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The Odd Couple and the Bomb

Like a story by Victor Hugo as told to Neil Simon, the events leading up to the first controlled nuclear chain reaction involved accidental encounters among larger-than-life figures, especially two who did not exactly get along—but had to

by William Lanouette

On the eve of World War II, European physicists Enrico Fermi and Leo Szilard both moved into the King's Crown Hotel, near Columbia University in New York City. Although they had previously exchanged letters, they met by chance at the hotel in January 1939. The encounter led to one of the more colorful—and contentious—partnerships in the history of science.

Each man was a refugee from European fascism, and each possessed essential pieces to the puzzle that would ultimately release the energy of the atom. They quickly realized, however, that a joint effort would require them to overcome deep differences in their worldviews, work styles and basic personalities. Had Fermi and Szilard failed to persevere in their often uncomfortable collaboration, the world's first controlled nuclear chain reaction would not have been developed by 1942, and the Manhattan Project would not have built the first atomic bombs by 1945. As Szilard later reflected, "If the nation owes us gratitude—and it may not—it does so for having stuck it out together as long as it was necessary."

Crossed Paths

The 38-year-old Enrico Fermi had just arrived in New York from Rome. The trip included a stop in Stockholm to receive the 1938 Nobel Prize in Physics, for work in which he had bombarded the element uranium with neutrons, which created new transuranic (heavier-than-uranium) elements. Fearing new racial laws in fascist Italy, Fermi and his Jewish wife decided against returning home. Instead he accepted one of four American offers and took a job at Columbia.

Leo Szilard, a 40-year-old Hungarian Jew, came to New York by a more circuitous route. He left his native Budapest in 1919 for Berlin, where he studied and worked with Albert Einstein. Initially, the two shared some ideas and several patents for an electromagnetic refrigerator pump [see "The Einstein-Szilard Refrigerators," by Gene Dannen; SCIENTIFIC AMERICAN, January 1997]; two decades later their relationship would take on vast historical significance.

When Adolf Hitler took power in 1933, the wary Szilard fled to London. That same year, he conceived the idea for a nuclear "chain reaction" that, according to his 1934 patent application, might produce "electrical energy" and possibly "an explosion." Such chain reactions would eventually take place in nuclear power plants and in nuclear weapons. First, however, an element that could foster a chain reaction would have to be discovered. After four years of failed experiments at the University of Oxford and then at the universities of Rochester and Illinois in the U.S., Szilard, too, came to Columbia.

Fermi was a rigorous academic whose life centered on a brilliant physics career; he had little interest in politics. A homebody, he soon moved his family from the King's Crown to a house in suburban New Jersey. He awoke at 5:30 each morning and spent the two hours before breakfast polishing his theories and planning the day's experiments. Rare among 20th-century scientists, Fermi was a gifted theoretical physicist who also enjoyed working with his hands. When not lecturing, he toiled in the laboratory with his dedicated assistants, making and manipulating equipment.

An unemployed "guest scholar" with no classes or lab of his own, the bachelor Szilard rarely taught, published infrequently and dabbled in economics and biology. He lived in hotels and faculty clubs and enjoyed soaking for hours in the bathtub to dream up fresh ideas. (One later inspiration was that the National Science Foundation should pay second-rate scientists *not* to conduct research.) Szilard read newspapers avidly, speculated constantly about financial, political and military affairs, and always kept two bags packed for hasty escapes from any new eruptions of fascism.

A late sleeper, he often appeared at Columbia only in time for lunch, after which he would drop in on colleagues, posing insightful questions and suggesting experiments *they* should try. "You have too many ideas," future physics Nobel laureate Isidor Isaac Rabi finally said to him. "Please go away."

The late Massachusetts Institute of Technology physicist Bernard Feld worked with Fermi and Szilard as the latter's research assistant at Columbia. He summed up the two men: "Fermi would not go from point A to point B until he knew all that he could about A and had reasonable assurances about B. Szilard would jump from point A to point D, then wonder why you were wasting your time with B and C."

