The Einstein-Szilard Refrigerators

Two visionary theoretical physicists joined forces in the 1920s to reinvent the household refrigerator

by Gene Dannen

In July 1939 Leo Szilard visited Albert Einstein to discuss the danger of atomic bombs. Szilard was alarmed by the recent discovery of uranium fission: he had realized almost six years earlier how a "chain reaction" could dangerously multiply such a process. Szilard's warning that nuclear weapons might be possible—and that Nazi Germany might build them—convinced Einstein to write his famous letter to President Franklin D. Roosevelt urging faster research efforts.

When Szilard visited Einstein on Long Island, N.Y., that day, he was also reviving a collaboration dating from Berlin's golden age of physics. It is part of the lore of physics that Szilard and Einstein held many joint patents, filed in the late 1920s, on ingenious types of home refrigerators without moving parts. But little information beyond the patents was thought to survive.

In the process of researching Szilard's life, I have been able to piece together almost the full story of this partnership. In Stockholm, I discovered that appliance manufacturer AB Electrolux still keeps files on two patents purchased from Einstein and Szilard. And in Budapest, the primary engineer for the inventions, Albert Korodi, shared cherished memories of the enterprise. Korodi, who died recently at the age of 96, had preserved copies of engineering reports—including the only known photographs of the Einstein-Szilard prototypes—that were long believed lost.

From these sources and from correspondence in the Leo Szilard Papers at the University of California at San Diego and from the Albert Einstein Archives at Princeton University (originals of the latter are at the Hebrew University of Jerusalem), a detailed picture of the Einstein-Szilard collaboration has emerged. The project was more extensive, more profitable and more technically successful than anyone guessed. The story illuminates Einstein's unlikely role as a practical inventor.

Inventing with Einstein

Szilard and Einstein met in Berlin in 1920. Einstein, then 41, was already the world's most renowned physicist. Szilard, at 22, was a brilliant and gregarious Hungarian studying for his doctorate in physics at the University of Berlin. For his dissertation, Szilard extended classical thermodynamics to fluctuating systems, applying the theory in a way that Einstein had said was impossible. The "Herr Professor" was impressed, and a friendship grew.

After graduation, Szilard later recalled, Einstein advised him to take a job in the patent office. "It is not a good thing for a scientist to be dependent on laying golden eggs," Einstein said. "When I worked in the patent office, that was my best time of all."

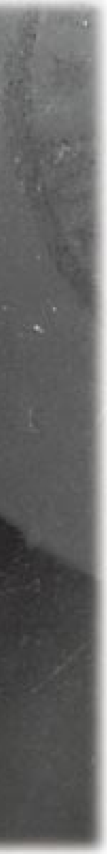
Despite this suggestion, Szilard chose an academic career at his alma mater and soon solved the problem of Maxwell's Demon. This imp, first imagined by James Maxwell, could seemingly violate the second law of thermodynamics by sorting fast and slow molecules, thus confounding their natural tendency to become disordered. The demon could then power a perpetual-motion machine. Szilard showed that this was false: the apparent gain in order was supplied by the information used to produce the effect. His solution included the idea of a "bit," later to be recognized as the cornerstone of information theory. In late 1924 Nobel laureate Max von Laue selected Szilard to be his assistant at the university's Institute for Theoretical Physics.

