and she had recurrent depressive crises that heavily affected the family’s life. Enrico’s unexpressed grief, his dismay, and sudden loneliness increased his already strong attitude to studying, and were somewhat relieved by a new friendship with Enrico Persico, a schoolmate of Giulio’s. This friendship was destined to be a lifelon one.[3]

It was evident already from his early teenage years that Fermi had strong scientific interests, and these were further enhanced by his acquaintance with Adolfo Amidei,[4] his father’s friend and colleague. A letter sent by Amidei to Segrè in 1958[5] is very useful to draw a picture of young Enrico scientific education between 13 and 17 years of age. We learn that when he was 13 years old, Enrico had read and studied a treatise on projective geometry,[6] and Joseph A. Serret's trigonometry treatise; at 14, Ernesto Cesaro's "Corso di analisi algebrica con introduzione al calcolo infinitesimale" [A course on algebraic analysis with an introduction to infinitesimal calculus] and Luigi Bianchi's notes for his courses on analytic geometry at the University of Pisa; at 15, Dini's "Lezioni di calcolo infinitesimale e integrale" [Lectures on infinitesimal and integral calculus] (again, notes for a course at the University of Pisa); at 16, Siméon D. Poisson's "Traité de mécanique" [A treatise on mechanics], and at 17, Hermann Grassmann's geometric calculus, preceded by Giuseppe Peano's operations for deductive logic.

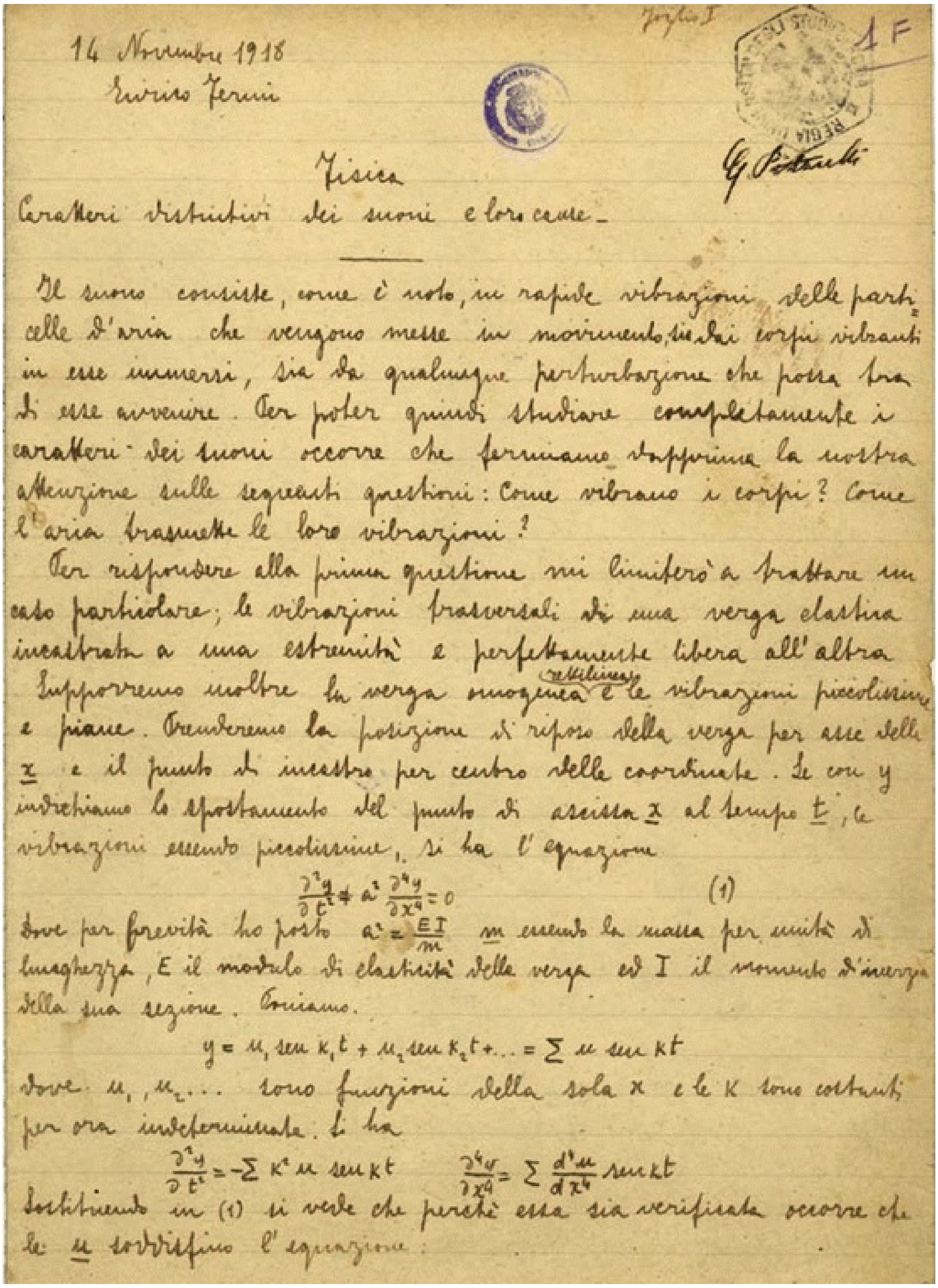
But these books that Amidei gave to Fermi were not enough. From a postcard he sent to Persico o 7 September 1917, we learn that to prepare his admission exam to the Scuola Normale di Pisa (following Amidei's suggestion), Fermi also studied Chwolson's physics treatise[8] and other books.

