NATIONAL ACADEMY OF SCIENCES

ENRICO FERMI

1901—1954

A Biographical Memoir by

SAMUEL K. ALLISON

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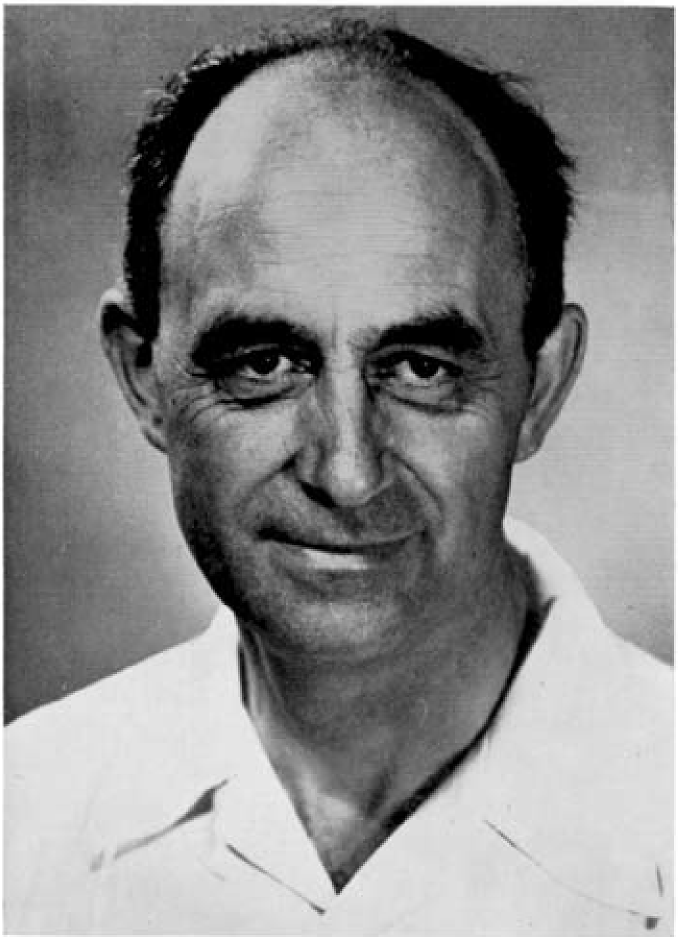

ENRICO FERMI

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ENRICO FERMI, destined to be the first man to achieve the controlled release of nuclear energy, was born in Rome on September 29, 1901. His father, Alberto Fermi, was employed in the administration of the Italian railroads, finally rising to the position of division head. His mother, who had been Ida de Gattis, was a school teacher before her marriage. There were three children, of whom two, Enrico and Maria, who was two years his senior, survived to adulthood.

Fermi's higher education began in November, 1918, when he entered the Reale Scuola Normale of Pisa where, because of his obvious promise, he had obtained a fellowship. He received the degree of Doctor of Physics, *magna cum laude,* from Pisa in 1922, presenting for his thesis some experimental work on X-rays.[1] From the list of his publications we see that during his student days he was already working on problems in relativistic electrodynamics.

Fermi next spent seven months at Göttingen, which was at that time at the pinnacle of its fame in physics. He had been awarded a fellowship from the Italian Ministry of Public Instruction. His principal interest was in studying with Professor Max Born, but the stay at Göttingen was not a happy one. In his later years he

[1] Many years later I teased him by remarking that this work couldn't have been much good, since no reference appears to it in the compilation *X-Rays in Theory and Experiment* which I wrote with Prof. A. H. Compton. Enrico flashed back that this merely demonstrated an inadequacy of that volume.

occasionally spoke with some resentment of this period; according to him the faculty there assumed an attitude of omniscience and it did not occur to them that they might encourage a young man from Italy by listening to what he had to contribute.[2]