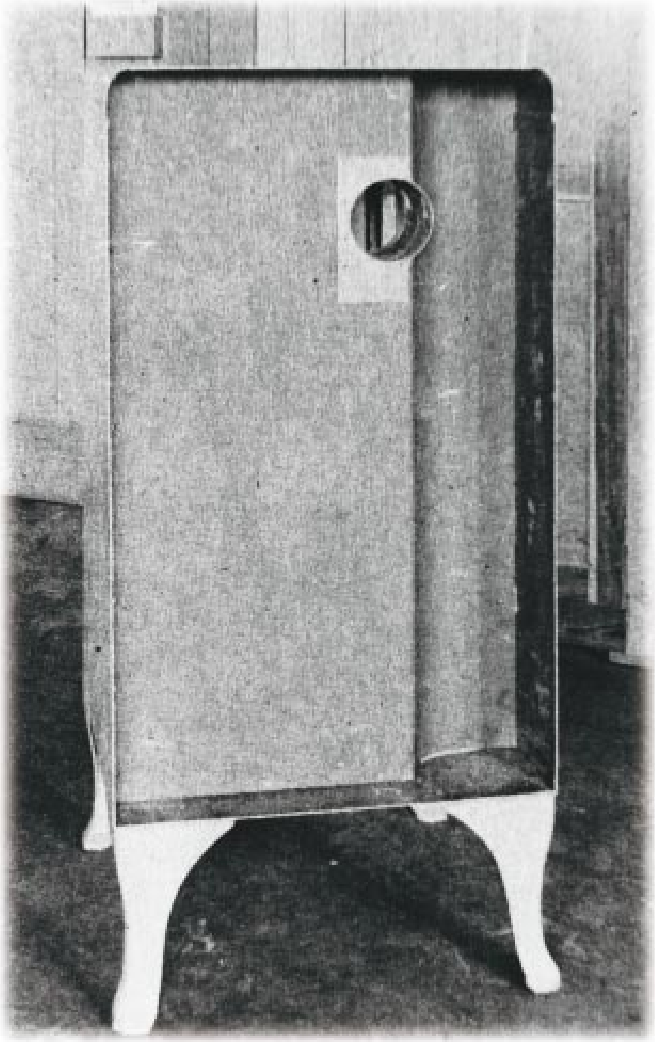
LEO SZILARD PAPERS, MANDEVILLE SPECIAL COLLECTIONS LIBRARY *University of California, San Diego*

REFRIGERATOR CABINET (*center*), seen from the rear, awaits installation of an electromagnetic pump invented by Leo Szilard (*left*)

By the mid-1920s, Szilard had become a frequent visitor to Einstein's home. In some ways, the two men were opposites. Szilard was outgoing and self-confident (some said arrogant); Einstein was modest and retiring. In more important ways, however, they were kindred spirits. They shared a joy in ideas, a strong social conscience—and a fondness for invention.

According to the late Massachusetts Institute of Technology physicist Bernard Feld, who heard the story from Szilard, the refrigerator collaboration began with a newspaper article. One day Einstein read about an entire family—parents and several children—who had been killed in their beds by the poisonous gases leaking from the pump of their refrigerator. At the time, such accidents were a growing hazard. Mechanical home refrigerators were starting to replace traditional iceboxes. Chemistry, however, had yet to produce a nontoxic





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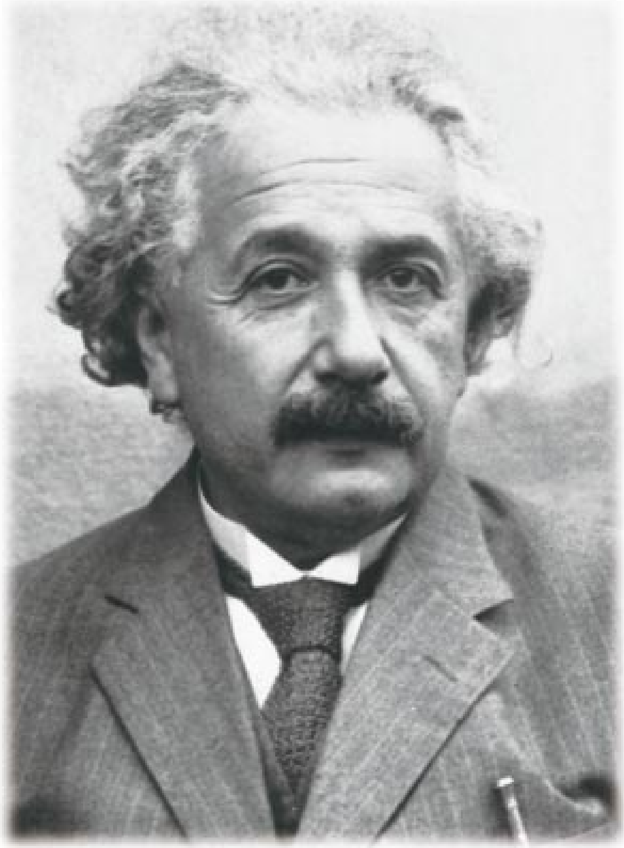

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and Albert Einstein (*right*). The refrigerator, developed at the A.E.G. Research Institute in Berlin, was never marketed, partly because of the Great Depression.

refrigerant. The three cooling gases then commonly used—methyl chloride, ammonia and sulfur dioxide—were all toxic, and the quantities in a refrigerator could kill.