Young Enrico, however, had more extended interests than just theoretical studies. He shared with Persico his enthusiasm and dedication to mathematics and physics; when he was between 14 and 17 years old they performed several experiments. They measured the value of the gravitational acceleration and of the terrestrial magnetic field in Rome, and the density of the water from Acqua Marcia.[9]

On entering his 18th year of life, Fermi was a true prodigy; he had a deep mathematical and physical education, great experimental skills, and most of all, a huge fascination for knowledge.

1.2 No man's land and the international milieu

"Distinctive features of sound and its causes" was the title of the dissertation Enrico Fermi was required to write to gain admission to Pisa's Scuola Normale (Figs. 1.1 and 1.2). What he produced i not the output of a brilliant high school student, but rather the work of somebody in possession of advanced notions in mathematics and physics. He started with a study of the partial differential equation governing the motion of a vibrating rod, which he solved using a Fourier series expansion. Even the members of the examining board were incredulous at the extent of Fermi's skills. One of them, Giulio Pittarelli, professor of descriptive geometry at the University of Rome, met Fermi personally, and at the moment of parting, he told him that "in his long career he had never seen anything like this, that Fermi was a most extraordinary person and was destined to become an important scientist."[10]



Foglio I

1 F

14 Novembre 1918
Enrico Fermi

G. Pittarelli

Fisica

Caratteri distintivi dei suoni e loro cause –

Il suono consiste, come è noto, in rapide vibrazioni delle particelle d'aria che vengono messe in movimento sia dai corpi vibranti in esse immersi, sia da qualunque perturbazione che possa tra di esse avvenire. Per poter quindi studiare completamente i caratteri dei suoni occorre che fermiamo dapprima la nostra attenzione sulle seguenti questioni: Come vibrano i corpi? Come l'aria trasmette le loro vibrazioni?

Per rispondere alla prima questione mi limiterò a trattare un caso particolare; le vibrazioni trasversali di una verga elastica incastrata a una estremità e perfettamente libera all'altra.

Supporremo inoltre la verga omogenea rettilinea e le vibrazioni piccolissime e piane. Prenderemo la posizione di riposo della verga per asse delle <u>x</u> e il punto di incastro per centro delle coordinate. Se con y indichiamo lo spostamento del punto di ascissa <u>x</u> al tempo <u>t</u>, le vibrazioni essendo piccolissime, si ha l'equazione

$$\frac{\partial^2 y}{\partial t^2} + a^2 \frac{\partial^4 y}{\partial x^4} = 0 \qquad (1)$$

dove per brevità ho posto $a^2 = \frac{EI}{m}$ <u>m</u> essendo la massa per unità di lunghezza, E il modulo di elasticità della verga ed I il momento d'inerzia della sua sezione. Poniamo.

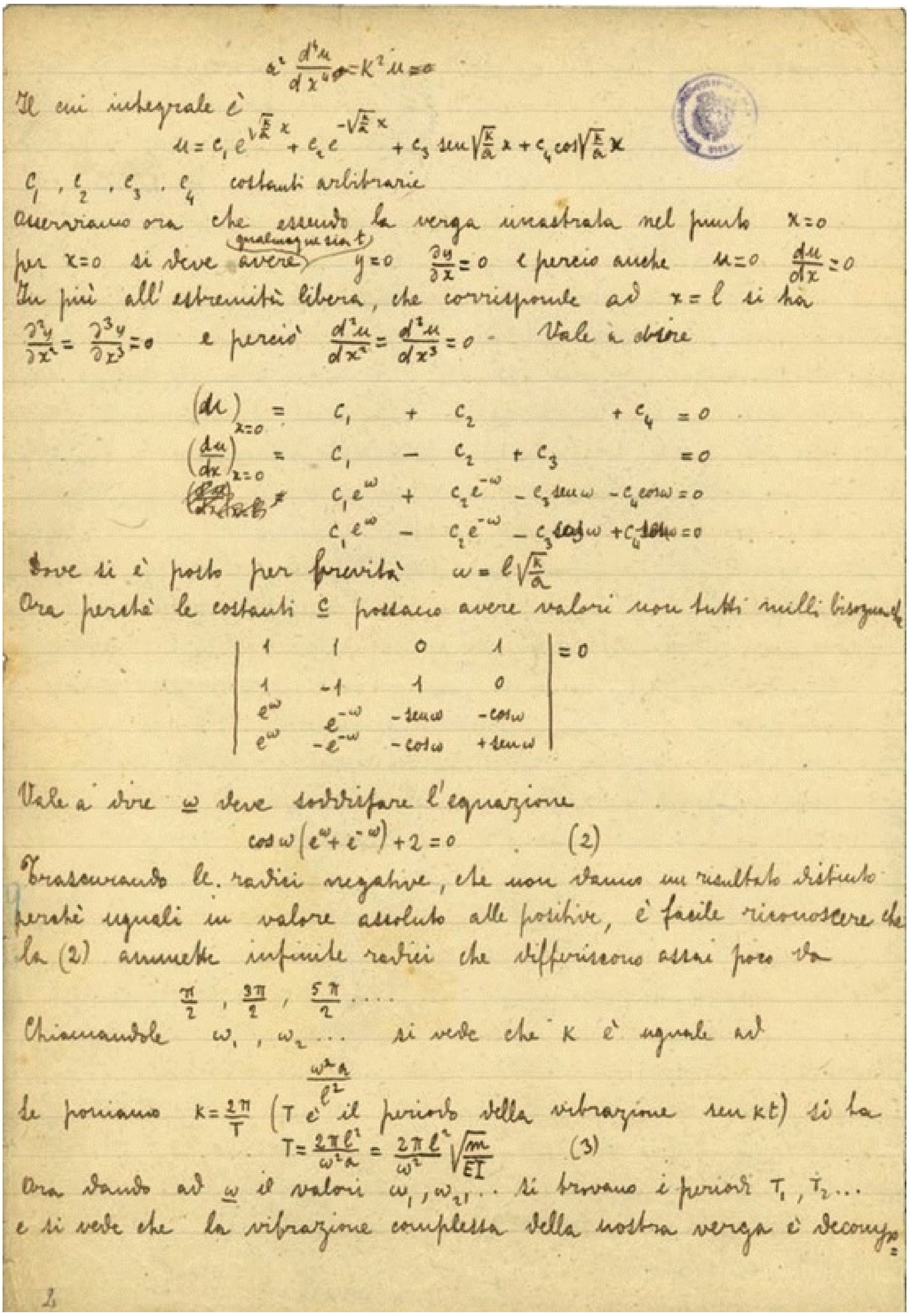
$$y = u_1 \operatorname{sen} k_1 t + u_2 \operatorname{sen} k_2 t + \ldots = \sum u \operatorname{sen} kt$$

