X. Enrico Fermi

"Se queste interpretazioni sono corrette, si avrebbe qui la formazione artificiale di elementi radioattivi che emettono normali particelle "beta" a differenza di quelli trovati dai Joliot che emettono invece positroni."[189]

Enrico Fermi was born in Rome, Italy on the 29th of September 1901. He was the third child of Ida de Gattis (1871–1924), an elementary school teacher who married (1890) Alberto Fermi (1857–1927), an inspector in the Ministry of Railways. His maternal grandfather was an army officer from the Adriatic city of Bari, near the heel of the Italian boot. His paternal grandfather, Stefano Fermi (1818–1905) was a robust descendant of generations of farmers in Borgonure, near Piacenza, in the heart of the fertile Po Valley, south of Milan; he left the farm to become County Secretary in the Duchy of Parma and married Giulia Bergonzi (1830–?), who had been taught to read her catechism but never learned to write. The Fermis were hardworking men who constituted models of their own concept of success: seeking modest prosperity without achieving wealth. At birth Enrico had two siblings: Maria (1899–1959) and Giulio (1900–1915).

Enrico's parents lived in an apartment at 19 Via Gaeta; when he was seven years of age, the family moved to 133 Via Umberto, near the railroad station (Fig. X-1). At the age of 10, Enrico entered the secondary school system at the Ginnasio-Liceo Umberto I. Latin, Greek, and French were compulsory; the curriculum included geography and history. Readings of the Divine Comedy left a lasting impression on the sensitive child, but he already favored mathematics and physics and was soon attempting an understanding of abstract problems.

At the end of the day's work, Enrico was in the habit of fetching his father at his office, and they walked home together. His father's deputy, Adolfo Amidei (1877–1969), a 37-year-old engineer, often walked part of the way with them. *Ingegnere* Amidei had received advanced university training; in conversation with the 13-year-old boy, he was impressed by the depth of Enrico's mathematical interests and by his thoughtful questions. Their fortuitous encounter was to have fateful consequences for the boy. Amidei loaned him a book on projective geometry; upon returning the volume, he was surprised that the youngster had solved all of the 200 problems listed. The loan of other books on trigonometry, calculus, etc. followed; Amidei strongly advised the study of German to facilitate reading of current literature.[369]

Fig. X-1. The Fermi children (1905): Giulio (1900–1915), Enrico (1901–1954), and Maria (1899–1964). (Courtesy of Nella Fermi Weiner, Ph.D.)

Enrico's older brother was his playmate, constant companion, and best friend; Giulio developed a pharyngeal abscess, and during anesthesia, preliminary to an incision and drainage, he unexpectedly died (1915). His mother cried inconsolably and long. An introverted and taciturn youngster, Enrico suffered his sorrow in silence; he eventually found solace in the friendship of his brother's classmate, Enrico Persico (1900–1969). Fermi impressed his friend with knowledge beyond his years, self-assurance, and originality. The youngsters discussed all kinds of subjects and took long walks across Rome. On Wednesdays they favored visiting the free market at *Campo dei Fiori* in order to browse through the secondhand volumes in the bookstalls. On one of these occasions, Enrico found and bought an 1840 edition, in Latin, of *Elementorum Physicae Mathematicae*, by Father Andrea Caraffa, S.J.

While studying physics, Enrico was also developing his amateurship as an experimenter; he built electric motors, mechanical toys, and airplane models. With Persico he attempted an accurate measure of the density of tap water and of the acceleration of gravity at Rome. They also made a study of the mechanics of tops and developed a satisfactory theory of their own. Fermi spent considerable time in the city's public library, studying various aspects of advanced physics (Fig. X-2).

Amidei's interest in Enrico's education was sustained; he brought him books on theoretical mechanics, deductive logic, and vector analysis. Enrico's dedication shortened his secondary schooling by one year (1918). Amidei persuaded him to apply for admission at the *Reale Scuola Normale Superiore* of Pisa. The Fermis, who had lost their other son, were reluctant to part with their youngest, who after all could register at the University of Rome. However, Amidei insisted that Enrico's exceptional capabilities should be given the special advantages of the Tuscan school: his parents were finally persuaded.[204]

Examinations for entrance to *Scuola Normale* were held in Rome. Enrico was given the topic: "Characteristic Properties of Sound." His response was a highly creditable essay of doctoral quality not expected from candidates at this level: a partial differential equation of a vibrating reed and its solution by means of Fourier analysis. Impressed by the high quality of the essay, his examiner, Prof. G. Pitarelli, asked him to come for an interview; Fermi was told that he was an extraordinary person destined to become an important scientist. He was admitted as first contender. The advantages that Amidei had sought had now become his: the security of room and board, excellent library facilities, supplementary courses, and the eventual doctorate from the University of Pisa. Fermi proceeded rapidly to the city where he was to spend four happy years of his youth.

The Scuola Normale was part of the University of Pisa; its students were housed in the Renaissance *Palazzo dei Cavalieri*. From a handsome square, not far from the Leaning Tower, rose a monumental *scalinata* to the entrance of the palace. The elegant exterior contrasted with the drab furnishings and the lack of calefaction; students were provided with charcoal ceramic braziers (*scaldini*) to be held on their laps while studying.[204] Pisa had a population of 50,000, one-fifth of which were students.

Enrico's early homesickness subsided with the friendship of Franco Rasetti,† a permanent resident of Pisa studying physics at the university. An unusual character, Rasetti was meticulous and precise; he had a prodigious memory and seemed more interested in fossils and lower animals than in people. Rasetti lived alone with his mother and on weekends they often invited Fermi to be their dinner guest; Mrs. Rasetti's homecooking was a welcome alternative to the school's monotonous diet of dried cod. Fermi and Rasetti were remarkably congenial; for relaxation they made excursions to the *Alpi Apuane*, which they climbed with equal agility. Their laugh, wrote Laura Fermi, was an identical loud and long cascade of mirth.[204] Fermi also joined Rasetti in his practical (*antiprossimo*) jokes. On one occasion, they both risked disciplinary expulsion from the university because of their pranks; fortunately their professor of physics, Luigi Pucianti (1875–1946), had the good sense to emphasize their academic record as a weighty factor in their favor.

Fermi read extensively on the theory of mechanics and turbines, in French, and on thermodynamics in German. He joyfully returned to Rome for the summer vacation of 1919; then, he went to spend time in his grandfather's house in Caorso, near Piacenza. In both places, he took time to review his acquired knowledge of physics. Treating advanced topics with didactic clarity, he wrote a summary of analytical dynamics, a resumé of the electronic theory of matter and discussions of diamagnetism, paramagnetism, relativity, and Lorentz's theory of electrons. The youngster was already acquainted with Boltzman's theories, with Bohr's papers on the hydrogen atom, and with Rutherford's book on radioactivity. His pencil-written but well arranged notes are preserved; they have a table of contents and a bibliographic list attesting to his orderly organized baggage of scientific information.

After two years in Pisa, Fermi had acquired the virtual status of a graduate student and was taking only advanced specialized courses; the staff of the department of physics as well as his fellow students, acquiesced the superiority of his knowledge of mathematics and physics and encouraged his leadership. He was the principal advocate of quantum mechanics and lectured on the theory of relativity at the university. He also became involved in a publishing enterprise of physics notes for students. Not yet 20 years of age, he was of short stature, had black hair and gray-blue eyes; his smile revealed a gap between his upper teeth left of the midline.

Experimental work and theoretical abstraction held equal weight in Fermi's view, and he enjoyed the

† See Biographical Notes on page 171.

alternation of both activities. Since the university's laboratories were poorly equipped, he learned at this early stage to build every gadget with his own hands: his sense of self-sufficiency was to become incurable. An interesting insight into the development of his views was given in his candid letters to his older friend, Persico, to whom he wrote details of his readings, ideas, distractions, and offered suggestions for a thesis. Upon Persico's graduation, he drew in his letter a pair of clasped hands in a gesture of congratulations.

Fermi's first published paper appeared in January 1921, "*On the dynamics of a rigid system of electrical charges in translational motion.*"[178] Meanwhile, he developed a well shielded x-ray apparatus to do experimental work. In the spring of his last year in Pisa, he presented a dissertation for habilitation in the *Scuola Normale Superiore*.[195] His theorem of probability encountered criticism from mathematicians on the jury. In July 1922 he presented his doctoral thesis on x-ray crystallography in the *Aula Magna* of the university before 11 capped and gowned professors; although the subject was an anathema to most of them, he was granted his Ph.D. *magna cum laude.*

Poincaré had been the first (1906) to spell out, quantitatively the velocity dependance of mass; he postulated cohesive forces (stresses) to cancel transformation laws, but his clarity diminished as he considered the internal stresses of electrons. Fermi (1922) was the first to notice that something was wrong with Poincaré's factors, but his arguments were not well written; they were ignored or misunderstood.[179]

Fig. X-2. High school student Enrico Fermi, aged 16. (Courtesy of Emilio Segrè, Ph.D.)

His school days at an end, Fermi returned to Rome and to his family. Investigating the possibilities of future work, he called on Professor Orso Mario Corbino (1867–1937). A Sicilian educated in Catania and Palermo, Corbino had become director of the *Institutio Fisico della Reale Università*; he was also a senator and had been Minister of Education. An affable and influential statesman, Professor Corbino had done original experimental work and had an understanding of theoretical physics: aware of the fact that Italian physics could not forever rest on Galileo and Volta, he dreamt of bringing it back to a creditable level. Fermi was surprised to find this politician-physicist capable of discussing intelligently his current work. In turn, Corbino recognized Fermi's capabilities and planned to utilize them; he saw him frequently. Fermi was in Corbino's office of the morning of the historic fascist *Marcia su Roma* which brought Benito Mussolini (1883–1945) to the head of the government of Italy. Two days later, Fermi was granted a fellowship from the Italian Ministry of Education. The awards committee, of which Corbino was a member, agreed unanimously, recognized the work already done and expressed their wish that the fellowship would allow the young scientist further opportunities to enlarge his knowledge. He decided to go to the University of Göttingen to study under Max Born (1882–1970), professor of theoretical physics, and James Franck (1882–1964), professor of experimental physics. He had chosen well, for the institution was seething with expectations of great discoveries about to occur. His contemporaries, Wolfgang Pauli (1900–1958) and Werner Karl Heisenberg (1901–1976), were busily engaged in fruitful cogitation and rather indifferent to newcomers. No one condescended to give the young Italian the encouraging pat on the back that he probably expected and needed: he was disappointed and failed to receive the stimulus that this seminal center should have offered him.

Returning to Rome, Fermi was offered a nontenure position for the academic year 1923–24, in charge (*incarico*) of a course of mathematics for chemists and biologists at the University of Rome. The position permitted him to work in close relationship with his friend, Persico, who had become Professor Corbino's assistant. A book on the theory of relativity was translated into Italian.[181,252] Although Fermi was only 22 years old, he was one of the authorities chosen by the publisher to add their comments in an appendix to the book.[175] Fermi's essay discussed the possible release of nuclear power. A paper that Fermi had written in Göttingen on the ergodic theorem[180] came to the attention of Paul Ehrenfest (1880–1933) in Leyden; he was impressed and sought to contact the Italian thinker.

George Eugene Uhlenbeck (1900–), one of Ehrenfest's students, was presently employed as a tutor in the Rome Embassy of The Netherlands; Uhlenbeck found Fermi, and a lifelong friendship was initiated between the two.

In May 1924 Fermi's mother died in Viggiú after a long siege of pulmonary tuberculosis. Little is known of their relationship except that Fermi admired her intelligence and her self-reliance; it is also true that she had made life at home sad for the Fermis, having never ceased mourning her first son.