Einstein was distressed by the tragedy. "There must be a better way," he said to Szilard. The two scientists reasoned that the problem was not just the refrigerant. Such leakages, from bearings and seals, were inevitable in systems with moving parts. From their knowledge of thermodynamics, however, they could derive many ways to produce cooling without mechanical motion. Why not put these to use?

There was personal incentive to try. At that time, evidently the winter of 1925–1926, Szilard was preparing to take the next step in a German academic career—to become a privatdocent, or instructor. As an assistant, he received a salary; as an instructor, however, he would be forced to scrape by on small fees collected from students. The inventions, if successful, could support Szilard's budding career.

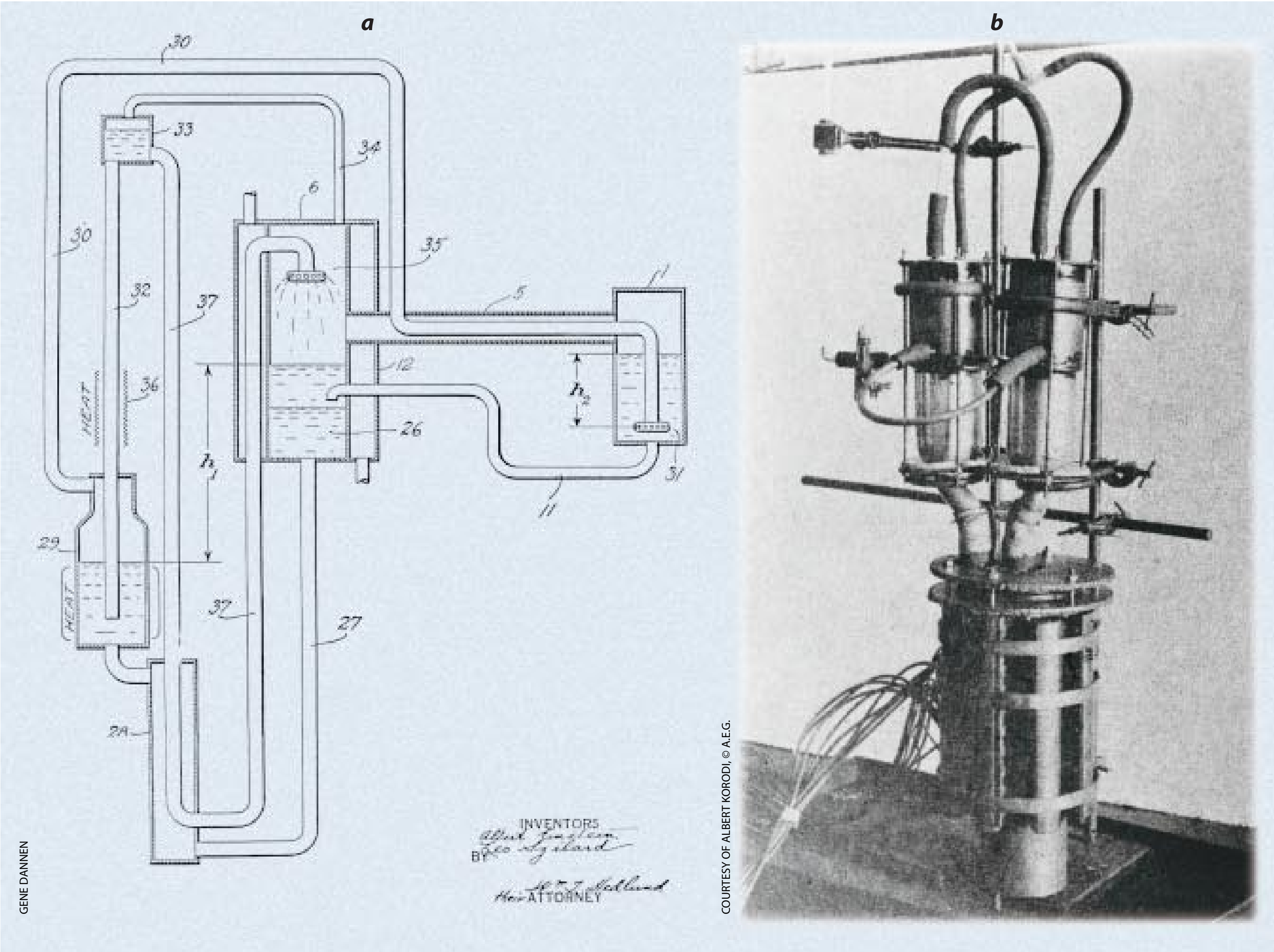
Einstein, who wanted to help his gifted young friend, agreed to a collaboration. A letter from Szilard to Einstein preserves the terms of their agreement. All inventions by either of them in the field of refrigeration would be joint property. Szilard would have first claim on profits if his income fell below the salary of a university assistant. Otherwise, all royalties would be shared equally.