During the following academic year (1923-1924), Fermi taught mathematics for chemists and science students in Rome, and attempted, unsuccessfully, to obtain the chair of mathematical physics at the University of Cagliari in Sardinia. During the winter of 1924, he made the acquaintance of George Uhlenbeck, a pupil of Professor Ehrenfest at Leiden. Uhlenbeck was temporarily in Italy as a tutor to the son of the Dutch minister. As a result of this, Fermi spent three months of the fall of 1924 in Leiden, with Professor Ehrenfest and his pupils, including Sam Goudsmit. His stay there was reflected in his publications concerning Ehrenfest's "adiabatic principle," and later, when Uhlenbeck and Goudsmit had emigrated to the United States and settled at Ann Arbor, friendship with these young men may have influenced Fermi in his decision to participate in the University of Michigan summer conferences on Theoretical Physics. This occurred in 1930, and the informality and easy efficiency of life in America made a favorable impression on him. In the period 1930-1937 he often returned for periods of a few months at a time.

During the academic year 1925, Fermi held the position of *incaricato* in Florence, and about this time took initial steps toward the first of his major contributions to physics, in that he thought about the application of Wolfgang Pauli's famous "exclusion principle" to the theory of a perfect monoatomic gas as a quantized mechanical system. He realized that a consequence of the theory might be that no two atoms of such a gas could be in the same quantum state, which would cause a non-classical velocity distribution in the gas,

[2] In a recent letter concerning this, Max Born states that he was actually somewhat in awe of this young stranger with his obvious ability and penetrating comments, and would himself have appreciated a pat on the back from Fermi.

diverging widely from the classical behavior at low temperatures. He published these theoretical results in the *Zeitschrift für Physik* in 1926. Their elaboration by him and by other physicists led to the famous Fermi statistics, to a deeper understanding of the conduction of electricity in metals, and to a widely used statistical atom model.

The year 1926 was an important one for Fermi and for physics in Italy. Senator Orso Mario Corbino, head of the Physics Department in Rome and a minister in Mussolini's cabinet, aspired to revive physics in Italy and particularly at the University of Rome. Corbino was energetic, intelligent, and had political power. He obtained authorization to establish a new chair of Theoretical Physics in Rome, and when Fermi competed for it and won it, supported him enthusiastically in his spectacularly successful attempt to gather together a school of vigorous young physicists. Thus Franco Rasetti, Emilio Segre, Eduardo Amaldi, Bruno Pontecorvo, and Ettore Majorana were among those who, at one time or another, were attached to this group and later became internationally known.

During the years 1926-1932 Fermi and his associates did first-class but conventional theoretical physics, within the pattern laid down by the physicists of northern Europe. These were the concluding years of the theory of atomic structure; with the invention of wave mechanics and the relativistic explanation of the electrons' intrinsic angular momentum, the theory as we know it today was completed, and Fermi helped complete the picture. He applied his degenerate gas theory to the electrons in atomic structure, producing a statistical atomic model, and in 1928 we see him calculating the Rydberg correction to S-terms using this idea.

During the interval 1930-1932 the attention of physicists all over the world began to shift from atoms to nuclei, and several outstanding accomplishments in nuclear physics in 1932 established the field as the one of major interest. Fermi was also attracted, and in 1933 his theory of β-ray emission proved to be one of his major contributions to physics. Although the natural radioactive emission of α, β, and γ-rays had been experimentally demonstrated at the turn of the century, no guide to the possible mechanism of the emission of the corpuscular radiations was available until Gamow and Condon and Gurney achieved a wave-mechanical interpretation of α-emission in 1928. It was Fermi, five years later, who pointed the way to the understanding of β-emission. The attack on the problem was based on the recognition that the neutrino-emission was an essential part of the β-ray process and that the neutrinos were a characteristic corpuscular radiation of the nuclear force field. This treatment of the problem as one similar to the radiation of photons from an electrical system in its change to a configuration of lower energy content was an early example of what is known as an approach through a "field theory." The ideas presented were so novel that Fermi had difficulty in publishing the theory; it was rejected by the editors of *Nature*. It appeared in German and Italian journals, however, and although its details have been greatly elaborated, its essential parts have survived the tests of theory and experiment. It was a major achievement.