Fermi spent the summer in the Dolomite Alps of northeast Italy; he enjoyed the challenge of mountain hiking, was particularly fond of the perennial snows and the distant views that gave wings to the imagination. Away from the city's bustle, he would sometimes lie in a meadow, pencil and tablet at hand, gradually developing the architecture of an original thought. Thus, he created his theory for the analysis of collisions of charged particles. He decomposed the electric field produced by the collision into harmonic components, he used information from optical processes to determine the results of the collision, and showed that it was the same as would be produced by equivalent light.[182] Bohr was critical of Fermi's assumption, yet the method was to be refined and to find rigorous quantum mechanics justification. E. J. Williams and Carl Friedrich Freiher von Weizsäcker (1912–) discussed its validity and limitations and gave it important applications. The method has become known as the Weizsäcker–Williams method.[368]

Awarded a Rockefeller Fellowship, Fermi went to the University of Leyden. The current interests in that center, statistical mechanics and spectroscopy, were precisely those most capable of exciting his own. The genial and affable Ehrenfest gave him the reassurance that he had missed in Göttingen: Ehrenfest's was an authoritative judgment of Fermi's abilities. His work and thinking during his short stay in Leyden are reflected in the various publications that followed. "It is probable"—wrote Segrè—"that his persistent reflections on the entropy of a perfect gas, on the Sackur–Tetrode formula, and on Stern's calculations of the entropy constant originated at that time."[369]

Returning from Holland, Fermi took a provisional job in the department of physics at the University of Florence, in charge of teaching theoretical mechanics and electricity. Rasetti was already there; his experimental work paralleled Fermi's work on theory. One interesting work that they achieved together was a study of the depolarization of resonance radiation by means of an alternating magnetic field.[202] Rasetti had experience with spectroscopic techniques, while Fermi calculated rather accurately the characteristics of the oscillator circuits. This work was their first significant experimental research. Their collaboration, reciprocal influence, and benefit was to last for over a decade.

As shown by the details of his letters to Persico,[369] Fermi now paid considerable attention to the changing academic rules for university competitions; he spent much thought pondering rumors and planning strategy. He took the steps that would start him on the academic ladder of his country. Aware of the requirements of *concorsos*, Fermi wrote a number of papers with scrupulous care as to originality; complying with fascist law, the papers were published in Italian, but when Fermi thought them sufficiently important, they were also published in German. Professor Corbino had long urged the creation of a chair of theoretical physics at the University of Rome and hoped that Fermi might win it. However, there were delays in opening the competition. On the basis of strategy, Fermi presented his credentials in another competition for a professorship of mathematical physics at the University of Cagliari, Sardinia. He lost to the other candidate, whom the committee judged more mature while expressing their appreciation for Fermi's scientific record. He felt and long resented the rebuff: he stayed in Florence.

A satisfactory equation of the state of a perfect gas and an expression of its entropy were longstanding problems in theoretical physics. Such giants as Ludwig Boltzmann (1844–1896) and Max Planck (1858–1947) as well as others had struggled with them; Fermi had meditated on them. An important step had been given (1924) by Satyendranath Bose (1894–1974) an unknown physicist from Calcutta. Bose sent a paper to Einstein in which he presented novel proof of the blackbody formula derived from classical statistical mechanics. Grasping its importance, Einstein translated the paper, wrote a few words of support and had the paper published in German. As it turned out, the Bose–Einstein formula was valid for light quanta but not for particles obeying Pauli's exclusion principle.

In Florence, Fermi resided in Arcetri, on the hill where Galileo had lived and died. With Rasetti, he spent considerable time catching geckos with silk lassos; while lying prone on the grass among the olive trees, he had plenty of time to think. Early in 1926 Fermi developed the needed new statistics.[183] Thus, the Bose–Einstein statistics apply to all particles of integral spin (photons, pions, etc.), now called *bosons*, and Fermi statistics apply to particles of half integral spin (electrons, protons, etc.), now called *fermions*. The importance of Fermi statistics was rapidly appreciated and extended to solid state systems. It was recognized as a fundamental contribution and brought Fermi to the forefront of theoretical physics. A few months later, Paul Adrian Maurice Dirac (1902–1984), independently discovered the same statistics and their quantum mechanics foundation.

The sustained efforts of Professor Corbino finally brought fruit: the Ministry of Education created the Chair of Theoretical Physics of the University of Rome (1927). The *concorso* was opened, and Fermi placed first. Thus, the youngest professor in the history of the university joined Corbino at the Physics Institute, 89A Via Panisferna (Fig X-3). On a hill near the center of

Rome, the site of an ancient monastery, the adapted building was adequate and ample for its purposes. The institute had an excellent library, and the equipment was fair. The beauty of its surroundings was enhanced by svelte palms and bamboo thickets: it was an attractive center of learning. Rasetti was also brought to Rome as an assistant (*aiuto*) to Corbino to take charge of experimental physics.

Once again in Rome, Fermi resumed living with his father and sister. The Fermis had become beneficiaries of housing reserved for railroad employees; they took residence at 12 Via Monginevra in the Città Giardino Aniene. Soon afterwards Alberto Fermi who had risen to Chief Inspector of the Railways, became seriously ill; his son and daughter took turns for weeks in their vigil with him: on May 7th, 1927 he died.

Fermi spent the summer in his favored Dolomite Alps where he donned his tyrolian leather shorts and met frequently with various friends and colleagues. Conscious of the need of an Italian text for advanced university students of physics, he decided to provide one. Without benefit of library references, he filled several notebooks. The pencil-written notebooks, without evidence of erasures or deletions,[368] were sent to the publisher in Bologna: the result was a volume, *Intraduzione alla Fisica Atomica*.[184]

In September 1927 an International Physics Conference was held in Como (Lombardy) on the centenary of the death of Alessandro Giuseppe Antonio Anastasio Volta (1745–1827). A pleiades of physicists from all parts of the world gathered at the border of the beautiful lake; the luxuriant vegetation was at its autumnal best. Present were Niels Bohr (1885–1962), Max Born (1882–1970), Arthur Compton (1892–1962), William Duane (1872–1935), Werner Heisenberg (1901–1976), Ernest Rutherford (1871–1937). Arnold Sommerfeld (1868–1951) presented a paper on the electron theory of metals with references to Fermi's statistics. Fermi was the most significant Italian voice at the conference: already known to them because of his published contributions, his senior colleagues listened attentively as he discussed Sommerfeld's paper.

The task of attracting graduate students to the new department was surprisingly successful. Emilio Segrè,† a student of engineering, was the first convert; he had heard Fermi's lectures and had seen him among the greats at the Volta Conference. Ettore Majorana (1906–1938),† also a student of engineering and Segrè's classmate, followed him. A remarkably fine mathematician with unusual clairvoyance, whimsical but unpretentious, Majorana proved the only one in the group who could discuss theory on an equal footing with Fermi. Corbino's recruitment among undergraduates brought forth Edouardo Amaldi (1908–).

In the manner adopted by many of his colleagues in other European centers, Fermi instituted a weekly colloquium at the institute: it was rather informal but enlightening. The discussions were sometimes limited

Fig. X-3. The Physics Institute of the Royal University of Rome at 89A Via Panisperna, a remodeled monastery. (Courtesy of Perluigi Cova, M.D.)

Fig. X-4. The Fermi–Capon wedding party outside of Rome's Municipal Palace (July 19th, 1928). Just behind the bride are her sister, Anna Montel Capon, and her brother, Alessandro Capon. The uniformed officer is Rear Admiral Capon; behind him is Senator Corbino, the short bald gentleman, and behind Corbino is Franco Rasetti. Other persons are not identified. (Courtesy of the Fermi Institute of Nuclear Studies.)

to comments on the current literature or to reviews of a particular subject. However, often a candent problem would present itself, and a searching discussion ensued. On these occasions, Fermi's method revealed itself: he was able to analyze any problem, however complicated, down to its essentials, denuding it from unnecessary mathematical vestments. Hans Albert Bethe (1906–) (Nobel 1967) wrote "When you left Fermi after one of these discussions, it was clear how the mathematical solution should proceed."[369] Although his method was frequently enlightening to well-informed colleagues, the reasoned unraveling was particularly inspiring to the young students. His pragmatic approach made physics clear, achieving important results with a minimum of effort.

Italian physicists, particularly those from Florence but also from Turin, Pisa, and other centers of learning, visited the Rome Institute and attended the weekly conferences.* Staff members visited foreign laboratories and established personal and professional links of lasting value: a fellowship allowed Rasetti to travel to Pasadena to work with Millikan on the Raman effect at the California Institute of Technology; Segrè went to Amsterdam to study spectral lines with Pietr Zeeman (1865–1943) (Nobel 1902) and to Hamburg to work with Otto Stern (1888–1969) (Nobel 1943). Amaldi went to Leipzig to work on x-ray diffraction with Peter Joseph William Debye (1884–1966) (Nobel 1936). In turn foreign physicists were welcome in the laboratories of the Rome Institute.*

At the end of his first academic year in Rome, Fermi had announced that he would do something wild, like buying an automobile or getting married: he did both. The automobile came first: a two-seater (Bebé) Peugot. Laura Capon (1907–1977) was a young university student, a classmate of Amaldi, who had met Fermi as a lecturer but also as a family friend and frequent companion on weekend outings, games, etc. in which Fermi usually indulged with the students. Signorina Capon was a young lady of great beauty and a person of substance; the daughter of a navy officer, she was a member of a nonobservant Jewish family; the Fermis, in turn, were nonpracticing Catholics: thus, they both were agnostics.* The wedding was a civil ceremony, and it took place in the municipal palace on July 19th, 1928. Fermi arrived late for his wedding[204];

* See Subject Notes on page 183.

he had been delayed sewing a tuck in the excessively long sleeves of his new shirt: the wedding photograph shows that he did not do a very good job (Fig. X-4). They started their honeymoon with a seaplane ride to Genoa, being among the first to make use of this commercial transportation. They proceeded by train to the small village of Champoluc in the beautiful valley that leads to the glaciers between Monte Rosa and the Matterhorn.

In Rome the newlyweds took a six-room apartment near the university. Fermi rose early and read for two hours before breakfast, then went to work at eight; at one o'clock, he returned home for lunch and relaxation until three. Work resumed and lasted until eight in the evening; he was never late for dinner. The university's salary was meager; in order to supplement his income, he decided to write a high school textbook of physics; with the help of his wife, the task took two years to complete. He accepted an appointment to judge applications for research projects for the National Research Council and he also worked for the *Encyclopedia Italiana* writing carefully a number of its articles.

Fermi's next work of note was his application of statistics to the atom; the idea was to compute the density of the electronic cloud around the nucleus as an atmosphere of a totally degenerate gas of electrons attracted by the nucleus. He made countless computations on an old desk calculator. Majorana, using another route, checked his figures and was surprised by their accuracy. Fermi was unaware that Llewellyn Hilleth Thomas (1903–   ) had invented the method one year earlier. The Thomas–Fermi atomic statistics gave a good approximation to a considerable number of solutions and became Fermi's favorites: he applied them to x-ray spectroscopy, to period systems of the atom, to optical spectroscopy, and to ions. Invited by Debye to a meeting in Leipzig, Fermi summarized these results in his presentation.[185]

Corbino was desirous to have Fermi recognized by the prestigious *Accademia Nazionale dei Lincei*; the Academy elected new members after formal nomination, evaluation of candidates, and more important, behind the scenes negotiations by the academicians. Corbino wrote a letter of nomination but because of his absence from the country, entrusted its presentation to an invidious senior colleague, who conveniently forgot. In 1929 Mussolini created a new *Reale Accademia d'Italia* with special prerogatives for its appointed members. Corbino used his bureaucratic influence for revenge: at his suggestion, Fermi was elected the only physicist among the first 30 academicians; they wore special regalia at official functions, including feathered headgear, and received a small emolument. Fermi was glad to accept the membership that doubled his income but was secretly embarrassed by the title of *Excellence* and by the trappings.[204] He was able to rescind his obligations to the Research Council and to the Encyclopedia in favor of his younger associates. Subsequently, he was also elected member of the *Accademia dei Lincei* at an unusually young age.*

The advent of quantum mechanics signaled a shift to nuclear physics. Resistance to the concept of quantum mechanics was particularly noted among the old established physicists, whereas the young, quite on the contrary, took it mostly on faith. Dirac had written a basic article on quantum electrodynamics. Fermi decided to attain the same results in a simpler manner. He developed the electromagnetic field by Fourier analysis, and he quantized the single harmonic components as oscillators, thus giving a Hamiltonian touch to Maxwell's theory[368]; he added a term representing the interaction of an atom with radiations and treated the complete system by perturbation theory.[187]

In an eloquent speech before the Italian Association for the Advancement of Science in Florence (September 1929), Corbino concluded that it was improbable for physics to make progress in its ordinary domain, that new discoveries could only be expected from studies of the atomic nucleus.[369] Fermi investigated the theory of hyperfine structure of the spectral lines and the nuclear magnetic moments, an appropriate transition from atomic to nuclear physics.[186] Rasetti went to learn nuclear techniques from Lise

Fig. X-5. Research collaborators (1934): Oscar D'Agostino (1904–1976), Emilio G. Segrè (1905–), Eduardo Amaldi (1908–), Franco Rasetti (1901–   ), and Enrico Fermi. (Courtesy of Professor E. Segrè.)