Early Designs

Then, as now, most refrigerators used mechanical compressor motors. A refrigerant gas is compressed, liquefying as its excess heat is discharged to the surroundings. When the liquid is allowed to expand again, it cools and can absorb heat from an interior chamber. Einstein and Szilard considered a different concept, used in so-called absorption refrigerators, to be the safer. In these devices, heat from a natural gas flame—rather than the push of a piston—drives the cooling cycle. One new design, by Swedish inventors Baltzar von Platen and Carl Munters, and marketed by AB Electrolux, was considered a breakthrough. Szilard devised an improvement.

In fact, the entrepreneurs did not stop with a single design; they came up with many. Einstein's experience as a patent examiner allowed them to do without the usual attorneys, and in early 1926 Szilard began filing a series of patent applications on their inventions. By the fall, they had decided on the three most promising designs.

Each refrigerator, it seems, was based on an entirely different physical concept—absorption, diffusion or electromagnetism. In a letter to his brother, Bela, written in October, Szilard described their progress. "The matter of the refrigerator patents, which I applied for together with Professor Einstein, has now come so far that I feel it is a reasonable time to get into contact with industry," he wrote. "All three machines work without moving parts, and are hermetically sealed.... One of these three types is nearly identical with one of the Electrolux company's machines (in my opinion the best at the moment).... The other two types are completely different from



GENE DANNEN

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DIVERSE PRINCIPLES lie behind the Einstein-Szilard refrigerators. An absorption design (*a*) purchased by AB Electrolux uses a heat source and a combination of fluids to drive the refrigerant, butane, through a complex circuit. The butane, initially a liquid, vaporizes in the presence of ammonia in the refrigerant chamber 1 (*at right*), taking up heat. The gaseous mixture passes to chamber 6 (*center*), where water absorbs the ammonia, freeing liquid butane to be recirculated. The electromagnetic pump (*b*) developed by A.E.G. pushes a liquid metal through a cylinder; here it is using mercury for test purposes. The

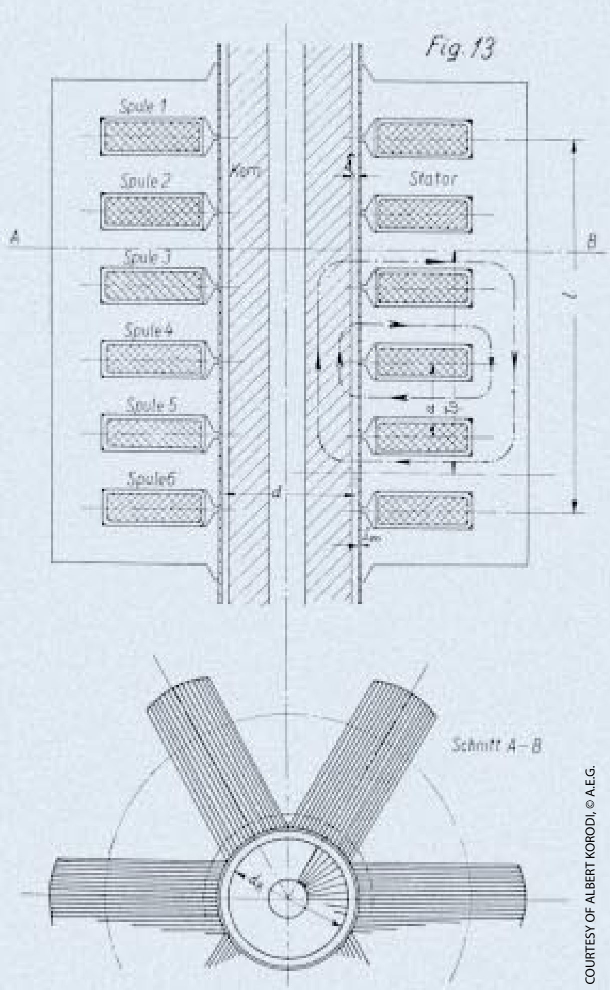
any other machines known until now."