dove $u_1, u_2 \ldots$ sono funzioni della sola x e le k sono costanti per ora indeterminate. Si ha

$$\frac{\partial^2 y}{\partial t^2} = -\sum k^2 u \operatorname{sen} kt \qquad \frac{\partial^4 y}{\partial x^4} = \sum \frac{d^4 u}{d x^4} \operatorname{sen} kt$$

Sostituendo in (1) si vede che perchè essa sia verificata occorre che le <u>u</u> soddisfino l'equazione:

Fig. 1.1 First page of Fermi's written exam to enter Scuola Normale Superiore



$$a^2\frac{d^4u}{dx^4} - K^2u = 0$$

Il cui integrale è

$$u = c_1 e^{\sqrt{\frac{k}{a}}x} + c_2 e^{-\sqrt{\frac{k}{a}}x} + c_3\,\mathrm{sen}\sqrt{\frac{k}{a}}\,x + c_4\cos\sqrt{\frac{k}{a}}\,x$$

c_1, c_2, c_3, c_4 costanti arbitrarie

Osserviamo ora che essendo la verga incastrata nel punto $x=0$ per $x=0$ si deve avere (qualunque sia t) $y=0$ $\frac{\partial y}{\partial x}=0$ e perciò anche $u=0$ $\frac{du}{dx}=0$

In più all'estremità libera, che corrisponde ad $x=l$ si ha $\frac{\partial^2 y}{\partial x^2}=\frac{\partial^3 y}{\partial x^3}=0$ e perciò $\frac{d^2u}{dx^2}=\frac{d^3u}{dx^3}=0$. Vale a dire

$$\begin{aligned}(u)_{x=0} &= c_1 + c_2 + c_4 = 0\\ \left(\frac{du}{dx}\right)_{x=0} &= c_1 - c_2 + c_3 = 0\\ &\ c_1e^{\omega} + c_2e^{-\omega} - c_3\,\mathrm{sen}\,\omega - c_4\cos\omega = 0\\ &\ c_1e^{\omega} - c_2e^{-\omega} - c_3\cos\omega + c_4\,\mathrm{sen}\,\omega = 0\end{aligned}$$

dove si è posto per brevità $\omega = l\sqrt{\frac{k}{a}}$

Ora perchè le costanti c possano avere valori non tutti nulli bisogna

$$\begin{vmatrix}1 & 1 & 0 & 1\\ 1 & -1 & 1 & 0\\ e^{\omega} & e^{-\omega} & -\mathrm{sen}\,\omega & -\cos\omega\\ e^{\omega} & -e^{-\omega} & -\cos\omega & +\mathrm{sen}\,\omega\end{vmatrix} = 0$$

Vale a dire ω deve soddisfare l'equazione

$$\cos\omega\left(e^{\omega}+e^{-\omega}\right)+2=0 \qquad (2)$$

Trascurando le radici negative, che non danno un risultato distinto perchè uguali in valore assoluto alle positive, è facile riconoscere che la (2) ammette infinite radici che differiscono assai poco da

$$\frac{\pi}{2},\ \frac{3\pi}{2},\ \frac{5\pi}{2}\ \ldots$$

Chiamandole $\omega_1, \omega_2 \ldots$ si vede che k è uguale ad $\frac{\omega^2 a}{l^2}$

se poniamo $k=\frac{2\pi}{T}$ (T è il periodo della vibrazione sen kt) si ha

$$T=\frac{2\pi l^2}{\omega^2 a}=\frac{2\pi l^2}{\omega^2}\sqrt{\frac{m}{EI}} \qquad (3)$$

Ora dando ad ω il valori $\omega_1, \omega_2, \ldots$ si trovano i periodi $T_1, T_2 \ldots$ e si vede che la vibrazione complessa della nostra verga è decomp

2

Fig. 1.2 Second page of Fermi's written exam to enter Scuola Normale Superiore

Enrico Fermi gained his admission to Scuola Normale, and in the fall of 1918 he enrolled at the University of Pisa. At first he chose Mathematics, but shortly afterwards he switched to Physics.