* See Subject Notes on page 183.

Meitner (1878–1968) at the Kaiser Wilhelm Institute of Berlin. Opinions varied, but the Fermi group shifted as rapidly as their skills permitted from spectroscopy to cloud chambers and bombardment with particles. Everyone at the Rome Institute shifted to reading nuclear physics (Fig. X-5).

In 1930 Fermi was invited to participate in a summer course offered by the University of Michigan at Ann Arbor. His friends, Else and George Uhlenbeck (1900–),† Jeantje and Samuel Abraham Goudsmit (1908–1978), recent immigrants, were there; Paul Ehrenfest (1880–1933) was also asked to participate. It was the Fermis' first visit to the United States. While he became appreciative of the research facilities, she became acquainted with the technical trappings that rather euphemistically disguise the American housewive's drudgery! Fermi's knowledge of the English language was primarily due to his extensive readings of books and journals; as a consequence, his vocabulary was satisfactory, but his pronunciation was not. His colleagues sat in his lectures in order to point out his failings: very good memory helped him to improve rather rapidly. He lectured on the quantum theory of radiation.[187] Fermi was also invited to participate on the Sixth Solvay Conference, held in Brussels in 1930: magnetism was the theme.

The Fermis lost their first baby through a breech presentation. On January 31, 1931, their second, Nella Fermi was born; fatherhood and its concerns were strange to Fermi: he barely was able to hold his delicate "bestiolina," but he learned.

Pauli had predicted the existence of an atomic particle that would re-establish the balance of energy impaired by the continuity of beta-ray spectra; this particle should have practically no mass and should carry no electric charge, so that, paired with a beta particle, the sum of their mass and charge would make the identification of the neutral particle almost impossible. Pauli had suggested the name *neutron*, which was not adopted and later used for Chadwick's discovery.

The *Fondazione Volta* of the Italian Academy organized a *Convegno di Fisica Nucleare*, which attracted to Rome (October 1931) a constellation of international talent: Niels Bohr, Arthur Compton, Marie Curie (1867–1934), Paul Ehrenfest, Werner Heisenberg, Robert Andrew Millikan (1868–1953), Ernest Rutherford, Arnold Summerfeld, and many others. Fermi played an important role in the organization of this first congress of nuclear physicists; Arthur and Betty Compton were dinner guests of the Fermis in their apartment. At one of the sessions of the congress, Fermi informally suggested another designation for Pauli's particle. In Italian the suffix *on* suggests large size; Fermi found more appropriate the suffix *ino*, a diminutive. *"I neutrone di Pauli sono piccolo e leggiere"*—said Fermi—*"esse devono essere chiamati neutrino."* Thus, the *neutrino* entered the vocabulary of physics, although years had to elapse before evidence of its existence was produced in the Savannah River project.

In 1933 Fermi returned to participate in a summer course in Ann Arbor where his friends Uhlenbeck and Goudsmit had settled. This time he was accompanied by Segrè; they bought a secondhand automobile in New York and drove it to Michigan and back. The car gave them mechanical difficulties, but Fermi was quite capable of facing them: in a service station where they saw him capably fixing his automobile, they offered him a permanent job!

The Seventh Solvay Conference (October 1933) took place again in Brussels; a great deal had transpired since the previous conference: the new theme was the nucleus. Although he did not participate in the main discussions at the conference, Fermi was alert to the work revealed and to the opinions expressed; he witnessed the rebuke of the Joliot-Curies by Lise Meitner and the sad reception given to the views of Ernest Orlando Lawrence (1901–1958).[329] In the company of Madame Curie the Fermis were dinner guests of King Albert at the Royal Palace.

Two months after the Solvay Conference, Fermi wrote his paper on beta decay, probably his most important theoretical essay. The theory of beta decay, considered as the spontaneous emission of electrons by the nuclei, offered difficulties because energy and momentum were not apparently conserved. Pauli's neutrino sought a way out of the paradoxes, but a new force had to be considered. To the electromagnetic and gravitational forces and to the strong force that binds nuclear particles together, Fermi added a new *force of weak interaction*, operating between particles, and postulated a fundamental constant of nature, now called the *Fermi constant*, the first manifestation of which was the beta ray.[188] Fermi's work transformed Pauli's qualitative hypothesis into a quantitative theory with predictive power.[190] The concept proved to be of paramount importance to subsequent research in nuclear and particle physics. Significant in itself, this work also inspired other important investigations into the theory of nuclear forces: it has stood the test of time.[369]*

Walther Wilhelm Georg Franz Bothe (1891–1957) and his collaborator, H. Becker, observed in Giesin (1930), that irradiation of light elements such as beryllium with alpha particles resulted in secondary radiations that were, surprisingly, more penetrating than gamma rays of radium. Their simple observation became the basis of remarkable new research that brought forth a revolution in nuclear physics. Irène Curie (1897–1956) and Frédéric Joliot (1900–1958) verified these findings and in the process, made the observation that interposed cellophane and paraffin increased the intensity of the beam: their conclusion was that highly penetrating radiations were capable of setting protons in motion (1932). The Joliot-Curies failed to recognize the release of neutrons, an identification which promptly followed when James Chad-

† See Biographical Notes on page 171.

* See Subject Notes on page 183.

wick (1891–1974), at Cavendish, simply recalled Rutherford's prediction of its existence.[329] However, as a result of their experience with this subject, the Joliot-Curies went on to make the transcendent discovery of the artificial production of radioisotopes (January 1934). Closely following the publication of this work, Fermi decided to shift from his theoretical preoccupations to an enticing experimental adventure: it proved to be a fateful decision. It was his purpose to irradiate, with neutrons, a series of elements, starting with hydrogen and continue in the order of increasing atomic numbers. Counters and other gadgets were unavailable and had to be produced through sheer ingenuity. The need was for a neutron source. Rasetti had learned to prepare neutron sources with polonium and beryllium, but such proved too weak. Giulio Cesare Trabacchi (1884–1958), director of the laboratories of the *Sanita Publica*, often gave them sympathetic help; Professor Trabacchi was the custodian of one gram of radium and operated a radium emanation extraction plant, which was fortuitously located in the Physics Institute. The principal purpose was to provide radon seeds to physicians for interstitial implantation in malignant tumors. The availablity of some of this radon encouraged Fermi to prepare a stronger neutron source. He placed beryllium powder in a glass bulb, evacuated the air and replaced it with about 50 millicuries of radon in each bulb. Trabacchi earned the affectionate sobriquet of "divine providence." A chemist had to be added to their forces in order to solve the serious problem of chemical analysis and identification of isotopes: Oscar d'Agostino (1904–1976) was an associate of Trabacchi who was at that time learning radiochemistry in the laboratories of the *Institut du Radium* of the University of Paris; in Rome for Easter vacation, d'Agostino was persuaded to cancel his return to Paris and to join the group. Segrè was in charge of procurement; with about a thousand dollars granted by the *Consiglio Nazionale della Ricerca*, he went from stores to markets obtaining small amounts of the necessary rare elements. The experiments proceeded as planned; irradiation of lithium, boron, carbon, etc. produced no results. As they progressed in the atomic scale and reached fluorine, their Geiger registered a few counts. Within a short time, d'Agostino had identified 12 new radioactive isotopes. An expeditious publication was sought: the formula was a weekly letter to the editor of *Ricerca Scientifica*, the first one of which appeared March 25, 1934.[189] Besides incorporating Amaldi and Segrè in the work, Fermi urged Rasetti to return from his prolonged vacation in Morocco. The weekly letters kept the scientific world abreast of their progress. Preprints of the letters were mailed to friends and other interested parties at home and abroad. Starting with letter III, the signatures appeared alphabetically: Amaldi, d'Agostino, Fermi, Rasetti, and Segrè[11] (Fig. X-5).

A few weeks after the beginning of their work, Fermi received an encouraging letter from Rutherford: "I congratulate you in your successful escape from the sphere of theoretical physics... . You may be interested to hear that Professor Dirac is also doing some experiments. This seems to be a good augury for the future of theoretical physics!"

Thirty-seven of the first sixty-three elements irradiated yielded positive results. Reaching the top of the atomic scale, they verified that no radioisotopes were produced between lead and uranium; they irradiated thorium and uranium, and obtained two radioactive isotopes but were unable to chemically identify the resulting isotopes: they concluded that they had produced transuranic elements. Fermi felt uncomfortable with the assumption and resisted the temptation, and pressures, to give names to the assumed transuranic elements. However, the possibility of fragmentation of the uranic atom did not occur to him!

The *Accademia Nazionale dei Lincei* held a solemn traditional convocation, in the presence of His Majesty the King, at the end of the academic year 1933–34. Professor Corbino was the designated speaker; he eloquently presented his address: "Perspectives of Modern Physics." He spoke proudly of the work of the men he called his "boys" and ended with the announcement of their creation of a new element. He mentioned Fermi's justifiable prudence and reserve but stated that in his opinion, the new element was a fact.[368,369]

The news of the discovery of element 93 was seized by the press and heralded as a cultural fascist victory, while the foreign press reported critical views of the work. Fermi was disturbed, yet he did not wish to disavow Corbino, a man whom he respected and to whom he was indebted. With the agreement of Corbino, a carefully worded statement was issued, but the speculation lingered.

Not even the demands of scientific research could be allowed to interfere with a well-earned academic vacation. The Fermis entrusted their infant daughter to a relative and left for a pleasant transatlantic trip that took them to Buenos Aires. A tour of lectures sponsored by the Italian government brought Fermi to Córdoba and other cities, then to Montevideo and to São Paulo and Rio de Janeiro. They were overwhelmed by the hospitality that was shown to them. Their return trip took them first to England to participate in an international congress of physics in London.

Segrè and Amaldi had gone to spend the summer in Cambridge; they wrote an English version of their work and delivered it to Rutherford, who corrected it and had it published.[197] While at Cavendish, Segrè and Amaldi did some laboratory work. When Fermi returned from South America, they reported to him some interesting observations on the decay period of neutron irradiated aluminum. Fermi mentioned their finding in a lecture. Shortly afterwards, Amaldi repeated the experiment and found a different decay period. Fermi was embarrassed and angry; his associates were scolded for their apparent carelessness.