Szilard quickly negotiated a contract with the Bamag-Meguin company, a large manufacturer primarily of gaswork equipment with factories in Berlin and Anhalt. In late 1926 Szilard began to supervise the development of prototypes at the laboratories of the Institute of Technology in Berlin. Albert Kornfeld, a Hungarian graduate from the electrical engineering department of the institute, started working on the refrigerators at this time. (Kornfeld later changed his name to Korodi, and I will use that name hereafter.) In 1916 Korodi had won the Eötvös Prize, the prestigious Hungarian mathematics competition for 18-year-old students. After meeting Szilard through the Eötvös competition, Korodi had studied with him at the Budapest Technical University. Later he followed Szilard to Berlin, where they lived in the same apartment building and became close friends.

Unfortunately, the agreement with Bamag-Meguin lasted less than a year. "Bamag-Meguin got in difficulties at that time. I think they dropped all uncertain projects," Korodi recalled. Within months, however, the inventors reached agreements with two other companies, one Swedish and one German.

The Swedish company was AB Electrolux. On December 2, 1927, Platen-Munters Refrigerating System, a division of Electrolux in Stockholm, bought a patent application for an absorption refrigerator from the two inventors for 3,150 reichsmarks, or $750. Both parties were pleased with the transaction. Electrolux's files show that it considered the purchase price "very cheap"; even so, Szilard and Einstein earned roughly $10,000 in today's dollars.

The application for a U.S. patent on the absorption device caused some polite consternation. "I would be interested to know if Albert Einstein is the same person who propounded the theory of relativity," wrote back the American patent attorney responsible for the case. If so, he continued, the patent office should not object to Einstein's unusual claim of dual Swiss-German citizenship: "Albert Einstein is listed in the Standard Dictionary under the word 'Einstein' as an adjective denoting a theory of relativity. The dictionary explains that the name is derived from Albert Einstein, a citizen of both Switzerland and Germany. With this designation in one of the accepted dictionaries, I think the Patent Office will not object c



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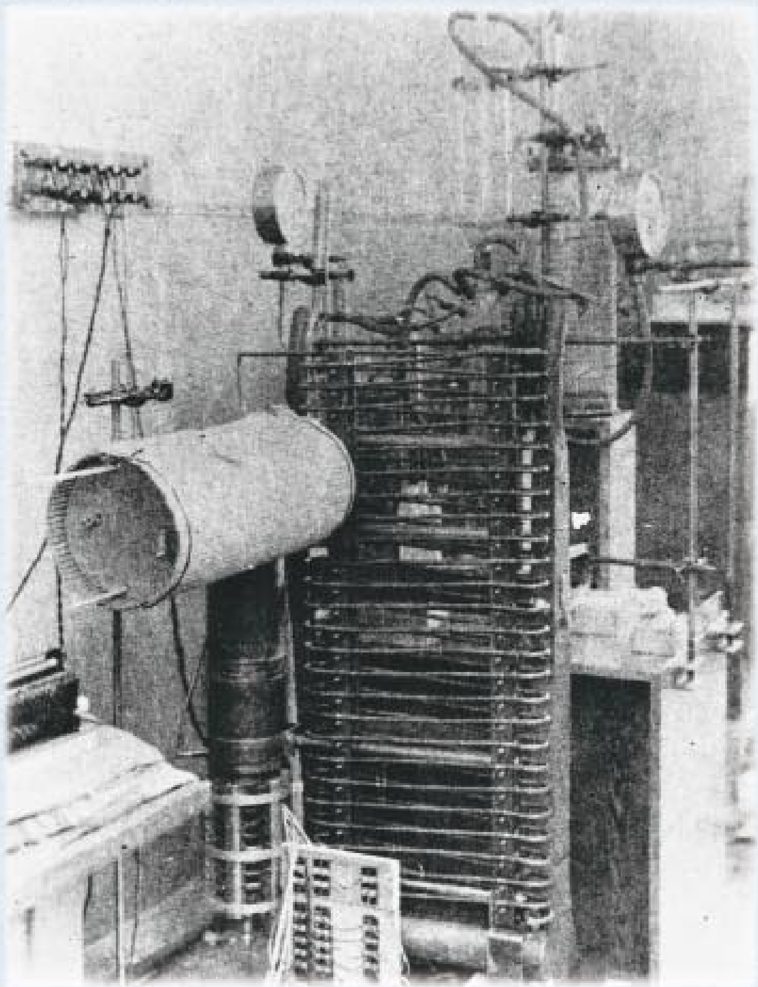