The years he spent in Pisa were very important for Fermi. He started a long and strong friendship with Franco Rasetti,[11] another physics student. During those years, he received many accolades, not only for his skills, but also for the enthusiasm and dedication he showed in deepening his (already remarkable) training in mathematics and physics. From his correspondence with Persico and from hi notes, meticulously written in a small booklet that was found in Chicago, we know that in those year he read several treatises: Poincaré's "Théorie des tourbillons" and "Leçons de mécanique celeste," Appell's "Traité de mécanique rationnelle," Planck's "Vorlesungen über Thermodynamik," and

Richardson's "Electron Theory of Matter." He also studied — but it is impossible to ascertain the ~~sources — Hamilton-Jacobi theory, Boltzmann's H theorem, Planck's black body radiation theory~~, and relativity theory. The booklet contains also a large collection of data about radioactive substance taken from Rutherford's "Radioactive Substances and their Radiations" and two large reference lists from a book by Townsend on the electrical properties of gases. The last notes in the booklet, which has 102 pages in total, are dated 29 September 1919. All this shows the extent of Fermi's scientific education when he was just 18 years old. The tight interplay between theoretical and experimental work that will become the trademark of Fermi's approach to research clearly emerged during those years in Pisa: on one hand, he was the most authoritative member of the Physics Institute for what concerns relativity theory and the quanta, while on the other hand, together with Rasetti and Nello Carrara, another fellow student at Scuola Normale, he did experimental work on X-rays, and designe and built discharge tubes that were better suited to that purpose. They worked in the laboratory of the Physics Institute, made available to the three students by the director Luigi Puccianti, who recognize Fermi's extraordinary talent and often asked him to explain the new theories that were emerging during those years.

As Fermi writes to Persico, "In the physics department I am slowly becoming the most influentia authority. In fact, one of these days I shall hold (in the presence of several magnates) a lecture on quantum theory, of which I'm always a great propagandist."[12] The new quantum theory and the theor of relativity were the two main theoretical issues that captivated the young scientist's interest. These ideas, which were not yet enjoying in Italy the attention they deserved, overturned many of the most rooted convictions in the physics of the early 20th century. The picture of nature they produced had some counterintuitive aspects that were founded on rather abstract argumentations, which were in tur based on complicated theoretical constructions. According to Rasetti, in Italy the new theories were " no man's land between physics and mathematics" and "Fermi was the first in the country to fill the gap."[13]

Fermi's scientific production started with relativity theory. In 1921, one year before he graduate the journal *Nuovo Cimento* published two papers on some relativistic issues,[14] and in 1922 the young scientist obtained his first remarkable result; he proved a theorem using a coordinate system that stil bears his name today.[15]

On the experimental side, he was busy with research on X-rays: the X-ray diffraction by curved crystals and the production of images with that method was the topic chosen by Fermi for his thesis. For Fermi, theoretical research and experimental work were not two unrelated skills or activities, as exemplified by what he wrote to Persico in 1920: "I have almost abandoned the idea to write my thes on the photoelectric effect in gases. I might instead study the interesting phenomena concerning the diffraction of X-rays by crystals, also because I hope to relate them with statistical physics; I believe indeed that the properties of Röntgen rays should be markedly different from what is predicted by th usual wave theory."[16] This standpoint, already present when Fermi was 19 years old, will characteriz his intellectual setting and attitude to research throughout his whole life, his "Galilean" approach: experience and theory are part of a close dialectic process that determines which scientific problems are interesting and deserve to be studied. Fermi defended his thesis on 7 July 1922, obtaining the highest grade (110/110 cum laude). After three days he also took the habilitation exam at the Scuola Normale, obtaining again the highest grade (50/50 cum laude).[17]

Orso Mario Corbino, senator, professor of experimental physics, authoritative researcher in the field of magneto-optics, and director of the Physical Institute of the University of Rome, was greatly influential in Fermi's life. The two scientists met at Fermi's initiative, when he returns to Rome afte finishing his university studies in Pisa. Corbino immediately realized that Fermi showed great promise for Italian physics, and since that moment he always used his prestige and influence to ~~support his research. On 30 October 1922 a committee made of two physicists, including Corbino~~, a chemist, and two mathematicians, awarded Enrico Fermi a grant for a visit abroad, writing a very appreciative report.[18] Fermi chose to go to Max Born's institute in Göttingen. He started his stay ther in the winter of 1923.

During his days in Göttingen, Fermi got in touch with some of the main scientists working on the development of the emerging theory of quantum mechanics. In addition to Max Born, he got acquainted with Werner Heisenberg and Pascual Jordan. His stay in Germany did not turn out to be s fruitful as it could have been,[19] but still allowed him to publish three important papers that drew the attention of another great physicist, Paul Ehrenfest,[20] who sent Fermi a letter via his student George Uhlenbeck. The acquaintance with the latter and the interaction with Ehrenfest were the reasons why Fermi decided to use a grant from the Rockefeller Foundation to visit Ehrenfest's institute in Leiden. Fermi obtained the grant thanks to Vito Volterra, a prominent mathematical analyst and a precursor o modern functional analysis.