At the end of their journey, the ship brought the Fermis to Naples, and they hurried to their little Nella in Florence. Fermi proceeded to Rome, where, vacations over, experiments resumed. A recent graduate of the University of Rome was accepted as a member of the group: he was Bruno Pontecorvo (1913–), a handsome and athletic Tuscan, a family friend of Rasetti.[329] Pontecorvo's signature appeared with the others in letter VII of the group to *Ricerca Scientifica.*[9]

The paper that Amaldi and Segrè had brought to London graded the radioactivity of isotopes as strong, medium, or weak; Amaldi and Pontecorvo were assigned the task of doing a more precise study. Irradiating silver with neutrons they observed that the resulting radioactivity was of vastly greater intensity when the irradiation was done on the wooden table top as compared with a marble top. Amaldi was reminded of his controversial measurements at Cavendish. They also found differences in the measurements of the irradiation done inside or outside a *castelleto* of thick lead. The group decided to test the role of lead, and for this purpose, a specially tooled lead wedge was prepared to be interposed between the neutron source and the detector. When everything was ready, arbitrarily, without aforethought or explanation, *intuitively* one is tempted to say,[93] Fermi decided to use a block of paraffin instead: the result was a hundredfold increase in the intensity of the resulting radioactivity. It was the morning of October 22, 1934. As was the custom, a two hour recess was taken for lunch and relaxation. Since his wife was not home, Fermi remained in the laboratory over the noon hour; when his associates returned, he had worked out an explanation: elastic collisions with hydrogen atoms slowed down neutrons, which thus, became more effective than fast neutrons.

In the afternoon of the same day, they verified that water also increased the radioactive intensity: to test this fact, they adjourned to the garden of the Institute and utilized the Corbino's goldfish pond. That evening they gathered at the Amaldis' apartment to draft an account of their discovery; after a loud interchange, they agreed to a text that was dictated by Fermi, transcribed by Edouardo and typewritten by Ginestra Amaldi. It read in part: "*A possible explanation of these facts seems to be that neutrons rapidly lose energy by repeated collisions with hydrogen nuclei. It is plausible that the neutron–proton collision cross section increases for decreasing energy...eventually reaching the energy corresponding to thermal agitation.*"[198]

As soon as Corbino was made aware of their latest discovery, he realized the possibility of industrial utilization. At a time when no one was thinking of nuclear power, the shrewd old professor vehemently urged them to protect their rights by registering their invention. Thus on October 26, 1934 they applied for a patent.*

Fermi's discovery of the hydrogen effect and of slow neutrons opened new avenues of research which he and his associates were prompt to undertake. Their work was intensive but not hurried. It was for them a period of heroic enthusiasm in research.[369] In the six weeks that followed the discovery, they measured the increased activity of various substances immersed in water. They tested the influence of the water's temperature on the deceleration of neutrons and concluded that neutrons could be effectively *thermalized.* They also measured the density of slow neutrons in a hydrogenous medium as a function of the distance from the source. They found that cadmium and other substances were remarkable neutron absorbers and measured the cross section of this effect.

The enhancement due to the use of slow neutrons obviously required a revision of previous unsatisfactory results, perhaps because of the weakness of the source; among these was the irradiation of boron, thorium, and uranium. Again, they observed the radioactivity resulting from the irradiation of uranium, and again they attributed it to transuranic elements and their decay products. For these experiments, they had covered their target with aluminum foil: this fact may have prevented the observation of the strong ionization pulses characteristic of fission, but it is conjectural whether they would have given it the proper interpretation.*

Fermi continued to work in order to develop a mathematical theory of the decelerated neutrons; the seeds of his ideas in this respect were given a second paper published in London.[194] However, it took another year before he was able to test and to round up the theory that brought him recognition and acclaim. Work was interrupted again for a summer at Ann Arbor; Uhlenbeck had been called to replace Ehrenfest in Leyden.

Upon his return to Rome, Fermi found himself alone with Amaldi: Rasetti had gone for a year to Columbia University; Segrè had married and accepted a professorship in Sicily; d'Agostino had taken a position with the National Research Council; Pontecorvo had gone to Paris to work under Joliot, and Majorana had withdrawn from work. To compensate for the loss of manpower, they worked with greater intensity from 8 A.M. to 7 P.M., often without a break. They made a systematic study of absorption properties of various neutron groups. The explanation of neutron groups as energy differences of resonant absorption lines was established by their experiments. They had difficulties with the apparent lack of correlation between the scattering and the capture cross section of heavy neutron absorbers, such as cadmium: the mechanism became clear only through Bohr's work on the compound nucleus. Fermi's ability to discern analogies between unrelated phenomena allowed him to transfer the concept of the scattering length and of resonance from the theory of the shift of spectral lines to that of neutron physics.[369]

The strong voice of Giulio, a brown-eyed son, engrossed the Fermi household on February 16, 1936; he completed with the newsboys' proclamations of fascists victories in Ethiopia in the *Messaggero Rosa*. Meanwhile, soldiers in Nazi uniform occupied the Rhineland, also defying alien opinion. Thus, the basis was being laid for the Rome–Berlin Axis, further consolidated by intervention in Spain.

In January 1937 Professor Corbino died of pneumonia; the directorship of the Institute was given to a longtime antagonist and the laboratories were moved to the University City with consequent disruption of work. Scientific output had evidently declined under the exigencies of war economy and social disruption. Italian troops fighting on the side of nationalist Spain suffered disaster in Guadalajara, while other Italians fought on the Republican side at Huesca.[388]* Returning from his usual summer trip to the United States, Fermi traveled with Swiss physicist Felix Bloch (1905–) (Nobel 1952), who had taken a position at Stanford University.

Fermi declined several enviable offers in the United States, and in the beginning of 1938, he moved his family to a newly purchased apartment in the vicinity of fashionable and beautiful *Villa Borghese*. It was the realization of Laura Fermi's dream and a sign of their loyalties, although Fermi's modest character contrasted with the boasting of fascism. Laura Fermi and Ginestra Amaldi wrote a book, "*Alchimia dei nostri tempi*," a popularization of their husbands' work.

The incorporation of Austria into the Nazi sphere (Anschluss) obliged Erwin Schrödinger (1887–1961) (Nobel 1933) to flee Vienna; he went to Fermi in order to seek protection in the Vatican. In the summer of 1938, Mussolini introduced in Italy the Nazi antisemitic legislation and persecution of Jews.[150] Segrè was eased out of his position in Palermo and accepted a position at the University of California at Berkeley. Navy Admiral Augusto Capon (1872–1943), Laura Fermi's father, was retired from active service.* Although some supported racism, the official act divorced fascism from the traditional conviviality of most Italians.

In the summer, the Fermis returned to the Dolomites. Cautiously but deliberately, Fermi wrote to his correspondents in the United States that the reasons for his previous refusal no longer prevailed; he mailed each letter from a different village. Offers of positions rapidly returned. He decided to accept the renewed offer of Columbia University but announced his plans as an academic visit to New York. In the fall, at a meeting in Copenhagen, Bohr confidentially had inquired whether Fermi would accept the Nobel Prize if offered. In November the expected call from Stockholm came through. This facilitated greatly the procurement of visas through bureaucratic machineries. Through personal influence, Fermi was able to retrieve his wife's passport, which, following racial laws, she had been required to turn in. Their decision to leave the country of their birth was known only to their closest friends and colleagues; the inexpressible solemn feeling was mixed with the fear of a last minute impediment. By

Fig. X-6. Nobel Laureats Enrico Fermi and Pearl Buck, in the center of the Concert Hall's stage (December 10, 1938) in Stockholm. (Courtesy of the Argonne National Laboratory.)

train and ferryboat they eventually reached Stockholm, their apprehension allayed only after the last frontier was crossed.

On December 10, 1938, Fermi received the Nobel Prize for Physics for his disclosure of new radioactive elements produced by neutron irradiation and "for his related discovery of nuclear reactions brought about by slow neutrons." Simultaneously, the Nobel Prize for literature was awarded to Pearl Sydenstricker Buck (1892–1973) "for her rich and truly epic descriptions of peasant life in China." Mrs. Buck, in beautiful evening decolleté, and Fermi, in formal white tie attire, sat on lion-embossed high leather chairs in the middle of the stage in Stockholm's Concert Hall and listened to music and speeches before King Gustavus V personally delivered the Swedish Academy awards (Fig. X-6). Fermi later delivered the traditional Nobel Lecture; he explained his shortcomings in chemical identification of the short-life radioactive materials in the course of their experiments. As he had not done previously, he now proposed the designations of *Ausonium* and *Hesperium* for the assumed elements 93 and 94 resulting from the neutron irradiation of uranium.[369] Lise Meitner (1878–1968), then working at the Nobel Institute in Stockholm, visited with the Fermis and was undoubtedly present during the lecture.

In Paris Irène Curie (1897–1956) and Pavle Petar Savitch (1909–) had reported that their neutron irradiation of uranium resulted in a radioactive element with 3.5 hours half-life that followed lanthanum (atomic number 57) in precipitation.[143] In Berlin, Otto Hahn (1879–1968) and Fritz Strassmann (1902–),

* See Subject Notes on page 183.

repeated the study, recognized a radioactive isotope of barium (atomic number 56) in addition to lanthanum and cerium: they hesitantly reported their as yet unexplained findings.[225]

Invited by the Bohrs, the Fermis went to Copenhagen and were guests at the beautiful House of Honor,[332] on Christmas Eve, they embarked on the *S. S. Franconia* with destination to America. Two weeks after the Nobel ceremonies, Lise Meitner and her nephew, Otto Robert Frisch (1904–1979), on leave from Bohr's institute, were spending a year-end vacation in Kungälv, southern Sweden, Meitner had experience with neutron irradiation and had repeated opportunities to cogitate on the subject. She had received from his former associate, Otto Hahn, an account of his recent experiments and puzzling results. Walking through the snow, Meitner and Frisch reached the conclusion that the resulting barium was a consequence of the splitting of the uranium atom. Meanwhile, at the *College de France*, Joliot had reached the same conclusion and was preparing an experiment that would prove it.[240] Returning to Copenhagen, Frisch planned a simple experiment that would produce evidence of what he called "fission."[211]

In New York on the second day of the new year, Fermi enthusiastically joined the Physics Department at Columbia University under the leadership of George Braxton Pegram (1876–1958). John Ray Dunning (1907–) was a member of the department and Herbert Lawrence Anderson (1914–) was a graduate student in the Pupin Laboratories. The Fermis took rooms in the King's Crown Hotel not far from Columbia.

Two weeks after their arrival the Fermis were again at the pier to welcome Niels Bohr. Invited to be a visiting professor at Princeton University, Bohr had been briefed by Frisch on the Meitner–Frisch views and on his plans for experimental demonstration of fission. During the voyage Bohr had discussed these matters with his associate Leon Rosenfeld (1904–). Shortly after their arrival Rosenfeld candidly commented the details at a journal club meeting in Princeton.

Concerned that the rapid spread of news would deprive Frisch and Meitner of their legitimate priority Bohr decided to make a public announcement, for the record, at the Fifth Conference of Theoretical Physics, held in Washington, D.C. (January 26, 1938). News had indeed spread rapidly: Willis Eugene Lamb, Jr. (1913–) heard Rosenfeld at Princeton and took the details to Dunning in New York. Fermi, attending the Washington meeting received a telegram from Dunning informing him that using an oscilloscope and ionization chamber he too had been able to observe the revealing fission pulses at Columbia.

Each nuclear fission resulting in the release of neutrons, they could in themselves cause subsequent and repeated fragmentations, that is, *a chain reaction*. This depended on the number of neutrons released from each fission and the number wasted because of inconsequential absorption or distance traveled. A chain reaction would result in the release of enormous amounts of power; the logical immediate considerations were its industrial utilization and the feasibility of an atomic war weapon of unprecedented destructive power.

Leo Szilard (1898–1964) had long foreseen the possibilities of a chain reaction; five years previously he had already taken a patent for it in London.[329] Now in New York he had been authorized to pursue his investigations at Columbia University; he also lived at the King's Crown Hotel. Szilard had rented one gram of radium and enlisted the help of Walter Henry Zinn (1906–): they verified the emission of fast neutrons when uranium was irradiated by slow neutrons.[387] Fermi borrowed Szilard's radium and with Anderson's help was also able to verify the fact.[12] In Paris, Joliot and his associates Hans von Halban, Jr. (1908–1964) and Leo Kowarski (1907–1979) proved also the release of fast neutrons in the fission of uranium.[393]

In March 1939, Dean Pegram wrote to Admiral Stafford C. Hooper that the explosive possibilities of uranium per pound were over one million times more poweful than other explosives. Fermi went to Washington and talked, in his usual low-key manner to a group of U. S. Navy officers: they were interested in the power potential for submarines but not in the explosive possibilities.