COURTESY OF ALBERT KORODI, © A.E.G.

blueprint (*c*) shows the cylinder lengthwise (*above*) and in cross section (*below*). Alternating current flowing through coils (arranged like spokes of a wheel) provides electromagnetic induction to drive the liquid, which acts as a piston to compress a refrigerant. A nearly complete refrigerator assembly (*d*) uses a potassium-sodium alloy—the pump is the dark vertical cylinder near the bottom—and a pentane refrigerant. The prominent array of condenser coils operates the same way as in modern refrigerators. The two photographs, from 1932, were recently discovered by the author.

to the statement that Prof. Einstein is a citizen of two different countries."

Electrolux also later purchased the diffusion design; the patent it took out on this invention, however, does not mention Einstein or Szilard. Nor did Electrolux ever develop either of the two patents. The documents show that, despite admiration for their ingenuity, the firm bought the designs mostly to safeguard their own pending applications.

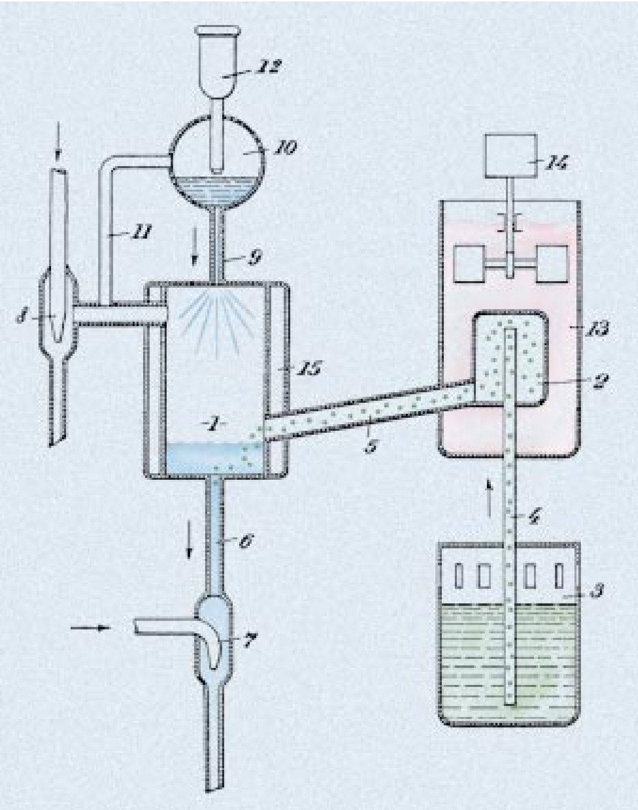
Another, much different Einstein-Szilard design produced a partnership with the Citogel company in Hamburg (the company's name means "quick freeze" in Latin). According to Korodi, the invention was Einstein's response to the diabolical complexity of absorption designs: "[He] proposed a quite simple and cheap system especially suited for small refrigerators."

The device, Korodi recalled, was "a small immersion cooler that could be dipped for instance in a cup of some beverage to be cooled." Requiring no conventional power source, it operated solely off the pressure of a water tap. The pressure powered a water-jet pump, producing a vacuum in a chamber from which water and a small amount of methanol were evaporated. The methanol was slowly used up, but the liquid was cheap and readily available. It could be expended and replaced, Korodi explained: "That was the idea of Einstein."

The cooler worked well, and a prototype was demonstrated under the Citogel name at the Leipzig Fair in early 1928. Korodi, who moved to Hamburg to work with Citogel on the invention, remembered Szilard's exasperation at the eventual outcome. Methanol in retail quantities did not turn out to be as cheap as expected. But more important, the ingenious cooler, which required reliable water pressure, met its match in the haphazard German water system. At the time, the pressure of tap water varied between buildings as well as from floor to floor within a building. In the end the variations proved too great, and the invention was not marketed.

The Einstein-Szilard Pump

The most revolutionary, and most successful, invention would become known as the Einstein-Szilard electromagnetic pump. It was a fully functional pump without mechanical moving parts. Instead a traveling electromagnetic field caused a liquid metal to move. The metallic fluid, in turn, was used as



WATER PRESSURE from a tap drives this small cooling device, developed (in simpler form) by Citogel in Hamburg. Methanol contained in chamber 3 evaporates in chamber 2, cooling the surrounding compartment 13. Turbine 14 churns ice cream or other frozen foods. The methanol dissolves in water in chamber 1 and flows out, so it has to be replenished. The device was not marketed because of variable water pressure in German buildings.