Fermi left for Leiden on September 1st, 1924, after devoting the summer to studying the scatterin between atoms and charged particles, obtaining some important results. He spent three months in Leiden, and contrary to what had happened in Göttingen, his stay was very fruitful, not only because of the scientific results he obtained, but especially for the stimulating and encouraging environment he found there. In addition to Ehrenfest, he got acquainted with several distinguished physicists, such as Hendrick Lorentz and Albert Einstein, and got in touch with some young researchers, for instance, Samuel A. Goudsmit and Ralph de Laer Kronig, who were to gain soon great prominence.[21] He established with Goudsmit and Kronig a friendship which lasted for his whole life.

Returning to Rome, Fermi faced the problem of finding a permanent job. The high regard he enjoyed in the more broad-minded scientific circles, and the interest of Antonio Garbasso, the directo of the Physics Institute in Florence, allowed him to be charged with teaching a course in mathematica physics at the University of Florence, where he reunited with Franco Rasetti, then Garbasso's assistant.

During his stay in Florence, Fermi initiated several lines of research, both experimental and theoretical. The collaboration with Rasetti, an outstanding experimentalist, was very fruitful. In a short note in the journal *Nature*, [22] published in April 1925, they announced the launch of a research program aimed to study the effects of an alternating magnetic field on the polarization of the resonance light of mercury vapors. Here again, it is enough to read the introduction to a subsequent paper[23] to understand how the "Galilean method" underpinned Fermi's approach to research:

> We intend in this work to study the effect of a high-frequency alternating magnetic field on the polarization of resonance light; in the present note we treat the theory of the phenomenon, in a following one we shall report on some experiences that have confirmed the expected results.[24]

Not just a series of experiments for measuring an effect, but a close interplay between theory and experiment, with the purpose of building up a theoretical model able to explain a given physical phenomenon. This perfect symmetry and reciprocal necessity between theory and experiment is also witnessed by Fermi's standpoint with respect to Heisenberg's matrix formulation of quantum mechanics;[25] he judges it too abstract to allow for a real understanding of the physical phenomena.[26] In other words, mathematics was for Fermi always functional to the knowledge of the physical realit while the empirical data are only meaningful within a suitable theoretical framework.[27]

In his time in Florence, Fermi, together with the experimental work with Rasetti, tackled a problem whose solution is one of his most important contributions to physics: the Fermi-Dirac statistics. ~~The year 1925 was also full of events concerning the academic world. In March he obtaine~~ his “libera docenza,”[28] and applied to a professor position in Mathematical Physics at the University of Cagliari. The examining board, with a 3-to-2 vote, granted the position to Giovanni Giorgi.[29] The failure of that application embittered Enrico Fermi, who was just 24 years old, but was in a sense providential, since it was probably what convinced Orso Mario Corbino (who commented on the outcome of the opening in Cagliari by saying “the prevailing criterion has been the length of the beard”) to push, supported by the great mathematicians Guido Castelnuovo, Federigo Enriques, and Tullio Levi-Civita, for the official recognition of theoretical physics as an academic discipline, with the creation of a dedicated chair.

1.3 Via Panisperna

> The committee, having examined Professor Fermi’s large and complex scientific work, unanimously recognizes its exceptional level, and believes that, in spite of his young age and after very few years of scientific work, he highly honors Italian physics. He fully masters the subtlest mathematical techniques, but uses them in a sober and pragmatic way, without losing sight of the physical problem, of the interplay among the physical quantities that are involved, and their concrete value. The most delicate concepts of classical mechanics and mathematical physics are familiar to him; he moves with complete assurance in the most difficult questions of modern theoretical physics, so that he is the most qualified person for representing our Country in this field of research, which is internationally the object of an increasingly intense activity. This committee therefore unanimously declares that Prof. Fermi fully deserves to fill this chair in theoretical physics, and believes that he gives the best hopes for the future development of theoretical physics in Italy.[30]

This is the final report of the board formed by Michele Cantone, Orso Mario Corbino, Antonio Garbasso, Gian Antonio Maggi, and Quirino Majorana, that on 7 November 1926 assigned to Enrico Fermi the professorship in theoretical physics that had been opened at the University of Rome. According to the rules of the time, the board selected three winners, ranked according to their merits In this case the second and third rank were given to Enrico Persico and Aldo Pontremoli,[31] who were then hired by the University of Florence and Milan, respectively.

Fermi’s arrival in Rome was for Corbino the first step toward the realization of a plan that he ha prepared with Fermi himself: to create, in Italy and in particular in Rome, a school of physics of international standing and up-to-date with the modern developments. To that end, Corbino called Franco Rasetti from Florence to be Fermi’s assistant. Also Enrico Persico maintained a close collaboration with the Roman group and aimed at joining it as soon as possible. Rome and Florence became thus the radiating centers of the new physics in Italy.