The following period 1934-1939 was one in which Fermi took up experimental nuclear physics, and by the irony of fate, it was through these experiments that the brilliant theoretician accomplished the work for which, at least by the public, he will be longest remembered.

Among the many notable developments in nuclear physics in the year 1932 was the identification of the neutron by Chadwick, and in 1934 Joliot announced the discovery of artificially induced radioactivity through the bombardment of aluminum by fast alpha particles. Fermi decided to try to produce artificial radioactivity through the attachment of neutrons to nuclei. For these experiments a source of neutrons was needed; also a Geiger counter to detect any radioactivity which might be produced. Through the courtesy of Professor G. C. Trabacchi, who was director of the physics laboratory of the Bureau of Public Health, the radon from a gram of radium was made available, and pumped into a capsule containing beryllium powder. Fermi made the Geiger counter himself.

The first Fermi element produced by neutron bombardment was $_9F^{20}$ with its half-life of 18 seconds. The group at Rome made a study of the neutron-induced activity of every element they could find. The techniques of chemical separation by means of precipitation with an inert carrier and other chemical procedures were carried out by Oscar D'Agostino, a young chemist who joined the group.

The irradiation of uranium with neutrons produced a mixture of new activities more complex than any arising from other elements. The emission of β-rays after neutron capture leads to an increase in atomic number, and it was logical to suppose that some of the queer chemical properties of the resultant activities were due to the as yet unknown element 93. Fermi, cautious from experience, did not announce this publicly, but his sponsor Corbino did, which caused Fermi considerable embarrassment. The true state of affairs, that the numerous activities were due to the fission products of U^{235} mixed with the activities of U^{239} and Np^{239} eluded Fermi's research group.[3] Part of their difficulties arose from the insufficient neutron source and resultant weak activities.

In October, 1934, after Fermi had returned to Rome from a summer tour of South America, Bruno Pontecorvo and Eduardo Amaldi of the group in Rome made the initial observation which led to the discovery of thermal neutrons, and it was soon found that the propinquity of hydrogenous material could enhance the neutron induced radioactivity by factors as large as 100. Fermi had the explanation in a few hours, ascribing the effect to the efficient moderation, through successive elastic collisions with protons, of the speeds of the nascent neutrons and the consequent rapid increase of the interaction cross-section as the square of the neutron's de Broglie wave length rose. There followed a series of researches on

[3] The first architect's sketches of the laboratory to be built for the Institute for Nuclear Studies at the University of Chicago showed a vaguely outlined human figure in bas-relief over the entrance door. When a group was speculating as to what the figure might represent, Fermi wryly guessed that it was probably a scientist not discovering fission.

thermal neutrons, their absorption, scattering, and diffusion through material media. The techniques and theory evolved were those used later in the exponential pile experiments which preceded the controlled uranium-graphite reactor.

During this period the political situation in Italy was steadily worsening, with the unpopular Ethiopian War, the sanctions of the League of Nations, and the increasing subservience to Hitler's Germany. In 1928 Fermi had married Laura Capon, the daughter of a highly cultured and respected Jewish family in Rome. The enactment of anti-Semitic legislation in Italy in 1938 forced him to think of emigration as a protection for his family, which now included two children, Nella and Giulio. It was also in this year that he was awarded the Nobel Prize "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."

Fermi decided to use the trip to Stockholm as the first stage of a journey to the United States, where he had been offered a professorship at Columbia University. The successful accomplishment of this plan ended the Italian period of his career.

Two weeks after Fermi's arrival at Columbia University, in January, 1939, Professor Niels Bohr landed from Copenhagen, bringing the news of the discovery of the fission of uranium under neutron bombardment. If it could be demonstrated that, in turn, neutrons were a fission product, the possibility for release of energy in macroscopic amounts was open. Many physicists at once attempted to detect neutrons from fission, and Fermi, with the group forming around him at Columbia, soon demonstrated their presence, which was also announced, practically simultaneously, from many other laboratories.