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a piston to compress a refrigerant. (The refrigerant cycle, after that point, was the same as in standard refrigerators.)

Korodi remembered vividly that the device was first envisioned as an electromagnetic conduction pump, with an electric current passing through the liquid metal. Mercury was an obvious first choice, but its low conductivity would provide very poor efficiency. Szilard then suggested an alternative liquid metal—a potassium-sodium alloy with much better conductivity. Although potassium and sodium were both solids at room temperature, an optimal mixture of the two was liquid above its melting point of –11 degrees Celsius. Unfortunately, the metals were chemically aggressive and would attack the insulation of the wires carrying current to the mixture.

Szilard and Korodi considered different insulating materials, then Szilard took the problem back to Einstein. "Einstein thought a few minutes," Korodi related, and proposed eliminating the need for such wires by applying indirect force from exterior coils, by induction.

The invention therefore became an induction pump. Korodi, who calculated the expected efficiency of the pump for potassium-sodium alloys, found that it was still much less efficient than standard compressors. What it lacked in efficiency, however, it gained in reliability. "It was worthwhile to make such a compressor," he stated: an Einstein-Szilard pump would not leak or fail.

In the fall of 1928 the Allgemeine Elektrizitäts Gesellschaft (German General Electric Company), or A.E.G., agreed to develop the pump for refrigeration. The A.E.G. was a prosperous Berlin firm with its own research institute, where it established a special department led by two full-time engineers. Korodi was hired to develop electrical aspects of the invention. Another Hungarian engineer friend of Szilard's, Lazislas Bihaly, was taken on to develop the mechanical side. Szilard, with the title of consultant, directed the team.

Korodi and Szilard received salaries of 500 reichsmarks a month, the equivalent of $120. "It was a good salary," Korodi observed, at a time when "a car, a Ford, cost $300." For Szilard, the A.E.G. contract was even more lucrative. Patent royalties, in addition to his consulting fees, eventually brought his income to a comfortable $3,000 a year (worth roughly $40,000 today).

Szilard and Einstein kept a joint bank account, but the sum Einstein actually accepted from the partnership remains unknown. Korodi described Einstein as far from a silent partner, however: he visited the laboratory at each stage of construction to check on the prototypes. Korodi also remembered visiting Einstein's Berlin apartment with Szilard, perhaps a dozen times, to talk about new inventions. "I didn't talk to Einstein about physics," he recalled with a laugh.

For Szilard, who did discuss physics with Einstein, the collaboration was funding an increasingly productive career. At the University of Berlin, Szilard was teaching seminars in quantum theory and theoretical physics with John von Neumann and Erwin Schrödinger. His other inventions during this period included the linear accelerator, cyclotron and electron microscope. Einstein, meanwhile, continued his tireless pursuit of the Unified Field Theory but also worked with other inventors on a gyrocompass and a hearing aid.

Even as the refrigerator advanced, however, dark clouds were gathering. In the Reichstag elections of September 14, 1930, the tiny Nazi party received almost 20 percent of the vote. Szilard, with his legendary foresight, saw what others did not. On September 27 he wrote to Einstein with a prophetic warning: "From week to week I detect new symptoms, if my nose doesn't deceive me, that peaceful [political] development in Europe in the next ten years is not to be counted on.... Indeed, I don't know if it will be possible to build our refrigerator in Europe."

A Working Refrigerator

Until recently, the only known detail of the Einstein-Szilard electromagnetic pump prototype was its objectionable noise. Although expected to be silent, the pump suffered from cavitation—the expansion and collapse of tiny voids or cavities—as the liquid metal was forced through the pump. Physicist Dennis Gabor, who was one of Szilard's best friends in Berlin, once commented that the pump "howled like a jackal." Another "earwitness," according to American physicist Philip Morrison, said it wailed "like a banshee."

Korodi, on the other hand, described the sound as resembling that of rushing water. Furthermore, as detailed in the A.E.G. final report, the noise depended on the force and speed of the pump. A combination of tricks—reducing the voltage at the start of each stroke, for example—eventually lowered the noise to acceptable levels.