Within days of the chance meeting between Fermi and Szilard at the King's Crown Hotel, Danish physicist Niels Bohr landed in New York with important word from Europe: physicist Lise Meitner, a Jew who had fled from Germany to Stockholm, had determined that Berlin chemists Otto Hahn and Fritz Strassmann had caused uranium to undergo "fission" via neutron bombardment. They had split the atom. (In 1966 the three would win the Enrico Fermi Award for this work.) Bohr's report helped Fermi come to a more complete understanding of his own 1934 uranium experiments; in addition to creating transuranic elements, he had unknowingly split atoms.

To Szilard, the news was more ominous. He realized that uranium was the element that could fuel the chain reaction described in his 1934 patent application. Betting on his political insight, he had assigned that patent to the British Admiralty in secret, lest he alert German scientists to the possibility of atomic explosives. The discovery of fission confirmed Szilard's fears that an atom bomb could soon be a decisive reality.

The notion of the nuclear chain reaction had first come to Szilard while he was standing on a London street corner in 1933. The neutron had been discovered only the previous year, and physicists now thought of the atom as resembling a solar system, with negatively charged electrons orbiting a nucleus of positively charged protons and neutral neutrons. Having no charge, a neutron hurled at an atom might stealthily penetrate the nucleus without being repelled. Szilard imagined that if a neutron hit a nucleus and split the atom, the breakup might release the binding energy that holds the atom together. Some of that atom's neutrons might in turn be released, which could hit and split other atoms. If more than one neutron was released from each split atom, the process could exponentially expand, with millions of atoms splitting in a fraction of a second and freeing vast amounts of energy. (Szilard would later learn that Bohr's news enabled Fermi likewise to envision a chain reaction, although he considered one extremely unlikely.)

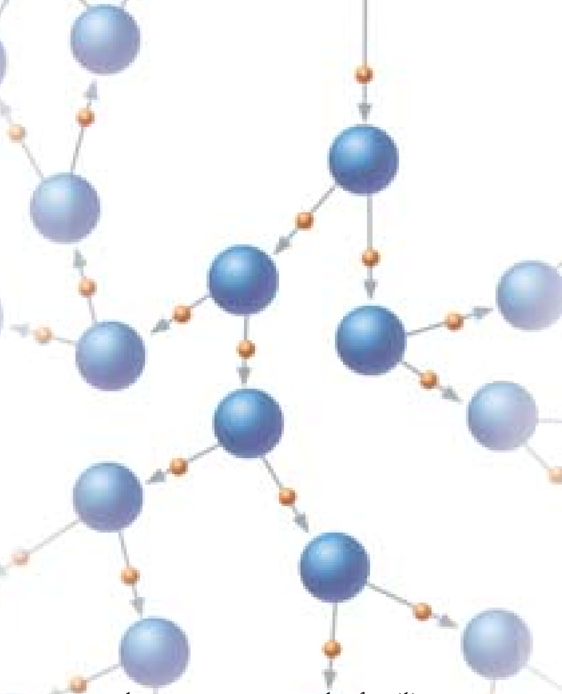
While Szilard was filing his patent in 1934, Fermi was in Rome, becoming the world's expert on neutron bombardment of atoms. He found that by passing the neutrons through paraffin wax he could slow them down, increasing the chance that they would be absorbed by the target nucleus. His work with uranium was puzzling. Sometimes the nucleus absorbed neutrons. (Because atomic identity is governed by the number of protons, the neutron absorption produced only heavier variants, or isotopes, of uranium.) But sometimes neutron bombardment created entirely new elements. German chemist Ida Noddack, following Fermi's experiments in journal reports, suggested a chemical analysis of the new species to see if they were the fragments of split atoms. But Fermi, concentrating on the physics of bombardment and absorption, did not pursue the implications of those new elements. Had he done so, he might have recognized nuclear fission years before Meitner.