Bohr, in collaboration with John Archibald Wheeler (1911–), brilliantly unraveled in Princeton the important difference between the more abundant uranium 238 and the more fissile uranium 235: a new intelligence.[60] The question now was, would it be possible to separate them? "*A task*—wrote Fermi—*that looked almost beyond human possibilities*."

Fermi decided to utilize a neutron moderator in an attempt to produce a chain reaction with nonseparated uranium. Deuterion was only available in small quantities; he tried without success a mixture of uranium oxide and carbon in the form of powdered graphite: it was not successful.

Accustomed to face challenges and deliberately to choose his own directions in order to find his own solutions, Fermi was well aware of the importance but not particularly pressed by any urgent need to pursue nuclear research. It was his fate to have to contend with Szilard's consuming desire to achieve prompt success in this pursuit. Szilard was a brilliant, dedicated, unabashed, and honest man, with as many powerful acquaintances as ideas, and possessed of amazingly pragmatic resourcefulness. Those who knew him said that he "surfaced" unexpectedly but no one questioned his honesty and altruistic purposes. Fermi was leaving for a summer in Ann Arbor and Berkeley, intending to study cosmic rays. Met by Szilard at lunch, and asked his opinion on a paper by Joliot just published, Fermi declared not to be impressed. It is to Fermi's credit that he was patient with Szilard's pressure but he lost his temper when Szilard insisted on his demand of not publishing the results of their research.

In the summer of 1939, millions were attracted to the New York's World's Fair with its *Trylon* and *Perisphere*. The International Congress of Cancer opened its sessions in Atlantic City in the first week of September just as the blitzkrieg roared in Europe.

Edward Teller was invited to take a year's leave of absence from George Washington University and to join Columbia University in teaching and research. Teller seemed to be a needed balm between Fermi and Szilard for he got along with both. Talking of fission while at lunch, Teller listened with interest to Fermi's suggestion that a nuclear bomb could create on Earth heat comparable to that of the stars, so that hydrogen atoms could fuse with a collossal release of energy. A quietly expressed Fermi thought became a rather ebulient concept in Teller's mind as he saw the implications and elaborated on them.[329] That day, wrote Teller's biographers, Fermi changed the direction of Teller's life.[37]

Szilard foresaw the possibility that uranium stored in Belgium might become available to the German government. Knowing that Einstein maintained correspondence with Belgian royalty, Szilard imagined that he could warn them. After discussing the matter with Eugene Paul Wigner (1902–) they came to the conclusion that it would be more fruitful to alert the U. S. Government. The result was the famous letter, addressed to President Roosevelt, drafted by Szilard, signed by Einstein, personally carried and read to the president by Alexander Sachs (1893–?): it indicated the uranium potential as an explosive and mentioned of Nazi interest in this mineral. The president appointed an Uranium Committee with Lyman James Briggs (1874–1963) as chairman. Not one of the committee members believed in the war potential of uranium but a grant of $6000 was made to allow further research: it permitted Fermi and Szilard to ascertain the absorption cross section of graphite.

An experimental pile required a spacious room and Dean Pegram finally found one in the basement of Schermerhorn; he also arranged to hire husky athletes to carry 50 to 100 pound containers of uranium and graphite. A large structure of graphite, with various arrangements of uranium distribution within it, was planned. Purification of both uranium and graphite and planning of the structure took hours, days, and months. Szilard and Fermi collaborated in this phase of their research. But progress was slow. A visiting radiochemist was amused to see physicists doing chemical separations with Fermi doing most of the work.

The uranium saga cannot be told without stopping to recognize and to pay tribute to a remarkable man: Edgar Sengier.[329] Born in Courtrai (Kortrije), Belgium, October 9, 1879, Sengier studied mine engineering and graduated from the University of Louvain in 1903. He took short-term employment in Birmingham, England, where he learned English and accounting: returning to Belgium he received employment in the coke industry, at Willebroeck. In 1907 Sengier went to China and eventually became director of the *Compagnie Internationale d'Orient*, concerned with the exploitation of tramways, railroads, electricity, coal, etc. In 1911, he was sent to the Belgian Congo by the *Union Minière*: after thorough study he recommended the mining of uranium in Katanga for the industrial production of radium. A most accomplished factory was eventually established in Olen, Belgium: the first few grams of radium produced were offered to the Radium Institute of Paris and facilitated Regaud's early trials of telecurietherapy. Sengier was designated to collaborate with Herbert Clark Hoover (1874–1954), in the relief tasks that followed the First World War. In 1939, Sengier was director of both the *Union Minière* and of the *Societé Générale de Belgique*; in May–June he had a private interview in Paris with Frédéric Joliot and learned of the war potential of uranium. Sengier granted seven tons of uranium ore to Joliot plus the loan of one gram of radium. Elsewhere (Chapter VIII) we have told the vicissitudes and fateful course of the heroic pursuit of Joliot, von Halban, and Kowarski.

In October 1939, ahead of the German armies, Sengier left Brussels with a few of his staff to establish offices in New York. Before leaving he gave orders to ship to the United States all of the available uranium ore at Olen; but they could not be carried out. From New York he quietly arranged for all of the uranium ore above ground in Shinkolobwe (Katanga) to be packed and shipped through the port of Lobito (Angola) with destination to Port Richmond, Staten Island, New York; over 1200 tons of ore were shipped. The precious hoard of some two thousand steel drums neatly labeled "*Uranium ore, Product of the Belgian Congo*," was warehoused in Staten Island. Contacted repeatedly by Thomas H. Finletter of the State Department, in the procurement of rare metals, Sengier tried to call attention to the uranium in his possession but he elicited no interest.* Sengier decided to wait.

Louis Alexander Turner (1898–?) predicted in 1940 that absorption of a neutron by the nucleus of uranium 238 would result in a new fissile element, but Szilard persuaded him not to publish until after the war.[391] Philip Hague Abelson (1913–) and Edwin Mattison McMillan (1907–) demonstrated that such absorption resulted in the production of *neptunium*(93).[275] Shortly afterwards Glenn Theodore Seaborg (1912–) and Arthur Charles Wahl (1917–) observed that the disintegration of neptunium resulted in a new element which they called *plutonium*(94); Emilio Segrè established that it was 1.7 times more fissionable than uranium 235, as had been predicted theoretically. The great interest of these discoveries was that it opened new possibilities that the highly fissile plutonium could be produced in a reactor. While strolling along the Hudson River, Fermi and Segrè had a long interchange of ideas on the subject of plutoni-

* See Subject Notes on page 183.

um; then they met at Columbia University with Pegram and Lawrence to discuss the production of the needed quantities of plutonium.

The Fermis had moved to an apartment on Riverside Drive; after six months in Manhattan they decided to invest some of the Nobel money in buying a house in Leonia, New Jersey, just across the George Washington Bridge. Their furniture had been shipped and had the time to arrive from Italy. Fermi liked suburban life but did not fall for the American passion of watering the lawn in order to make the grass grow and then have to mow it; yet he enjoyed the do-it-yourself chores imposed by the high cost of labor.

After one year of practical inactivity, the Uranium Committee was expanded to become the National Defense Research Committee, with Briggs retained as chairman; as it turned out not one of its members believed that uranium fission would become important to the war, but an additional grant of $40,000 was made to study the chain reaction.

In the spring of 1941, the Academy of Sciences appointed a committee to review the military importance of uranium, with Compton as its chairman. (See Chapter IX.) Not unlike its predecessor the committee was impressed by the difficulties of separation and was more attracted to its possibilities as a source of power. In the summer, a quickening of interest resulted from news coming across the Atlantic and opinions held by authoritative English scientists.[331] Work done at the Cavendish Laboratories by von Halban and Kowarski had resulted on a report of the MAUD committee to the British War Cabinet; copy of this report had been sent to Washington. Ernest O. Lawrence had personal conversations with informed English scientists who favored the gas-diffusion separation and appeared confident in the feasibility of a bomb. Urged by Lawrence, Compton conferred with Fermi, Urey, and Dunning at Columbia University; Fermi walked to the blackboard and developed, rather simply, an equation from which the critical size of a chain reaction could be calculated. From Fermi, Compton learned that the amount of fissionable material needed for an important atomic explosion would hardly be greater than one hundred pounds. Urey and Dunning were enthusiastic on the possibilities of gas-diffusion separation. In Princeton, Compton found Wigner confident that plutonium could be produced in a graphite reactor. In its next report the Academy's committee reflected this optimism and on December 6, on the eve of Pearl Harbor, decided on an all out effort to achieve the bomb.

Compton decided to concentrate the research efforts at Eckhart Hall at the University of Chicago. Reluctantly, Fermi agreed to move with his project and associates (February 1943); Laura and the children stayed in Leonia till the end of school and Fermi commuted from New York to Chicago. A large number of physicists, chemists, and other scientists also accepted including Anderson, Teller, Zinn, Szilard, and graduate students from Columbia and Chicago. In preparation for a test of controlled chain reaction Fermi delivered a series of lectures, with a resulting wide understanding by all, of the basic principles and problems. Anyone with a reasonable knowledge of physics easily understood the reasoning that led to the lattice constants, the size of the pile, the approach of criticality, the estimates of effectiveness, the working of controls, etc. Principal tasks were the choosing of a cooling system with low neutron absorption, the measuring of reproduction factors, the arrangement of solid rods of neutron absorbing substance for control at any level of energy production. Fermi's lectures were clear and convincing; many of his fellow scientists felt privileged to be edified on the subject. Fermi was no longer able to engage in minor experiments by himself, instead he could order them done and even have the data analyzed by theoretical physicists although he often preferred to do it himself. Exponential experiments were carried out under Walter Zinn.

In the summer of 1942, Fermi and his associates studied and discarded over 30 experimental pile designs. Work started on the preliminaries and construction of the reactor (CP-1).[1] Graphite had to be cut into appropriate size bricks; the oleaginous black dust made the floors slippery and gave the scientists a coal miners countenance. With the assistance of August Charles Knuth (1899–?), a millright, Zinn designed the dies for the pressing or uranium metal and oxide into compact slugs. The scarcity of uranium and of graphite offered difficulties but late in October enough uranium and over 200 tons of machined graphite were available. The pile was to be erected at a site in the Argonne forest near Palos Park, 20 miles from Chicago, but the construction was delayed by a workers' strike. Fermi suggested the alternate use of the University of Chicago stadium; he felt confident that this could be done without risk. After reflection Compton decided to authorize the suggestion without implicating higher university authorities. The chosen site was the 30×60 foot squash racket court in the west stands of Stagg Field. Work started feverishly on November 14: two crews operated around the clock, a day shift headed by Zinn and a night shift by Anderson (Fig. X-7).