University of Roma’s Physics Institute was located at Via Panisperna 89a, and was reasonably equipped for researches in spectroscopy. Rasetti and Fermi resumed their collaboration and did some experimental work to verify the Boltzmann distribution for thallium atoms between the ground state and the first excited state. The results were published in 1927.[32]

On September 11 to 29, 1927, the hundredth anniversary of Alessandro Volta’s death was commemorated in Como with an important international conference. Rasetti wrote:

> The entire Gotha of the world’s physics was there, including a dozen Nobel laureates, and the

> great fathers of quantum physics: Bohr, Planck, Compton, Laue, Sommerfeld, Heisenberg and ~~Pauli. Sommerfeld, the prestigious leader of the Munich school, presented some results in which~~ he and his collaborators showed that all the strange phenomena concerning electrons in metals, that had no classical explanation, were easily interpreted in terms of Fermi’s new statistics. It was a great triumph for him, and many Italian professors were very much surprised that young Fermi, hardly known in Italy, was already so famous in Germany.[33]

The Como conference was also attended by Emilio Segrè, an engineering student in Rome and a friend of Rasetti’s. He was fascinated by the scientific environment, and decided to turn his love for physics (to which he had not indulged as at the time the best students were directed to engineering) into his profession. In the fall of that same year, he switched to the Physics school. Two more studen followed his example: Ettore Majorana[34] and Edoardo Amaldi. This was the start of the “Via Panisperna boys,” the first students of Enrico Fermi’s.

Fermi’s “Galilean dominant” emerged also in his relation with the students. As Segrè wrote: “We mainly received a theoretical instruction, and Fermi made no distinction between future theoreticians or experimentalists. There were no exercises of experimental physics. All experimental problems we research, more or less easy and more or less original.”[35]

Parallel to the experimental work with Rasetti, his administrative duties, his activity as popularizer,[36] and the education of the students who had switched to physics,[37] Fermi continued his research in theoretical physics; unquestionably, the best result he got during these early Roman years was the application of his statistics to atomic electrons.[38] In his atomic model the electrons behave like a gas that surrounds the nucleus. The statistical treatment of atomic electrons, that was independently developed also by Thomas, and is nowadays known as the Thomas-Fermi method, was in those years central to Fermi’s theoretical work: he applied it to many cases, obtaining important information about a number of atomic properties and on the structure of the periodic system of the elements.

These years were also full of events in Fermi’s personal life. In 1928 he married Laura Capon and in 1929 he was appointed to the Royal Italian Academy. [39] This strongly improved his economic situation and allowed him to resign from other jobs, for instance, that of editor for *Enciclopedia Italiana*, that Fermi had accepted to improve his finances.

The international prestige enjoyed by the Roman group, and in particular by Enrico Fermi, can be seen in the many exchanges and study visits: Rasetti, funded by the Rockefeller Foundation, worked Millikan’s laboratory at the California Institute of Technology in Pasadena, where he performed experiments on the Raman effect; Segrè visited Zeeman’s laboratory in Amsterdam; Amaldi studied the diffraction of X-rays in liquids with Debye in Leipzig. Most travels were to attend conferences: in June 1928 Fermi was in Leipzig, in April 1929 in Paris and Zurich, in 1930 in Bucharest, and again in 1930, during the summer holidays, he was invited for the first time to America at the University of Michigan in Ann Arbor. At the same time, many foreign physics were hosted in Rome: Hans Bethe, Felix Bloch, Sam Goudsmit, Christian Møller, Rudolf Peierls, George Placzek, Edward Teller, and many more.

The purpose of these visits abroad was to improve the technical skills of the “Via Panisperna boys.” The young researchers also understood that the main area of their experimental work, spectroscopy and atomic physics, was losing momentum, and was no longer at the core of the experimental research in physics. Fermi’s theoretical work also confirmed this fact. His activity during that period concerned the most advanced developments of the new quantum mechanics. In 1930 he was invited to participate in a summer school in theoretical physics in the United States. He gave a memorable course, whose topic was the quantum theory of radiation. The lectures notes were ~~published in the journal *Review of Modern Physics* and became a standard reference in those years.~~[40]

So in 1930 there was marked contrast between the theoretical and experimental work of the Roma group: the first was very advanced, especially thanks to Fermi's research, while the activity in the second was hardly innovative. Fermi and his group knew the reason very well: experimental spectroscopy, and more general atomic physics, had by that time a well-defined theoretical status, an were not likely to give rise to new fundamental discoveries. This viewpoint was well summarized by Corbino in a speech delivered on 21 September 1929:

> One can therefore conclude that, while a great progress of experimental physics in its usual domain is quite unlikely, the assault of the atomic nucleus may offer many possibilities; this is the real field of tomorrow's physics. But to take part in the general movement, both nowadays and in the future, it is mandatory that our experimenters have a direct and certain access to the most recent results in theoretical physics, and that they can take advantage more and more liberally of the modern tools of investigation. To work in experimental physics without being daily informed of the progress in theoretical physics and without well equipped laboratories is like pretending to win a modern war without air force and artillery.[41]

Around 1930 Fermi and his group decided to become acquainted with the most sophisticated experimental techniques of the new nuclear physics, and to start a new line of research, which in a fe years was to give rise to extraordinary discoveries. The first steps in the realization of this project were two: visits of some young researchers of the Roman group to some of the most advanced foreig laboratories, and the organization in Rome of the first international conference on nuclear physics. S Rasetti left for Lisa Meitner's laboratory at the Kaiser-Wilhelm-Institut in Berlin-Dahlem, and Segrè for Otto Stern's laboratory in Hamburg.[42] Also the group's readings changed course. Edoardo Amald started systematically reading the newly published book by Rutherford, Ellis, and Chadwick,[43] which became the standard text for nuclear physics in those years.