At Columbia in the spring of 1939, Fermi and Szilard each tried experiments aimed at a better understanding of fission. Szilard offered Canadian physicist Walter Zinn a radium-beryllium neutron source he had just ordered from England. With it, Zinn and Szilard showed that more than two neutrons escaped during fission. Fermi and his assistant Herbert Anderson tried a similar experiment using a more powerful radon-beryllium source, with inconclusive results. Szilard guessed that the source was too strong, enabling some neutrons to pass right through the nucleus and making it hard to know if they were counting neutrons from fission events or merely the original neutrons. Szilard loaned Fermi his English neutron source, which gave much clearer results.

The two men then attempted to work together—with a resounding clash of individual styles. Szilard shunned manual labor in favor of brainstorming, but Fermi expected all his team members to participate in hands-on experiments. Although the men respected the other's abilities, they bristled in the other's company. Recognizing their mutual need, however, they reached out to Columbia's physics department chairman, George Pegram, who agreed to coordinate their separate work. Pegram's shuttle diplomacy harnessed Fermi's precision and Szilard's prescience. With Anderson, the combative colleagues succeeded in determining that by using slow neutrons "a nuclear chain reaction could be maintained."

Building the Chain

Although collisions between Fermi and Szilard were all too common, collisions between neutrons and nuclei were at first too rare. Passing the neutrons through so-called moderators, such as Fermi's paraffin, helped to slow them, making their collision with an atom's nucleus more likely. By 1939 physicists also knew that "heavy water" was an efficient moderator. Ordinary, or "light water," consists of two hydrogen



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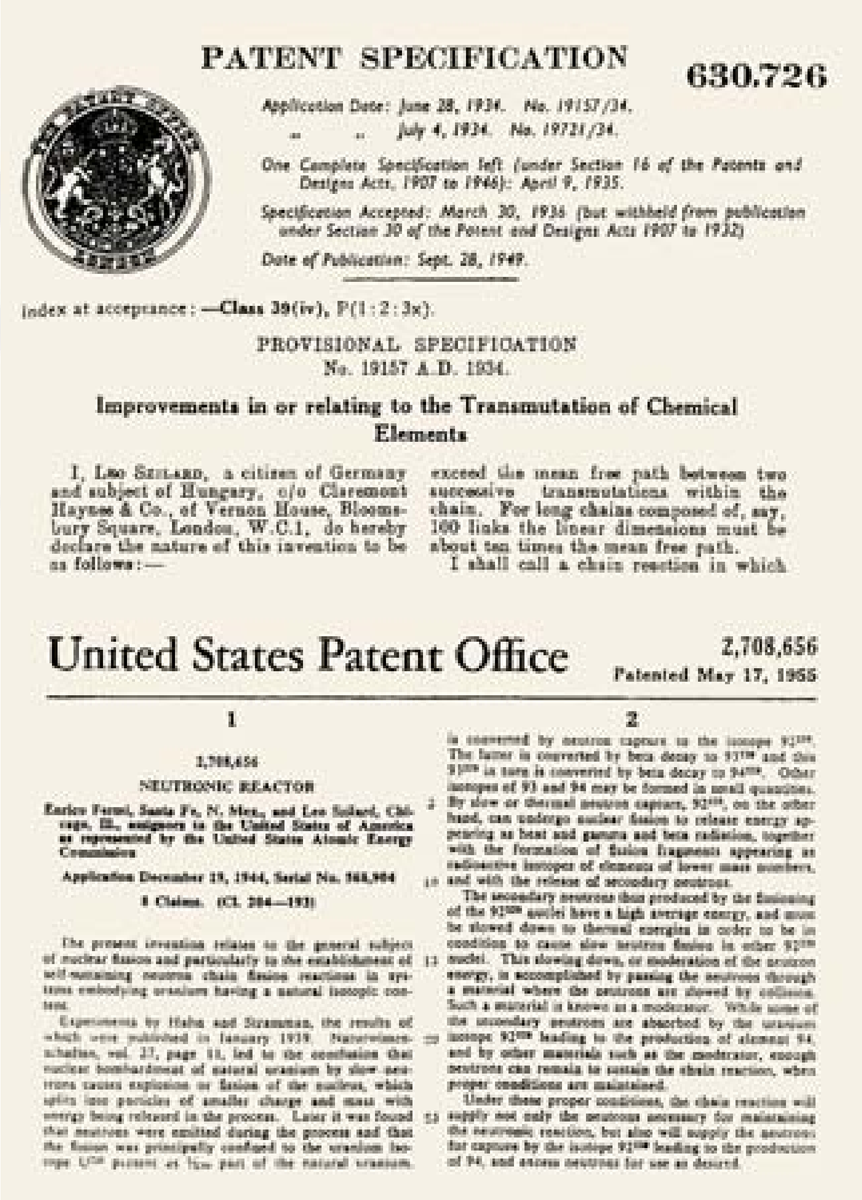
atoms and an oxygen atom, the familiar H_2O. In heavy water, two heavy isotopes of hydrogen, called deuterium, unite with the oxygen. (Heavy water is still used as an effective moderator for natural uranium fuel in today's nuclear reactors, whereas light water is used for enriched uranium fuel.) But heavy water was expensive and scarce. The large-scale experiments that Szilard had in mind would require a more common and affordable moderator. He would discover one that his German counterparts had overlooked.