Fermi was concerned with the parasitic neutron-capturing air and with the possibility of replacing it with helium. He requested a cloth container to envelope the entire structure: the "square baloon" was promptly provided (Goodyear) on Anderson's specifications. Shrouded in its baloon the pile consisted of an ellipsoid lattice of uranium metal and oxide slugs (about six tons of it), occupying a space 3.09×3.88 meters, all within a matrix of graphite. Each succeeding layer of bricks was braced by a wooden frame. The recording instruments to be embedded in the structure were the charge of Volney Colvin (Bill) Wilson (1910–). Hard-working Leona Woods (1919–), a comely brunette and the only woman in the crew, made the boron trifluoride counters; reserved and conservatively at-

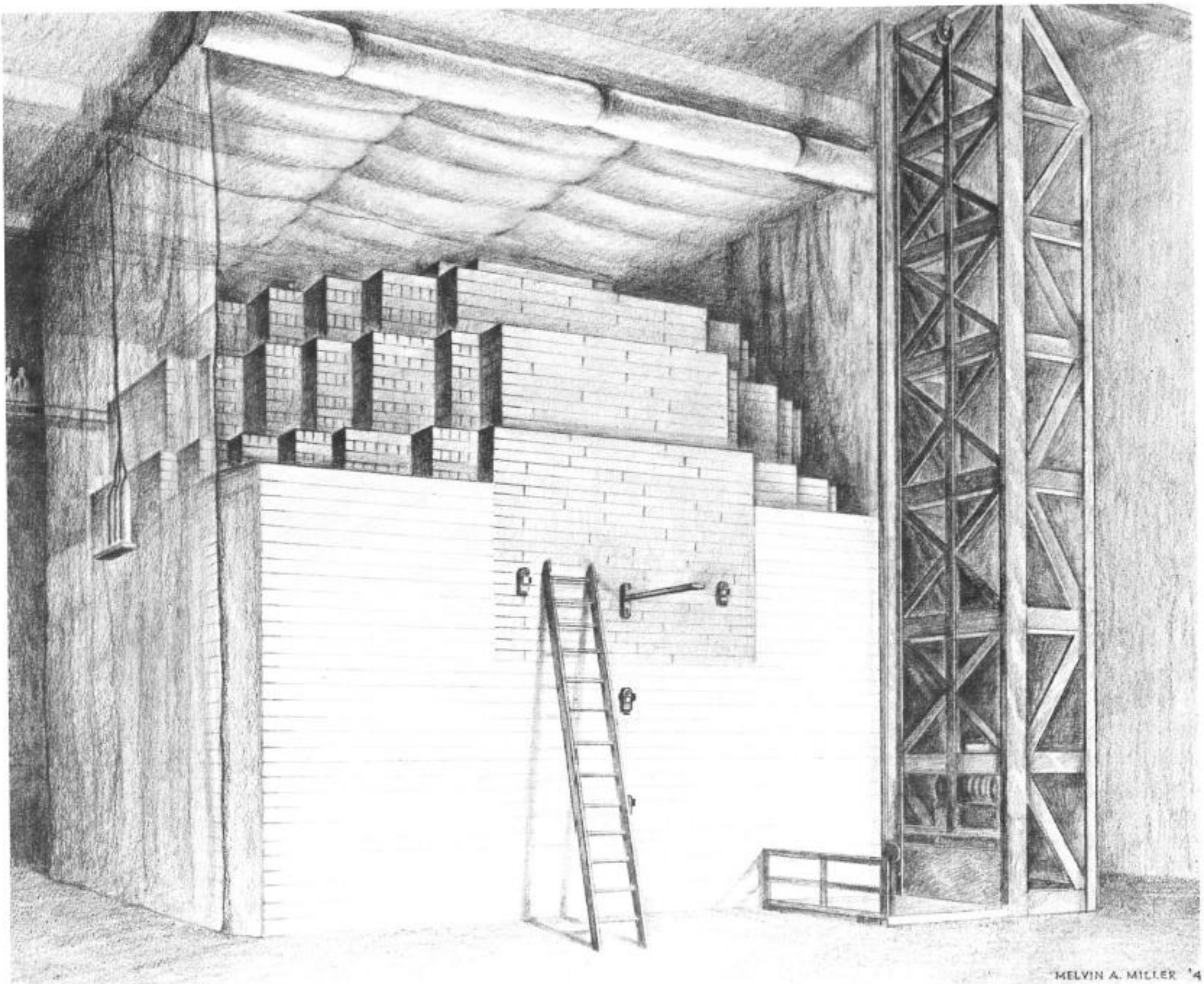

Fig. X-7. The Stagg Field chain reactor (CP-1) of the University of Chicago. (Drawing by Melvin A. Miller.) (Couresy of the Argonne National Laboratory.)

tired, she contributed the only feminine touch on the enterprise; she became Fermi's frequent companion and collaborator.[201] A good portion of this account is based on Anderson's and Leona Libby's[268b] eyewitness recollections.

In the summer of 1942 the uranium research was made the responsibility of the Army Corps of Engineers; Colonel Kenneth David Nichols (1907–) was in charge of procurement. An important meeting of the S-1 committee took place at the Bohemian Grove, in California, with Lawrence as host. The State Department had received from a Canadian company a request for an export permit to purchase uranium from the Union Minière in New York; the information had been passed to Colonel Nichols. Urged to obtain uranium ore Colonel Nichols visited Sengier in his offices in New York (September 18, 1942). The following short dialogue ensued:

—"I am Colonel Nichols and I am here to buy uranium."

—"Do you have contract authority?" inquired Sengier.

—"I am sure that I have more contract authority than you have uranium to sell."

—"I believe I know why you want uranium. I don't ask you to tell me but I do want your assurance that you do want it for war purposes."*

Within one hour Colonel Nichols left Sengier's office with a single sheet of paper from a yellow writing pad, authorizing the transfer to the U. S. Army of 2000 steel drums containing 1200 tons of the richest uranium ore. Before the end of the year Colonel Nichols contracted to purchase all of the additional 3000 tons of uranium already above ground in Katanga, 20 cargo ships transported the mineral from Africa; only two were sunk by enemy submarine action. The eventual price paid for the ore was nominal.

The pile was ready: the 57th and last layer of graphite bricks was placed and the chain reaction trial was scheduled for the next day, Wednesday, December

* See Subject Notes on page 183.

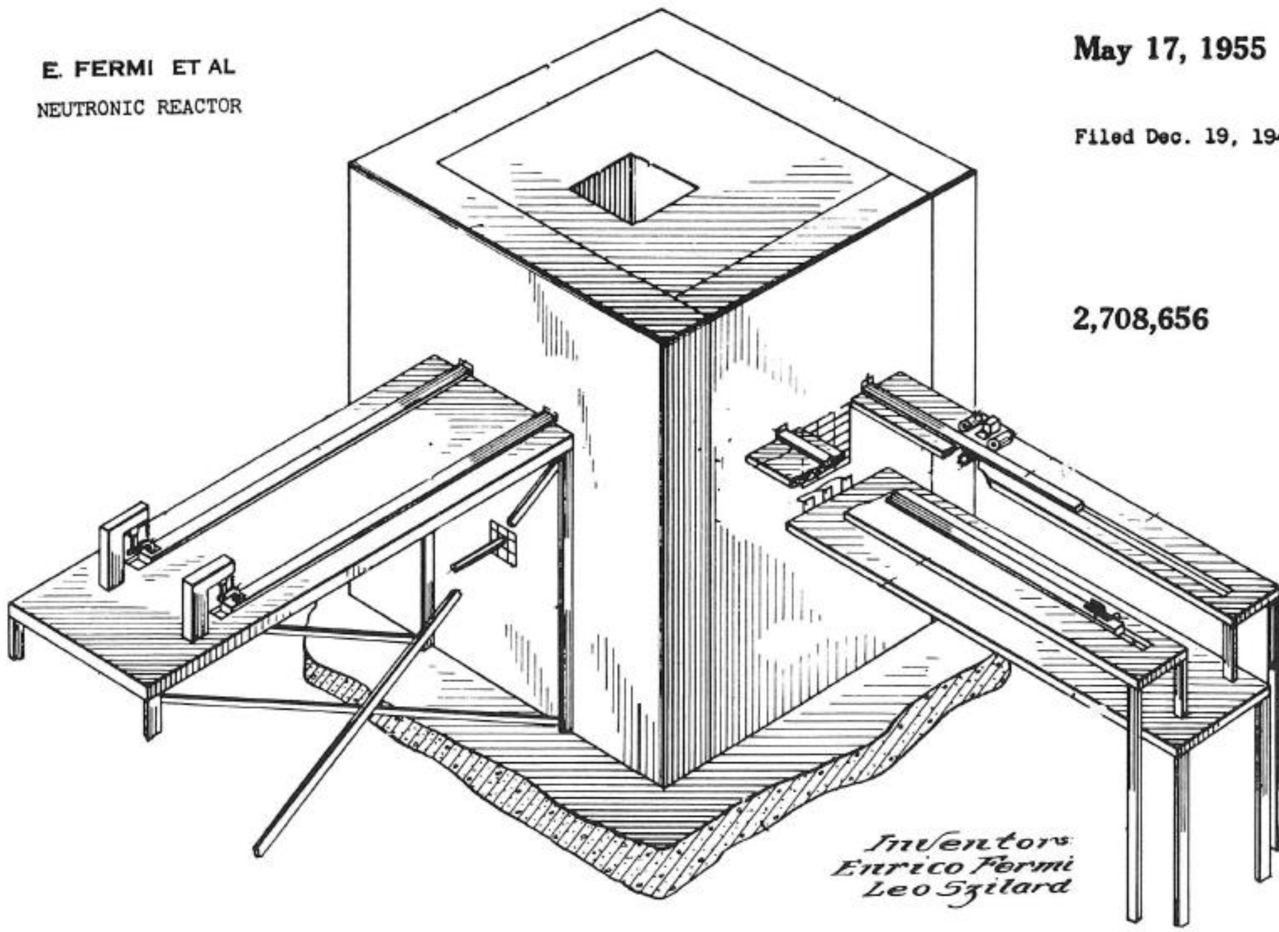

Fig. X-8. Diagram of the basic features of the Chicago pile (CP-1) as presented by Fermi and Szilard in their application for a U. S. patent. (Courtesy of the Argonne National Laboratory.)

2, 1942. At 8:30 A.M. the "metallurgists" started to assemble; they had come in subzero weather that camouflaged their nervous tension. Those not involved in the operation gathered on the balcony, on the north of the court, 20 feet above the ground and facing the pile; the control panels were there. A cadmium control rod was electrically operated from the panel. A vertical control rod ("The Zip") was held suspended; Norman Hilberry (1899–?) could cut the cord that held the weights, free the control to fall in place and stop the reaction. A horizontal *vernier* cadmium rod was to be hand operated by George Leon Weil (1907–), withdrawing it progressively to start the reaction and thrusting it into place to stop it. If everything failed, a "liquid control squad" was in readiness standing on top of the structure prepared to pour buckets of cacmium salt solution through the lattice: Harold V. Lichtenberger (1920–), Warren Edwin Nyer (1921–), and Alvin Cushman Graves (1909–1965).

Calm and confident, Fermi rehearsed the operation in mid morning: satisfied that the counters, the graphic indicators, that the automatic as well as the hand-operated controls functioned as expected, he declared: "Let's go for lunch." As in previous historic moments in his research nothing was permitted to interfere with lunch.

On the afternoon of this historic day, Compton was meeting with consultants of the S-1 Committee: a company (DuPont) was considering assuming responsibility for plutonium production. Informed that Fermi was ready, Compton left Eckhart Hall and brought with him Crawford Greenewalt a young engineer; they joined the onlookers in the balcony where, according to Robert George Nobels (1917–) the "big wheels" surrounded the panels; the team returned to the court. At 2:30 P.M. Fermi instructed George Weil to withdraw the *vernier*; after each foot withdrawn the neutron flux increased: eight, sixteen, thirty-two,...then it would level off. Fermi consulted his slide rule and jotted figures on the sides of it. At 3:20 P.M. he said to Compton: "*This is going to do it*," and shortly afterwards, "*The curve is exponential...the reaction is self-sustaining.*" There was no leveling off of the tracing. Satisfied that there was no need to proceed further, after a few minutes he ordered "*Zip in*": Zinn released his rope, the automatic controls were inserted and the vernier thrust in. It was 3:53 P.M.: an indescribable elation came over most of those present. The core crew remained to lock the controls and turn-off the power supply. From a paper sack, Wigner produced a bottle of Chianti; with no indication of conceit Fermi accepted the gesture and uncorked the bottle: in malapropos paper cups, all those present quietly celebrated the success of the enterprise with a memorable sip.*

"Fermi was," said Compton, "in as full control of his experimental crew as the captain of a ship engaged in critical action."[125] "The experiment" wrote Wigner, "was the culmination of the efforts to prove the chain reaction. The elimination of the last doubts...had decisive influence...on the design and realization of a large scale reaction to produce...plutonium."[402] After the S-1 consultants left, Compton called James Conant in Boston: "Jim" said Compton "the Italian navigator has just landed in a new world."