Fermi's new group, at first consisting of Herbert L. Anderson, Leo Szilard, and Walter H. Zinn, soon demonstrated, with the help of a trace of separated U^{235}, prepared by A. O. Nier of the

University of Minnesota, that, as Bohr had predicted, the rare isotope U^{235} was the thermally fissionable isotope of natural uranium.

The next step was of course to prepare an aggregate, containing uranium and a neutron moderator, which would allow the chain reaction to proceed. A few tests convinced Fermi that the reaction would not proceed with natural uranium immersed in ordinary water, due to the neutron absorption by hydrogen. Although he distrusted the experiments on which Halban, Joliot, and Kovarski based their claim that the reaction would proceed in heavy water, he did not doubt that if enough of this material could be prepared in pure form, success would be assured. Time was of the essence, however, if we were racing the Germans, and Fermi wanted to attain the result using naturally available materials, avoiding the necessity of an isotope separation. The discussions of the group led to the selection of graphite as the moderator for the neutrons from natural uranium, and the problem then became one of obtaining several tons of pure graphite and pure uranium.

In May, 1942, at the University of Chicago, where the effort to produce the chain reaction had been concentrated, Fermi and his group demonstrated, by means of measurements in a sub-critical assembly, or "exponential pile," that if sufficient material of the same purity could be made available, the chain reaction would begin. Sufficient material was available on December 2, 1942, and the predicted reaction took place.

In the period 1942-1944, Fermi performed many experiments with the chain reactor, and assisted in the planning of the heavy water reactor erected at the Argonne Laboratory in Palos Park, southwest of Chicago. Neutron fluxes enormously greater than those available at Rome were at his disposal.

On July 11, 1944, Fermi and his wife became naturalized citizens of the United States.

In the late summer of 1944, Fermi went to Hanford, Washington, to consult with the DuPont Company during the start-up period of the plutonium producing Hanford piles. The start-up was not routine; the pile was rendered sub-critical by a decrease in the neutron reproduction factor approximately 10 hours after initial operation. Fermi and Professor J. A. Wheeler soon diagnosed the difficulty as due to the very high neutron absorbing power of one of the fission products, Xe^{135}. Fortunately, the pile could still be operated by removal of some of the safety rods and other minor changes.

At this same time Fermi completed the move of himself and his family from Chicago to Los Alamos, where the final work on the bomb assembly was accomplished. The important decisions concerning the Los Alamos program had been made by this time. Fermi served as Associate Director, consultant, and critic to all the experimental physics projects under way, and directed a small group carrying out neutron cross section measurements using the "water boiler," a small reactor operating with uranium enriched in U^{235} and water as moderator. At the first bomb test, near Alamogordo, New Mexico, on July 16, 1945, Fermi observed the explosion from a site near the barracks which had been erected to house the army group stationed there to carry out the construction work in preparation for the test. He afterward told his friends that in his astonishment at the great burst of light and his preoccupation with his simple experiment of dropping bits of paper to observe the lateral displacement of the air as the shock wave passed, he did not hear the sound of the bomb. Three hours later, he toured the bomb crater in a lead lined tank, collecting samples of radioactivity.

After the war he was offered and accepted the Charles H. Swift Distinguished Service Professorship of Physics at the University of Chicago, and became a member of the newly created Institute for Nuclear Studies of that University. Until the facilities of the new Institute were constructed, he worked at the Argonne National Laboratory on experiments involving neutrons. Here he studied neutron diffraction by crystals, and carried out experiments in the attempt to detect even a minimal interaction between neutrons and electrons.