As Szilard had feared, German atom-bomb research was well under way by the spring of 1939. Both German and American physicists also recognized that graphite—the soft form of carbon that is used as pencil lead—could be a moderator. But German scientists gave up on it because it absorbed too many neutrons; they instead concentrated on heavy water, always in short supply. Szilard, who often personally took trains to Boston or Buffalo to procure raw materials for Fermi's experiments, realized that commercial graphite also contained small amounts of boron—a voracious absorber of neutrons. He ordered custom-made, boron-free graphite, which eventually led to one of the most caustic Fermi/Szilard confrontations.

Anderson measured neutron absorption in the pure graphite and found that it would indeed make a good moderator. Szilard recommended that the test results remain secret. Fermi, ever the professional scientist, objected to the breach of the long-standing academic tradition of peer-reviewed journal publication. "Fermi really lost his temper," Szilard would later recall. "He really



PATENT SPECIFICATION 630,726

Application Date: June 28, 1934. No. 19157/34.
" " July 4, 1934. No. 19721/34.

One Complete Specification left (under Section 16 of the Patents and Designs Acts, 1907 to 1946): April 9, 1935.

Specification Accepted: March 30, 1936 (but withheld from publication under Section 30 of the Patent and Designs Acts 1907 to 1932)

Date of Publication: Sept. 28, 1949.

Index at acceptance:—Class 39(iv), P(1:2:3x).

PROVISIONAL SPECIFICATION
No. 19157 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, Leo Szilard, a citizen of Germany and subject of Hungary, c/o Claremont Haynes & Co., of Vernon House, Bloomsbury Square, London, W.C.1, do hereby declare the nature of this invention to be as follows:—

exceed the mean free path between two successive transmutations within the chain. For long chains composed of, say, 100 links the linear dimensions must be about ten times the mean free path.

I shall call a chain reaction in which

United States Patent Office 2,708,656
Patented May 17, 1955

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2,708,656
NEUTRONIC REACTOR

Enrico Fermi, Santa Fe, N. Mex., and Leo Szilard, Chicago, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application December 19, 1944, Serial No. 568,904

8 Claims. (Cl. 204—193)

PATENT awarded to Szilard in England for the chain reaction idea was assigned to the British Admiralty and remained secret until after the war. A U.S. patent for the actual reactor was awarded jointly to Fermi and Szilard.

thought this was absurd." Pegram once again interceded, however, and Fermi reluctantly agreed to self-censorship under these special circumstances.

With the graphite moderator, Fermi thought there might now be at least a ray of hope for a self-sustaining chain reaction. On the question of how realistic that hope was, Fermi and Szilard had also shown distinctly different modes of thinking. Szilard fretted that the Germans were ahead in a nuclear arms race; in the American vernacular that Fermi enjoyed trying out, he reacted to Szilard's speculation with "Nuts!" Fermi thought that any atom bombs were perhaps 25 to 50 years away and told colleagues that actually creating the self-sustaining chain reaction was "a remote possibility" with perhaps a 10 percent chance.