Fermi trudged over the dry snow on his way home. Laura Fermi was in the final preparations of a party for their friends that had been planned weeks before and happened to coincide with the fateful date. Tired, cold, and in need of relaxation Fermi faced his anxious wife's request to return outdoors to buy cigarettes to offer their guests! As their friends arrived, braving the inclement weather, they would shake hands and congratulate Fermi; puzzled, his wife inquired in vain to learn the reason: "He sank a Japanese Admiral" humored Leona Woods.

The West Stands reactor (CP-1) remained in place only long enough for engineers to become acquainted with it (Fig. X-8). It was dismantled and transported to the Argonne site where a second reactor (CP-2) reached criticality in March 1943. In Chicago, for relaxation, Fermi, Miss Wood, and Anderson used to go swimming in late afternoons in the frigid waters of Lake Michigan, off the breakwater rocks at 55th Street. At the Argonne they went for walks or bicycle rides. In all of these activities, in tennis, pitching pennies, etc. Fermi was always an enthusiastic competitor desirous to win and excel and usually did. Eugene Farmer was Fermi's official alias which always aroused suspicion from checking authorities because of his accent; John Baudino, a young lawyer was assigned as his bodyguard: he proved to be a congenial and cheerful friend and companion.

Urey had argued in favor of a heavy water moderator; as soon as sufficient amounts of it were produced in Trail, British Columbia, Zinn and his group took charge of building another reactor (CP-3) with Fermi's encouragement. Fermi was able to return to his basic research interests with a few devoted associates, among them were John and Leona Marshall.

Work done during this period was classified and not published until after the war. The work, wrote Segrè, forms the starting point of an elegant branch of physics of neutrons. Fermi systematically used the concept of scattering lengths which he had developed years before; the papers are models of simplicity. In solving such problems as shielding a power reactor, insuring thermal stability, he showed considerable engineering talent: his methods are now routine in reactor technology.

Another reactor was being built at Oak Ridge (Site X) and plans for construction of a large plutonium producing reactor at Hanford (Site W) were making heavy demands on scientists and shifting the center of activities. A serious problem developed that paralyzed the Hanford reactor: Fermi was called to help. With the aid of Wheeler and Greenewalt he found that the trouble was a result of a radioactive poison: xenon 135; he predicted that successful operation would result by charging the reactor to the maximum in order to produce enough radioactivity to burn out the poison.

Los Alamos (Site Y) had been developing rapidly; Fermi had been involved in defining its problems and facilitating its program from the beginning. In the summer of 1944 J. R. Oppenheimer pressed him to move to the mesa and make himself available; Oppenheimer hoped that Fermi's tempered judgement would mediate conflicting views that threatened the harmony of the project. From Hanford Fermi proceeded to Los Alamos where his wife and children had preceded him. He was given the title of Associate Director with several projects under his section (F); but he took special interest in the water boiler, a small homogeneous reactor containing a water solution of enriched uranium salt, located in Omega Canyon, near the mesa; Joan Hinton assisted him in this project. In addition Fermi was available in consultation to anyone in need and was asked to lecture on a variety of subjects. John von Neumann was the other oracle in the scientific community. Fermi and von Neumann had genuine admiration for each other and developed a strong friendship: adept to numerical calculations Fermi naturally developed great interest in electronic computers as did von Neumann.

In New Mexico, the Fermis re-encountered Elfriede and Emilio Segrè; the "Basilisk" had been there for over one year. In addition Herbert Anderson and Samuel Allison were there and also a number of old acquaintances: Mitzi and Edward Teller, Hans Bethe, Genia and Rudolf Peierls, whom they had met in Rome a decade previously. Peierls had recently arrived as chief of the British Mission. Niels Bohr and his son Aage also came. We have recounted elsewhere (Chapter VII) how Bohr's discussions awoke the conscience of the scientists, including Oppenheimer's and gave them a sense of their responsibility in the development of atomic warfare.

In many ways, wrote Laura Fermi, Los Alamos was a socialistic community run by the U. S. Army. Apartments were allotted discriminatingly: number of rooms according to size of the family, rent according to size of the paycheck. The Fermis declined the privilege of a house in "Bath Tub Row," reserved for "big wheels." Wives were encouraged to take ancillary jobs and, if they did, were provided with domestic help.

* See Subject Notes on page 183.

Censorship was evident. At 7:00 A.M. a siren (Fermi called it Oppie's whistle) gave one hour's notice of the start of the long day's work. Fermi enjoyed the opportunity of open air relaxation on Sundays. With his family, associates, or visitors he took long hikes in the Sangre de Cristo Mountains climbing Lake Peak for a look at the valley of the Pecos and walking along the Frijoles Stream; by the tall Ponderosas and through the narrow canyons he learned to keep away from skunks and to be alert to the sound of rattle snakes in the sage brush. He also went trout fishing or exploring old Pueblo ruins. In the winter of 1944–45 he enjoyed skiing on Sawyer Hill often in the company of the surprisingly deft Niels Bohr.

In the beginning of 1945 it became evident that a test of the implosion mechanism of the plutonium bomb was necessary. Fermi took part in the long and elaborate preparations of Project Trinity. Appointed by the Secretary of War to an advisory committee and instructed to evaluate the various views on the eventual use of the bomb, Fermi, Compton, Lawrence, and Oppenheimer met for two days in Los Alamos and unanimously, though reluctantly, concluded that there was no alternative to the direct military use of the bomb (June 16). One month later, at Alamogordo, Fermi was part of a group of observers who waited in the dark listening to Allison's count down, 10 km away from the tower where the first plutonium bomb was exploded (July 16). The night before, during dinner, Fermi worried General Groves by inviting bets on whether the destruction will extend to the observers or to the whole of New Mexico. Prepared to estimate the power of the explosion, in his own informal way, he dropped a number of small pieces of paper as the blast reached them: judging by the distance they traveled he estimated 20 kilotons (TNT equivalent), a figure comparable to that obtained by other means. Present in Alamogordo on that historic occasion were Rudolph Peierls, and Otto Frisch who five years previously had made the first estimate of the critical size of the uranium bomb; present was also Klaus Fuchs who had already betrayed the trust of his British and American hosts. Fermi went with Anderson in a heavily shielded army tank to scoop crystalized sand from the bomb crater for analysis.

Following the end of the Second World War, Fermi taught a course of lectures on nuclear physics, including thermonuclear reactions. He loved to teach and there is little doubt that if Los Alamos had been a university he may have chosen to remain there. Meanwhile Compton had ambitious plans to develop three new institutes (nuclear physics, radiobiology, metallurgy) at the University of Chicago; President Hutchins and the administration were eager to support him. Fermi was offered the directorship of the Institute for Nuclear Physics but he successfully urged that it be offered to Samuel K. Allison. Free from administrative duties, for which he had no inclination, he was able to give himself to teaching and research while collaborating wholeheartedly with Allison (Fig. X-9). He became Charles H. Swift Distinguished Service Professor of Physics at the University. He began lecturing in January 1946; a number of graduate students, freed from war obligations, came to study under him. His lectures were simple and clear. The staff of the new Institute included impressive protagonists in nuclear research: James Franck (1882–1964), Harold Clayton Urey (1893–1981), Edward Teller (1908–), Eugene Paul Wigner (1902–), Willard F. Libby (1908–). At the Institute, said Allison, Fermi was the outstanding source of intellectual stimulation: he attended every seminar and brilliantly essayed every new idea or discovery. He arrived first in the morning and left late at night, filling each day with his outpouring of mental and physical energy. The Fermis bought a house at 5327 University Avenue, to where their furniture from Italy was now moved. In the basement, power tools formed a shop. Nella was now a young lady attending college and Giulio went to the University Laboratory School.

One of the early appointees of the Argonne National Laboratory was Maria Goepper-Mayer (1906–1972) who had an unusual grounding in mathematics and quantum mechanics. She pursued the investigation of the notion of nuclear shell structure. Discussing these matters with her, while running to the telephone, Fermi asked: "Is there any evidence of spin-orbit coupling?" It was the suggestion that she needed for she immediately identified the key numerical relationship. Returning after a few minutes Fermi was impressed by her rapid solution. She developed an orbit-coupling model and later collaborated with T. Hans D. Jensen (1907–) on the elementary theory of shell structure for which they both received the Nobel Prize in 1963.

In October 1946 the U. S. Atomic Energy Commission was created and Fermi received one of the first appointments to the General Advisory Committee. These duties plus his great interest in electronic computers took him back frequently to Los Alamos. In Chicago the laboratory shelves were bare and a cyclotron would not be in operation for months. But Zinn's heavy water reactor was operational at Argonne and it was natural to take advantage of it. Fermi and Leona Marshall made studies of the interference phenomena and of the spin dependence of scattering[200,201] of slow neutrons. He also collaborated with Teller,[203] with whom he had heated discussions on cosmic rays; this led him to put down his own ideas of their origin[191] (Fig. X-10).

In 1949, a conference was called in Basel, Switzerland, on high energy physics, followed by another conference in Como, Italy, on cosmic rays. Fermi participated in both. In Basel he swam in the Rhine; in Como he met Amaldi and other friends and played tennis with Pontecorvo. It was Fermi's first return to the country of his birth. In Milan and Rome he lectured under the auspices of the restored *Accademia dei Lincei* now presided upon by the venerable Professor

Fig. X-9. Lecturer Fermi at the blackboard (1946). (Courtesy of the Fermi Institute of Nuclear Studies, University of Chicago.) Signature.