The completion and successful operation of the 450 Mev synchrocyclotron of the Institute at Chicago brought Fermi back from the Argonne. He was intensely interested in the mesons which the machine produced so copiously. The flux of mesons was sufficient for scattering experiments including determinations of angular distribution. Fermi worked enthusiastically at the measurements, even breaking a habit of long standing not to work at night. He was disappointed, however, in that the observed angular distributions did not lead to a uniquely determined potential function for the interaction of π-mesons with protons. He found time in this period to formulate a theory of the origin of cosmic rays, based on the interstellar magnetic fields proposed by the Swedish physicist Alfven; he also formulated a theory of multiple meson production in the collision of ultra high energy corpuscles.

In the last year of his life he made an important contribution to the physics of nucleons by an interpretation of the polarization of proton beams on scattering. The phenomenon had been detected by C. L. Oxley at Rochester, and experimental work on it was under way at Chicago, owing to the activities of John and Leona Marshall. In seeking the cause of the polarization, Fermi ascribed it to a strong coupling between the nucleon spins and orbital momenta, the effect postulated in the shell model of atomic nuclei. Fermi developed this theory in his typically brilliant fashion, during an afternoon's conversation with Professor Emilio Segre. A subsequent experiment by the Marshalls confirmed his prediction as to the spin direction of the polarized beams.

The last summer of his life, in 1954, was, on the whole, a happy one. He spent it in southern France and in Italy, where, as always, he was idolized by his physicist friends. The final stages of his incurable illness, after his return to Chicago at the end of September, 1954, were mercifully shortened beyond expectation by death in his sleep at his home, on Sunday morning, November 30, 1954.

No one who had more than casual acquaintance with Fermi failed to recognize in him a man of really extraordinary intelligence and mental brilliance. His preeminence as a human being undoubtedly arose from the fact that with this were combined great physical and mental energy, plus stability and balance. He was perfectly well aware of his unusual mental qualities, but remained simple and unassuming. He liked to expound and explain physics, and there are numerous stories concerning his incredible ability of giving extemporaneous discourses on the most detailed and abstruse phases of the subject. He was keenly competitive and enjoyed winning games, and tiring out his younger companions on vigorous walks, climbs and swims. In political matters, he was more to the right than most physicists, being quite skeptical of any extension of governmental powers which he believed might interfere with the possibility of each individual acting for himself. He habitually associated with young people and remained young in spirit throughout his life. His inner stability and calm arose from complete confidence in his own ability to steer a successful course through the vicissitudes of life. He became embarrassed and uneasy if treated as a person to whom special privileges should be given, and was perhaps overpunctilious in his observation of the rules and regulations to which all were subjected during the war. At the laboratory he was among the first to arrive in the morning and the last to leave in the evening, inspiring his co-workers by his outpouring of boundless intelligence and energy during each day.

In his untimely death, the Academy, to which he was elected in 1945, has lost a member of truly outstanding distinction, and the world of science one of its really great physicists.

HONORS

Degree of Doctor of Physics, University of Pisa, 1922.

Premio Matteucci Medal, 1926.

Honorary degree of Doctor of Science, Ruprecht Karls Universität, Heidelberg, June, 1936.

Nobel Prize in Physics, 1938.

Citation: 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.

Civilian Medal of Merit, 1946.

Citation: Dr. Enrico Fermi for exceptionally meritorious conduct in the performance of outstanding service to the War Department in accomplishments involving great responsibility and scientific distinction in connection with the development of the greatest military weapon of all time, the atomic bomb. As the pioneer who was the first man in all the world to achieve the nuclear chain reaction, and as Associate Director of the Los Alamos Laboratory, Manhattan Engineer District, Army Service Forces, his essential experimental work and consulting service involved great responsibility and scientific judgment, his initiative and resourcefulness, and his unswerving devotion to duty have contributed vitally to the success of the Atomic Bomb Project.

Honorary degree of Doctor of Science, Washington University, February, 1946.

Honorary degree of Doctor of Science, Yale University, July, 1946.

Member by presidential appointment of the General Advisory Committee of the Atomic Energy Commission, 1946-1950.