The 1931 conference in Rome was a very important event and can be considered as the birth of nuclear physics as an officially recognized discipline. The conference took place on 11 to 18 October and hosted about 50 internationally renowned physicists, including Bohr, Compton, Curie, Millikan, Pauli, and many others. The agenda included the most urgent questions concerning the understanding of the nuclear structure, and there were opportunities for ample, usually informal, discussions. Often these produced bold new hypotheses, in the attempt to solve the serious anomalies which at that time hampered any comprehension of the structure of the atomic nucleus.

Many years later, recalling that delicate moment when the entire group reshaped its line of research, Rasetti wrote:

> The change required considerable effort, and was not done by chance or just to follow the fashion. It took place as a result of a conscious and well planned decision that came after a lot of discussion. The first step toward its realization was Rasetti's trip to Dahlem, to learn some techniques in nuclear physics. The 1931 Rome conference helped us to get acquainted with the most interesting current problems, and as a consequence, there was a change of topic of the assiduous readings that took place at the institute."[44]

The first nuclear physics conference preceded by one year the "annus mirabilis," the wonderful year, i.e., 1932, when three great discoveries were made in rapid succession: the neutron, deuterium (the mass 2 hydrogen isotope) , and the positron (the positive electron). In the next chapter we shall examine in some depth these three intricate stories, corresponding to extraordinary discoveries whic quickly changed the landscape of the 20th century physics.

The 7th Solvay conference took place on October 22nd to 28th, 1933, and had nuclear physics as its central theme. The discoveries of the previous year on the one hand threw new light on the structure of the atomic nucleus, but on the other hand generated even more serious problems, due to the lack of a coherent theoretical framework. Fermi knew very well what were the basic questions tha a theory of the atomic nucleus had to answer, and was ready to deal with the challenge offered by the discoveries of the previous year. Coming back from Brussels at the end of the Solvay conference, he solved in a few months one of the most taxing problems of the time, the interpretation of the energy spectrum of the β decay; more than that, he formulated a general theoretical framework for dealing with nuclear phenomena. The first version of the paper was submitted to the journal *Nature*. The pape was rejected as it “contained abstract conjectures that are too far from physical reality to be of some interest to the reader.” Fermi did not give up, as he was conscious of the importance of his work. According to Segrè, “Fermi was fully aware of the importance of his accomplishment and said that h thought he would be remembered for this paper, his best so far.”[45] The paper was sent to *La Ricerca Scientifica;* [46] an ampler and more detailed version was published by the authoritative German journ *Zeitschrift für Physik,* [47] and immediately afterwards by *Il Nuovo Cimento* in Italian.[48]

1.4 The Pope, the Divine Providence, and the slow neutrons

As gold hunters abandon the almost exhausted veins when the news of a fresh deposit spreads, no matter if they need to open their way by brute force, so the Roman group launched into its most important intellectual adventure as soon as they were informed that in France the Joliot-Curies had been able to make some light elements — like aluminum — radioactive by irradiating them with α particles emitted by polonium.

Until then radioactivity was supposed to be a specific property of some heavy elements, such as uranium, thorium, actinium, radium, and polonium, and a property that cannot be modified, exactly a it is not possible to change the periods of revolution of the planets around the sun. The work of the tw French scientists showed that an element which is usually stable, like aluminum, can become radioactive; a kind of microscopic equivalent to a change in the orbit of Jupiter.

The radioactivity obtained by the Joliot-Curies was very weak, and took place only in a few light elements. Fermi was the first to understand that this effect can be substantially amplified by using neutrons instead of α particles. Neutrons have no electric charge and therefore can penetrate the atomic nucleus without being repelled. In March 1934 he suggested Rasetti to try to irradiate some substances with neutrons produced by polonium and beryllium sources. These experiments did not succeed. Rasetti left for a short holiday in Morocco, but Fermi continued the experiment; he changed the sources, that were probably too weak, replacing polonium with radon, which makes for a much stronger source. He analyzed systematically all elements in the periodic system, starting with hydrogen. He detected some effects with aluminum and fluorine. The results were published in the paper “Radioattività indotta da bombardamento di neutroni I,”[49] submitted to *La Ricerca Scientifica* on 25 March 1934.[50]

“The Pope” was right. This was Fermi’s nickname in the Roman group, in view of his infallibilit By analogy, Rasetti was the “Cardinal Vicar”[51] or the “Venerable Master”; Professor Giulio Cesare Trabacchi, a chemist and director of the Physical Institute for Public Health, was the “Divine Providence,” as he was in possession of a gram of radium, to be used for medical purposes. Indeed providentially, he was able to supply the radon necessary for the experiment. The “Cardinal de propaganda fide"[52] was Enrico Persico, who had moved from Florence to Torino, and turned the latte into a propagating center of the new physics. The "Abbots" were the young scientists in the group, Edoardo Amaldi and Emilio Segrè. Ettore Majorana had two nicknames, to be used according to necessity, "the Holy Ghost," or "the Great Inquisitor." Corbino was "God Almighty," of course.

The discovery of neutron-induced radioactivity triggered a period of intense activity in the Roma group. As Edoardo Amaldi remembers,

> A feverish activity started immediately at the Physics Institute of the University of Rome. The experimentation was organized on a large scale, so to make attempts in many directions and avoid the risk of missing some interesting phenomenon. Fermi not only supervised our work but also took part in all physical measurements and chemical manipulations, also making with his hands chemical glassware and mechanical parts."[53]

In four months of frenzied work the group produced more than 40 radioactive elements, some of an unknown chemical nature. This made the collaboration with a chemist necessary. After professor Trabacchi's suggestion, the group was joined by Oscar D'Agostino, a young employee of the Public Health Institute, who at the moment was working in the Joliot-Curies' laboratory in Paris supported b a grant.