"Ten percent is *not* a remote possibility if it means that we may die of it," Isidor Rabi replied. Szilard noted how differently he and Fermi interpreted the same information. "We both wanted to be conservative," Szilard later recalled, "but Fermi thought that the conservative thing was to play down the possibility that this may happen, and I thought the conservative thing was to assume that it would happen and take the necessary precautions."

These precautions included Szilard borrowing $2,000 to support Fermi's research. Nevertheless, in the summer of 1939 Fermi showed his relative lack of concern over the implications of nuclear research by leaving for the University of Michigan to study cosmic rays. The world's first successful design for a nuclear reactor was thus created neither in a lab nor a library but in letters.

Szilard, typically, urged starting "large scale" experiments "right away." Fermi, typically, remained skeptical. Szilard proposed stacking alternating layers of graphite and uranium in a lattice, the geometry of which would define neutron scattering and subsequent fission events. Fermi countered with a homogeneous design in which the uranium and graphite would be mixed like gravel. The suggestion angered Szilard, who concluded that Fermi preferred it only because it was an easier configuration about which to make calculations. Fermi responded that further reflection had convinced him of Szilard's lattice idea. Once sold, Fermi applied his substantial ingenuity to determining the lattice's physical properties and coordinating the personnel necessary to make a reactor.

Friends in High Places

Szilard recognized that despite his and Fermi's brainpower, they would still need help from important allies for their collaboration to succeed. They would get it from an unlikely trio: Franklin D. Roosevelt, J. Edgar Hoover and Albert Einstein.

During the summer, Szilard learned that Germany was restricting uranium supplies. He assumed that this indicated fission research and wanted to alert the federal government. With the instincts of a public relations expert, he turned to his mentor and friend Einstein, who was living at a summer cottage on Long Island, about 70 miles east of New York City. Szilard told the renowned physicist about the chain reaction. "I haven't thought of that at all," Einstein replied, seeing at last a mechanism that might make real the mass-energy conversion of his famous equation.

Szilard made two visits to Einstein, the second to discuss a letter for him to sign. "Szilard could do anything, except he could not drive a car," recalls his second-trip chauffeur, a fellow Hungarian refugee scientist. "And I could drive a car. And, therefore, I drove Szilard to the summer place.... Einstein was a democrat in that he invited not only Szilard for a cup of coffee but also his driver." Edward Teller was thus present when Einstein, wearing an old robe and slippers, read and agreed to sign the now well known letter to President Roosevelt. The letter, dated August 2, 1939, began, "Some recent work by E. Fermi and L. Szilard. . . ." It proceeded to warn of German atomic weapons research and urged the U.S. to do its own.

Szilard passed the letter to investment banker Alexander Sachs, who was a New Deal adviser and had access to the president. World War II began on September 1, and in October, when Roosevelt finally received the letter, he agreed that some action was needed "to see that the Nazis don't blow us up." To that end, he created a federal Uranium Committee, with Szilard and other émigré scientists as members. Within weeks they had gained a commitment of $6,000 for research at Columbia.

After the war, Einstein said he had "really only acted as a mailbox" for Szilard. In 1940, however, Einstein was once again forced to play a decisive role when the U.S. Army almost denied Fermi and Szilard security clearance. Investigators, basing their conclusions on information from "highly reliable sources," came to the paradoxical conclusions that Fermi, a refugee from fascism, was "undoubtedly a Fascist" and that Szilard, in terror of the Nazis, was "very pro-German." Perhaps Szilard's cries that Germany could win the war accounted for the latter misinterpretation. (The report also spelled Szilard's name in two different ways, both of which were wrong.) The army decided of each man that "employment of this person on secret work is not recommended," despite the fact that the only secret work in question in the U.S. at the time was taking place in the minds of Fermi and Szilard.