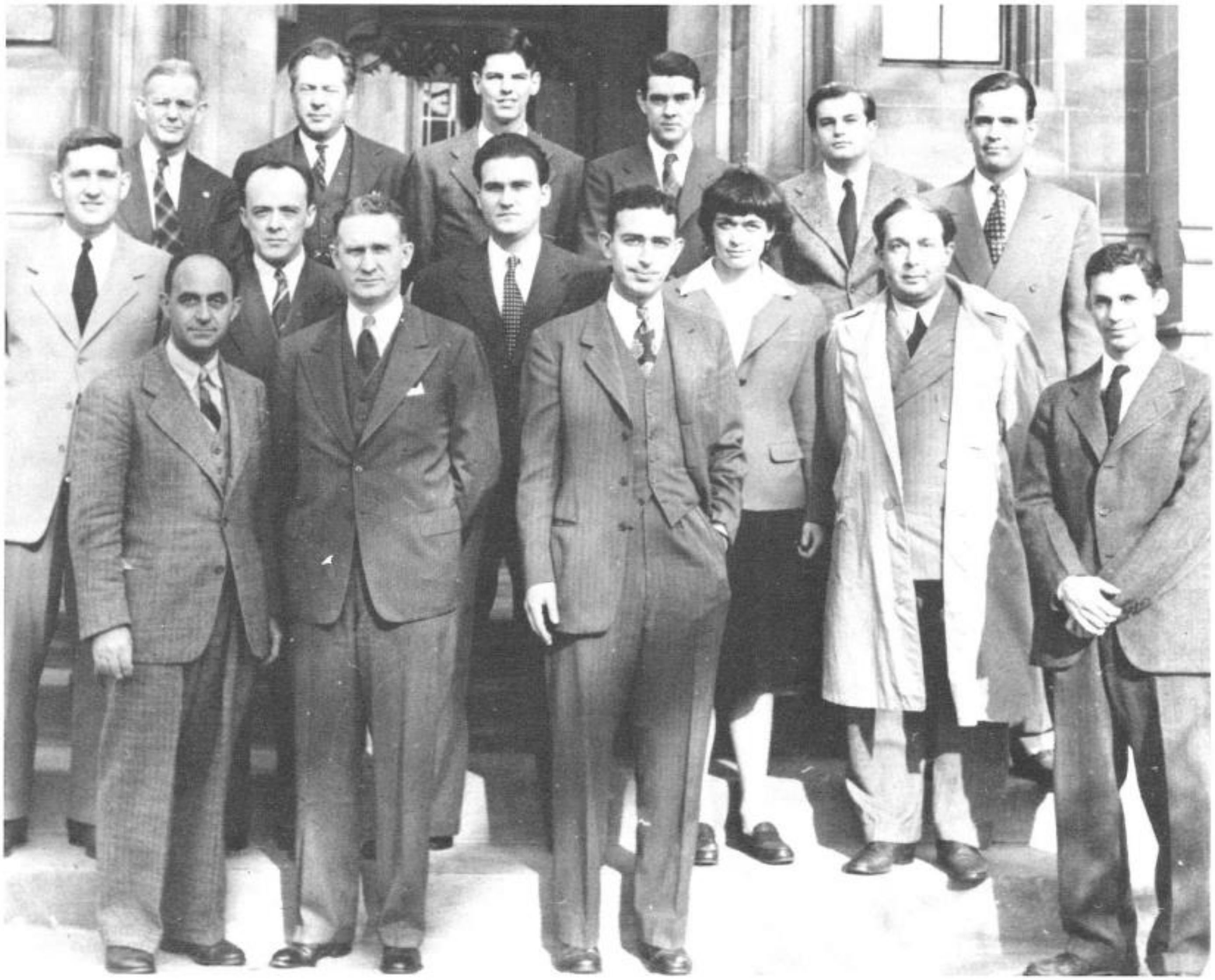

Fig. X-10. Group of participants in the First Chain Reaction in front of Eckart Hall on its fourth anniversary (December 2, 1946). *Front row*: Enrico Fermi (1900–1954), Walter Zinn (1906–), Albert Wattenberg (1917–), and Herbert Lawrence Anderson (1914–). *Middle row*: Harold Melvin Agnew (1921–), William James Sturm (1917–), Harold V. Lichtenberger (1920–), Leona Woods Marshall (1919–), and Leo Szilard (1898–1964). *Back row*: Norman Hilberry (1899–?), Samuel King Allison (1900–1968), Thomas Brill (1920–), Robert George Nobles (1917–), Warren Edwin Nyer (1921–), and Marvin Robert Wilkenning (1918–). (Courtesy of the Fermi Institute of Nuclear Studies, University of Chicago.)

Guido Castelnuovo (1865–1952) a notable mathematician who had known Laura and Enrico Fermi as youngsters.

Fermi had great confidence in his analytical powers and seemed to be always in control of his thoughts, but he was well aware of his fallibility in matters other than physical. Among intellectual friends he would venture to express opinions that carried no consequences but out of a genuine integrity he was reluctant to pass judgement on serious problems or persons. His position on the General Advisory Committee of the Atomic Energy Commission was to bring him to emit a serious opinion that proved controversial. On September 23, 1949, President Truman announced the detection of an atomic explosion in the Soviet Union. The AEC asked the General Advisory Committee for their recommendation in reference to the development of the hydrogen bomb. Unable to attend, Glenn Seaborg had sent a letter stating that he had been "unable to conclude that we should not." Meeting in Washington under J. Robert Oppenheimer as chairman the committee members listened to Ambassador George Frost Kennan (1904–) and General Omar Bradley (1893–1981) then, in a closed session, unanimously rejected the plan. "We are all agreed—said the report—that it would be wrong at the present moment to commit ourselves to an all-out effort...towards its development... . We are all reluctant to see the U. S. take the initiative in precipitating this development." Fermi and I. I. Rabi stated in addition, in a written common statement: "*The fact that no limits exist to the destructiveness of this weapon makes its very existance and the knowledge of its construction a danger to humanity... . We think it is wrong, on fundamental ethical princi-*

ples, to initiate the development of such a weapon." It has often been overlooked that both these quoted statements condemned the *initiative* at a time when there was no certainty that it was possible to produce a thermonuclear weapon.*

The recommendation of the GAC was adopted by the AEC but within weeks President Truman disregarded their decision and authorized a crash program. Within months Stanislaw Marcin Ulam (1909–) made new calculations and proposed a new approach on the basis of which a thermonuclear device became a possibility. Teller was now able to impress his colleagues of the feasibility of the hydrogen bomb and many of his previous antagonists now were willing to help.

In the spring of 1951 the University of Chicago synchrocyclotron became operational. Fermi had prepared himself, his associates, and students for the eventual experiments on high energy physics. He developed methods for calculating orders of magnitude, cross section, collisions of pi-mesons, etc. (They coined the new names: pions, muons.) Moreover he spent time with the computers at Los Alamos to check on his statistical methods.[194] These studies were later collectively published in a book on elementary particles.[192]

Fig. X-12. Laura and Enrico Fermi (1954) with his ever-ready slide rule. (Courtesy of the Argonne National Laboratory.)

Fig. X-11. Portrait of Fermi. (Courtesy of the Fermi National Accelerator Laboratory.)

In 1953, Fermi was asked to deliver the Sixth Henry Morris Russell Lecture by the American Astronomical Society: he delivered his views that cosmic rays are accelerated at the expense of turbulent energy and that cosmic radiations and magnetic fields must be counted as very important factors in the equilibrium of interstellar gas[193] (Fig. X-11).

The notorious Inquiry in the Affair Oppenheimer brought Fermi to testify (April 20, 1954). He was questioned rather briefly on the subject of the General Advisory Committee's recommendation against a crash program to develop the H bomb and about Seaborg's letter: the point sought was to emphasize Oppenheimer's role. Fermi regretted to his last days that he was not given a chance to express his opinion of Oppenheimer's character and loyalty.

In the summer of 1954 Fermi returned to Italy to teach a course on pions and nucleons at the summer school of the Italian Physical Society, in Villa Monastero, in Veronna, Lake Como. He also lectured at Les Houches, in the Chamonix Valley in Haute Savoie, France. Here was Fermi at the height of his powers, wrote B. T. Fields, bringing order and simplicity out of confusion, finding connections between seemingly unrelated phenomena: wit and wisdom emerging from his lips in a resonant voice that never lost its soft Italian accent (Fig. X-12).

* See Subject Notes on page 183.

Fig. X-13. Aerial view of handsome Robert Rathbun Wilson Hall of the Fermi National Accelerator Laboratory in Batavia, Illinois. Named after its designer and first director, the architecture is said to have been inspired by the unfinished but glorious foreshortened structure of the Cathedral of Beauvais, near Paris. (Courtesy of Fermi Lab.)

During his vacation in the Alps, Fermi noticed unusual anorexia and resulting loss of weight. Upon his return to Chicago he entered Billing's Hospital where a diagnosis of inoperable carcinoma of the stomach was established. Many of his friends went to Chicago to visit him in his hospital bed, most were impressed with his rapid physical deterioration and all admired his moral fortitude. Some recalled pleasant memories and assured him of their unfaltering loyalty[268b]; one admitted to a semireligious compulsion to confess to him as a priest.[89] To one of his visitors Fermi murmured, "*I hope it won't last long anymore.*" It did not. He died on November 29, 1954.

Rather expeditiously at the suggestion of the Atomic Energy Commission, the United States Government created an award consisting of a medal and a cash prize: it was delivered to Fermi shortly before his death. The prize called the Fermi Award is now offered annually. Fermi had previously received the Hughes Medal of the Royal Society (1942), the Congressional Medal of Merit (1946), the Bernard Medal (1950), the Rumford Medal (1953), and the Planck Medal (1954). He had also received doctorates *honoris causa* from Columbia (1946) and Harvard University (1948).

The University of Chicago Institute of Nuclear Studies is now named after Fermi. The National Accelerator Laboratory is also named after him and popularly known as the Fermilab (Fig. X-13). It is operated by the University Research Association in Batavia, Illinois, 30 miles west of Chicago. The Central Laboratory is an attractive 16-story building inspired by the cathedral of Beauvais; it contains a synchrotron, a scientific instrument of remarkable proportions permitting the study of subnuclear particles; an extraordinary monument to the memory of an extraordinary man.

Herbert Anderson affectionately referred to Fermi as "my boss, the sawed-off little wop." Ulam described him as short, sturdily built, with strong arms and legs and moving rather fast. His eyes, darting at times, would be fixed reflectively when he was considering some question, his fingers often nervously playing with a pencil or slide rule. He usually appeared in good humor, a smile perpetually playing around his lips.[392] Fermi, added Ulam, had tremendous self-assurance, will-power, and persistance rather than obstinacy. The whole process of wresting from Nature her secrets, wrote Anderson, was for Fermi an exciting sport which he entered sith supreme confidence and great zest; he possessed a sure way of starting off in the right direction. He had a supreme sense of the important, dissecting problems, setting aside irrelevancies in order to attack each part separately. He possessed great mathematical technique that he used keenly. But first and foremost, wrote Leona Libby, he was a physicist, day and night, with the slide rule at the ready in his breast pocket and his mind relating ideas to numbers.[268b] When he talked he strived for the utmost simplicity: ideas appeared natural, direct, clear. Sublimated common sense characterized his thoughts.[392] On any problem confronted he was able to bring to bear his profound feeling for physical laws.[93] He sketched his ideas qualitatively and briefly, so that one caught the image and felt a desire for deeper understanding.[268b] He was an extremely lucid lecturer, wrote Chen Ning Yang (1922–) (Nobel 1957), the very simplicity of his reasoning conveyed the impression of effortlessness, but the impression was false.[194] The typical style of Fermi's writing, wrote Segrè, is a close reflection of his personal and intellectual history, his papers make easy reading so that an able student may profit by their study but they often have deep recondite implications; his writings are not noted for literary style but he was almost pedantic as to scientific precision.[369]

Chandrasekhar listed Fermi's contributions: transport in general relativity; discovery of slow neutrons; Fermi–Dirac's statistics; Fermi's resonance; theory of beta-decay; first sustained chain reaction; mechanism for acceleration of charged particles in random magnetic fields; discovery of the first resonance in the proton–pion scattering.[93]

In conversation Fermi looked inquisitive and his interlocutor usually was treated to Socratic questioning rather than to expressions of opinion. He avoided impulsive gestures and deliberately controlled gesticulations and mannerisms. Usually calm and mildly amused, rarely impatient; he smiled and laughed readily. He accepted unpleasant situations with sweet reasonableness: he was, wrote Leona Libby, an amazingly comfortable companion.

Surprisingly, Fermi had no interest in any of the arts. Listening to a colleague playing on Teller's Steinway piano he admitted that his appreciation of music was limited to simple tunes. Accompanying friends on a visit of the Chicago Museum of Modern Art he entertained himself computing ratios of limb length to stature from various paintings. Poetry and philosophy did not appeal to him; he thought of them as passé. For a man of his keen intellect he appeared remarkably devoid of the cultivated appreciation, and enjoyment, of beauty in its various manifestations that we call culture.

Fig. X-14. "Nuclear Energy," twelve-foot bronze sculpture by Henry Moore, standing at the site of the first sustained chain reaction at the University of Chicago.

Fermi had what Ulam called a semi-logical whimsical humor: commenting on Segrè's struggle to hook a fish he said that it was a battle of wits; he once asked Teller, if Hungarians are so smart how come they have invented nothing? If he lost 6 to 4 in a tennis match he declared the result invalid because the difference was less than the square root of the number of games.

Anyone with more than a trivial acquaintance with Fermi, wrote Samuel Allison, would recognize at once that he possessed the most extraordinary endowment of the highest human capabilities. One might have encountered in someone else his physical energy, or his basic balance, or his simplicity, his sincerity or even his mental brilliance; but who, in his lifetime, asked Allison, has seen such qualities combined in one individual?[194]