During the systematic analysis of the effect produced by neutrons on all chemical elements, the group also irradiated specimens of thorium and uranium, the last elements in the periodic system, wi atomic numbers 90 and 92, respectively. This experiment had an added complication: the two elements are naturally radioactive, and their emissions interfere with the effects of the neutron bombarding. A series of preliminary operations were needed to get rid of this problem. In the summe of 1934 the group obtained a surprising result: during the irradiation of uranium by neutrons, two nev elements were produced, having atomic weights 93 and 94 — bigger than that of uranium. They were provisionally christened *hesperium* and *ausenium*, a choice which attests the exasperated nationalism prevailing in Italy at that time.[54] Unbeknown to Fermi, Corbino, in a speech held at Accademia dei Lincei in the presence of the King on the occasion of the closing of the academic year, announced: "I think I can safely conclude that a new element [number 93] has been discovered."[55]

Corbino's brag vexed Fermi, who was not sure about the interpretation of the experimental result The triumphal overtones of the Italian press, which celebrated the supposed supremacy of the fascist culture, annoyed Fermi very much; the announcement was too hasty, and the interpretation of the results was uncertain and not well documented enough.

Indeed, the truth was different. Ida Noddack, a German chemist, sent Fermi an extract from a paper of hers, where she speculated that the experiments of the Roman group did not reveal the existence of new transuranic elements, but could be differently interpreted as due to a new nuclear reaction, the fission of the uranium nucleus.[56] Noddack's suggestion however was not taken into consideration, and Fermi missed the opportunity to tie up his name with the discovery of the nuclear fission. This was the only great blunder of his career.

In the late 1934 summer another young physicist, Bruno Pontecorvo, who had just graduated in Rome under Rasetti's supervision, joined the group, and was charged to perform with Amaldi more precise measurements of the neutron-induced radioactivity. The results they got were bewildering. In some cases, the response of the irradiated substances seemed to depend on the surface they lay on; th effects were very different whether the substances were set on a wooden table or a marble slab. To understand this odd behavior Fermi undertook a deeper analysis; among other things, he investigated the absorption of neutrons by a lead wedge interposed between the source and the substance to be irradiated.

~~In the morning of October 22 Fermi was alone in the laboratory; the other members of the gr~~oup were busy with exams.[57] The “Pope” was starting the measurements when, on impulse, he decided to replace the lead wedge with a paraffin slab. The results were surprising and unexpected: the instruments recorded a sharp increase of the induced radioactivity with respect to the measurements taken in the absence of the paraffin slab. In the late morning Fermi called his collaborators to witness the strange phenomenon. As Segrè tells:

> At first I thought a counter had gone wrong, because such strong activities had not appeared before, but it was immediately demonstrated that the strong activation resulted from filtering by the paraffin of the radiation that produced the radioactivity.[58]

It was not difficult to check that the increase in the radiation was due to the paraffin: by replacing the latter with some other substances the effect disappeared. Everybody was bewildered, but Fermi maintained his aplomb, and uttered a sentence that became famous: “Let’s go to lunch.”

Again according to Segrè,

> By the time we went home for lunch and our usual siesta, we were still extremely puzzled by our observations. When we came back at about three in the afternoon, Fermi had found the explanation of the strange behavior of filtered neutrons. He hypothesized that neutrons could be slowed down by elastic collisions, and in this way become more effective — an idea that was contrary to our expectation.[59]

The hypothesis that the hydrogen nuclei in the paraffin decrease the speed of the neutrons, so that the nuclei in the target can more easily capture them, was again checked in the afternoon of the same day. A new experiment was performed, using the goldfish pool in the garden of the institute as filter for the neutrons. In the evening of that same day, Fermi, Amaldi, Pontecorvo, Rasetti, and Segrè signed a note for *La Ricerca Scientifica,* announcing their discovery.

It is quite reasonable to wonder what urged Fermi to replace the lead block with paraffin. This question is not easily answered. When the members of the group asked him this same question, Ferm smiled, and mockingly answered, “C.I.F. (Con Intuito Fenomenale, that is, with an extraordinary intuition).”[60] There is however a very important testimony by Subrahmanyan Chandrasekhar, a famous Indian theoretical astrophysicist. After telling him about Hadamard’s hypothesis on the psychology of the mathematical invention,[61] Chandrasekhar asked Fermi if he thought that that hypothesis is reasonable also in physics. Fermi’s answer was:

> I will tell you how I came to make the discovery which I suppose is the most important one I have made. And he continued: We were working very hard on the neutron induced radioactivity and the results we were obtaining made no sense. One day, as I came to the laboratory, it occurred to me that I should examine the effect of placing a piece of lead before the incident neutrons. And instead of my usual custom, I took great pains to have the piece of lead precisely machined. I was clearly dissatisfied with something: I tried every excuse to postpone putting the piece of lead in its place. When finally, with some reluctance, I was going to put it in its place, I said to myself: No! I do not want this piece of lead here; what I want is a piece of paraffin. It was just like that: with no advanced warning, no conscious, prior, reasoning. I immediately took some odd piece of paraffin I could put my hands on and placed it where the piece of lead was to have been.[62]