Honorary degree of Doctor of Law, Rockford College, 1947.

Transenster Medal from University of Liége, Belgium, February, 1947,

Honorary member of Sons of Italy in America, 1947.

Franklin Medal and Honorary Member of Franklin Institute, April 1947.

Honorary degree of Doctor of Sciences, Harvard University, June, 1948.

Citation: Theorist and experimentalist, an entire physics department in himself, a bold navigator through the ocean of man's ignorance, the discoverer of a new continent of subatomic riches.*

* This part of the citation is a paraphrase of the oft-quoted telephone message from A. H. Compton to Mr. J. B. Conant, announcing, under secrecy, the initiation of the chain reaction on December 2, 1942. "The Italian Navigator has reached the New World," Compton said.

Medaglia Donegani Per la Chimica, 1948.
Honorary fellow of the Royal Society of Edinburgh, Scotland, July, 1949.
Member (foreign), Royal Society of London, April 1, 1950.
Barnard Medal for Meritorious Service to Science, Columbia University, June, 1950.
Dr. Bimala Churn Law Gold Medal, 1951.
Vice President of the American Physical Society for 1952.
Honorary degree of Doctor of Science, University of Rochester, New York, 1952.
President of the American Physical Society for 1953.
Hughes Medal.
First Fermi Prize awarded by the Atomic Energy Commission, 1954.

KEY TO ABBREVIATIONS

Acc. Brasil. Cien. = Accademia Brasileria de Ciencias
Accad. d'Italia Mem. = Accademia d'Italia, Rome, Memoirs
Amer. Journ. Phys. = American Journal of Physics
Ann. Inst. H. Poincare = Annals de l'Institut Henri Poincare
Astrophys. Journ. = Astrophysical Journal
N. Cimento = Nuovo Cimento
Phys. Rev. = Physical Review
Phys. Zeits. = Physikalische Zeitschrift
Proc. Amer. Phil. Soc. = Proceedings of the American Philosophical Society
Proc. Roy. Soc. = Proceedings of the Royal Society, London
Prog. Theor. Phys. = Progress of Theoretical Physics
Rend. Lincei = Rendiconti Lincei, Accademia nazionale dei Lincei, Rome
Rend. Seminario matematico = Rendiconti Seminario Matematico, Rome Universita
Rev. Mod. Phys. = Review of Modern Physics
Ric. Scient. = Ricera Scientifica
Soc. It. Progr. Sci. = Societa Italiana per il Progresso delle Scienze
Zeits. f. Physik = Zeitschrift für Physik

BIBLIOGRAPHY

It is convenient to list Fermi's publications under four categories:

I. Research reports contributed to scientific journals.
II. Declassified reports to the Metallurgical Laboratory released as documents of the Atomic Energy Commission.
III. Lectures, Addresses, and General Articles.
IV. Books.

This classification has been followed with one or two minor exceptions.

I. RESEARCH REPORTS CONTRIBUTED TO SCIENTIFIC JOURNALS

1921

Sull'elettrostatica di un campo gravitazionale uniforme a sul peso delle masse elettromagnetiche. (On the Electrostatics of a Uniform Gravitational Field and the Weight of Electromagnetic Mass.) N. Cimento, 22(6):176-188.

Sulla dinamica di un sistema rigido di cariche elettriche in moto traslatorio. (On the Dynamics of a Rigid System of Electric Charges in Translatory Motion.) N. Cimento, 22(6):199-207.

1922

Sopra i fenomeni che avvengono in vicinanza di una linea oraria. (Concerning the Phenomena Which Take Place in the Vicinity of an Hour Line.) Rend. Lincei, 31(5):21-23, 51-52, 101-103.

Correzione di una grave discrepanza tra la teoria delle masse elettromagnetiche e la teoria della relativita. Inerzia e peso dell'elettricita. (Correction of a Serious Discrepancy between the Electromagnetic Theory of Mass and the Theory of Relativity. The Inertia and Weight of Electricity.) Rend. Lincei, 31(5, i):184-187, 306-309.