Had the army been heeded, of course, funds would have run out, and all the embryonic federal atomic research by Fermi and Szilard would have ceased. This mistake was averted when the Federal Bureau of Investigation, under pressure from the White House, was ordered to "verify their loyalty to the United States." FBI director J. Edgar Hoover sent agents to interview Einstein (whose pacifist views would later cause his own loyalty to be questioned). With Einstein's good word, federal money flowed in to Columbia in November 1940, although suspicions of Fermi and Szilard would abate only years after they became U.S. citizens.

Funding in place, Fermi's team now worked systematically to construct "piles" (Szilard's lattice) of uranium and graphite, to test for the ratio and geometry that would optimize a chain reaction. The day before the Japanese attack on Pearl Harbor, President Roosevelt approved an all-out federal commitment to research the A-bomb. In the spring of 1942 Fermi, Szilard and the rest of the Columbia team moved to the University of Chicago, where they established a top-secret "metallurgical laboratory" for chain-reaction research. The army's Manhattan Project took over control of the effort in June. Ironically, at this same moment in history, Germany scaled down its own A-bomb work, convinced that the undertaking was impractical for the current war.

In the fall, a pile was constructed, with uranium spheres embedded in graphite blocks. On December 2, 1942, in a squash court under Stagg Field, the university's football stadium, Fermi directed the experiment that initiated the world's first controlled, self-sustaining nuclear chain reaction. After the historic experiment, Fermi and Szilard found themselves alone with their reactor. They shook hands, Szilard remembered, "and I said I thought this day would go down as a black day in the history of mankind."

Later Conflicts and Harmony

Near the war's end in 1945, Fermi and Szilard differed once again. Szilard had hastened the A-bomb's development as a weapon of defense against Germany. With Hitler's defeat, Szilard argued that the bomb should not be used offensively against Japan but instead be demonstrated to encourage surrender. Fermi, as scientific adviser to the administration's high-level committee on options for bomb use, argued that a demonstration would be impractical. The administration agreed, with the subsequent August devastation of the cities of Hiroshima and Nagasaki.

After the war, Fermi favored continuing army control of atomic research, while Szilard successfully lobbied Congress for a new, civilian Atomic Energy Commission. The two men found common ground in opposition to Szilard's old friend Teller in 1950, when both objected to U.S. development of the hydrogen bomb. Fermi called the H-bomb "a weapon which in practical effect is almost one of genocide."

A joint patent for the Fermi-Szilard "neutronic reactor" was first published in 1955, a year after Fermi's death. Szilard pursued molecular biology and nuclear arms control until his death in 1964. Fermi summed up Szilard by calling him "extremely brilliant" but someone who "seems to enjoy startling people." Szilard reflected on Fermi by writing, "I liked him best on the rare occasions when he got mad (except of course when he got mad at me)."

The Author

WILLIAM LANOUETTE received a doctorate in politics from the London School of Economics in 1973. His thesis, comparing the use and abuse of scientific information by U.S. and U.K. legislators and government officials, prepared him well for his current work as an energy/science policy analyst at the U.S. General Accounting Office. He has written about atomic energy and science policy for more than 30 years, in such publications as the *Atlantic Monthly,* the *Bulletin of the Atomic Scientists* and the *Economist.* The author of a biography of Leo Szilard, Lanouette has lectured widely about the politics and personalities of the Manhattan Project. He is an avid oarsman, and his next book will be about the lucrative rise and scandalous end of professional rowing in 19th-century America. Lanouette thanks Nina Byers, professor of physics at the University of California, Los Angeles, and independent scholar Gene Dannen for helpful additions to this article.

Further Information

Enrico Fermi: Collected Papers. Vols. 1 and 2. University of Chicago Press, 1962 and 1965.

Collected Works of Leo Szilard. Vols. 1, 2 and 3. MIT Press, 1972, 1978 and 1987.

Genius in the Shadows: A Biography of Leo Szilard, the Man behind the Bomb. William Lanouette (with Bela Silard). University of Chicago Press, 1994.

Enrico Fermi, Physicist. Reprint. Emilio Segrè. University of Chicago Press, 1995.

An Enrico Fermi Web site can be found at www.time.com/time/time100/scientist/profile/fermi.html

A Leo Szilard Web site is at www.dannen.com/szilard.html