From an engineering viewpoint, the noise problem was mostly cosmetic. The truly interesting challenges arose in working with chemically reactive metals. Special equipment was developed to fill the pump without the (possibly explosive) oxidation of the sodium and potassium. Despite this difficulty, Korodi emphasized that there would have been no danger to refrigerator owners. The Einstein-Szilard refrigerator was a sealed system, with the liquid metals fully contained in welded stainless steel.

Many problems had been solved, but the noise was still under attack, when a full prototype was constructed. "In two years," Korodi stated, "a complete refrigerator was built, which worked—operated—as a refrigerator." On July 31, 1931, an Einstein-Szilard refrigerator went into continuous operation at the A.E.G. Research Institute. For comparison with existing units, the apparatus was mounted in the cabinet of a four-cubic-foot (120-liter) General Electric model G40 refrigerator. With a potassium-sodium alloy as its liquid metal and pentane as a refrigerant, the prototype operated at 136 watts, consuming 2.3 kilowatt-hours a day.

"The efficiency was as good as it was calculated," Korodi insisted. But for the A.E.G., battered by the growing worldwide depression, the refrigerator was not good enough. Improvements in conventional refrigerators, in addition to the economic slump, were shrinking the potential market. The 1930 American demonstration of a nontoxic "Freon" refrigerant, in particular, promised to eliminate the danger of leaks. (Only decades later, of course, would it be realized that such chlorofluorocarbons might endanger the ozone layer of the entire planet.)

Work continued in the A.E.G. laboratory for another year, resulting in improved pump prototypes and a change in liquid metals. The internal heat of the pump had proved sufficient to keep pure potassium above its melting point of 63 degrees C. A four-month-long test operation with potassium was successful, increasing the electrical efficiency from 16 to 26 percent. The Depression-ravaged A.E.G., however, was not persuaded to continue the research.

Szilard tried to interest manufacturers in Britain and America, also to no avail. In 1932 the A.E.G. Research Institute was reduced by half, eliminating all but essential projects. Korodi helped to write the 104-page final report on the Einstein-Szilard refrigerator development: *A.E.G. Technischer Bericht 689,* dated August 16, 1932. (It is fortunate that Korodi kept a copy of this manuscript, because the A.E.G.'s files were destroyed in World War II.)

Only months later Adolf Hitler's appointment as chancellor ended Berlin's golden age of physics. Szilard fled to Britain and then to America. Einstein found refuge at the Institute for Advanced Study in Princeton, N.J. Korodi returned to Budapest, where he found work with the Hungarian division of Philips and built a successful career in telecommunications. He died in Budapest on March 28, 1995.

Applied Physics

In the seven years of their collaboration, Szilard and Einstein filed more than 45 patent applications in at least six countries. Although none of their refrigerators reached consumers, the designs were ingenious applications of physical principles. The Einstein-Szilard pump, in particular, eventually proved its value. The built-in safety of its design later found a more critical task in cooling breeder reactors.

As intended, the inventions had supported Szilard's academic career in Germany. His savings, moreover, saw him through two more years in Britain. After selflessly helping fellow refugee scholars find university positions, he turned to nuclear physics and conceived the neutron chain reaction in the autumn of 1933. Szilard's early research on atomic energy was in fact made possible by this money.

For decades, it seemed a mere curiosity that Szilard and Einstein should have chosen to design refrigerators. Today, with refrigeration technology again a priority—this time the earth's ozone layer might be at stake—the challenge of the problem has become clear. For Szilard and Einstein, the inventions were more than a brief interlude. From their first collaboration in physics to their later efforts in controlling the threat of nuclear weapons, Szilard's and Einstein's scientific accomplishments and their commitment to humanity were closely intertwined. SA

CAROL GRAM PAULSON

ALBERT KORODI (1898–1995) was the primary engineer for the inventions. He is holding the Tivadar Puskás Award of the Hungarian Scientific Society for Telecommunications, which he received in 1993.

The Author

GENE DANNEN is an independent scholar who has been researching the life of Leo Szilard for 15 years. This article is adapted from his forthcoming book on Szilard's role in the birth of the nuclear age. He owes special thanks to the Mandeville Special Collections Library at the University of California, San Diego; the department of rare books and manuscripts at Princeton University Libraries; Egon Weiss for permission to use Szilard's unpublished letters; Henry Throop and Carol Paulson for conducting interviews with Albert Korodi; and Mihály Korodi. Dannen can be reached by e-mail at danneng@peak.org

Further Reading

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The author maintains a Leo Szilard Page on the World Wide Web at http://www.peak.org/~danneng/szilard.html