I raggi Roentgen. (X-Rays.) N. Cimento, 24(6):133-163.

Ueber einen Widerspruch zwischen der eletrodynamishen und der relativistischen Theorie der elektromagnetischen Masse. (On a Contradiction between the Electrodynamic and the Relativistic Theory of the Electromagnetic Mass.) Phys. Zeits., 23:340-344.

1923

Sul peso dei corpi elastici. (On the Weight of Elastic Bodies.) Memorie Lincei, 14(5):114-124.

Sul trascinamento del piano di polarizzazione da parte di un mezzo rotante. (On the Rotation of the Plane of Polarization in a Rotating Medium.) Rend. Lincei, 32(5):115-118.

Sulla massa della radiazione in uno spazio vuoto. (On the Mass of Radiation in Empty Space.) Rend. Lincei, 32(5):162-165.

Dimostrazione che in generale un sistema meccanico normale e quasi ergodico. (Proof That in General a Normal Mechanical System Is Quasi-ergodic.) N. Cimento, 25(6):1-5.

Formazione di immagini coi raggi Roentgen. (On the Formation of Images with X-Rays.) N. Cimento, 25(7):63-68.

Correzione di una contraddizione tra la teoria elettrodinamica e quella relativistica delle masse elettromagnetiche. (Correction of a Contradiction between the Electrodynamic and Relativistic Theories of the Electromagnetic Mass.) N. Cimento, 25(7):159-170.

Il principio delle adiabatiche e i sistemi che non ammettono coordinate angolari. (The Adiabatic Principle and Systems Which Do Not Admit of Angular Coordinates.) N. Cimento, 25(7):171-175.

Dimostrazione che in generale un sistema meccanico normale e quasi ergodico. (Demonstration That in General a Normal Mechanical System Is Quasi-ergodic.) N. Cimento, 25(7):267-269.

Beweis dass ein mechanisches Normalsystem im allgemeinen quasiergodisch ist. (Proof That in General a Normal Mechanical System Is Quasi-ergodic.) Phys. Zeits., 24:261-265.

Alcuni teoremi di meccanica analitica importanti per la teoria dei quanti. (Some Theorems of Analytical Mechanics Important in Quantum Theory.) N. Cimento, 25(7):271-285.

Sulla teoria statistica di Richardson dell'effetto fotoelettrico. (On Richardson's Statistical Theory of the Photoelectric effect.) N. Cimento, 26(7):97-104.

Generalizzazione del teoremi di Poincare sopra la non esistenza di integrali uniformi di un sistema di equazioni canoniche normali. (Generalization of Poincare's Theorem on the Non-existence of Uniform Integrals of a System of Normal Canonical Equations.) N. Cimento, 26(7):105-115.

Sopra la teoria di Stern della costante assoluta dell'entropia di un gas perfetto monoatomico. (On Stern's Theory of the Absolute Constancy of the Entropy of a Perfect Monatomic Gas.) Rend. Lincei, 32(5, ii):395-398.

Sulla probabilita degli stati quantici. (On the Probability of Quantum States.) Rend. Lincei, 32(5, ii):492-495.

1924

Sopra la riflessione e la diffusione di risonanza. (On the Reflection and Diffusion of Resonance Radiation.) Rend. Lincei, 33(5, i):90-93.

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1925

Sulla teoria dell'urto tra atomi e corpuscoli elettrici. (On the Theory of Collisions between Atoms and Electrically Charged Particles.) N. Cimento, 2:143-158.

Sui principi della teoria dei quanti. (On the Principles of the Quantum Theory.) Rend. Seminario matematico, 2:2.

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1926

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Unmetodo statistico per la determinazione di alcune proprieta dell'atomo. (A Statistical Method for the Determination of Some Atomic Properties.) Rend. Lincei 6(6):602-607.

1928

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